Climate, Energy and Urbanization

A Guide on Strategies, Materials and Technologies for Sustainable Development in the Desert

ASU National Center of Excellence for Smart Innovations
Arizona State University

Climate, Energy and Urbanization is ...

a comprehensive resource tool for those interested in learning about and implementing new concepts into the way we plan, design and build our cities. Focused on two of the most pertinent issues for our desert metropolis – climate and energy - this Guide provides design solutions toward reducing Urban Heat Islands and ensuring that new construction in the Valley of the Sun is built with energy and water sustainability in mind.

Climate, Energy and Urbanization is for...

- *Planners and designers who want to learn about different design strategies and materials choices that can reduce energy demand in their next project.*

- *Public officials who want to know more about the elements of urban heat islands and strategies that can be implemented immediately to cool their communities.*

- *Architects, engineers and general contractors looking for easy to read descriptions, the costs, pros and cons, and local suppliers of various systems, products and materials that can be used in their next LEED™ development project.*

- *Business leaders and entrepreneurs wanting to know more about the major sustainability issues facing the Valley and mitigation strategies being recommended by government and nongovernmental organizations.*

- *Community organizations and citizens wanting to learn more about sustainability, urban heat island mitigation and sustainable building design.*

And how we can...

- *decrease Valley-wide energy consumption and dependence*
- *reduce green house gas emissions and smog formation*
- *decrease nighttime temperatures in urban areas*
- *make cities more comfortable and fulfilling places to live, work and play*

Climate, Energy and Urbanization

A Guide on Strategies, Materials and Technologies for Sustainable Development in the Desert

Prepared for:

The City of Phoenix

Prepared by:

The National Center of Excellence on
Sustainable Material and Renewable Technology (SMART) Innovations
Global Institute of Sustainability / Ira. A. Fulton School of Engineering / College of Design
Arizona State University

August 2008

Climate, Energy and Urbanization is available at http://www.asusmart.com/climateandenergyguide as an Adobe PDF file for viewing or printing.

Suggested format for citing this publication:
Carlson, J., Golden, J. 2008. *Climate, Energy and Urbanization: A Guide on Strategies, Materials and Technologies for Sustainable Development in the Desert.* Prepared for the City of Phoenix, Arizona, USA.

DISCLAIMER

This guide presents best practices for urban heat island mitigation and high performance building design. They are not intended to be comprehensive or complete in all cases. Responsibility for the technical integrity of the project remains with the architect, engineer, or consultant.
This guide was prepared by Arizona State University and sponsored by the City of Phoenix. Any opinions expressed in the guide do not necessarily reflect those of Arizona State University or the City of Phoenix, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement. Further, no warranties or representations, expressed or implied, as to the fitness for particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this guide is given. No representation that the use of any product, apparatus, process, method, or other information will not infringe on privately owned rights is given and Arizona State University and the City of Phoenix will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of information contained, described, disclosed, or referred to in this document.

Table of Contents

Preface

In this guidebook, we hope to increase understanding of the issues of urban development and the opportunities available to lessen urban environmental impact. Phoenix, Las Vegas and Albuquerque, the three largest urban centers in the Desert Southwest, have experienced rapid change and growth over the last decades. This growth has resulted in doubling or tripling the amount of urban infrastructure – roads, parking lots, buildings and utilities – constructed.

'Urban Sustainability' is a concept that recognizes the interdependence of the human-built and natural systems and the negative consequences of not matching urban resource consumption to local conditions. These consumption patterns have as much to do with the design and planning of our cities as they do with our individual choices and lifestyles. Design choices and policies that govern how we build our cities today will lock in the way we will consume energy, water and other resources and determine the quality of life for generations to come. Vulnerability, adaptability and flexibility to respond to shortages and changes in our resource needs must be factored early into the planning process. To make this change in planning our cities a reality, one needs to be knowledgeable about the leading issues and what options there are for development projects.

Sustainability in the Desert Southwest, more than any other region, is strongly influenced by our relationship to the sun. Solar heat gain impacts our energy and water use in buildings and also causes changes to the urban microclimate. ***Climate, Energy and Urbanization*** looks at the materials from which we construct our cities – the 'built environment' as termed in this guide – and the resultant increase in average minimum temperatures known as 'Urban Heat Island' effect. Many cities are experiencing this urban phenomenon that spirals the use of energy and water to compensate for increases in urban temperatures, and it is particularly evident in arid urban regions.

Urban heat islands directly affect all three imperatives of sustainable development. It alters weather patterns, increases air pollution formation and energy and water consumption, impacts the durability of roads and other materials, and degrades thermal comfort, agricultural production and vehicle efficiency, all of which impacts business and tourism. This guidebook suggests cost effective measures and strategies that city planners can implement to immediately address this problem, as well as suggestions for implementing policy at the organizational and governmental level.

Each chapter is written on a separate topic to enable readers to select only the section or chapters that pertain to their particular interest or project needs.

Chapter 1: Urban Sustainability in a Desert Region – *Introduces sustainability with a specific focus on the current trends of urban environmental problems found in Arizona metropolitan areas.*

Chapter 2: Urban Heat Island Mitigation – *Strategies and materials for mitigating urban heat islands and providing action plans for cities to integrate these strategies into development and renovation plans.*

Chapter 3: Design for Climate and Energy – *Key concepts and strategies for planning and designing high performance, sustainable buildings, specifically focused on energy efficiency and water conservation.*

Chapter 4: Systems, Products and Materials – *Compilation of summaries providing information on a wide range of systems, products and materials used for Urban Heat Island mitigation and high performance building design.*

We hope that the following information will be transferable to other desert environments and that it will start a dialogue on how to approach the issues of urbanization in our unique desert climate.

Chapter 1:

Urban Sustainability in a Desert Region

Chapter 1 Table of Contents

Introduction

As we enter the 21st century, the human population continues to grow at an unprecedented rate. Meeting the needs and wants of our increasing population has heightened the pressure on water, energy, and other natural resources as never before. Recent advances in meteorology, remote sensing, and communications have revealed the uglier side of human population growth. Current consumption and pollution trends are exposing the fragility of the earth's ecosystems. Issues such as global climate change have gained a level of public awareness and concern unlike any environmental issue heretofore, finding their way to the headlines of all major media sources and spurring bold actions by corporations, governments, and NGOs. Other impacts such as declining fish populations, species extinction, conflicts over mineral, water, and oil reserves, and urban heat island (UHI) are also gaining media attention. It is unclear to what extent can we continue to pressure these earth systems before they reach an irreversible tipping point. Citizens the world-over are demanding change and leadership from their governments. Despite this public awareness and mounting pressure for new policies, there is a lack of focus and full understanding of the problems at hand. Common terms widely used among champions of change are "Sustainability" and "Sustainable Development." Although the terms seem self-explanatory, it can often mean different things to different people.

This chapter aims to bring clarity to the often cloudy subject of sustainability and sustainable development particular to the Phoenix region. Defining these concepts is the first step in moving the region along a common pathway. There are indicators that can be used to assess the sustainability of metropolitan centers, and we will determine what these indicators reveal about Phoenix, and what insights they might lend in reversing or slowing the negative trends as our region continues to grow and mature.

The Built Environment

The collective of products and processes of human creation defines the built environment. When we think about protecting and restoring the environment, we often envision the sky, forests, free- flowing rivers, and other natural systems. Although these systems might seem untouched, nothing is totally free from human influence and impacts. Nearly all environments in which we interact are products of human activities. Humans have arranged, maintained, or controlled nearly every piece of the earth (Bartuska 2007).

The shear magnitude and complexity of the built environment requires an organizational framework to jumpstart discussion. The built environment can be organized into the following seven categories.

Products

...materials and commodities humans use to perform specific tasks. Examples range from graphic symbols for communicating, tools for constructing, materials for building, and machines for communicating and transporting.

Interiors

...a grouping of products, enclosed within a structure, created to enhance activities. Examples include living rooms, kitchens, and bathrooms.

Structures

...planned groupings of spaces built of products. Houses, schools, factories, and highways are all example of structures, which usually include both interior and exterior forms.

Landscapes

...exterior areas and settings. Built landscape spaces are grouped with structures such as courtyards, parks, and gardens. National parks and forests can be considered natural landscapes..

Cities

...a grouping of structures and landscapes that define the economic, social, cultural, and environmental characteristics of a community. The complex and diverse arrangement of structures can be organized into neighborhoods, subdivisions, villages, or towns.

Regions

...cities and landscapes grouped together and defined by political, social, economic, or environmental characteristics. This could include multiple cities, multiple counties, and regional groupings such as the Southwest.

Earth

...all the components; regions, cities, and landscaped grouped together—the ultimate human artifact.

Urban Areas

Urban areas can be defined as areas of increased density of human-created structures. Although the term city or town is often used interchangeably with urban areas, "urban" typically refers to a certain population density. *The US Census Bureau defines an urban area as "core census block groups or blocks that have a population density of at least 1,000 people per square mile (386 per square kilometer) and surrounding census blocks that have an overall density of at least 500 people per square mile (193 per square kilometer)."*

Within this definition, there are two general categories of urbanization in the US. Urban areas denote areas with 50,000 or more people, while areas under 50,000 people are called urban clusters. The first urbanized areas were designated in the 1950 census, while **urban clusters** were added in the 2000 census. There are about 1,371 urban areas and urban clusters with more than 10,000 people in the US.

Each urban area is unique, varying in the quality of its infrastructure, resources used in its daily operation, and the resulting environmental impact of its wastes and emissions, all of which define the quality of life in the urban area. The effectiveness and quality of the governing bodies, municipalities, and other local institutions also define the general quality of an urban area.

Developed Vs. Developing Countries

The distribution of wealth generally divides countries into two categories: **developed** and **developing.** The countries that have made major social, political, and economic progress in recent history are considered developed. These countries have organized, structured economies generally based on services and manufacturing industries. Other characteristics of developed countries include good educational opportunities for its citizens, a high per capita GDP, low population growth rates, and readily available health services. Developing countries, where 75% of the world's population resides, generally have agrarian-based economies, are experiencing rapid population growth, and have limited or underdeveloped natural resources.

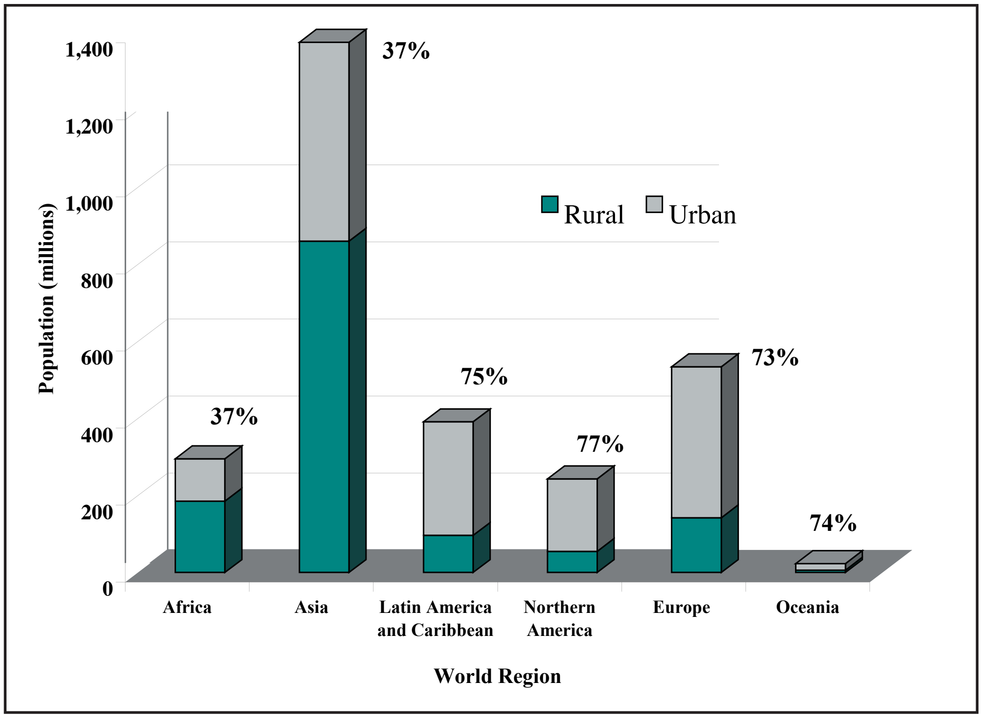


Figure 1-1. Population in urban and rural for major world areas, in 2000. Percentages represent urban areas (UN 2002).

These combined characteristics often result in a lack of basic necessities of life for most residents of developing countries. Over the last 100 years, the world population living in urban areas has increased from 160 million to over 3 billion and is likely to nearly double again by 2025.

In the US alone, rapid urbanization will result in an expansion of the urban built environment to 427 billion ft2 by 2030, an increase of more than 40% since 2000. This rate of urbanization is unprecedented in human history and is happening across the globe (Figure 2-1) with the most dramatic transition from rural to urban is occurring in less-developed countries. The problems of developing countries are severe and deserve adequate study and attention from the global community. The nature of these problems differs greatly than those of the more developed countries, thus requiring different tools and strategies.

The massive influx of population into urban centers within countries with slow development and/or limited resources has resulted in abject poverty and social inequality. Rural immigrants whose desire for higher incomes and improved quality of life brought them to urban centers are met with the opposite conditions; being forced to scrape an existence in the makeshift shelters with scant infrastructure on the outskirts of cities.

An estimated 600 million urban citizens in less developed countries are living where "their lives and health are continually threatened because of the inadequate provision of safe, sufficient water supplies, sanitation, removal of solid and liquid wastes and health care and emergency services" (Cainross et al. 1990).

The priorities for both developed and developing countries should focus on meeting the basic needs of its citizens. These needs can be met by constructing and maintaining appropriate dwellings, energy sources, freshwater supplies, sanitation systems, and educational and health-care services (Devuyst 2001). While this guidebook focuses upon the problems of developed countries, and Phoenix in particular, as we improve our understanding and develop solutions for the problems of developed areas, the more likely these methods will be transferable to other nations.

Resource Consumption in Urban Areas

Since the industrial revolution, technological advances have improved life in the developed counties. Most of the problems faced by urbanites of the 1800s have been eliminated, creating life standards within developed countries that far exceed those of other, less-developed nations. The higher incomes in urban centers have also adversely resulted in lifestyles that are based on consumption. The UN report, *"Our Common Future,"* states that the world's wealthiest 25% consume 80% of the world's economic output (WCED 1987). Overconsumption is a major cause of much of today's global environmental degradation. It is estimated that 64% of the world's economic consumption and pollution can be linked to cities in the richest countries (Santamouris 2000).

Urban areas take up just 2% of the earth's surface but account for an unbalanced amount of resource usage. For example, urban areas account for about 75% of industrial wood use and 60% of water use (Worldwatch Institute 2002). The extent of urban impacts upon the environment increases not only as population grows but also as per capita demand for resources rises.

Collectively, the materials/building sector accounts for over 20% of the US economy. Activities associated with constructing and using pavements, infrastructure, and buildings consume 65% of electricity, 37% of primary energy, 25% of water supplies, and 30% of all wood and materials. The urban built environment and its occupants generate 35% of solid waste, 36% of carbon dioxide (CO_2) and 46% of sulfur dioxide (SO_2) emissions, 19% of nitrogen oxides (NO_x) and 10% of fine-particulate emissions. Additionally, 75% of the 3.4 billion metric tons of new materials that are used in the US economy are used by the construction industry and, at the end of the 20th century, only 5% of all materials used were renewable.

SUSTAINABLE DEVELOPMENT

Sustainability is a characteristic of a process or state that can be maintained indefinitely. The term has been recently used to describe the coexistence of human systems with the earth's ecological system without either system being damaged. Many consider **sustainable development** as a continuation of the environmental movement that began in the 1960's with more of a focus on integration of economic development and the protection and restoration of natural systems. The beginnings of the sustainable development movement can be traced back to the 1960s and Rachel Carson's book ***The Silent Spring (1962)*** in which she brought awareness to the detrimental effects pesticides have on bird populations. In the following years a number of publications, including Paul Erlich's ***Population Bomb (1968)*** and the Club of Rome's ***Limits to Growth (1972)*** drew attention to global-development issues and natural-resource depletion. The first use of the term "sustainable development" took place when the *International Union for the Conservation of Nature* published the World Conservation Strategy in 1980. In 1986, the UN held meetings of the *World Commission on Environment and Development* to study the dynamics of global-environmental degradation and make recommendations for the long-term viability of human society. The Commission was chaired by Gro Harlem Brundtland, then Prime Minister of Norway. The product of this meeting was their report, *"Our Common Future"* (Bruntland 1987). The **Bruntland Report**, as it came to be known, was the benchmark for thinking about the global environment, and popularized the term "sustainable development." At the time, it was defined as ***"development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN with United Nations1987).***

Sustainable development encompasses a much broader spectrum of policy issues than simply those relating to the natural environment. With this definition, sustainable development seeks to unite economic, environmental, and social issues - three concepts once thought of as mutually exclusive. For the first time in western society, technological progress, wealth development, and human prosperity did not have to be at odds with the protection and conservation of that natural environment. In support of this concept, the UN has produced several documents, most recently the 2005 World Summit Outcome Document.

This report solidified the three components of sustainable development by referring to the "interdependent and mutually reinforcing pillars" of economic development, social development and environmental protection. Each component is as important as the other, and it is at the confluence of these three agendas sustainable development exists.

Figure 1-2. Diagram showing the overlapping pillars of sustainability: social, economic, and environment.

Public organizations are beginning to take into account a broader view of their oversight and policy responsibilities, ranging across social, economic, environmental, ethical, cultural, political, and even religious interests. (Hall 2004).

A global blueprint for sustainability, called **Agenda 21**, was agreed upon at the United Nations Conference on Environment and Development in 1992, held in Rio de Janeiro and commonly referred to as the Rio Earth Summit. Chapter 28 of Agenda 21 identifies local authorities as the sphere of governance closest to the people, and calls upon all local authorities to consult with their communities and develop and implement a local plan for sustainability - a "**Local Agenda 21**" (LA21). Many communities around the world have created sustainability programs to meet this call to action. LA21 provides a framework for implementing sustainable development at the local level by building upon existing local government strategies and resources such as land planning, vegetation management plans, and transportation strategies to better integrate environmental, economic and social goals.

The Difference between Green Development and Sustainable Development

There is a lot of talk about what it means to be "green." Marketing slogans are rampant with 'green products', 'green buildings' and 'green innovations'. **Green development** does not necessarily have the same goals as Sustainable Development. The designation 'green' usually implies that it prioritizes environmental sustainability over economic and cultural considerations. Sustainable development requires that a product, process or policy address each of the three pillars before it is considered a more 'sustainable' option. An example of this can be found in many developing countries or lower income areas of the US: While environmentally preferable products such as bamboo flooring or roof integrated solar power may decrease environmental impact, they are more expensive to purchase and may be financially unattainable for a small business owner in a developing community. In many cases, cutting-edge green facilities would not contribute to overall sustainability if they require high maintenance costs, which may not be sustainable in regions of the world with less financial resources. On the other side of the spectrum, an inexpensive power generator will likely have a lower efficiency, harmful emissions and a much shorter operational life, costing more in terms of energy, health and maintenance than a slightly more expensive and better quality product. This balance of economic, environmental, and social considerations is sometimes difficult to judge without investigating all of the factors. For this reason, government and industry organizations are beginning to offer certification and labeling systems that help to reduce the ambiguity and take the guesswork out of the purchasing equation.

Life Cycle Assessment

A **life cycle assessment (LCA)** is a technique to assess the environmental impact of a given product or service throughtout its lifespan. This method of measuring the environmental impact is also refered to as life cycle analysis, life cycle inventory, ecobalance, cradle-to-grave-analysis, well-to-wheel analysis, and dust-to-dust energy cost. Regardless of terminology, the method can be applied to just about anything in the built environment, including buildings, cities, and even countries. It is a fundamental, data intensive accounting of all the resources used and waste produced over the entire lifetime of a product, from material extraction, use and operation to final disposal.

The goal of an LCA is to enable the consumer, designer, or decision maker to determine which choice is least burdensome to the environment and society. The term "life cycle" implies that a thorough and fair assessment of a product has been conducted, reviewing everything from raw material production, manufacture, distribution, use, maintainence and disposal and all intervening transportation steps. A full LCA of a product, service, or company can be daunting, and inaccurate or missing data can greatly sway results and are highly dependant on the cooperation of the supply chain in accurately reporting the energy, wastes, and costs throughout the manufacturing process. For these reasons, the uncertainty of the accuracy in an LCA can be quite large.

The International Standards Organization (ISO) has created a procedure for conducting an LCA. This procedure can be found in ISO 14000s for environmental management. More specifically, ISO sections 14040:2006 and 14044:2006 address Life Cycle Assessment.

Life Cycle Management integrates sustainability and life-cycle assessment thinking into everyday management, planning, and decision-making processes, using various approaches, concepts and tools and operating at either a management system level, a program level, or a technical level. Organizations can further deploy each of these systems, programs, and tools in different ways. However, to be effective, the introduction of LCM in an organization must be an upper-management decision and aligned with an organization's policies and strategy (UNEP 2005).

The entry of LCM concepts into a public entity typically correspond to an organizational function, such as planning, public works, engineering, airport operations and public health or environmental health and safety (EHS). It is often an organization's department of environment or sustainability who initially suggests implementation of a life cycle management system. However, in public organizations, many times it is the general public that compels an organization to adopt sustainability approaches to decision making.

The following sections examine the development patterns of the Phoenix metropolitan area, the main urban environmental and sustainable development issues facing the region, and ideas for prioritizing these issues. Emphasis will be given to sustainability in the urban built environment and will lay the groundwork for the strategies presented in this guidebook.

Rapid Urbanization

International attention is being paid to sustainable development at a time when urban areas are gaining an estimated 67 million people per year—about 1.3 million every week, during the greatest population increase our planet has ever witnessed. By 2030, approximately 5 billion people are expected to live in urban areas—60% of the projected global population of 8.3 billion (United Nations 2002).

The rapid urbanization of the **Phoenix region** exemplifies what is occurring around the globe. Arizona has one of the fastest growing populations in the US and the Phoenix area is one of the most rapidly urbanizing regions. As presented in Figure 1-3, rapid urbanization has transitioned native vegetation to manmade materials used for buildings and transportation networks over the years 1912 to 2000.

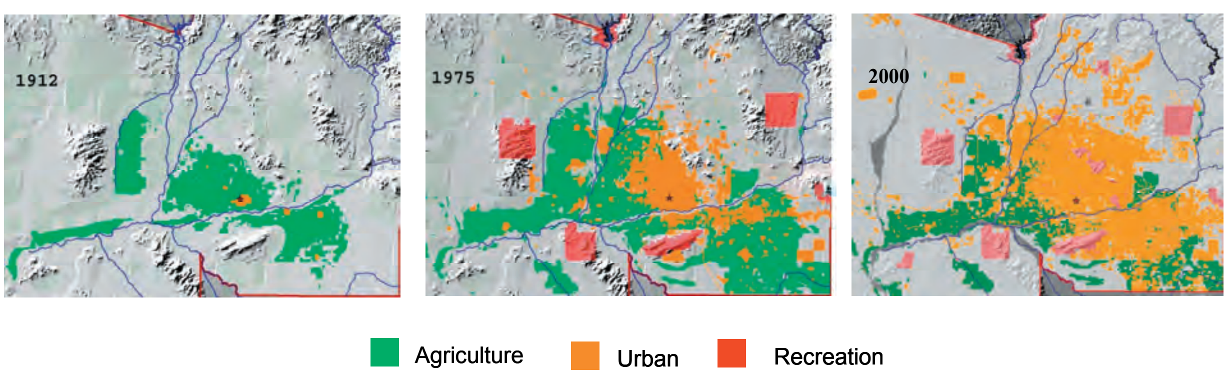


Figure 1-3. The rapid urbanization of the three-county Phoenix region 1912, 1975, and 2000.
Source Maricopa Association of Governments (MAG)

Phoenix has an arid, semitropical climate, with an average of 300 sunny days per year and 89 days during which the temperature reaches or exceeds 100°F (38°C). Most of these warmer days occur from early June through early September.

In 2007, beginning on April 24th, there were 112 days during which Phoenix reached over 100°F. This is nine days more than Yuma and 51 days more than Tucson, Arizona. During that same summer, a new record of 32 consecutive days over 110°F was recorded in Phoenix. The normal annual rainfall recorded at the Phoenix Sky Harbor Airport is 8.29in (211mm) with the wettest time in March, averaging 1.07in (or 27mm) (Schmidli 1996).

The climate of Phoenix is similar to many of the world's most rapidly urbanizing regions. Areas of China, the Middle East, South America, and India will all face climatic and natural resource challenges similar to Phoenix as they rapidly urbanize. Figure 1-4 below, taken from the recent UN's Millennium Ecosystems Assessment Report, shows major urban centers located in dryland systems around the world (United Nations 2005).

Table 1-1 displays urban population and densities within different world ecosystems on each major continent. The Phoenix region is a dryland ecosystem.

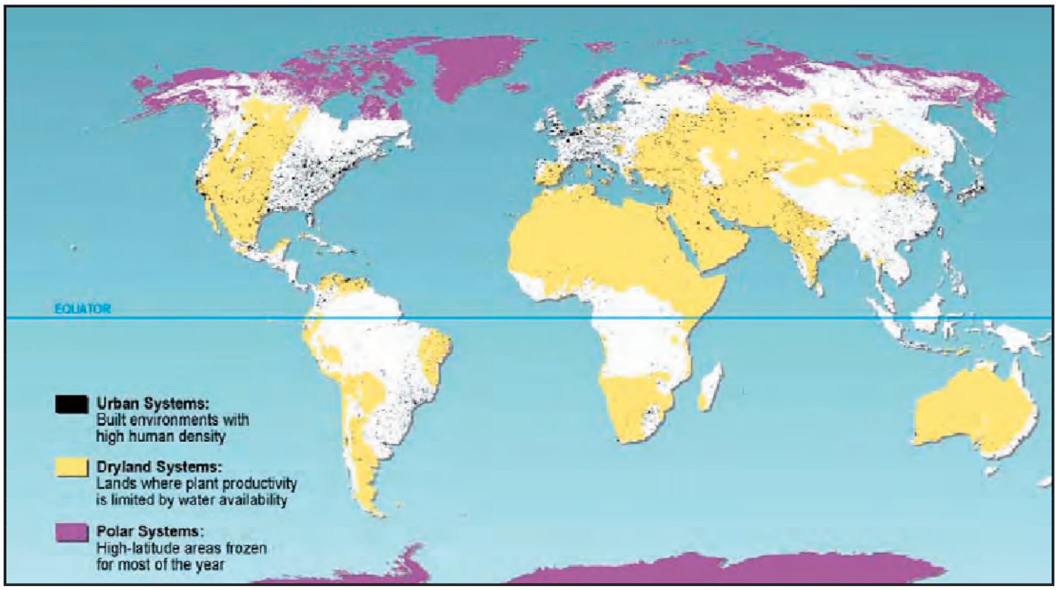


Figure 1-4. Urban and dryland systems of the world. Source: UN Millennium Ecosystems Report, 2005

System	Africa	Asia	Latin America	Oceania	Europe	North America	World
Share of population that reside in urban areas							
			(percent)				
Coastal	71.5	55.7	82.1	89.2	83.7	90.4	64.9
Cultivated	40.5	36.6	68.8	71.1	71.6	97.5	45.3
Dryland	43.5	37.7	67.0	54.2	67.4	**88.2**	44.8
Forest	22.7	23.2	58.9	47.0	56.2	69.3	35.6
Inland water	51.2	41.3	74.6	80.5	79.1	85.3	51.8
Mountain	21.7	23.0	57.8	12.4	47.9	66.1	30.3
Overall	38.4	37.5	67.9	70.8	70.9	81.5	46.7
Urban population density							
			(persons per square kilometer)				
Coastal	2123	1934	789	610	640	497	1119
Cultivated	1279	1352	548	300	630	258	793
Dryland	1200	1034	541	159	522	**265**	749
Forest	967	956	685	300	387	206	478
Inland water	1647	1536	655	451	604	302	826
Mountain	810	879	746	191	387	154	636
Overall	1278	1272	656	427	588	289	770

Table 1-1. Urban population and densities by major ecosystems and continent (CIESIN et al. 2004)

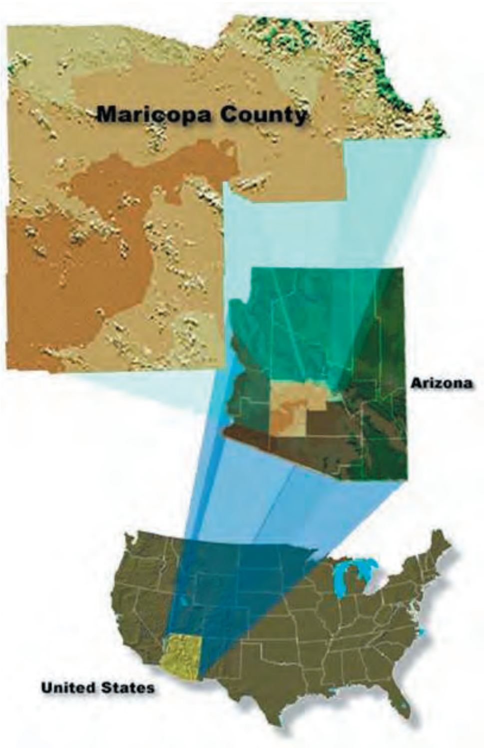
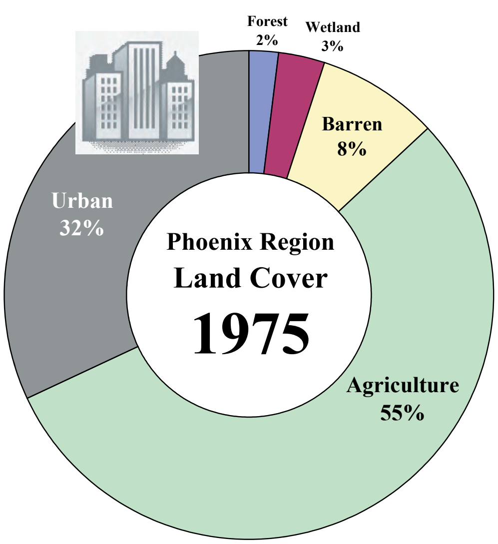


Figure 1-6. The Phoenix region is located in the desert Southwest. The City of Phoenix is located in Maricopa County. However, the Phoenix metro area stretches into the counties of Yavapai and Pinal.

Phoenix, the capital of Arizona, has a population of over 1.5 million people, making it is the fifth-largest city in the US. The population has grown by 15% since 2000 when it was ranked as the 14th most populous city in the nation, and Phoenix now has a population density of 3,186 people per square mile. The **Phoenix metropolitan area** includes 23 cities and towns and 3.3 million people. The 1970s to 1990s were times of rapid growth in population and developed land. While development has become denser since the 1970s, the average density increase is relatively low at two households per acre, and most development is spread out, similar to the development patterns introduced in the 1950s. The US EPA selected Phoenix as one of five states to receive demographic data review from the period 1970 to 2000. This study explored the relationship between population growth, land development, and other indicators of both environmental health and quality of life (US EPA 2000).



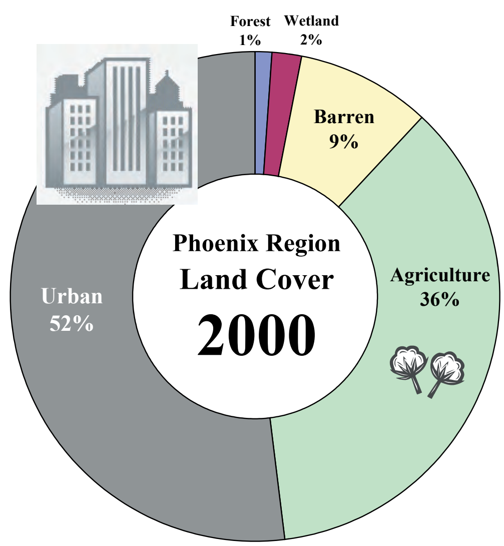


Figure 1-7. Land-cover change from 1975-2000 in the Phoenix area, shows a clear increase in urban land cover and decrease in agricultural land (Data Source: Analytical Tools Interface for Landscape Assessments (ATILA) metric data).

Agriculture was the dominate land cover in the area up to the 1970s. Fields of cotton, citrus, and wheat were in close proximity to the city, and spread to the southeast along the natural water flows. Cattle and dairy farms were also a major source of income. As the population grew, much of this agricultural land was converted into residential subdivisions and commercial properties. Agricultural land conversion was most economical as this land was accessible by road and adequate supplies of water were already allocated to these properties. As the city expanded, it also grew to the north, where much of the land was state desert land and required full scale land development, placing more infrastructure costs on the developers.

Over the 30-year period of 1970-2000, the average urban population density in the Phoenix region slightly increased to 5.89 people per acre (2.59 = 1 average US household in 2000). A transportation research study suggested that this population density is much lower than the 15 people per acre needed to support public transit (Ewing 1999). When only new development in the metropolitan areas is considered, the trend is much different. During each decade from 1970 through 2000, population density was 30% more dense in the new development areas than the areas developed during the preceding decade (Figure 1-8). This trend is likely to have continued since 2000 with new multifamily residential buildings in both infill locations and on the newly developed fringes.

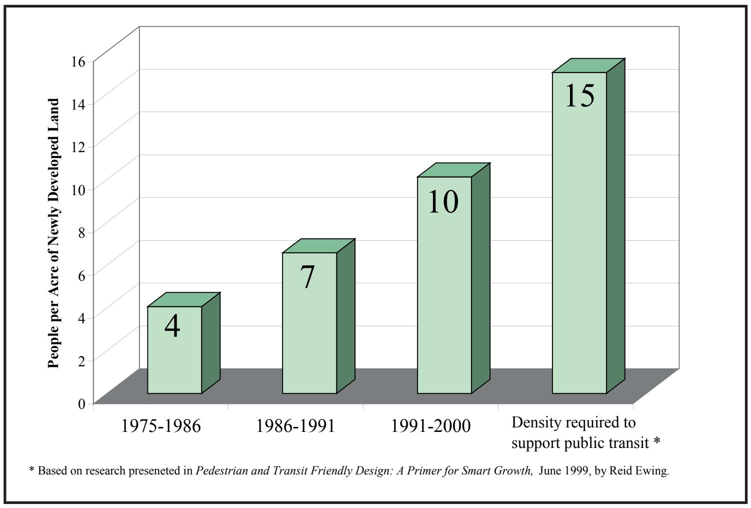


Figure 1-8. Phoenix Population Density of New Development (Sources: Analytical Tools Interface for Landscape Assessments [ATILA] metric data and US Census).

The population of **Maricopa County**, which includes most of the Phoenix metropolitan areas, is expected to more than double over the next 50 years from its population of 3.7 million in 2006 to 7.9 million by 2055 (AZ Department of Economic Security). This continued growth will drive the construction for new living, working, and recreational facilities and has the potential of increasing the urban environmental problems that Phoenix already faces. Planning for this growth will require a new approach to development—one that is environmentally, economically, and socially sustainable.

Next, we will discuss the most common environmental problems found in the urban areas of developed nations. Particular attention is given to the problems that the Phoenix region faces as it continues to grow and mature.

Urban Environmental Problems

Urbanization over the last century has resulted in many environmental problems, including atmospheric pollution, depletion and degradation of forests, deterioration of water resources, loss of countless species, and rapidly declining marine resources, all of which can be linked directly or indirectly to human activity.

Urban centers are situated within a variety of natural ecosystems. These concentrations of human activity affect and are affected by natural cycles. Urban areas import water, energy, and materials which are transformed into goods and services

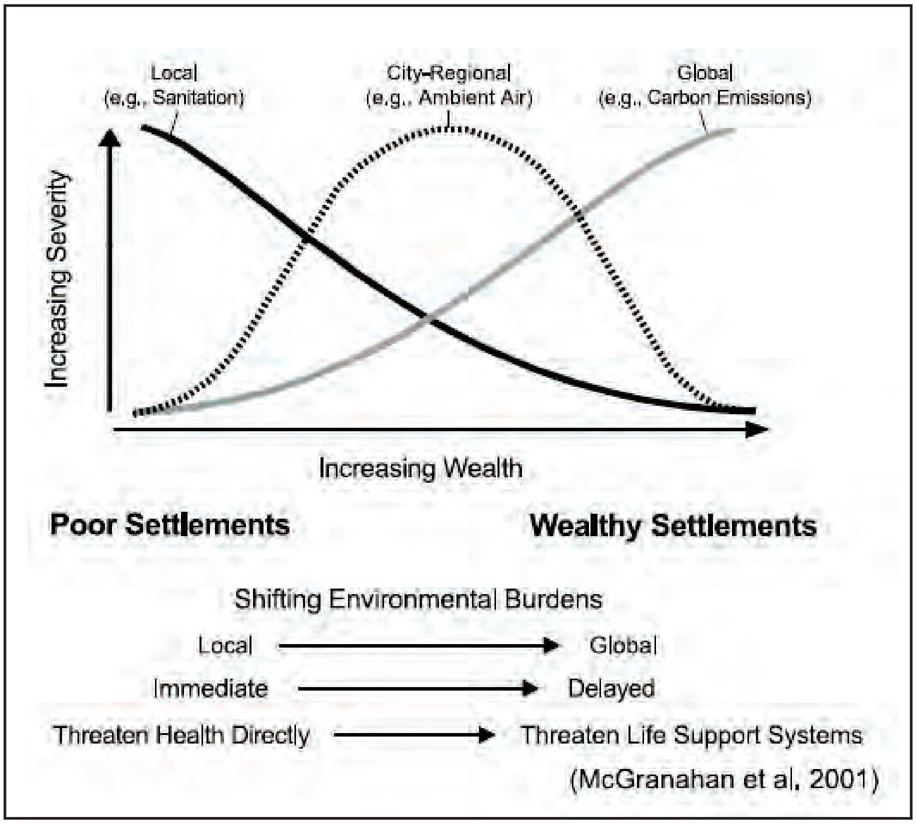


Figure 1-9. The shifting environmental burdens as wealth of cities increase.
Source: McGranahan et al. 2001

and then released back into the natural system in the form of air emissions, waste, and degraded energy. Degraded energy is defined here as energy that is released into the environment that no longer serves a useful purpose. Exhaust heat from combustion, noise from machinery, and solar thermal energy stored in urban construction materials are all examples of degraded energy that affect the ambient environment. When urban centers exceed the natural capacity of the local ecosystem to assimilate and process these wastes they ultimately cause a shift or change in the local, regional, and even global environment. The environment within urban centers directly affects the health, productivity, comfort, and well being of its inhabitants. Urban environmental pressures can come from a variety of sources including air pollution, noise, traffic congestion, thermal climate change, and poor land use. These pressures will often increase as an area becomes more densely urbanized if the necessary infrastructure is not effectively planned and implemented to meet this growth.

Urban environmental problems can also have different consequences at different spatial scales. If we think of these three spatial scales as local, regional, and global, we can better define these problems and describe how they impact the environment around us. Historically, the burden of environmental problems is shifted as societies experience economic development (Figure 1-9). Where poor settlements battle with sanitation that impact human health, wealthier cities are able to shift these environmental burdens away from the local level. The resulting shift, however, has a far greater impact on the systems at a global scale.

Problem and Characteristics	Intra-Urban (Urban Systems as Human Habitats)	Urban-Region (Urban Systems and Their Biospheres)	Urban-Globe (Urban Systems and Global Ecosystems)
Priority Problem Identified	unhealthy and unpleasant living environments	deteriorating relations with adjoining ecosystems	excessive "ecological footprints"
Urban areas most closely associated with problems	low-income cities and neighborhoods	large, middle-income, industrial cities	affluent cities and suburbs
Indirect driving forces	demographic change, inequality; trade and development that ignores ecology of infectious diseases and urban ecosystem services	industrialization, motorization; trade and development that ignores impacts on adjoining ecosystems	material affluence, waste generation; trade and development that ignores global ecosystem impacts
Direct driving forces	inadequate household access to safe water, sanitation, clean fuels, land for housing	ambient air pollution, groundwater degradation, river pollution, resource plundering, land use pressures	greenhouse gas emissions, import of resource and waste intensive goods (linear vs. circular flows)
Negative impacts associated with problem	spead of infectious diseases, loss of human welfare and dignity	loss of natural ecosystem services, "modern" diseases, declining agroecosystem productivity	global climate change, loss of biodiversity, depletion of globally scarce natural resources
Temporal characterization of key processes	rapid	varied	slow
Example of historically relevant response	sanitary reform	pollution controls	sustainable ciites?

Table 1-2. Priority problems in urban systems and ecosystem services at three different spatial scales Source: UN 2005

The urban environmental problems can be grouped into three general categories:

1) *Over Consumption of Energy, Water and Material Resources*
2) *Production of Waste, Harmful Emissions and Degraded Energy*
3) *Lack of Infrastructure to Ensure Health and Well Being of Inhabitants*

The urban environmental problems outlined above characterize the most pertinent issues in both the developing and developed world. Each urban center also has its unique problems that relates to the geographical location, historical development patterns, and lifestyles of its inhabitants.

Development in the Phoenix region is unique in that it is...

- *the fastest growing metropolitan area in the country*
- *centered in one of the driest and sunniest climates in the world*
- *has a finite water supply and a recent history of drought*
- *spread out, creating a dependency on personal automobiles for transport*
- *dependant on other regions for most of its food, water, materials, and energy*
- *has a pronounced urban heat island*

These regional problems present both challenges and opportunities. The following sections discuss these regional sustainability issues in greater detail and their implications for future development in the Phoenix region. They are presented within the three major contexts that affect all urbanized centers.

Overconsumption of Resources

ENERGY

Urban quality of life and the environmental quality of modern cities directly correlates to energy. The development, operation, and renewal of urban centers dramatically impacts energy consumption. A World Bank study shows that a 1% increase in capita GNP leads to an almost equal increase in energy consumption (Santamouris 2000). This study also reported that energy consumption increased twice as fast as the rate of population growth in urban areas (2.2% per 1% in population change).

For developed nations, the greatest priorities for cities should be aimed at reducing overconsumption, increasing the use of renewable resources, and limiting the production of waste and degraded energy to a level that can be handled by the local and regional ecosystems that support the urban area.

Energy Production and Utilization

Understanding energy production and utilization is one of the most important components of sustainable development. Viewing energy from a historical perspective reveals how quickly energy production and utilization became a part of modern society and also offers insights into what to expect for global demand as other nations begin to follow the same energy-hungry patterns and dependence. First, the primary energy sources categories will be defined. This will give a background to the trends of the nation's acquisition and use of energy over the last fifty years.

Primary energy can be grouped into three broad categories: fossil fuels, nuclear, and renewable energy. The largest energy source, **fossil fuels,** constitutes 80% of the US energy fuel mix, includes coal, petroleum, and natural gas. The annual consumption of fossil fuel in the US in 1949 was 29 quadrillion British thermal units (Btu). In 2006 this consumption had reached 85 quadrillion Btu (EIA 2007).

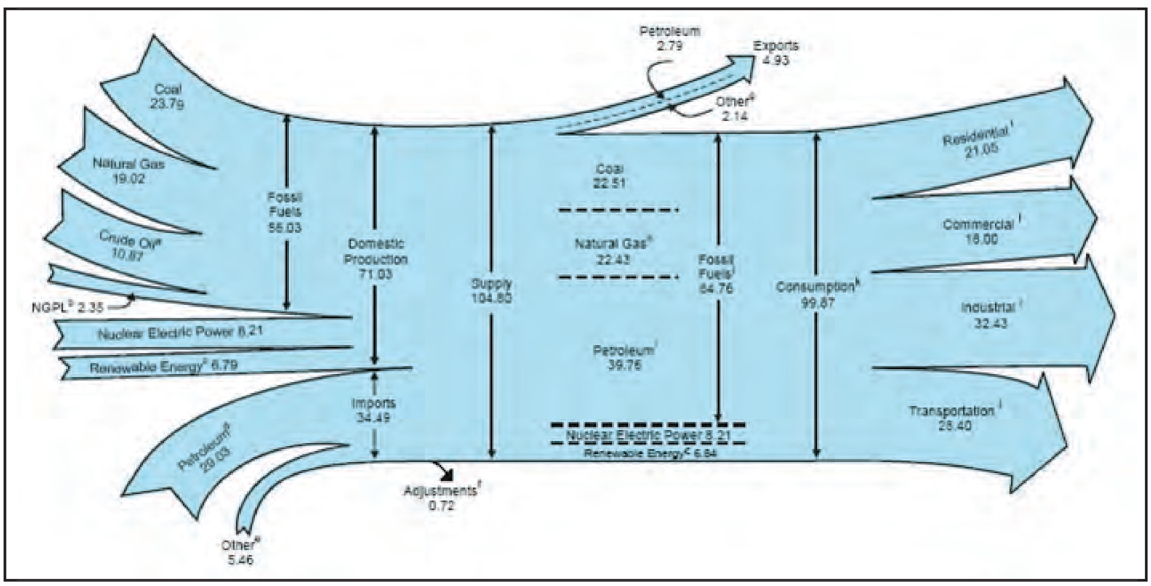


Figure 1-10. United States energy flows from source to utilization in 2006 (Quadrillion Btu) Source: EIA, 2007

Nuclear power was used for the first time in 1957 and experienced rapid growth through the eighties, leveling off in the nineties and remained fairly constant since. In 2006, nuclear energy was responsible for 19% of all electrical production in the US and 8% of all energy (EIA 2007). While nuclear energy does not contribute to global warming, the spent cores are highly radioactive and there is no know permanent disposal method, presenting a unique and dangerous long-term environmental problem.

Renewable energy is naturally regenerative energy, as opposed to fossil fuels and nuclear power which are based on finite resources. Renewable energies typically have replenish cycles of several years or less (Figure 1-11). The major forms of renewable energy include: hydro; bio-energy - including biomass (wood and agricultural waste), biofuel (plant derived ethanol and biodiesel), or biogas (methane); geothermal; solar; and wind. Before the 19th century, wood was the primary fuel source with wind and hydro also in use. Renewable energy has recently gained attention once again as the world is more aware of the limited supplies and impacts of fossil fuel dependence. In 2006, renewable energy accounted for only 7% of US total energy consumption (EIA 2007), and 42% of this was hydroelectric power generation. Due to government policies and incentives, renewable energy is expected to be the fastest growing energy sectors in US in the following decades.

Energy Source	Typical Time to Replenish this natural resource after it is used	
Solar Energy photovoltaic, solar thermal or passive solar	Seconds	RENEWABLE RESOURCES
Wind Power energy from wind	Seconds or Minutes or Hours	
Hydropower energy from flowing water	Days or Weeks or Months	
Bioenergy biomass energy	Months or Years or Decades	
Fossil Fuels coal, oil, and natural gas	Millions of Years	NON-RENEWABLE RESOURCES

Figure 1-11. Energy sources and typical times to replenish
Source: Salt River Project, 2004

Historical Background

In 1950, energy production from petroleum outpaced the use of coal, and remains the single largest energy source, mainly in the transportation sector. In the 1960s the growth of automobile ownership caused the US's petroleum consumption to outpace its production, and the US began importing energy from other countries. Relations and import costs with these exporting countries are likely to be intensified as petroleum demands increase in the US and globally over the coming decades. The US dependence on foreign oil is an important matter of national security, leading politicians to consider alternative sources and energy conservation for more than just environmental reasons. Coal remains the largest energy source for electrical power generation, and the US produces all of its own electrical energy.

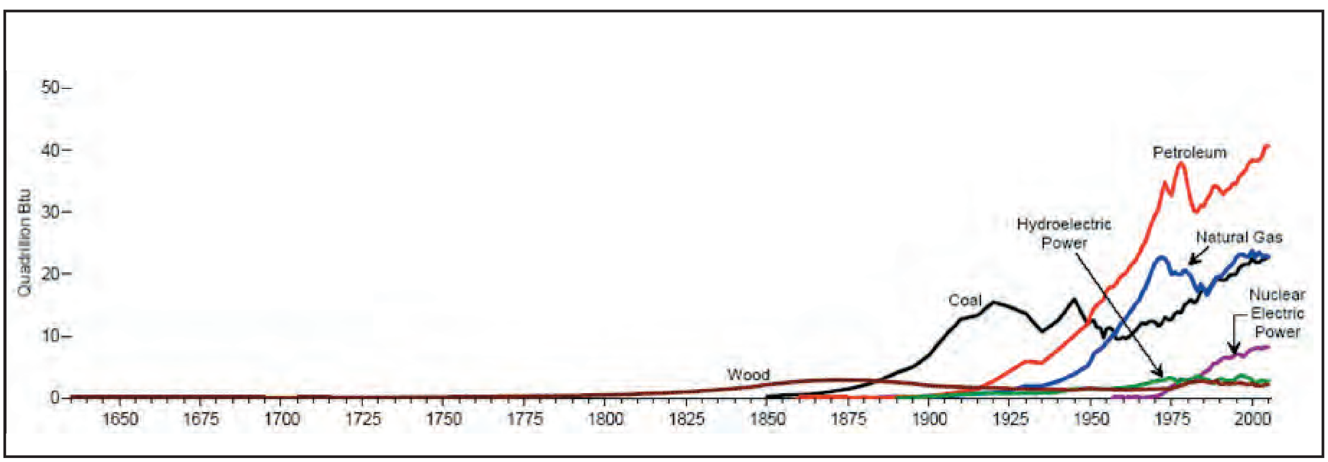


Figure 1-12. US Energy consumption by source from 1635 to 2006. EIA 2007

Energy use per person in the US was roughly 215 million Btu in 1949 (Figure 1-15). This increased until the late 70's and has remained around 330 million Btu since. The leveling effect may be evidence of efficiency improvements from generation to the end use since the 1970s. Despite this leveling off, it is over 50% more than per capita consumption in 1949.

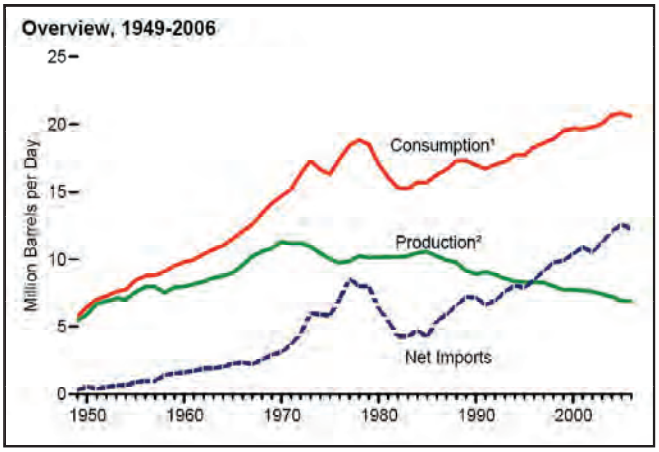


Figure 1-13. US petroleum consumption, production and imports since 1949. Source: EIA, 2007

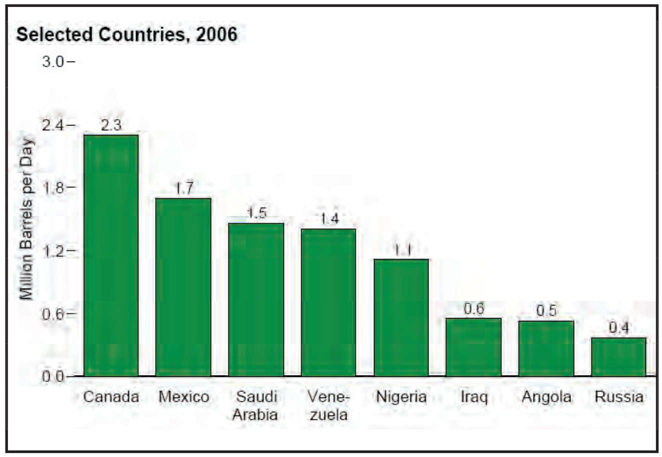


Figure 1-14. Barrels of petroleum imported every day from various countries in 2006. Source: EIA, 2007

Another interesting trend is the amount of energy consumed, compared to the normalized value of one dollar's worth of US output of goods and services. Since the 1970s there has been a decline in the energy required to produce one dollar worth of product (Figure 1-16). This could be the result of improvements in efficiency or the gradual change of the economy from manufacturing to services.

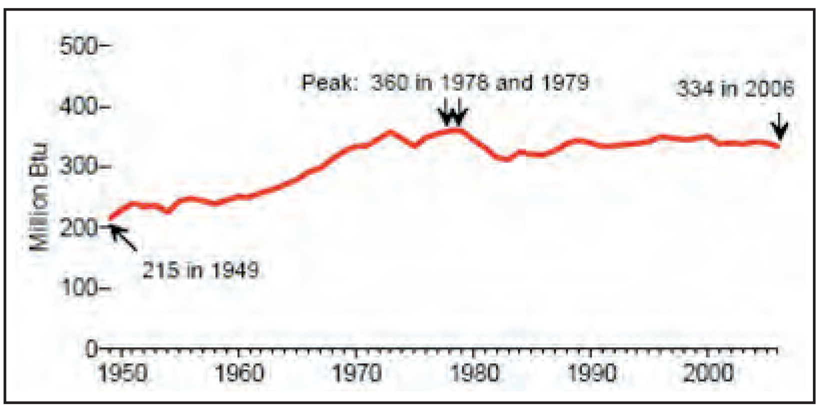


Figure 1-15. Energy consumption per person in the United States from 1950 to 2006. Source: EIA, 2007

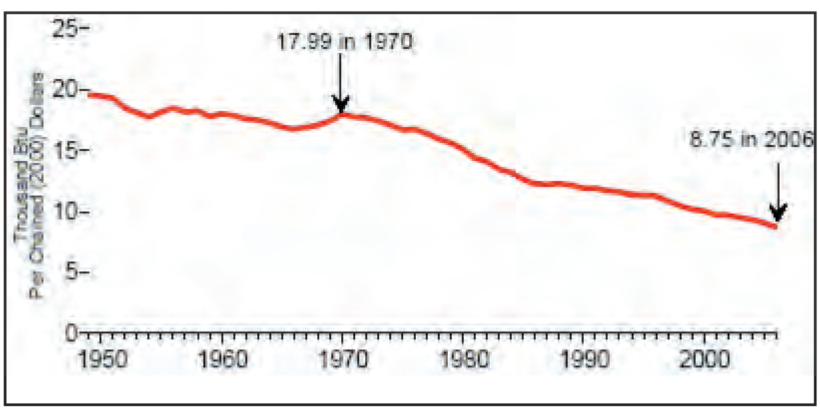


Figure 1-16. Energy use per real dollar of gross domestic product. EIA, 2007

Fossil fuels have dominated energy consumption in the US since the late eighteen hundreds while renewable energy (hydroelectric) has remained steady. In 1988, nuclear power exceeded renewable production (Figure 1-17).

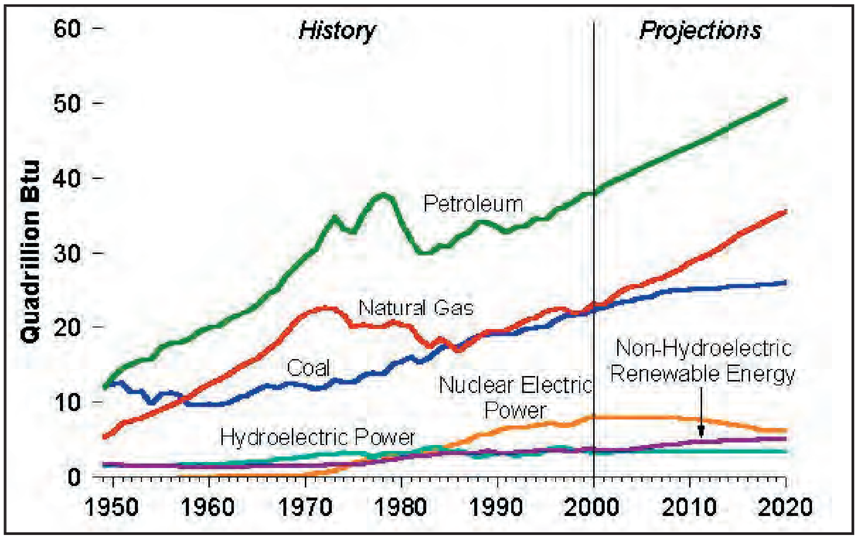


Figure 1-17. Historical energy consumption and outlook for the US, 1949-2030.
Source: EIA 2007

The future of energy consumption in America, assuming current laws, regulations, and policies, is not much different than what we see today. Projections show growth at a steady rate for all sources except for natural gas and nuclear energy, which remain constant (Figure 1-17). With the exception of any major discoveries or policy changes in the near term, our reliance on fossil fuels; petroleum, natural gas, and coal will most likely continue to intensify.

Renewable energy is one possible alternative to fossil fuels and imported petroleum. Government policies, technological efficiencies and current production methods continue to limit the expansion of renewable energy mainly because change to these technologies is not economically sustainable for utility companies. Hydroelectric power comprises most of the nation's current renewable energy, but due to environment restrictions and limited water supplies, no new hydroelectric power plants are planned for the near future. Biofuels have seen a rapid increase over the last four years with new ethanol and biodiesel plants popping up all over the Midwest. Due to the competing needs for corn and other agriproduct sources, the increase demand for biofuels are expected to force corn prices to increase, also affecting the costs of meat production and other products. In addition to food supply concerns, corn production is enhanced with nitrogen-based fertilizers created using petroleum. The balance of energy and emissions associated with production and combustion are leading experts to discourage the future development of biofuels using conventional growing techniques.

Greenhouse Gas Emissions from Energy Generation

Carbon dioxide (CO_2) is the most significant greenhouse gas in the atmosphere. The other greenhouse gases: methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) are just as dangerous but not being emitted at the rate of CO_2. The carbon in fossil fuels combines with oxygen during combustion to form carbon dioxide. In 2005, carbon dioxide emissions in the US reached 6 billion metric tons, up nearly 20% over 1990 levels (Figure 1-18). Combustion of fossil fuels in electrical power production and transportation are the primary sources of anthropogenic CO_2 emissions that have led to global warming.

While the general industrial sector decreased carbon emissions from 1980 to 2005, the transportation, and residential and commercial sectors are continuing to rise (Figure 1-19). The residential and commercial carbon emissions are directly related to the electrical and natural gas energy used within buildings. The commercial building sector has seen a 60% growth rate

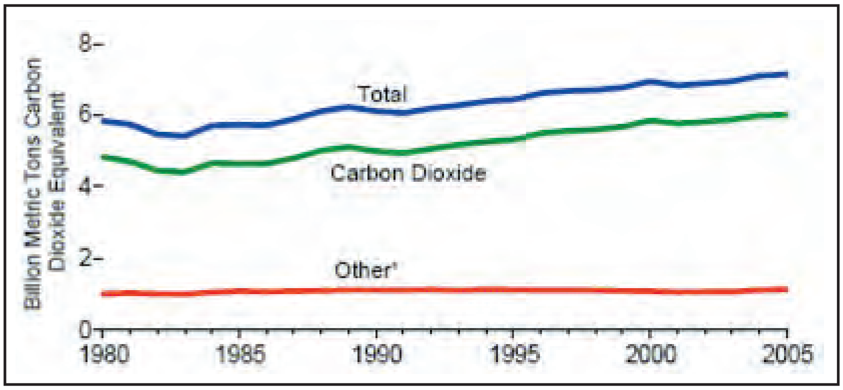


Figure 1-18. Greenhouse gas emissions, based on global warming potential. Source: EIA, 2007

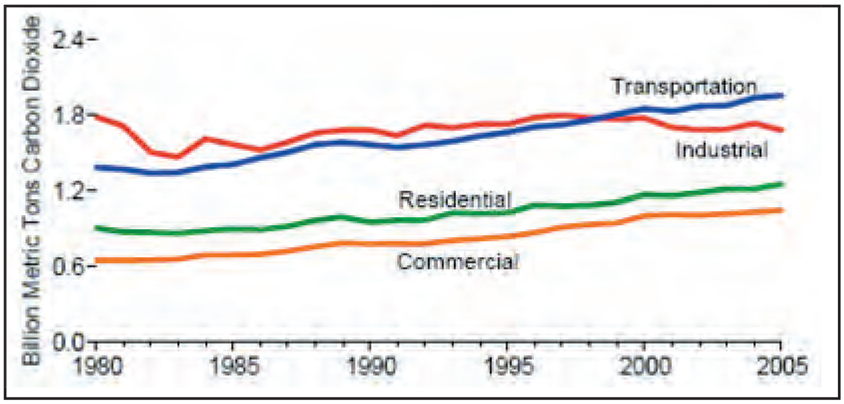


Figure 1-19. Carbon dioxide emissions from energy use. Source: EIA, 2007

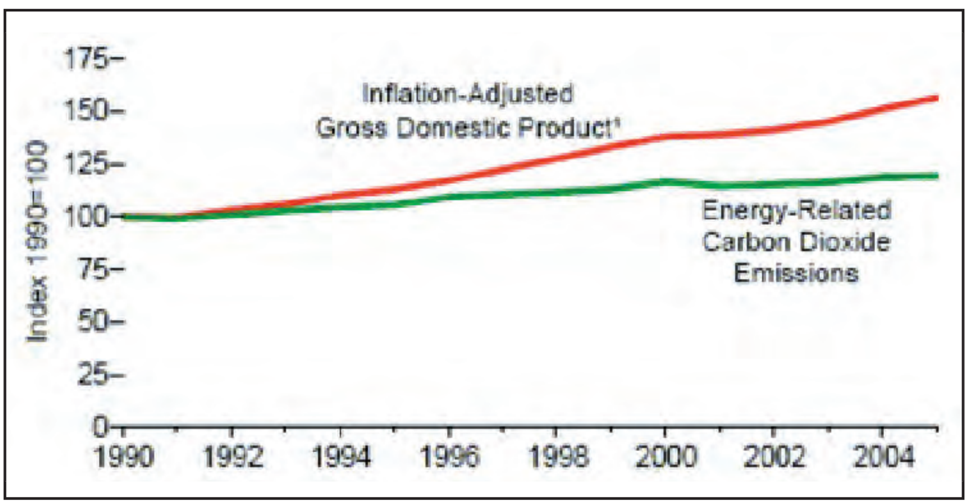


Figure 1-20. Gross domestic product versus energy related carbon dioxide emissions. Source: EIA, 2007

since 1980s in CO_2 related emissions. Slowing this trend requires new energy cognizant approaches to the way buildings are designed and operated.

The installation of efficiency improvements and emissions controls on power plants has created a recognizable decrease in the CO_2 emissions. The decoupling of GDP and energy related consumption since 1990 suggests that economic growth is possible without the increase of energy consumption. All this leads to the conclusion that energy production, and energy use must be more tightly regulated and controlled to reduce US carbon dioxide emissions.

Methane emissions were 9% of total greenhouse gas emissions in 2005. Energy, waste management, and agricultural activity account for nearly all methane emissions in the US. 60% of energy related methane releases is during the production, processing and distribution of natural gas (EIA 2007).

Energy Use and Vulnerability in Arizona and the Phoenix Region

Arizona boasts the most solar potential in the US and yet energy production in the state is almost entirely based on fossil fuels. The state has a substantial amount of natural coal deposits, concentrated in the northeast Navajo area of the state in an area called Black Mesa Basin, but few other fossil fuel resources.

Figure 1-21. Arizona energy sources, power plants and electricity transmission locations. EIA 2007.

Large volumes of coal are transported within and out of the state on railways, with one third of the coal mined in Arizona delivered to Nevada while the other two thirds are burned at generators around the state. The remainder of energy used in Arizona is from natural gas, nuclear and hydroelectric power.

Several major natural gas pipelines originating in Texas and the Rocky Mountains supply Arizona markets as they flow towards southern California. Three fourths of this natural gas is used for electrical generators, and the remainder for residential and industrial heating.

Nuclear power comes from the state's sole nuclear plant, Palo Verde. The plant, located 60 miles outside of Phoenix provides about a quarter of the state's electrical power and is the nation's largest nuclear plant. Glen Canyon Dam and the Hoover Dam both sit on the Colorado River in northern Arizona and produce the state's largest renewable energy supply.

Arizona has the greatest potential for using solar power in the country but because of the ample supply of coal and nuclear power in the area, solar generation facilities are few. Even passive solar technologies such as solar hot water collectors are in limited use, making plant generated electricity the primary energy source for both heating and cooling buildings.

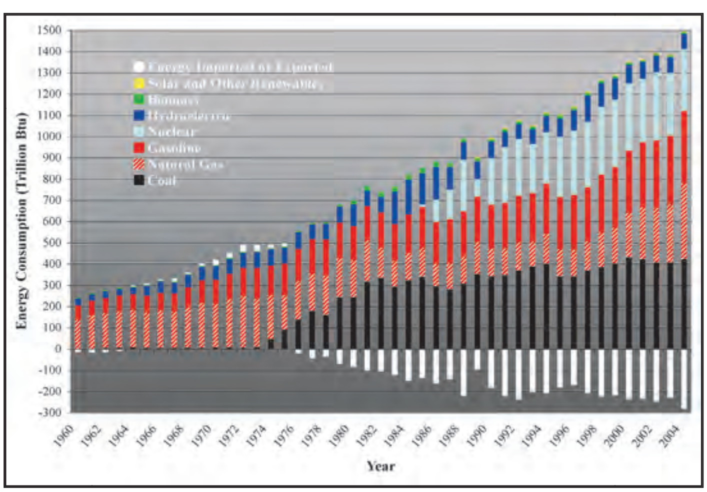


Figure 1-22. Energy sources in Arizona from 1960 to 2004. Negative consumption values on the graph indicate exported energy outside of Arizona. Source: EIA, 2007

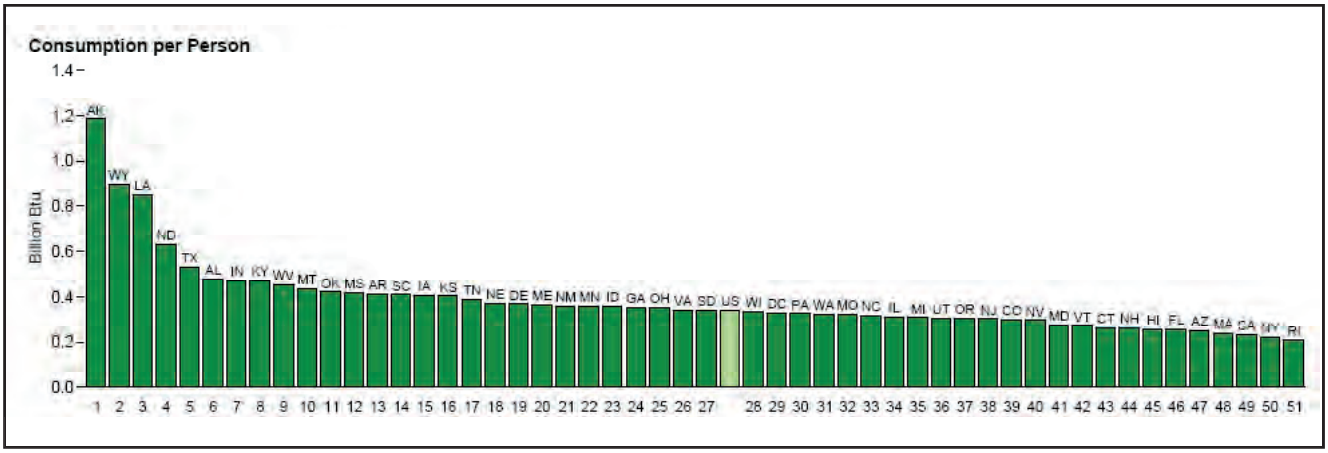


Figure 1-23. Energy consumption per person by US State. Arizona is among the lowest per capita energy consumption in the US in 2006. Source: EIA, 2007

When compared to other states' per capita (per person) energy consumption, Arizona is the fifth lowest in the United States. However, the graph in Fig. 1-23 may be misleading as an indicator of how much energy the average person uses, as it expresses gross usage in the state. In states with heavy manufacturing and/or mining industries such averaging will show considerably higher per capita consumption than states having high populations or service oriented economies. In comparison with other states, Arizona does not have an energy intensive economy.

The majority of energy used by the average Arizona consumer is in the form of electricity. In 1999, the total electrical energy consumed in Arizona amounted to 58,143,730 MWh. This electrical demand was met by a diverse fuel mix comprised of 46% coal, 36% nuclear, 12% hydro electric, and 6% gas (DOE 1999). Arizona's electrical generation was nearly twice that consumed at 107,965,747 MWh. Much of this excess energy is lost in energy distribution, called line losses, or it is distributed and sold to other states, predominately Nevada and California. As of 2000, there were 22 generation plants in Arizona operated by eight companies.

Generator Operator	Annual Generation (MWh)
Arizona Electric Power Coop Inc.	3,459,141
Arizona Public Service Co	55,149,770
CalEnergy Company Inc	440,836
Salt River Proj Agr lmpr & Pwr Dist	28,660,576
Snowflake Division	212,993
Tucson Electric Power Co	7,566,594
USBR-Lower Colorado Region	6,964,807
USBR-Upper Colorado Region	5,511,030
Total In-State Generation	107,965,747

Table 1-3. Arizona generation by operation, 2000. (Source: U.S. DOE, 2000)

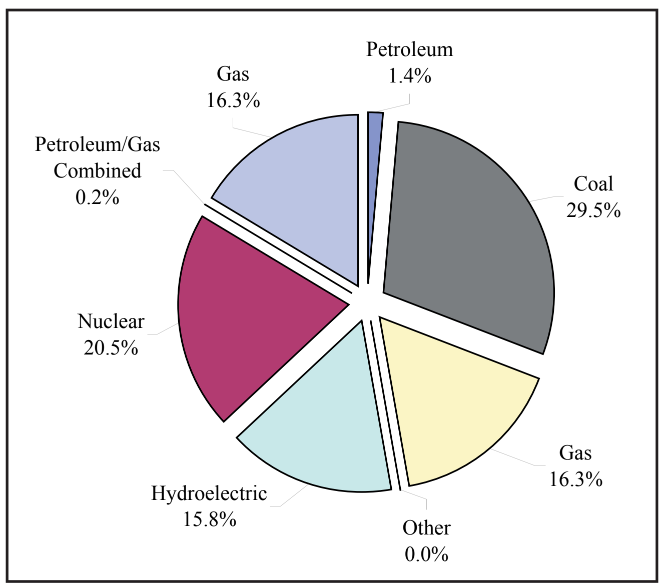


Figure 1-24. Industry generating capability in Arizona by primary energy source, 1999. Source: U.S. DOE, 1999

The generating mix capacity in Arizona as reported by the Department of Energy (DOE) shows a potential balance between fossil fuels, nuclear, and hydroelectric as shown in Figure 1-24. Actual generation in Arizona, however, is much more heavily dependent on coal and nuclear, as these two energy sources offer the most inexpensive and readily available energy in Arizona. (Figure 1-25)

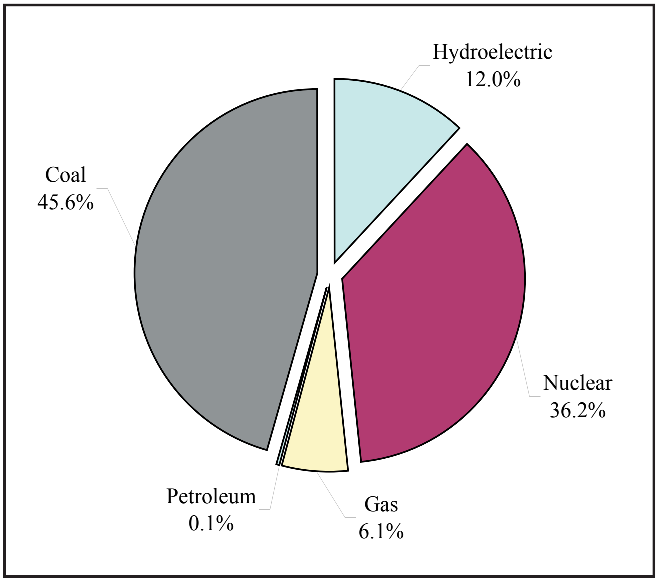


Figure 1-25. Actual industry electrical generation by energy source in Arizona, 1999. Source: U.S. DOE, 1999

Arizona does not currently have a petroleum refinery and relies on two pipelines to supply petroleum products such as gasoline, diesel and aviation fuels One pipeline originates in Southern California and one from El Paso, Texas. The lines are vulnerable to disruption and can have major implications on the gasoline supply in the Phoenix region. In the summer of 2003, a rupture in the line from El Paso shut down the line between Tucson and Phoenix for several days, causing a fuel shortage in the Phoenix area. To alleviate the pressure on petroleum supplies, a new refinery in Yuma, Arizona is proposed to be operational by 2010. The refinery would receive crude oil piped in from Mexico to produce an oxygenated motor gasoline blend which is used year round in the Maricopa County to limit automobile impact on air quality.

The electric power industry in Arizona ranked 18th highest in carbon dioxide (CO_2) emissions in 2004 and continues to rise as energy production increases, and coal remains the dominant energy source. Other combustion related pollutants include sulfur dioxide (SO_2), and nitrogen oxides (NO_x). Due to new air emissions control regulations both SO_2 and NO_x have been on a downward trend since 1989 (Figure 1-26).

Renewable Energy Policy and Incentives

Solar Energy in Arizona

Global spending on solar is expected to increase from $2.3 billion in 2006 to more than $16 billion in 2010. In Arizona, utility incentives to help buy down the cost of solar energy systems has increased from $500,000 in 2003 to more than $12 million in 2006. Combined with local and federal incentives, solar funding for Arizona ratepayers could reach $30 million by 2010 (Arwood 2006).

The Federal Energy Policy Act of 2005 (EPACT 2005) allows homeowners a federal tax credit of 30% for qualifying solar electric (PV) or solar water-heating expenditures, up to a maximum of $2,000 per technology. For businesses, the incentives have also been increased from 10% to 30% with no cap limit. EPACT

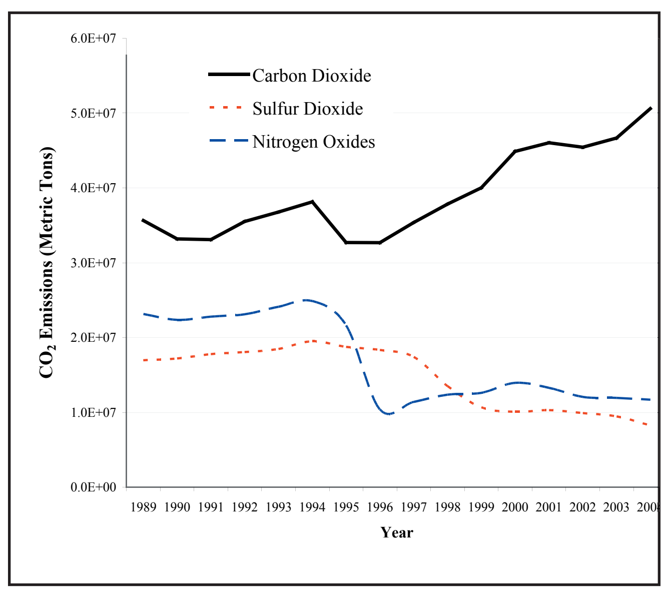


Figure 1-26. Arizona airborne emissions, electricity sector, 1989-2004, metric tons. Source: EIA-767 and EIA-906 Survey, Energy Information Administration.

2005 only allotted for two years of incentives, but companion bills are likely to continue the incentives through 2015 (Arwood 2006).

The **Western Governor's Association (WGA)** chaired by Arizona Governor Janet Napolitano met on June 11, 2006 to adopt a broad based set of proposals for meeting future energy needs of the region. They released a report entitled "Clean Energy, a Strong Economy and a Healthy Environment". The goals set in the report are to develop 30,000 megawatts of clean power by 2015, increase energy efficiency by 20%, and ensure secure, reliable transmission for the next 25 years (WGA 2006). The report made sixteen different recommendations to increase and extend the production tax credit for renewable-energy technology for 10 years and to raise the cap on residential investment tax-credit to $10,000 for renewable energy or distributed-generation systems.

The **Arizona Corporation Commission (ACC)** became a leader in renewable energy regulation when it required that Arizona utilities have at least 1.1% of their generation mix from renewable sources. In 2006 the ACC increased that commitment to 15% by 2025.

One provision in the Commission's new Renewable Energy Standard is a 30% set-aside for distributed energy sources. This includes rebates to customers that generate their own electricity on site from renewable energy, and expands the eligible equipment to more then just solar PV and water heating.

With so many incentives and government requirements, solar energy should be booming in Arizona and around the United States. The demand for photovoltaic solar energy systems is unfortunately outpacing production, leading to higher costs globally. The main source of this lag is the production of polysilicon, the base material and most critical component of photovoltaic technology. According to Michael Rogol of Credit Lyonnais Securities Asia (CLSA) in a recently published report on the shortage of polysilicon, as recently as five years ago the solar industry silicon demand was quite small. Since 2001 the market has skyrocketed, resulting in 48% of the global silicon production going towards solar and the other 52% to the electronics industry. Another 40% growth in the solar industry was experienced in 2006 but the silicon supply only grew from 36,000 tons to 38,000 tons between 2005 to 2006. Rogol predicted that the production is not expected to catch up to demand until 2010, when the production of raw silicon is expected to double current production to nearly 85,000 tons a year.

In 2005, silicon solar cell production equated to 1.7 gigawatts (GW) globally and by 2010 that number is expected to reach 10 GW (Arwood 2006). One gigawatt is roughly equivalent to the average electrical power needed to supply 300,000 US homes. This growth of nearly 17%, far exceeds the 5% growth projected for the electronics industry. Because more than 30% of the raw material costs for solar cells are spent on silicon, the shortage will have a much greater impact on the solar industry than on the electronics sector, where only 1% of the costs are for silicon.

Over 90% of current solar cell production is silicon-based. The gap in silicon production will open doors for the under-represented emerging solar technologies that utilizes less or no silicon. Two technologies that will benefit are thin film photovoltaic products and concentrating solar power.

Thin film technologies use a coating that can generate electric power without the use of silicon. It is also possible to apply this film to almost any surface. The increased demand for thin film would be good for two Arizona based solar companies, First Solar of Scottsdale and Global Solar in Tucson.

Polysilicon shortages may also shift public attention to **Solar Concentrating Power (CSP)** technologies. When utilized in large scale production, solar concentrating power offers the most cost effective energy production, in comparison to other solar power systems. CSPs come in many shapes and sizes: parabolic troughs, dish, and solar towers. One of the most successful companies in the industry, Stirling Energy Systems (SES), is based in Phoenix. SES manufactures a Stirling Dish System that converts thermal energy into electricity using a highly efficient Stirling engine generator at the apex of a mirror array. The company is currently building a plant in California that will supply 1,700 megawatts to Southern California. Unlike PVs, CSP systems rely on direct and not diffuse radiation. Therefore, CSPs are most appropriate for areas with consistent clear skies and sun. Arizona will likely see a great increase in CSP systems to meet the renewable energy portfolio by 2015.

WATER

The City of Phoenix lies at the nexus of the Salt and Gila rivers in the Sonoran Desert. For nearly 2,000 years, the native Hohokam culture inhabited this land, creating .a sophisticated system of canals to channel the water from these rivers to crops, and traces of these canals were still in evidence when modern settlers arrived in the area. Canals and water have remained the lifeblood of the region. Aggressive modern water projects brought agriculture to the region, leading to a steady increase in population. After the invention of air-conditioning, there was a rapid increase in development of the region. With population increase, the demand for water increased. Throughout the 1960's, most of the area's water came from groundwater sources.

The overdependence on groundwater led to an unsustainable condition that ultimately caused the gradual sinking of some areas over the aquifer. The **Central Arizona Project (CAP)**, completed in the late 1980s, is an aqueduct system that brings water from the Colorado River. The CAP was paid for and used mostly by farmers in its earliest function, but as the urban areas began to rapidly grow, CAP water was used to meet the demand from urbanized areas. The CAP and other surface water projects, such as the many reservoirs constructed in the region, have all but eliminated the dependence of groundwater in the area. Private land owners, however, continue to draw groundwater on their property despite the long-term implications. Recent drought has induced a growing concern about water scarcity in the region. On the positive side, a large percentage of new development has replaced what once was agrarian land where agriculture practices used a much larger amount of water per acre compared to residential and commercial buildings, and this water savings is expected to enable the expansion of the urban area for several years before water becomes a pressing economic issue. At present, the cost of water is so low that most governmental conservation efforts go unheeded. Water conservation, however, will be crucial to meeting the future demand of Phoenix's growing population. Local governments and utilities are beginning to promote water-conservation campaigns and integrate conservation policies such as landscaping ordinances and plumbing codes into future development requirements.

Arizona's Water Supply

Arizona uses roughly 8.1 million acre-feet of water every year. One acre-foot equates to 225,851 gallons, equal to the annual consumption of a five-person household. Arizona's water supply is comprised of four basic sources: Colorado River water (34.5%), surface waters other than Colorado River water (17.2%), groundwater (35.8%) and effluent reclaimed water (12.3%)(ADWR 2002). The rate at which any give water source is used depends upon its relative quantity, quality, reliability, and economic feasibility.

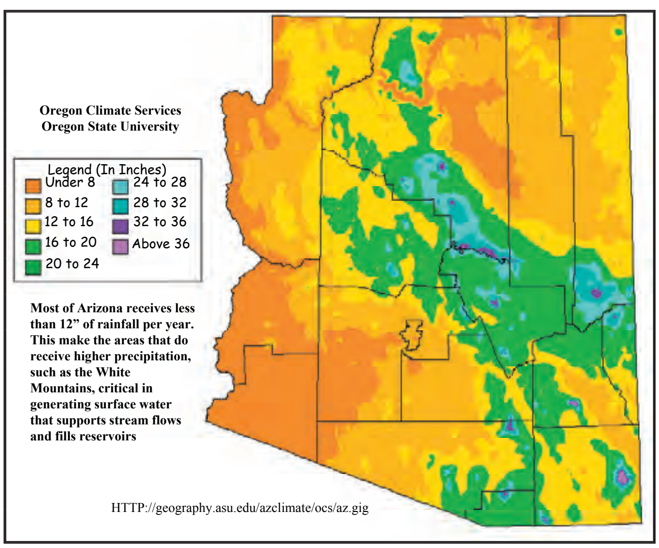


Figure 1-27. Arizona's average annual precipitation.

Surface Water

Surface water from Arizona's lakes, rivers, and streams is a renewable resource. In spring, snowmelts replenish the surface-water supplies, if inconsistently. Because a large percentage of the state is desert, the amount of water varies from year to year, season to season, and place to place. To decrease the fluctuations in the water supply and to increase reliability, a highly developed system of storage reservoirs and delivery methods have been constructed throughout the state (ADWR 2002). The largest and most important reservoirs are located on the Salt, Verde, Gila. and Aqua Fria rivers.

Colorado River Water

Colorado River water is categorized separately from the other surface water rivers of Arizona because it is has important legal and political implications for the Southwest and the Phoenix region. The federal government constructed a number of reservoirs to use Colorado River water in several states including Arizona, California, Nevada, New Mexico, Utah, Colorado, Wyoming, and Mexico. Several legal authorities quantify the rights to the Colorado River. This legal arrangement, referred to simply as the "Law of the River," mandates that 2.8 million acre feet each year be allocated to Arizona. Mohave, La Paz, and Yuma counties depend almost entirely on the Colorado River supply. The remaining 1.6 million-acre feet is then delivered to Maricopa, Pinal, and Pima counties via the Central Arizona Project (CAP) canal.

Water Source		Million Acre-Feet (maf)		% Total
SURFACE WATER				
Colorado River		**2.8**		**34.5%**
CAP	1.6		19.7%	
On-River	1.2		14.8%	
In-State Rivers		**1.4**		**17.2%**
Salt-Verde	1.0		12.3%	
Gila & Others	0.4		4.9%	
GROUNDWATER		**2.9**		**35.8%**
RECLAIMED WATER		**1.0**		**12.3%**
Total		8.1 maf		

Table 1-4. Arizona water supply and annual water budget for 2006. (ADWR 2006)

Groundwater

Groundwater constitutes 36% of the state's water. This natural water source is found beneath the ground in natural reservoirs called aquifers. This water, often millions of years old, has been pumped out at a steady rate over the last century. When groundwater is pumped out faster than it is replenished, the condition is called overdraft. Location relative to end use, depth below the surface, and water quality limit the availability of groundwater. The long-term water sustainability of the region depends on our ability to manage and prevent overdraft of Arizona's aquifers. In 1980, Arizona implemented the Groundwater **Management Code** to promote the conservation and long-range planning of water resources.

Reclaimed Water

Reclaimed water, or effluent, is water that has been treated at a wastewater treatment plant for reuse, and constitutes 12% of Arizona's water supply. Reclaimed water is treated to a high quality, in some applications higher than drinking water requirements. For this reason, reclaimed water is a safe and economic resource for purposes such as agriculture, golf courses, parks, industrial cooling, or maintenance of wildlife areas. Reclaimed water can be considered a growing water resource in Arizona, as the more the population grows and water use and disposal increases, the more reclaimed water can be available. Lack of piping infrastructure to end use points remains a problem.

Future Challenges and Opportunities

The **Arizona Department of Water Resources (ADWR)** suggests that Arizona's water supply faces both short- and long-term challenges.

Rural Water Supply

Water supply conditions in rural Arizona communities comprise the most severe water problems in the state. Rural areas continue to grow in population as new communities develop without adequate water supply or financial resources. The demand on groundwater is excessively high, and the withdrawal of water continues to impact the natural water flows that support riparian and recreational areas. The water-supply challenges of these rural communities will only increase as drought conditions persist.

Colorado River Operational Planning Framework

As populations continue to grow and drought conditions persist in the Colorado River Basin states, managing the Colorado River grows increasingly complex. The key issues of the 21st century will require the establishment of agreed-upon criteria for decision making in drought conditions, new management methods, and coordination between the seven states of the Colorado River Basin.

Long-Term Challenges and Opportunities

To effectively manage and set goals for Arizona's vital groundwater supply, ADWR has designated groundwater basin areas based on the physiography, surface- drainage patterns, subsurface geology, and aquifer characteristics. Of the basins, four were designated **Active Management Areas**: Phoenix AMA, Tucson AMA, Prescott AMA, and Pinal AMA.

There is concern about the ability of these AMAs to achieve and maintain their long-term management goals. Even though a substantial amount of progress has been made through the use of surface water, conservation programs, and conversion of water rights, most of ADWR's projections are indicating shortfalls in the future. The Phoenix AMA, for example, has been continually reducing its groundwater overdraft quantities, but even in 2025, Phoenix may still exceed its groundwater withdrawal goals. The Tucson AMA will also make great reduction in groundwater overdraft, but ADWR projections show that area becoming steadily more dependant on the CAP water flows. The Prescott AMA is using and committing future surface water supplies to new subdivisions, which may result in doubling the long-term sustainable supply of groundwater.

The AMAs are a very important part of Arizona water-supply management and achieving the statutory goals of the AMA will help to ensure adequate, dependable water supplies for Arizona communities in to the future. The success of the AMA management goals will depend on both regulatory and nonregulatory programs and policies, cooperation between regional entities, and technically advanced long-term planning.

Energy = Water

Energy and water, two of the most important components of modern civilization, are interdependent in several ways, and are often used to indicate the economic and environmental sustainability of urban areas. Water supply extraction, delivery, and processing of water can be energy intensive, and this is particularly true in areas such as Phoenix which rely heavily on water supplies that are not readily accessible. Wells, canals, and water-treatment plants use pumps, valves, and gates that consume electrical energy to manipulate water from source to use and then back to the ecosphere.

Water has been used for centuries to generate mechanical and electrical power, up to the Mega Watt hydroelectric dams of present-day Arizona. Today, nearly 12% of Arizona's energy comes from hydroelectric power plants. (DOE 1999) The remaining 88% of Arizona's energy generation each year is from thermoelectric power plants fueled by either coal or nuclear power. Thermo¬electric power plants generally burn a fuel to transform water into steam that is then sent through a turbine generator

Water use	Percent
Domestic Wells	1%
Livestock	1%
Aquaculture	1%
Mining	1%
Industrial	5%
Public Supply	11%
Irrigation	34%
Thermoelectric Power	48%

Table 1-5. Water withdrawals by use in the US in 2000 (Golden 2006).

to produce electrical power. Water is used directly as the working fluid, and it is also used to cool the steam to complete the power cycle. In the US, thermoelectric power generation withdraws more water than any other water usage, including agricultural irrigation and municipal consumption (Table 1-5).

In 1985, freshwater withdrawals in the US averaged 338 billion gallons a day (Bgal/d). By 2000, this number had increased 21% to 408 billion gallons a day. Most of this increased use was from groundwater sources, an increase in groundwater withdrawal of 14% to 83.3 Bgal/d. Approximately 195 Bgal/d, or 48%, of all freshwater and saline water withdrawals were used for thermoelectric power (Golden 2006), with 56 billion gal/day of saline (ocean) water for electrical generation cooling in coastal areas. For every 100 gallons withdrawn from surface water for cooling in these power plants, 98 gallons is treated and returned to the source body while 2 gallons are lost to evaporation. The total consumptive loss for once-through cooling systems is nearly 18ft2/s (0.5m3/s) per 1000 MW, and 30ft3/s (0.9m3/s) per 1000MW for cooling towers (Golden 2006).

The National Energy Technology Laboratory (NETL), operated by the DOE, estimated that 25 gallons of water is required to produce 1 kWh of electricity from a coal plant (Feely et al. 2005). Another study showed that 1 kWh of electricity requires 37 gallons of water for fossil-fueled plants and 56 gallons for nuclear-powered plants (Scharff 2002).

Figure 1-28. Steam cloud generated from cooling towers at APS's Ocotillo thermoelectric power plant in Tempe, AZ (Source: City of Tempe).

An ASU research study estimated the total water withdrawal and consumption for energy use for an average family in Arizona. Results showed that the annual energy use in an average house in Phoenix equates to 8,420 gallons of water and, of that, 6,530 gallons is lost to evaporation during the thermoelectric generation process (Golden 2006). This connection between water and energy use is a growing concern for cities experiencing water availability problems. Power-plant water consumption may conflict with either existing or potential downstream municipal water use or with in-stream water uses. As populations and energy demands grow, so will the need for water for thermoelectric power plants. One option for municipalities and power utilities is to require that cooling towers use reclaimed water for thermoelectric generation. Palo Verde Nuclear Generating Station, operated by Arizona Public Service, produces over 1,200 MW of power using reclaimed water from nearby Phoenix in their two reactor cooling loops. Though Palo Verde sits in one of the driest places in the US, it has an enormous cooling pond and canals to manage its water needs.

Some renewable- energy technologies such as wind turbines and photovoltaic panels operate using little or no water. This additional benefit of renewable energy should be taken into consideration in areas with limited water resources.

RESOURCE USE

Every human requires a certain amount of natural resources to support them throughout their lives. These natural resources are the foundation for the products we use, the food we eat, the water we drink, the energy we use to light and heat our homes, and in the ecosystem that degrades our wastes.

This portion of world resources is often referred to as a person's 'ecological footprint' and is defined as follows:

Ecological Footprint - "The area of land and water required to produce the resources consumed and to assimilate the wastes generated by a population on a continuous basis, wherever on earth that land is located" (Wackernagel and Rees 1996).

The ecological footprint can be calculated for a single person, a family, a building, a city or an entire country. Given the current world population, there are only about 1.5 hectares of ecologically productive land and only about 0.5 hectares of productive ocean per person on earth (Wackernagel and Rees 1996). Calculations of various countries per capita ecological footprint reveals a great divide between the footprints of wealthy countries and less- developed ones. High-income countries generally have ecological footprints of 5 to 6 hectares while the top wealthiest exceed 10 hectares per capita. In addition, in some underdeveloped countries, the average person can often have ecological footprints of much less than 1 hectare (Wackernagel et al. 1997).

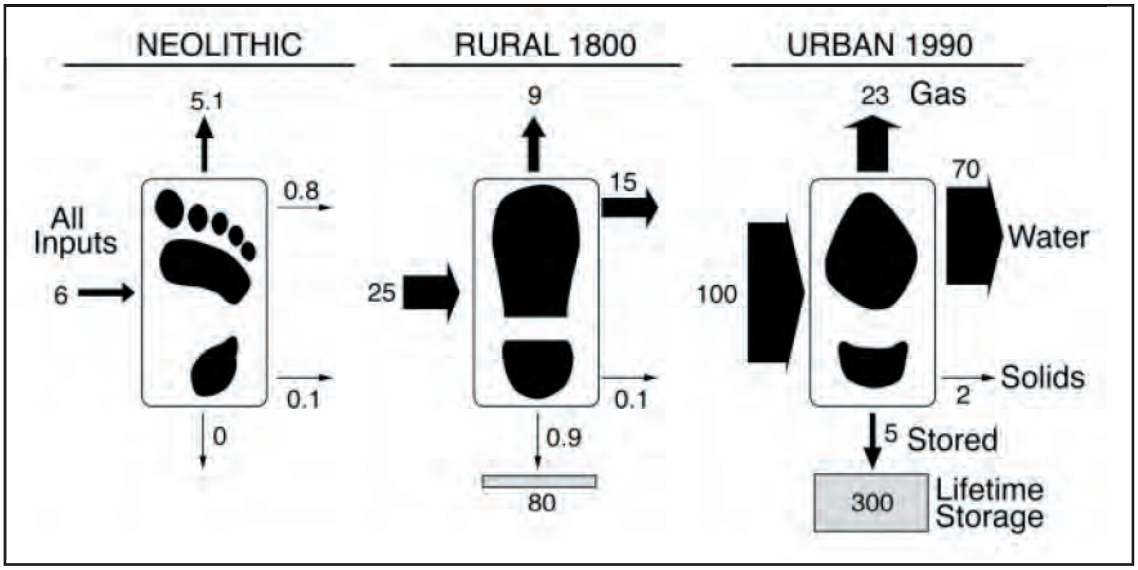


Figure 1-29. Material budget (tons per year) for an individual human from Neolithic to modern times. Lifetime storage refers to the materials that are in the form of buildings and products (Decker et al. 2000).

The ecological footprint of a city is a function of the combined footprints of its average citizen multiplied across the entire population. For London, England the estimated area of land required to assimilate its CO2 emissions, provide food and forest products is 120 times that total land area of the city (Sustainable London Trust 1996). Other cities such as Toronto, Canada with a population of 2.38 million requires a land area 288 times its size, and Vancouver, Canada's ecological footprint requires 319 times its land area.

It is important to note that, if the entire world was brought up to the resource consumption standards of the average American, we would require the equivalent ecological capacity of six earths.

Waste, Emissions and Degraded Energy

SOLID WASTE

The US EPA categorizes solid waste as either municipal solid waste or non-municipal solid waste. **Municipal solid waste (MSW)** is defined as wastes such as durable goods, nondurable goods, containers and packaging, food scraps, yard trimmings, and miscellaneous inorganic wastes from residential, commercial, institutional, and industrial solid waste sources. This form of solid waste is under the control of occupants in the home, business, or office and therefore draws the most public attention and concern. Most reported recycling rates for a metropolitan area is based on materials recycled from MSW, however the total waste stream produced in the US also includes **non-municipal solid wastes (NMSW)** from heavy industrial and commercial sources. NMSW can range from construction and demolition debris, automobile bodies, municipal sludge, combustion ash, and other industrial processes. These wastes are a significant part of the total US waste stream. 'Diversion rates' are based on both forms of solid waste streams, and signifies all waste recycled, reused, or otherwise reworked and kept from disposal areas.

In 2000, the US EPA released a report entitled Municipal Waste Generation, Recycling and Disposal in the US: Facts and Figures. This study characterizes the municipal solid waste stream for the Year 2000. The total solid waste generated in 2000 was 231.9 million tons, an increase of nearly 1 million tons from the previous year, while the total per person waste generation decreased during the same period. This indicates that US has increased its rate of recycling as population has grown. The breakdown of the US waste stream as reported for 2000 is shown in Figure 1-24 .

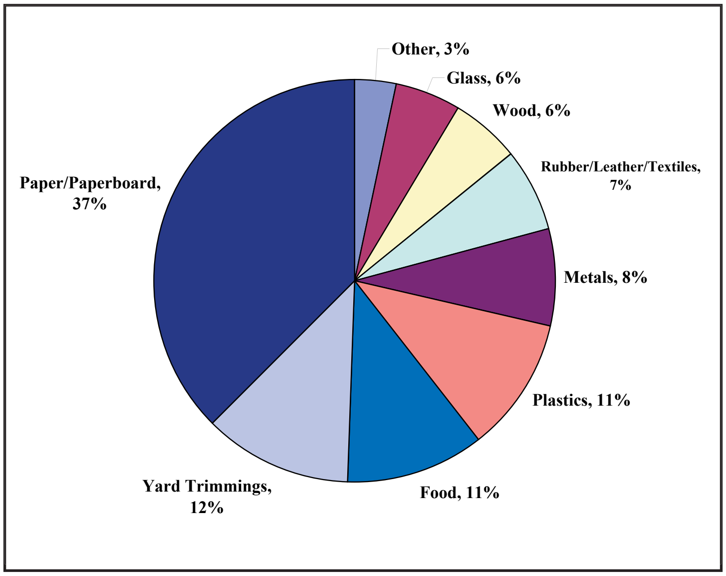


Figure 1-30. Municipal solid waste stream for the US in 2000. a total of 231,900,000 tons (EPA 2000).

Recycling in Arizona

In 1990, the Arizona State Legislature passed the Recycling Act and since then Arizona has increased the amount of waste recycled or diverted from landfills. Progress has been hindered, however, due to factors unique to Arizona. Compared to other states, Arizona has low landfill disposal fees and available open land for future landfills. These factors result in recycling costs that are greater than the cost to dispose the materials for many areas of the state. This economic disincentive had resulted in limited recycling increases in areas located far from recycling markets. Recycling programs have had some success in urban areas where local municipalities target their residents and encourage them to recycle. In 2002, the three Arizona jurisdictions saving the most landfill space by recycling were the City of Phoenix, Maricopa County, and the City of Mesa.

The City of Phoenix offers a comprehensive set of recycling and waste-reduction programs with curbside recycling for single-family homes and three drop-off locations for recyclables within the City limits. Two material-recovery facilities (MRFs) are responsible for processing all of the City's municipal solid waste, one located on 27th Avenue and the other at Hudson Baler. Household hazardous waste (HHW) and battery, oil, paint, and antifreeze collection events are also offered regularly. The City's landfills can also accept clean loads of "green" waste that are chipped and then reused as landscaping mulch. The City was able to divert an additional 504,000 cubic yards (173,000 tons) over any other Arizona jurisdiction in 2002. The total solid waste generated and diverted for a variety of jurisdiction is given in Table 1 6. In terms of total diversion rate, Phoenix was the fourth highest (12%) in the region, behind Scottsdale (13%), Chandler (14%) and the extraordinary rate of Wickenburg (95%). The more telling indicator is the waste generated and diverted per person. Table 1 6 indicates that the average person in the region generates 2,125 lbs of solid waste a year and recycles about 190 lbs per year (9%). The citizens of Kearny, Arizona can boast that they generated nearly 500 lbs less than the average (1,689lb total per person), and the citizens of Surprise are reported as having the highest generation of 2,490 lbs per person. Due to the variety and level of recycling programs and citizen involvement, there is a wide range in the rate of waste diverted.

Jurisdiction	County	Population	Waste Generated (tons)	Waste Generated per person (lbs per capita)	Reported as Diverted (tons)	Waste Diverted per Person (lbs per capita)	Diversion Rate
Apache Junction	Pinal	32,800	34,800	2,122	549	34	1.6%
Avondale	Maricopa	40,445	42,900	2,121	18	1	0.0%
Buckeye	Maricopa	10,650	11,290	2,120	0	0	0.0%
Carefree	Maricopa	3,095	3,280	2,120	72	46	2.2%
Casa Grande	Pinal	27,290	28,900	2,118	1,633	120	5.7%
Cave Creek	Maricopa	3,900	4,130	2,118	120	61	2.9%
Chandler	Maricopa	176,581	186,875	2,117	26,369	299	14.1%
Coolidge	Pinal	8,085	8,570	2,120	957	237	11.2%
El Mirage	Maricopa	11,915	12,630	2,120	did not respond to questionaire		
Eloy	Pinal	10,675	11,320	2,121	did not respond to questionaire		
Fountain Hills	Maricopa	20,235	21,400	2,115	0	0	0.0%
Gila Bend	Maricopa	2,000	2,120	2,120	did not respond to questionaire		
Gilbert	Maricopa	122,360	129,700	2,120	11,985	196	9.2%
Glendale	Maricopa	224,970	238,000	2,116	20,034	178	8.4%
Goodyear	Maricopa	22,820	24,200	2,121	451	39	1.9%
Guadalupe	Maricopa	5,230	5,540	2,119	did not respond to questionaire		
Kearny	Pinal	2,250	1,900	1,689	63	56	3.3%
Litchfield Park	Maricopa	3,845	4,080	2,122	5	3	0.1%
Mammoth	Pinal	1,780	1,890	2,124	20	23	1.1%
Maricopa County	Maricopa	216,515	230,000	2,125	16,596	153	7.2%
Mesa	Maricopa	414,075	439,000	2,120	43,491	210	9.9%
Paradise Valley	Maricopa	13,664	14,500	2,122	did not respond to questionaire		
Peoria	Maricopa	108,364	114,900	2,121	576	11	0.5%
Phoenix	Maricopa	1,344,775	1,430,000	2,127	172,572	257	12.1%
Pinal County	Pinal	83,575	88,600	2,120	4,108	98	4.6%
Queen Creek	Maricopa	4,940	5,240	2,121	0	0	0.0%
Scottsdale	Maricopa	209,960	223,000	2,124	27,952	266	12.5%
Surprise	Maricopa	30,848	38,400	2,490	18	1	0.0%
Tempe	Maricopa	159,435	169,000	2,120	10,110	127	6.0%
Tolleson	Maricopa	5,040	5,340	2,119	0	0	0.0%
Tucson	Pinal	498,305	528,000	2,119	20,563	83	3.9%
Wickenburg	Maricopa	5,265	5,580	2,120	5,303	2,014	95.0%
Youngtown	Maricopa	3,155	3,340	2,117	3	2	0.1%
Totals	**Maricopa + Pinal**	**3,828,842**	**4,068,425**	**2,125**	**363,566**	**190**	**9%**

Table 1-6. Solid waste generated and diverted by local government jurisdictions (ADEQ 2002)

Residential Curbside Recycling

Residential curbside recycling is the most convenient and effect method for citizens to recycle. A residential curbside recycling program is defined by the ADEQ as "any program that collects a variety of materials left in close proximity to their sources on a regularly scheduled basis." The program requires the collection of at least one recyclable material beyond green waste. In most instances, a recycling bin is supplied to each household, and recycling is picked up once a week, where solid waste pick-up is twice a week. Curbside recycling significantly promotes recycling and creates a habit for households where the program is offered. In most cases in the Phoenix region where recycling rates are low, curbside recycling is not the implemented method used.

The method of collection and required sorting of collected materials can vary between programs. The recyclable materials may be source separated by the recycling program participant, sorted at the curb, or commingled where the jurisdiction sorts the 'total' residential waste stream. Total sorting facilities are often referred to as "dirty material recovery facilities." Curbside recycling programs can be carried out and operated by municipal solid waste management departments, large hauling companies, or small businesses. The City of Phoenix operates the largest recycling program in the state of Arizona, while Jerome has the smallest. There are nearly 974,000 homes that are currently being served by a curbside recycling program in Arizona, representing 48% of the total population (2,570,000). Arizona's history of curbside recycling dates to 1988 when the City of Tempe began the first trial program of 816 homes. In 1992, Gilbert was the first city to offer the service to all single-family homes. Curbside recycling around the county has shown growth as metropolitan areas began introducing programs across jurisdictions.

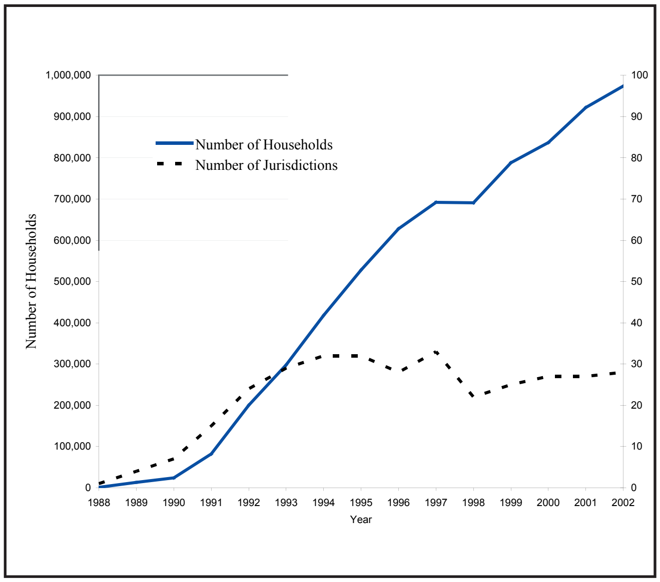


Figure 1-31. Curbside recycling from 1988 to 2002 in Arizona by number of households and number of jurisdictions. Several curbside programs were discontinued because of lack of funding from 1995 to 1998 (Source: ADEQ 2002).

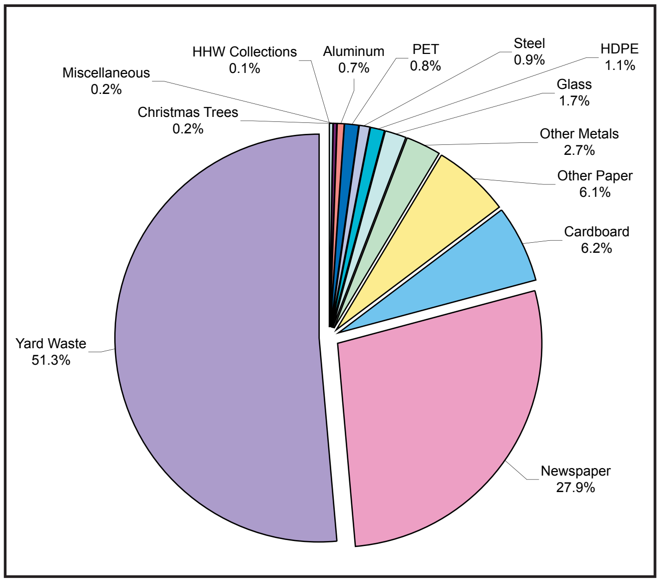


Figure 1-32. Diverted municipal solid waste (by tons) for the City of Phoenix in 2002. Total diverted = 172,572 tons (12.1%) (Source: ADEQ 2002).

Category	Description
Office paper	includes white ledge, color ledger, mixed office, computer print-out and high grade paper.
Other paper	included undifferentiated papers, magazines, phone books, kraft bags, asceptic packaging, polycoated packaging, mixed paper, mixed residential paper, groundwood paper, hard/soft cover books, paper sludge, pulp subsititute, bulk mail, and undifferentiated paper.
Green/wood	includes undifferentiated vegetation, pallets, and dimensional lumber.
Organics	include manure, animal bedding, crop residuals, and waste water sludge.
Aluminum	includes aluminum cans, aluminum foil, aluminum scrap and undifferentiated aluminum.
Steel	includes tin cans, bi-metal cans, aerosol cans, oil filters, scrap steel, steel/iron scrap, ferrous scrap, and undifferentiated steel.
White goods	includes appliances and white goods/scrap.
Other metals	includes scrap metal, copper, aluminum/steel cans, lead acid batteries, brass, non-ferrous scrap, and undifferentiated metal.
PET	Polyethylene Terephthalate (#1 plastic) includes clear PET, green PET, #1 plastic soda bottles, and undifferentiated PET,
HDPE	High Density Polyethylene Plastic (#2 plastic) includes natural #2 plastic water/milk jugs, colored HDPE, HDPE bags, and undifferentiated HDPE.
Other plastics	includes LDPE (#4), polystyrene (#6), ABS, injection mold plastics, and undifferentiated plastics.
Glass	includes flint (clear), amber, green, mixed, and undifferentiated glass.
HHW	collections include used motor oil, antifreeze, latex paint, oil paint, paint sludge, flammable liquids, Freon, drop-'n-swap items, compressed gas, Cl-flammables, solvents, mercury, and household batteries.
Miscellaneous	includes waste tires, mattresses and box springs, asphalt, wire and cable, textiles, other fiber, toner cartridges, transparencies, construction debris, demolition debris, fluorescent bulbs, carpet, carpet foam, and electronic scrap.
Unspecified	includes undifferentiated curbside and undifferentiated drop-off.

Table 1-7. Category descriptions of diverted municipal solid waste in Arizona.

Recycling Programs Costs and Revenues

Recycling programs are not free, but if organized correctly, can create a revenue opportunity for the jurisdiction that implements them. The cost of operating and maintaining a recycling program includes:, land needed for holding and sorting, insurance, equipment, personnel, consultants, construction, any mandated procurement programs (purchasing recycled-content materials), and other related costs. The costs reported by Arizona jurisdictions in 2002 was as low as $1,200 per year for the City of Page to as high $9.9 million for the City of Glendale.

Revenues can be generated by recycling programs, mostly from the resale of usable items or the sale of a recyclable waste stream. In 2002, the City of Mesa reported a recycling revenue of $11,376,182, or nearly $7 million more than what was spent on the program The total statewide recycling revenue generated by all jurisdictions was over $18 million. Avoided costs from diverting waste from a landfill or incinerator should also be considered when calculating the total economic benefit of recycling programs. These savings can be estimated based on the tipping or disposal fees that would have otherwise been charged by the waste-collection company.

Symbols and Public Awareness

An important part of any recycling program is public education and awareness. These campaigns help to educate the consumer on which items can be recycled in their community. The standard recycling symbol, three chasing arrows, indicates that the product is recyclable (Figure 1-33). When the recycle symbol is set on a black background it indicates that the product used recycled material during its manufacture (Figure 1-34). The "recycled content" symbol will also include the percentage of the product made of recycled content. These symbols help consumers to quickly choose recycled and recyclable products.

Figure 1-33. The symbol indicating a recyclable product.

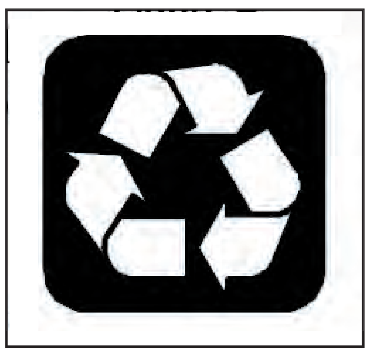


Figure 1-34. The symbol that the product is made of recycled content.

Figure 1-35. The logo for the Arizona Recycling Program.

The Arizona Recycling Program travels to schools, conferences, and other civic gatherings to promote the concepts of reduce, reuse, recycle, and buying recycled material products. The Arizona Recycling Program also has a symbol for their program on literature, education campaigns, and fundraising events.

Solid Waste and Energy

Using recycled materials reduces the amount of waste landfilled but it also reduces the energy needed to produce a product from new materials. Buying products with recycled content creates a demand for waste materials collected in recycling programs and stimulates markets producing these products. Over 37 % of the waste stream in the US is paper, and most paper products have recycled content. Abitibi Consolidated, Inc. located in Snowflake, Arizona uses old newspapers to produce new newsprint. This closed loop type arrangement significantly reduces energy, prevents pollution and slow the depletion of natural resources (ADEQ 2002).

Composting and Energy

Yard trimmings and kitchen scraps represent 23% of the MSW stream in the US. Organic materials such as these can be composted relatively easily at home or local collection facilities.

Composting is a process that involves mixing together yard waste such as grass, leaves, and landscape trimmings, along with selected food scraps to promote decay, resulting in compost.

Compost is the natural decomposition of plant material and other once-living materials. The finished product of a composting system is a dark, earthy substance that can be used to enrich garden soil. Backyard composting is an excellent way for residents of Arizona to reduce their total waste stream, and while reducing the energy required for transporting, processing and disposing of this waste material. There are several backyard composting programs located in Arizona to assist home gardeners in developing their backyard composting systems.

WATER QUALITY

Water quality and quantity are essential to the long term sustainability of Arizona and the Phoenix Region. Water quality is defined by its physical, chemical, biological, and aesthetic (visible appearance and odor) characteristics. Public and ecosystem health is greatly influenced by the quality of water in these systems. For this reason, the US EPA ranks water quality as one of the highest-priority environment issues.

Groundwater is a major component of the public water supply and is vital to the health of the river and wetland systems in Arizona, and its availability and its quality has influenced the development of agriculture and cities in Arizona. As agricultural land is converted urban use, groundwater sources are in closer proximity to industrial development and risk contamination and depletion.

To aid and encourage the management and viability of these groundwater supplies, the **Arizona Department of Environmental Quality (ADEQ)** adopted the groundwater basin boundaries delineated by ADWR's Groundwater Management Act as 'active management areas' (AMAs): Phoenix AMA, Tucson AMA, Prescott AMA, Pinal AMA, and Santa Cruz AMA. These basins were chosen because they lie under the largest population centers and comprise the majority of groundwater supplies in the state. Figure 1-36 highlights each of these Arizona AMAs.

Chapter 2 of **Arizona State Environmental Quality Act, Title 49,** adopted in 1986 deals with water

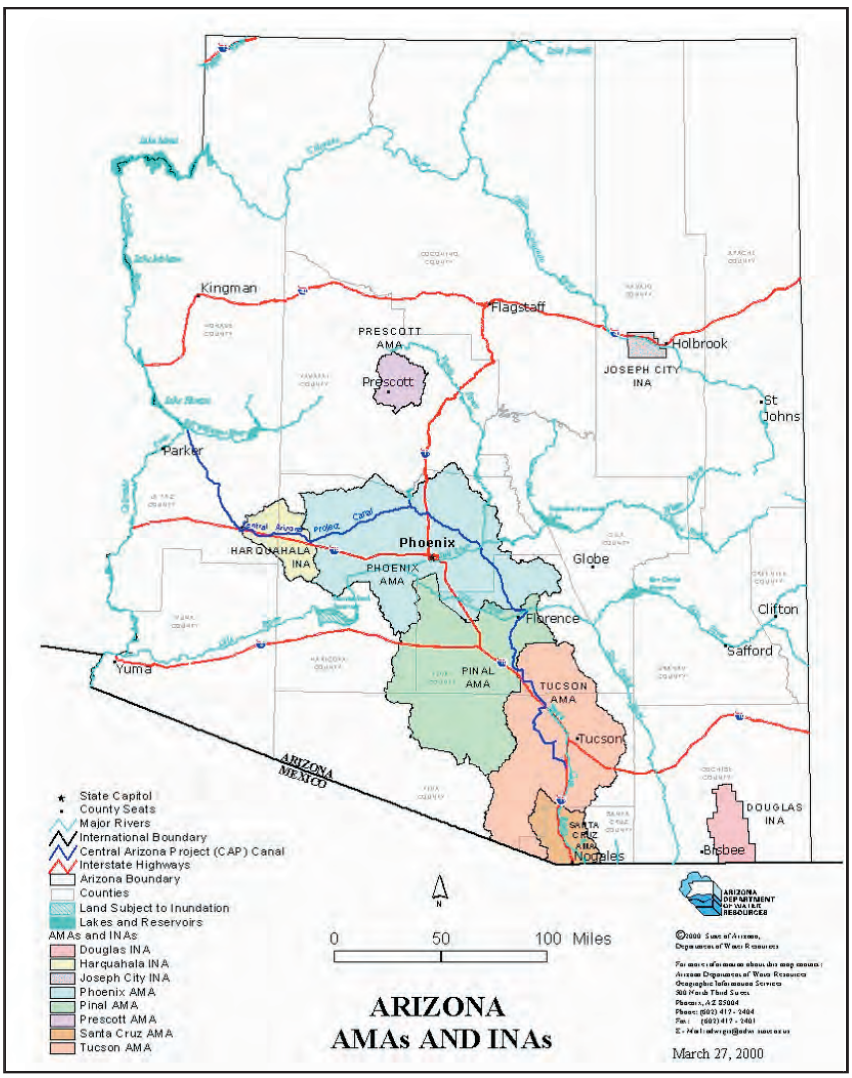


Figure 1-36. Arizona's Active Management Areas (AMA) and Indian Nation Areas (INA).

quality in both surface and groundwater sources. The law helps to manage and protect water quality and remediate point and nonpoint sources of pollution. The statute aims to "protect water quality for all present and reasonably foreseeable future uses." Title 49 established the Aquifer Protection Permit (APP) Program, industrial best available demonstrated control technology (BADCT), best management practices (BMP), and the Water Quality Assurance Revolving Fund (WQARF), all important groundwater protection and cleanup programs in Arizona. These programs have led to the near elimination of prohibited discharges to groundwater. Most contamination sites are the result of historic discharges that occurred before the introduction of Title 49 in 1986.

Groundwater quality can be affected by many different sources. The most significant contributing sources in Arizona include agricultural activities, wastes from industries, leaking underground storage tanks, septic tanks, landfills, mining and wastewater treatment plants. These sources leak volatile organic compounds (industrial solvents), nitrate, sulfate, metals, pesticides,

Volatile Organic Compounds

Solvent disposal is the leading cause of **Volatile Organic Compounds (VOC)** contaminated groundwater in Arizona. Aerospace and electronic companies are historically located in areas where these compounds have been found. Many manufacturing facilities use solvents for degreasing and their careless disposal has been documented since the 1950s. Historic industrial procedures included pouring these solvents into dry wells, releasing into surface impoundments, leach fields, and dry washes (Graf 1986). Dry- cleaning establishments were also notorious for disposing and leaking volatile organic compounds on site. Many wells in Phoenix, Tucson, and Payson have been closed due to VOC contamination.

Nitrates

The second most prevalent pollutant in the state's groundwater is **nitrate**. Both human activities and natural sources influence nitrate levels. Most human-related sources are from the percolation of water runoff from irrigation, septic tanks, wastewater treatment plants, and feedlots. Nitrate is unaffected by soil filtration and therefore concentrations remain the same as it moves with the groundwater.

Glendale, Mesa, Chandler, and Phoenix sit on the Salt River Valley aquifer with nitrate concentrations so high that it is not suitable for direct consumption. In more rural areas of the state, septic tanks may be the primary source of nitrate contamination making many wells unsuitable for drinking.

Major Cations and Anions (Dissolved Mineral Content)

An important water quality indicator is **total dissolved solids (TDS)**. This indicates the relative level of dissolved mineral content and can vary widely in aquifers. High level so TDS render water unsuitable for drinking.

Metals

Some heavy metals occur naturally in groundwater. **Arsenic** is a naturally occurring heavy metal in Arizona. The federal and state maximum arsenic level was 0.05 milligrams per liter and that limit was lowered to 0.01 milligrams per liter by the US EPA in 2006. Much of Arizona's water exceeds this level, making municipalities across the state implement treatment, blending, or use of alternative water supplies. Human-related metal contaminations can be chromium from metal plating and electronics manufacturing, as found in Phoenix and Tucson areas. Manganese, copper, iron, and chromium, are a result of mining operations and tailing ponds. Landfills can also be a source of metals such as iron, manganese, and barium.

Pesticides

Two pesticides were repeatedly discovered in groundwater before 1980 in Arizona. Now banned because of their potential carcinogenicity, dibromochloropropane and ethylene dibromide were commonly used starting in the 1950s in Yuma and the Salt River Valley to prevent nematodes in soils of citrus and cotton fields. Currently, pesticides atrazine, methomyl, metribuzin, and prometryn have been found in areas of Maricopa and Yuma counties at levels far below regulated limits.

Petroleum Hydrocarbons

Leaking underground storage tanks (LUSTS) usually contain petroleum-based fuels and are a major source of groundwater contamination in urban areas. As of 2002, there were 27,641 underground storage tanks containing regulated substances in Arizona. Of these, nearly 7,945 have been reported to be leaking. According to the ADEQ 5,523 of these leaking tanks have been remediated, disposed of, or properly closed. It is estimated that 19% of all LUSTs have resulted in adverse effects to groundwater quality. LUSTs are mostly associated with service locations such as utility, transportation, and shipping companies, municipal facilities, pipelines and mining, food, lodging, high tech, and paint companies.

The chemicals most often detected LUST-related chemicals are:

- benzene
- toluene
- ethylbenzene
- xylene
- total petroleum hydrocarbons (TPH)
- methyl tertiary-butyl ether (MTBE)
- 1,2-dichloroethylene (1,2-DCE)

Radionuclides

Uranium, radon, and radium are radioactive elements that occur naturally in soil and water throughout Arizona. Sources of groundwater contamination by radionuclides results from uranium mining. ADEQ and ASU have found radon concentrations of 300 picocuries per liter are considered naturally occurring. This level does not exceed exposure limits but is an interesting and unique characteristic of groundwater here.

Bacteria

Over 17 % of the state population uses septic systems to treat human waste. There are about 400,000 septic tank systems in operation. Groundwater contamination by bacteria can be linked to poorly designed septic systems and bad water supply well placement. Microorganisms in septic waste, which should be removed by passing through a few feet of soil, but in same locales are insufficient if the soil depth is too shallow or the soil itself is lacking the proper natural microbial life. Poor construction of water wells, or proximity of water supply wells to effluent flows is a common reason for microbial contamination in groundwater.

The Phoenix and Tucson metropolitan areas host most of the groundwater quality problems, however all 10 of Arizona's watersheds have been contaminated at different levels of severity. Despite the efforts of the ADEQ's Groundwater Quality Act and ADWRs groundwater protection programs, there are still many groundwater quality problems in the state that are directly related to human activity, indicated by levels of pollutants that exceed natural levels. Due to the presence of these pollutants, all public water supply is strictly regulated and monitored before being delivered for domestic use.

AIR QUALITY

Air pollution is a major concern within urban areas. Transportation, industrial processes, construction, and the combustion of fuels are typical sources of urban air pollution. Sulfur dioxide, carbon dioxide, particulate matter, nitrogen oxide, and carbon monoxide are among the most common urban pollutants which can negatively impact human health, as well as the façades of historic monuments and buildings.

Increases in urban temperatures can affect the rate of the formation, concentration, and distribution of urban pollution, as well as the rate of chemical reaction of airborne pollutants such as ozone. A study of daily peak temperatures in Los Angeles showed a decided correlation between air temperature and the number of days the city exceeds air-quality standards. The US EPA also reported that a 5oF increase in air temperature results in a 10% increase in the number of total pollution-warning days.

Some of the same factors that lead to increased urban temperatures (urban heat island effect) also trap airborne pollutants. City canyons, i.e. the gap spaces between tall buildings and building orientations can create pockets of pollutants sheltered from the wind and result in higher localized air pollution concentrations. Outdoor pollution is also a leading factor in the formation of sick-building syndrome, a term describing indoor air-quality conditions that lead to decreased comfort, productivity, or health of building occupants. The deterioration of older cities can have major implications on indoor air quality (Godish 1989). A list of the potential sources of both outdoor and indoor air contaminants is provided in Table 1-9 below.

Sources of Outdoor and Indoor Emissions and Principal Pollutants

SOURCES	PRINCIPLE POLLUTANTS
Predominantly outdoor	
Fuel combustion, smelters	sulfur dioxide and particles
Photochemical reactions	ozone
Trees, grass, weeds, plants	pollens
Automobiles	lead, manganese
Industrial emissions	lead, cadmium
Petrochemical solvents, vaporization of unburned fuels	volatile organic compounds, polycyclic aromatic hydrocarbons
Both indoor and outdoor	
Fuel burning	nitrogen oxides and carbon monoxide
Fuel burning, metabolic activity	carbon oxides
Environmental tobacco smoke, re-suspension, condensation of vapors and combustion products	particles
Biologic activity, combustion, evaporation	water vapor
Volatilization, fuel burning, paint, metabolic action, pesticides, insecticides, fungicides	volatile organic compounds
Fungi, molds	spores
Predeominantly indoor	
Soil, building construction materials, water	radon
Insulation, furnishing, environmental tobacco smoke	formaldehyde
Fire-retardant, insulation	asbestos
Cleaning products, metabolic activity	ammonia
Environmental tobacco smoke	polycyclic aromatic hydrocarbons, arsenic, nicotine, acrolein

Table 1-9. Sources of outdoor and indoor emissions and principal pollutants. (UN Millennium Ecosystems Report 2005)

The **Federal Clean Air Act of 1970** requires that all states develop air-quality monitoring networks to characterize and track human health exposure and the effects of criteria pollutants. In 1977, an amendment to this Act mandated that visibility be monitored in certain designated national parks and urban areas. The Phoenix region also monitors visibility year round to assess urban haze. These monitoring networks are comprised of individual stations, as shown in Figure 1-37 and their data helps the Arizona Department of Environmental Quality (ADEQ) bring information to citizens and to other air-quality control agencies.

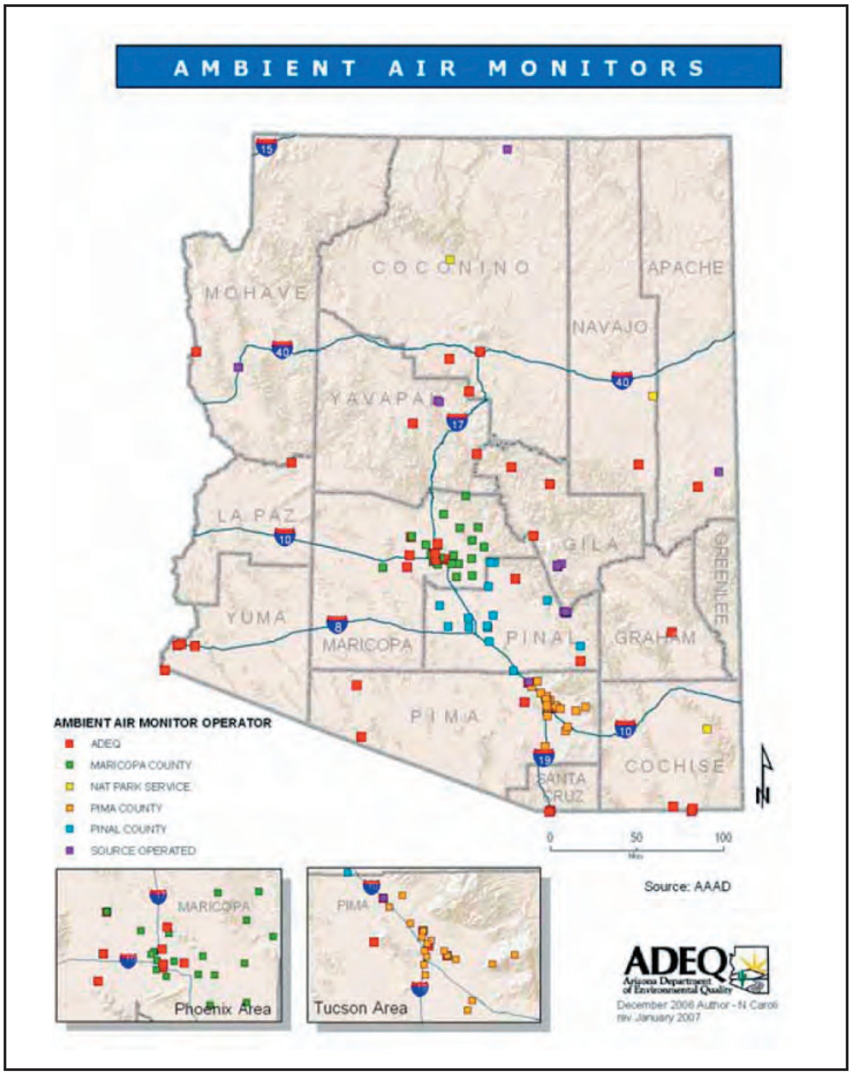


Figure 1-37. Ambient air monitoring stations located with in Arizona (Source: ADEQ 2006).

Criteria Pollutants

The **criteria pollutants**, as indicated by the Clean Air Act of 1970, include carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, suspended particulate matter, and total particulate lead. The following list describes these pollutants, their major sources, treatment methods, and trends for the Phoenix region.

Carbon Monoxide (CO)

A colorless, odorless, and tasteless gas, **Carbon Monoxide (CO)** is the product of incomplete fuel combustion. The adverse health effects of CO results from its ability to chemically bind with blood hemoglobin, blocking oxygen uptake. This reduced oxygen transport can lead to nervous system effects including time-interval discrimination, light sensitivity, increased reaction time, headache, fatigue, and dizziness (ADEQ 2006). Breathing CO also aggravates arteriosclerotic heart diseases. A total of 52% of CO emissions are from on-road motor vehicles and the other 45% are from off-road vehicles used mainly in construction or lawn maintenance. The highest concentrations are found along busy city streets and in neighborhoods where emissions from upwind sources get trapped. CO is inversely related to temperature in combustion engines - the hotter the engine, the less CO is formed. Therefore, the winter months see the highest concentrations of CO.

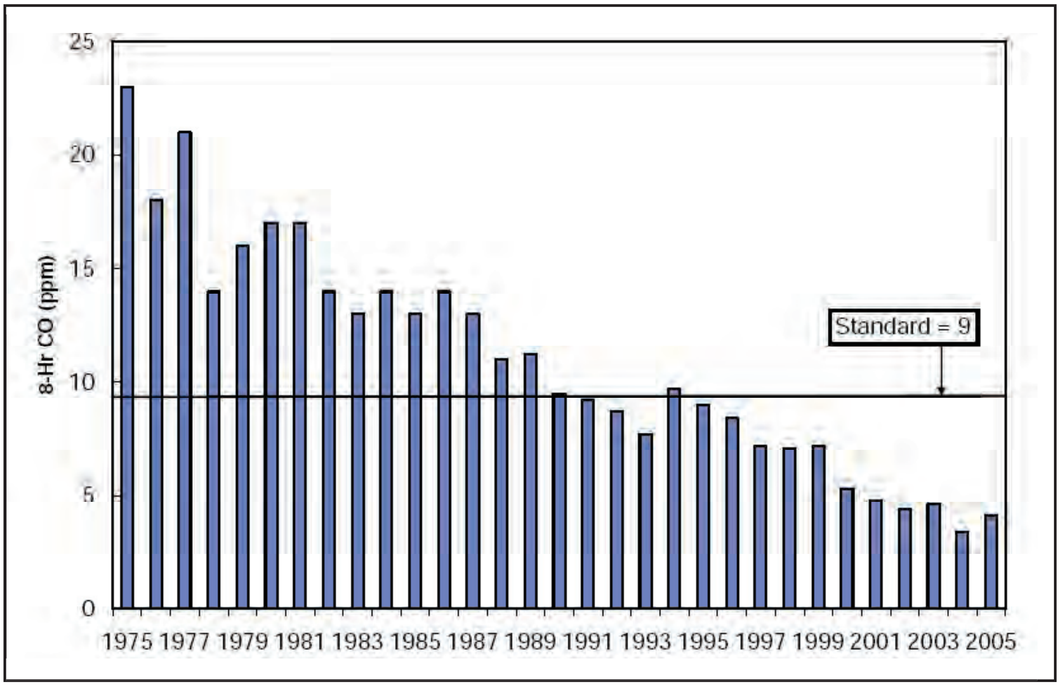


Figure 1-38. 8-hour CO maxima at 18th St and Roosevelt in central Phoenix. (Source: ADEQ 2006).

During the 1970s and 80s, CO levels in the Phoenix metro area were repeatedly high, exceeding the maximum acceptable level at least 100 times a year. Since 1996, CO levels have declined, attributable to the installation of catalytic converters, electronic-ignition systems, use of oxygenated fuels, and mandatory inspections for vehicles. In Central Phoenix, the monitoring station at 18th Street and Roosevelt has recorded a steady decrease in CO since 1975 (Figure 1-38).

Nitrogen Dioxide (NO_2)

Nitrogen dioxide, a byproduct of all combustion, is a reddish-brown gas formed by the oxidation of **nitric oxide** (NO). Respiratory damage such as cilia destruction, alveolar tissue disruption, and obstruction of respiratory bronchioles has been linked to low levels of NO_2. In addition to its health effects, NO_2 plays a major role in forming ozone (O_3) and reduced visibility in Phoenix (ADEQ 2006). Nitrogen oxides are formed from the emissions of cars and trucks (58%), off-road vehicles and equipment (trains and construction machinery), (27%), electric power plants (7%), stationary sources (4%) and biogenic emissions from soil (4%).

Nitrogen oxides from combustion gases are broken up into 95% NO and 5% NO_2; however, once in the air, NO quickly oxidizes to NO_2. As with carbon monoxide, NO and NO_2 are highest near major transit corridors. NO_2 tends to peak in the late afternoon and early evening rush hour. Nitrogen oxide can help reduce ozone by chemical reaction at night, reducing ozone levels to near-zero levels. This causes a dip in ozone concentration at night in urban areas along highways as compared to rural areas with lower NO emissions.

Nitrogen-oxide emissions have been greatly reduced over the last two decades due to changes to vehicles like the retardation of spark plug timing, lowering the compression ratio, exhaust-gas recirculation systems, and three-way catalysts, as well as reformation of gasoline and mandatory vehicle-emission inspections. There are currently 11 stations monitoring NO and NOx (NO + NO_2) concentrations in Phoenix and Tucson (ADEQ 2006).

Sulfur Dioxide (SO_2)

Sulfur dioxide, a colorless gas with an irritating odor, can lead to serious environmental and health-related consequences. SO_2 is a leading cause of acid rain, the artificial decrease of rain water pH. Acid rain can severely impact plant growth and sensitive water bodies. Elevated concentrations of SO_2 can alter human upper respiratory airway function, including increasing nasal-flow resistance and decreasing the nasal mucus flow rate. This resistance often produces acute bronchioconstriction for exercising asthmatics. The primary source of SO_2 emissions in Arizona has historically been the smelting of sulfide copper ore. Most fuels also have small quantities of gaseous SO_2 and particulate sulfate, SO_4. According to ADEQ, 32% of SO_2 emissions come from industrial point sources, 26 % from area sources, 23 % from off-road vehicles and equipment, and 19% from on-road vehicles.

SO_2 is removed from the air by plants through dry deposition. From there, water transforms it into sulfuric acid and then to sulfate. In most cases, concentrations in urban areas around Phoenix are well below the 80 μg/m3 federal standard, and range from 3 to 10 μg/m3.

The major turning point for SO_2 emissions in Arizona was in the 1980s when major controls were installed on all copper smelters. Vehicular SO_2 and SO_4 emissions have also been reduced significantly as petroleum refineries are required to produce reduced sulfur content diesel fuel and gasoline.

Ozone (O_3)

Ozone is a colorless, slightly odorous gas that can be beneficial or detrimental depending on its location in the atmosphere. In the stratosphere (high above the surface), ozone blocks harmful ultraviolet (UV) radiation and is vital to the health of humans and ecosystems. At the ground level, O_3 is a major pollutant and adversely impacts the health of humans, animals, plants, and materials. The effect of O_3 on humans is both physiological and pathological, and even short exposure periods of < 12 hours to ozone concentrations between 0.1 to 0.4 parts per million can increase respiratory rates and pulmonary resistance, and change lung contraction and expansion (ADEQ 2006). This alteration is particularly severe in exercising adults, shown by signs of throat dryness, chest tightness, substernal pain, coughing, wheezing, pain while breathing deep, shortness of breath, and headache.

Even in low concentrations, O_3 can inhibit the immune systems of animals and severely disrupt plant respiration rates. Signs of damage to plants can appear as specks on the tips of confer needles and upper leaf surfaces of dichotomous plants. Plant scientists consider ozone to be the most damaging urban air pollutant for plants, causing 90% of the damage worldwide (UN

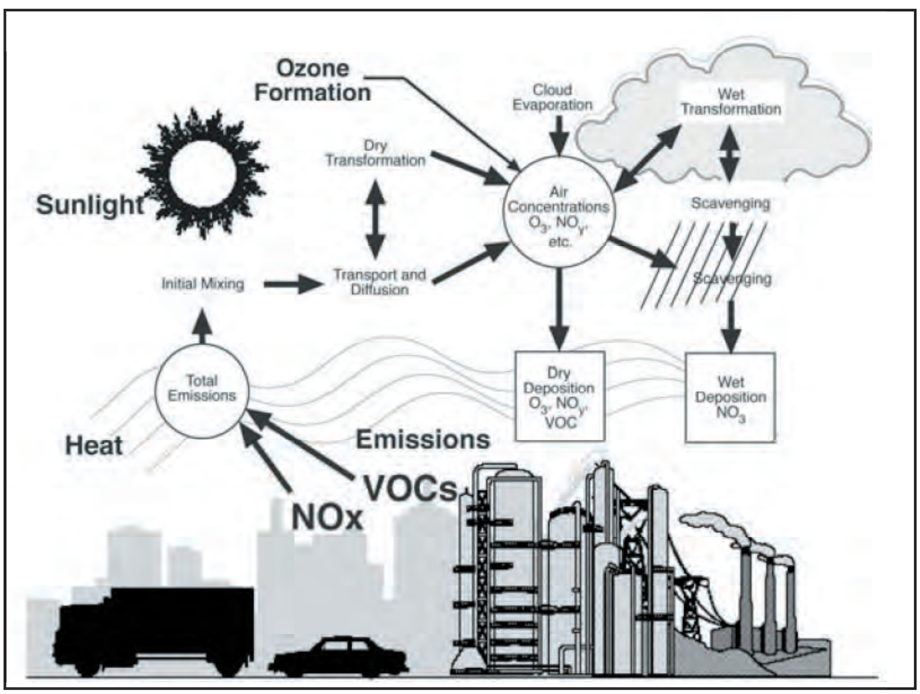


Figure 1-39. Ozone formation in an urban environment (Source: Houston Advanced Research Center and the National Resource Council Report on Ozone 1991).

2005). Ozone is the product of a photochemical reaction involving volatile organic compounds, nitrogen oxides and sunlight. Volatile organic compound (VOC) emissions in Phoenix are from: cars and trucks (31%), off-road vehicles and equipment (27%), small stationary sources (20%), biogenic emissions including grass, shrubs and trees (17%) and point sources (5%). (ADEQ 2006). Figure 1 39 shows the various interactions that lead to O_3 formation in the urban environment.

Ozone concentrations are regularly present during the day in urban and rural areas, and peak during the summer months when sunlight, biogenic emissions, and evaporative hydrocarbon emissions peak. After sunset, O_3 formation drops to almost zero due to the absence of photons from the sun, but quickly increases during the morning and afternoon. Efforts to reduce ozone and smog formation focus on the major precursors VOC and NOx. Engine modifications, catalytic converters, improved fuel tanks, carbon canisters in the fuel lines, vehicle inspections, and modifications to gasoline are being used. Despite these efforts, meeting the ozone eight-hour standard has been difficult.

As of 2005, there were 35 air-quality stations reporting ozone scattered around the state of Arizona, mostly in urban neighborhoods and within close proximity of sources.

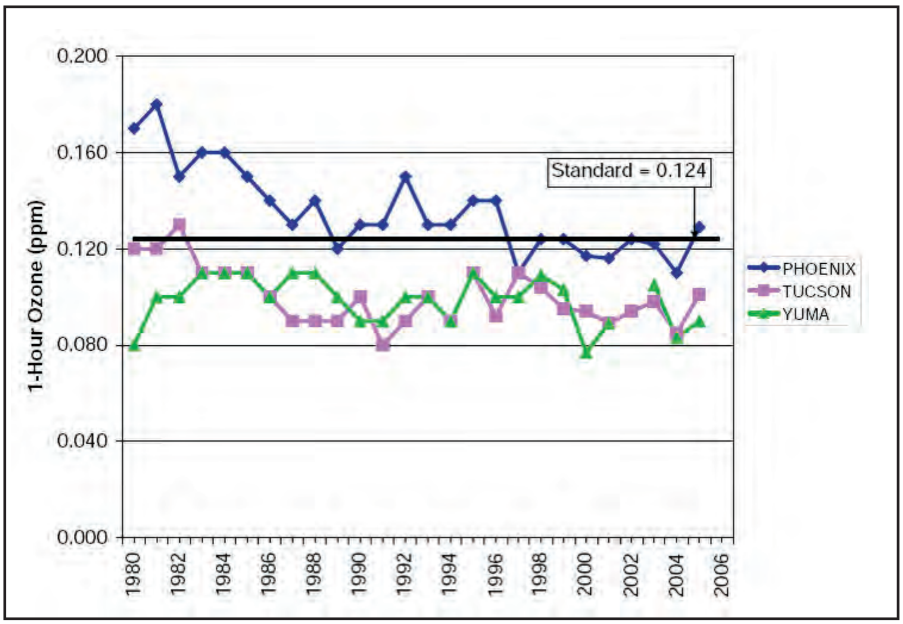


Figure 1-40. Maximum 1-hour ozone concentrations in Phoenix, Tucson and Yuma, AZ, 1980–2006 (Source: ADEQ 2006).

Maximum one-hour ozone concentrations have declined in Phoenix since the 1980s (Figure 1-40). Phoenix experienced a 32% decline over the last 25 years, and the ozone standard has not been exceeded since 1996. This decline can be attributed to the implementation of many exhaust controls for automobiles.

Particulate Matter (PM)

Particulate matter (PM) is a very important air pollutant in Arizona. Particulate matter are very small solid and liquid particles that vary widely in size, geometry, chemical composition and physical properties. PM reduces visibility and affects public health. Sources of PM can be both natural and human induced. Pollen and wind can release particulates into the air while more anthropogenic sources might include soot, fly ash, and dust from both paved and unpaved roads. **PM2.5**, which indicates fine particles of less than 2.5 microns in aerodynamic diameter, can be formed by agglomeration or coagulation in vapors, so they are often emitted during combustion or soils mixing. Larger, coarse particulates ranging in diameter from 2.5 to 10 microns are formed from direct grinding of materials and soils. Coarse emissions are comprised of dust caused by:

- re-entraining dust from paved roads
- driving on unpaved roads
- earthmoving associated with construction

These three activities cause 70% of all coarse particulates in Phoenix.

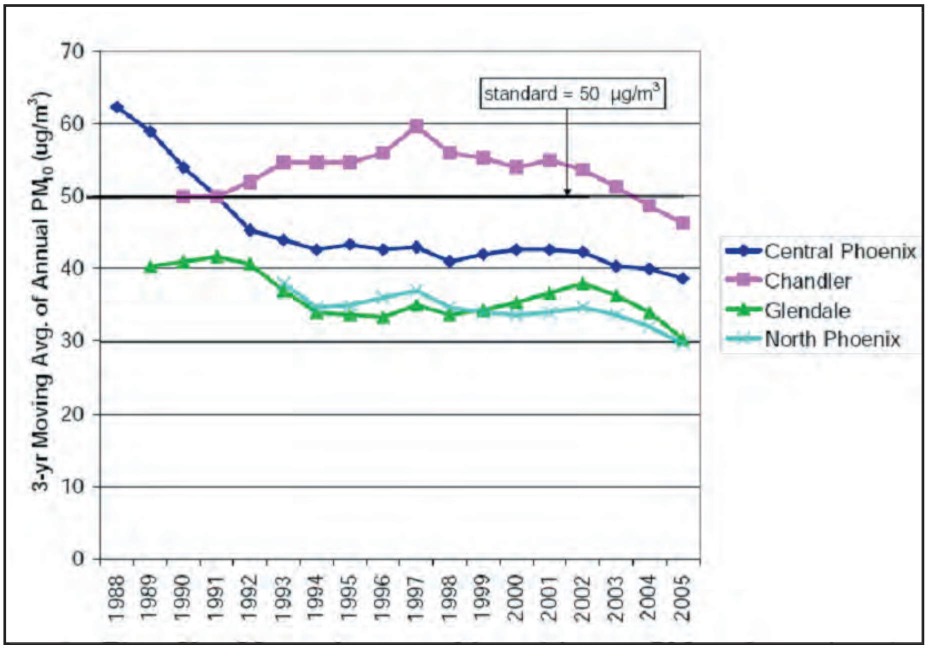


Figure 1-41. Three-year moving average of annual average PM10 at four metro Phoenix sites with moderate PM10 levels (Source: ADEQ 2006).

Health effects differ by the size and shape of the particulates. Large particulates (> 10 microns) are caught in the upper respiratory tract while smaller particulates (2.5 to 10 microns) can be inhaled and are deposited in the lower respiratory system, more damaging because are so small that they are respirable, entering the pulmonary tissues and remain there.

In 1995, the Arizona Comparative Environmental Risk Project ranked particulate matter as the highest environmental health risk in the state. The study estimated 963 premature deaths a year were caused by exposure to **PM10** concentrations. In 1991, Maricopa County had 667 deaths attributed to PM, compared to 88 for Tucson. Increases in respiratory disease, asthma, and coughs were also due to the elevated PM10 levels in that year. The relative levels of particulate matter differ by location in the city. Although PM2.5 is found in most areas, concentrations are typically higher in the urban center due to moving vehicles disturbing fine road dust, but are also seen on the urban fringes where construction and land development is occurring.

To reduce coarse particulates, Maricopa County created Rule 310, the dust-abatement rule. This rule regulates dirt moving and track-out dust from construction sites, and dust from unpaved parking and vacant lots. Fine particulates have been reduced because of stiffer vehicle regulations on the precursory elements that form particulates.

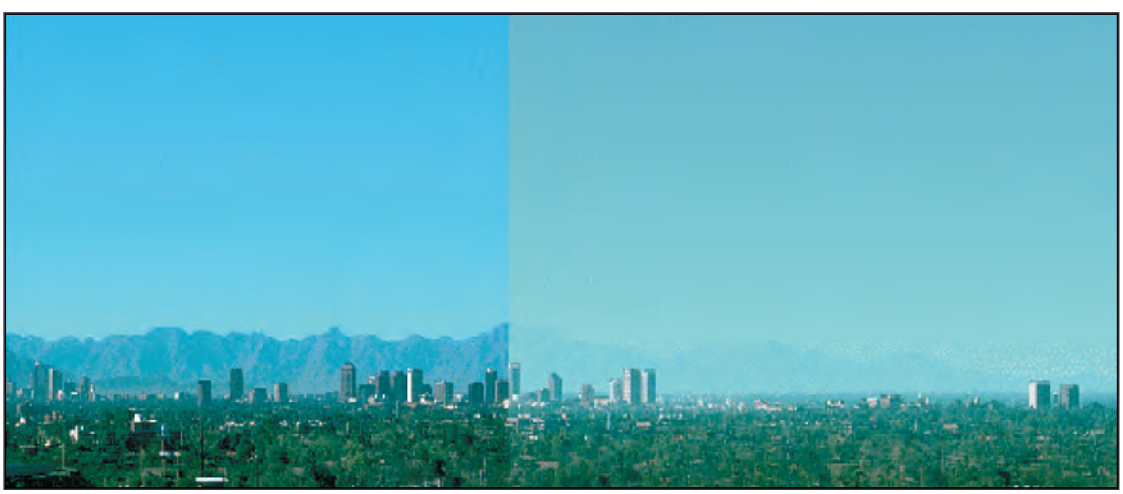


Figure 1-42. Average best and average worst visibility in Phoenix (Source: ADEQ).

Visibility

Visibility in Phoenix is an important air quality indicator, and an obvious signal of air quality conditions for residents. Visibility, or more specifically the extinction of light as it passes through the atmosphere, is influenced by a variety of factors, and ozone and particulate matter have the greatest bearing on visibility in Phoenix. Figure 1-42 shows how a clear day in Phoenix compares with an 'average visibility day'. The highest visibility days are usually on weekends with steady breezes. The lowest visibility days are often weekdays with their increased vehicle road miles and weekday construction activities which add to particulate matter and ozone formation.

Although visibility in Phoenix has not had as drastic an improvement as those of other criteria pollutants, there has been a steady improvement since the late 1990s. In general, the visibility during the dirtiest 20% of days increased by 7% since 1994. This improvement rate is much slower (3%) for the mean and cleanest days (2%) as evidenced in Figure 1-43. 1

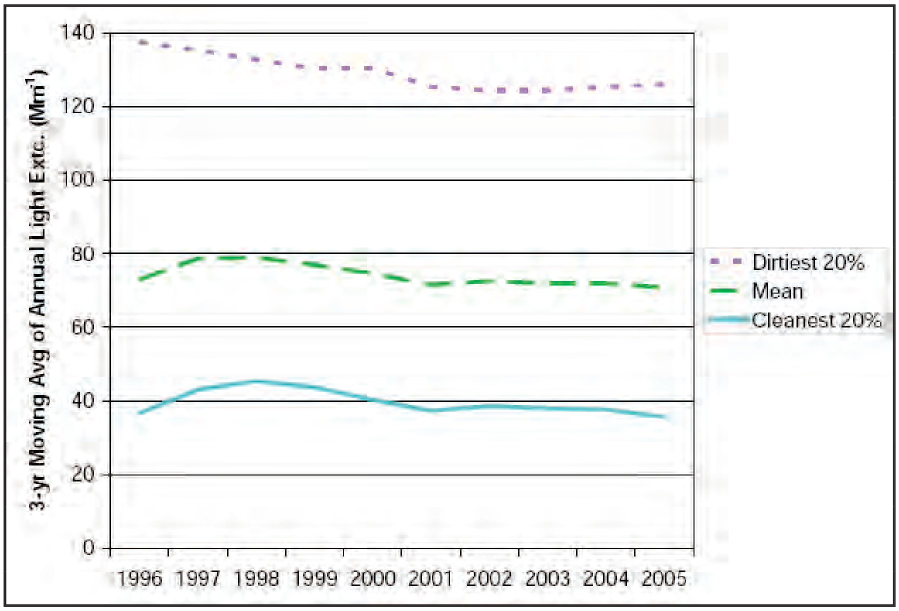


Figure 1-43. Light extinction trends in Phoenix (Source: ADEQ 2006).

Despite the rapid urbanization in the Phoenix region, pollutant levels continue to decline. Most national criteria pollutant air quality standards have been met since 1997, with the notable exception of eight-hour ozone standards during the summer months and the PM10 standards near construction-dominated areas. This improvement in air quality in Maricopa County directly results from federal and local air quality control programs, and shows how government programs positively affect the urban environment and sustainability in the Phoenix region.

NOISE POLLUTION AND ACOUSTIC COMFORT

The United Kingdom (UK) has been a leader in noise reduction legislature and has produced research that finds that noise levels of 40 - 55 decibels is annoying to receptors, that at levels between 55 and 60 decibels sleep is disturbed, and levels of 70 decibels can affect health and school performance.

A long running UK study published in 2007 named the 'Attitudes to Noise from Aircraft Sources in England' (ANASE) concluded that even relatively low levels of noise can cause annoyance and that:

"...noise from (transport and industrial) sources can cause conversation to be disrupted, sleep disturbance or simply generate feelings of annoyance. Consequently, the enjoyment of homes, gardens and open spaces can be adversely affected by this environmental noise. Concern has been raised about the effects of noise on mental health, cardiovascular and physiological functions and the effects on performance such as learning acquisition by children".

A seven month investigation in 2002 – 2003 by Maidstone Borough Council studied effects from two major highways, M2 and M20 corridors in Kent, England. The study found that measured highway sound levels were significantly above what had been expected, registering up to 60 to 70 decibels, and enough to alter pupils' school performance and disturb the sleep of residents.

The *British Medical Journal* released an abstract regarding noise pollution in 2003 which summarized that "Noise interferes in complex task performance, modifies social behavior and causes annoyance. Studies of occupational and environmental noise exposure suggest an association with hypertension..... and in children chronic noise exposure impairs reading comprehension and long term memory and may be associated with raised blood pressure". The World Health Organization website states that heath risks identified with noise includes "interference with social behaviour, such as aggressiveness, protest and helplessness".

Concerns of noise from highways have often been overshadowed by investigations into noise pollution from airports. In early 2004 the Mayor of London issued the 'Ambient Noise Strategy' requiring review of noise from railroads, airports, highways and streets and industrial plants. The study estimates that:

- 54% of the population of the UK lives in dwellings exposed to external daytime noise levels above 55 decibels,
- 67% of the population of the UK lives in dwellings exposed to external night time noise levels above 45 decibels.

A result of this study effort was the issuance of 'The Environmental Noise (England) Regulation of 2006' regulating noise sources above 55 decibels in outside settings. Also noted, prior to the implementation of this Directive, noise tended to be assessed only when a change to transportation or industrial was expected to occur. The European Union has also begun to regulate outdoor machinery and has produced 'noise labeling requirements' for equipment.

Further analysis to noise has produced statements that this is considered a social equity issue, with high percentages of noise suffers are "poor people in noisy neighborhoods, suffer from 'unacceptably' high noise levels". The 'Community Noise Research Strategy Plan' (CALM) from the publication 'Research for a Quieter Europe in 2002' outlines study and strategy for road transport, railway, air traffic, maritime transport and outdoor equipment.

The City of Phoenix began using rubberized asphalt pavement in 1964, reducing noise levels from City Street traffic an average of 3 to 5 decibels, although reductions of 10 decibels have been noted. Highway noise barriers as mitigation strategies cut the sound that reaches homes by 10 – 15 decibels.

Recently, **Arizona Department of Transportation (ADOT)** began the 'Quiet Pavement Pilot Program' an aggressive 115 mile rubberized asphalt paving program estimated to cost $34M. Rubberized asphalt reduces noise in the 500 to 4,000 Hertz frequency band.

ADOT noise criteria sets acceptable limits for highway noise as:

- Sensitive park land - 57 decibels ('A' Category');
- Typical parks, homes, churches, schools, libraries, hospitals – 67 decibels ('B Category');
- Other developed land - 72 decibels ('C Category');
- Interiors of home and community buildings - 52 decibels ('E Category').

Overall, ADOT states its goal is to reduce noise levels to 64 dBA , lower than the Federal noise abatement criteria of 67 dBA outlined in the **Federal Highway Administration Noise Abatement Criteria** (23 Code of Federal Regulations Part 772). Several issues have been noted with these regulations and policies: only homes or community areas within 1000 feet of the highway right-of-way are considered in these analysis or factored into any mitigation action; any mandated soundproofing has a goal to reduce noise only 5 decibels 'where feasible'; and rubberized asphalt does nothing to reduce noise in the lower Hertz frequencies.

Low frequency noise (LFN) is generally defined as noise in the 100 to 150 Hertz range and is sometimes referred to as 'infrasound'. LFN is now a recognized problem in many developed countries and there is considerable interest in this newly recognized phenomenon and its often powerful health effects. While there are numerous articles on the effects of LFN on marine life, study of human health effects is fairly new.

The Federal Aviation Administration (FAA) requires assessment of noise surrounding airports, culminating in a 'Part 150' study which produces mapping of the noise level contours from aircraft activities. The FAA can use federal funds for interior sound mitigation of homes, schools, churches and other community buildings that are impacted with noise above the 65 decibel level. Airport and community activists have promoted the reduction of the 65 dBA level to 60 or even 55 dBA level, but to date the FAA has not agreed.

Urban Climate Change

As the Phoenix region has transformed from desert and rural agriculture to urban built environments, many factors have induced climatic changes. Native vegetation, a source of evapotranspiration and shade, is removed during this land conversion. Next, engineered materials used to provide shelter, mobility, sanitation, and culture are set in place to form the urban setting (Golden 2004). These foreign materials often reflect less of the sun's energy (lower albedo), are impervious (preventing natural water migration through the soil and impacting air flows), and alter radiative characteristics by their geometry, size, and orientation. These surface materials include streets, roofs, walls, lawns, landscaping, and parking lots. The impact of urbanization is increasingly important not only within the urban core but in regions that surround and supply necessary resources such as energy and water (McMichael et al. 2002).

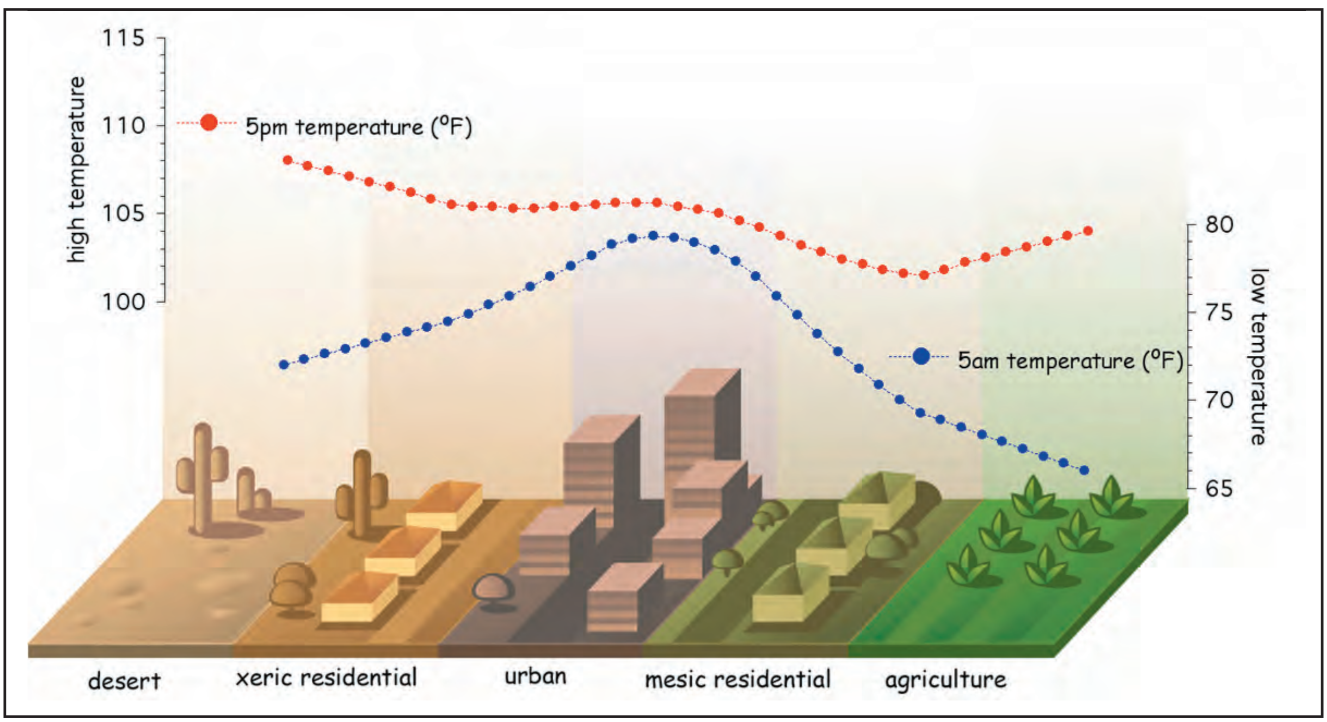


Figure 1-44. The regional UHI effect for maximum day time and minimum nighttime temperatures over different land covers. Source: Zehnder et al. 2004

One of the more prevailing issues facing rapidly urbanizing regions is the increase in average minimum temperatures that appears to correlate to urban growth (Figure 1-44). This phenomenon, known as the **Urban Heat Island (UHI)** Effect, can be observed in metropolitan areas around the world. UHI is particularly evident and detrimental in arid urban regions.

Historical Overview of Phoenix's Urban Heat Island

The UHI in Phoenix is one of the strongest in the world, with an increase of 0.860F per decade since the 1960s (Brazel et al. 2000). As presented in Figure 1-45, average regional temperatures have increased 5.6°F over that time period, but a threefold increase has occurred in the region's urban areas. Over the last 50 years, the average difference between minimum ambient air temperatures of rural and urbanized areas of Maricopa County has increased by 8°F. In extreme instances, such as highly developed areas with minimal vegetation, this difference is as much as 15°F at night (Brazel et al. 2007).

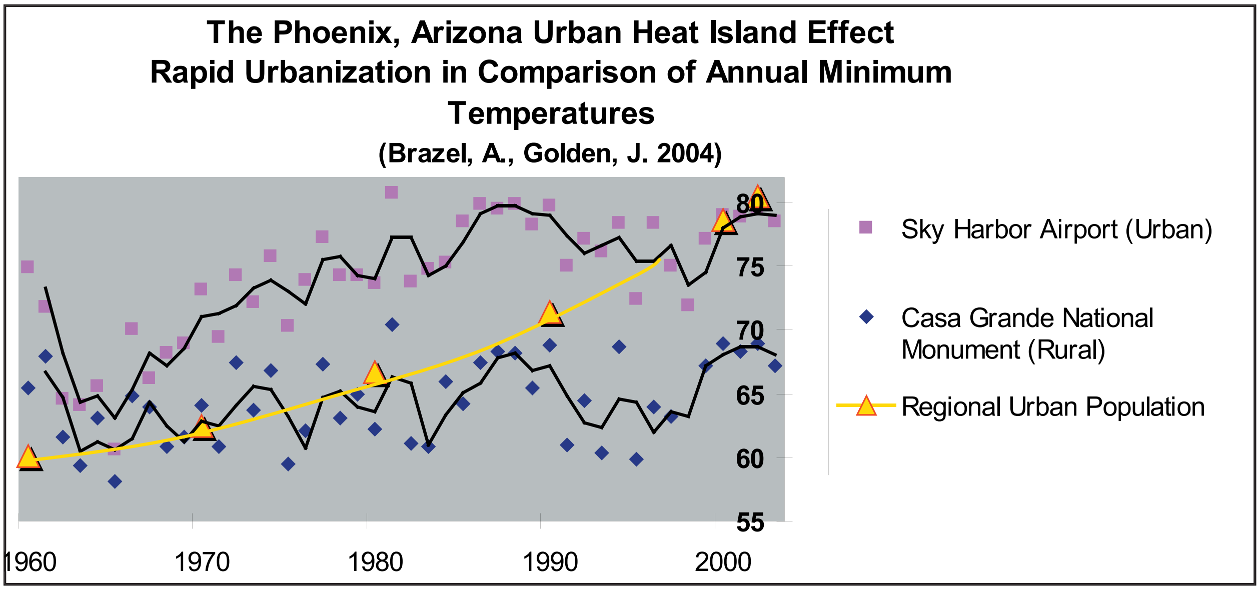


Figure 1-45. The increasing Phoenix UHI effect as a function of population growth and urbanization (Golden 2004).

It is important to distinguish between a nighttime (post-sundown) UHI effect and a daytime UHI effect. Depending on the location being examined, the Phoenix region actually experiences both a daytime and nighttime UHI effect.

The plots in Figure 1-46 are daytime and nighttime ground level (< 3m height) air temperatures observed in Phoenix. Note that the urbanized areas and the surrounding desert reach similar temperatures during the day. At night, the UHI is much more pronounced, and areas shown in yellow indicate warm temperatures and correspond with Phoenix's downtown area.

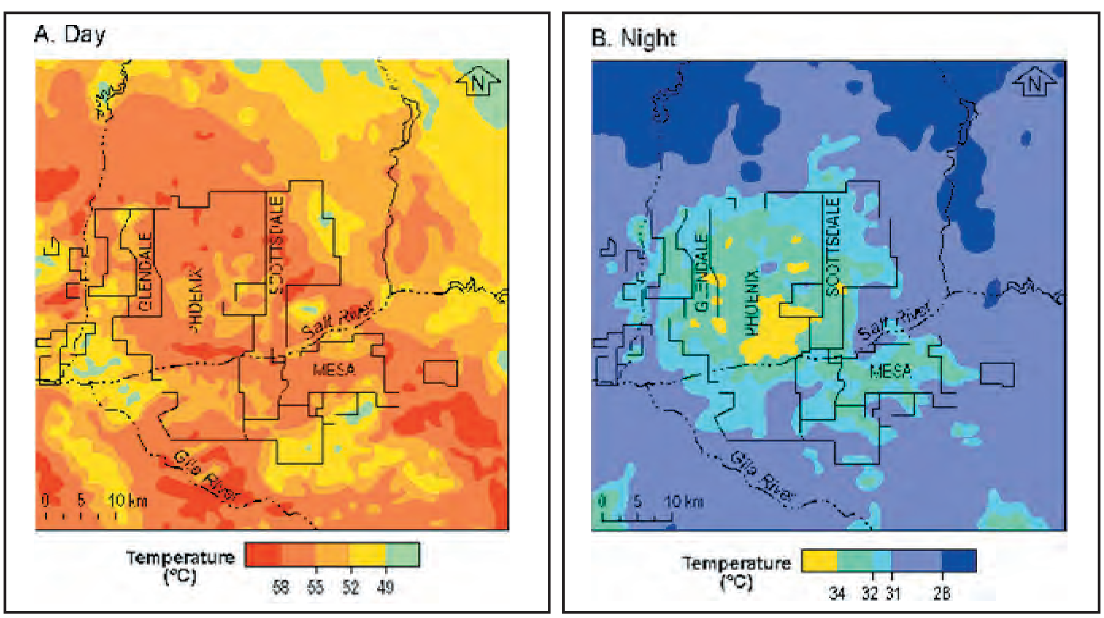


Figure 1-46. Surface temperature plots of the Phoenix area showing the difference between (a) day and (b) night. (Source: Balling and Brazel, 1989).

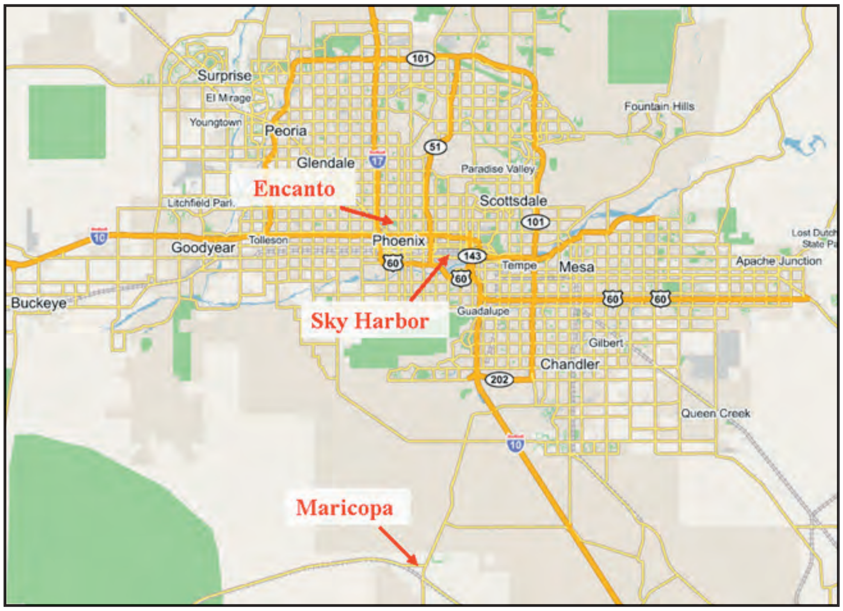


Figure 1-47. Three locations used for comparison of air-temperature variations in the Phoenix area: highly vegetated Encanto Park, Sky Harbor International Airport, and the primarily agricultural City of Maricopa (Source: Google Maps 2006).

(Baker, L.. el. al. 2002)

As will be discussed in Chapter 3, there are alternative material and spatial designs that can directly affect the intensity of the UHI effect in a given location at a given time of the day.

Air temperatures at Sky Harbor International Airport are often among the warmest in the Phoenix area, likely due to the large mass of pavements required to support aircraft traffic. A recent study conducted by ASU compared the average diurnal temperatures of three locations in and around the Phoenix area. The three locations—Encanto Park, Sky Harbor Airport, and the town of Maricopa—are at the same elevation. Their spatial relationship is indicated in Figure 1-47.

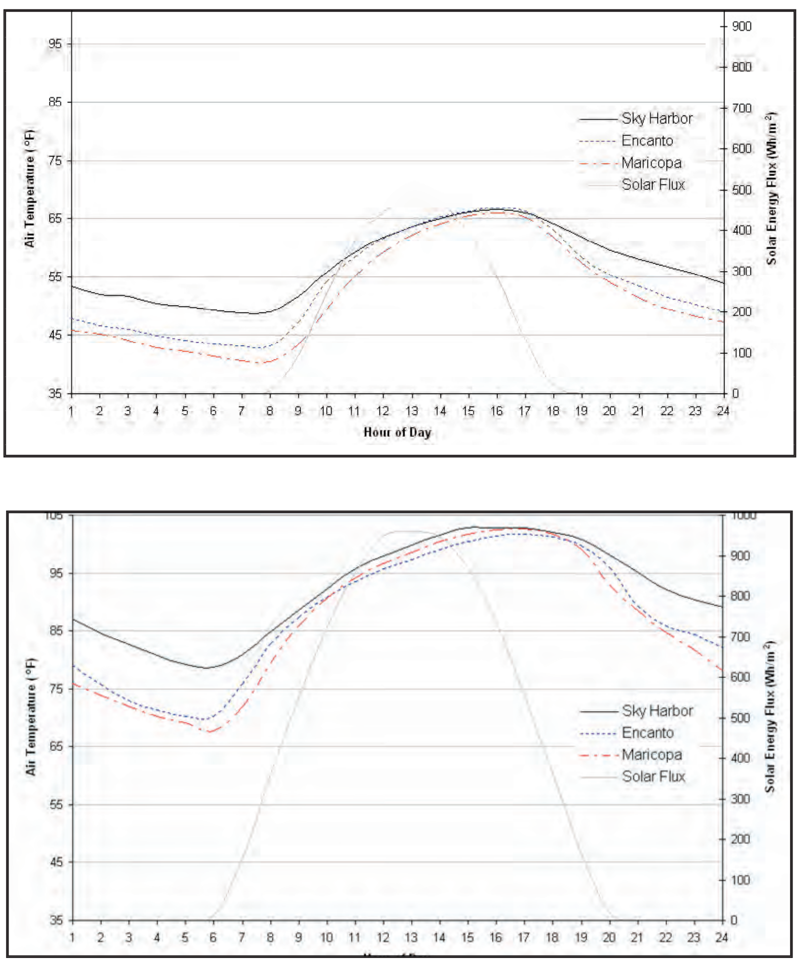
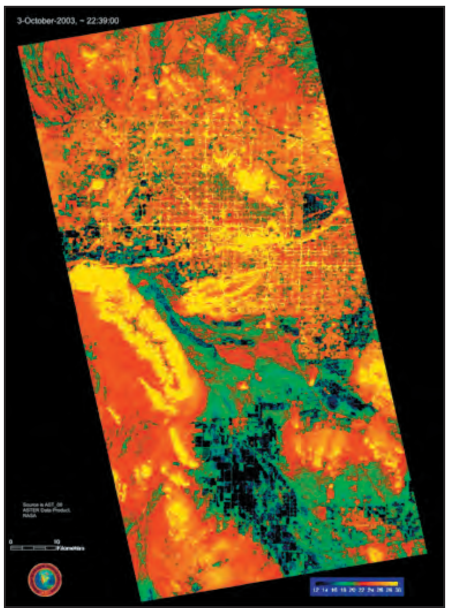


Figure 1-48. Comparing average monthly diurnal air temperatures among three locations in the Phoenix area during (a) January and (b) June 2004. In both instances average air temperature is 10oF higher at Sky Harbor Airport than in Maricopa at 5 am, even though the peak daytime temperatures are almost the same (Source: AZMet and ASOS 2004).

The study revealed that during both January and June of 2004, Sky Harbor Airport remained, on average, nearly 100° warmer at night than the other two locations, even though they reached the same daytime high (Figure 1-48). This result is a direct example of the heat island phenomenon occurring at highly paved areas.

The image on the left in Figure 1-49 was taken of the Phoenix region from an ASTER Satellite at 11pm one night in October 2003, with colors representing surface temperature. The image on the right of Figure 1-49 highlights the hottest 20% of the surfaces in the same location. Certain surfaces stand out more than others: the mountains, downtown Phoenix, the airports, major city streets, and highways are clearly visible in both images. The thermal properties of concrete and asphalt behave similar to the dense granite mountains, capturing and storing solar energy. In a city spread out like Phoenix, the primary causes of the UHI effect is increased thermal storage created by urban materials and the loss of evapotranspiration due to the loss of native vegetation.



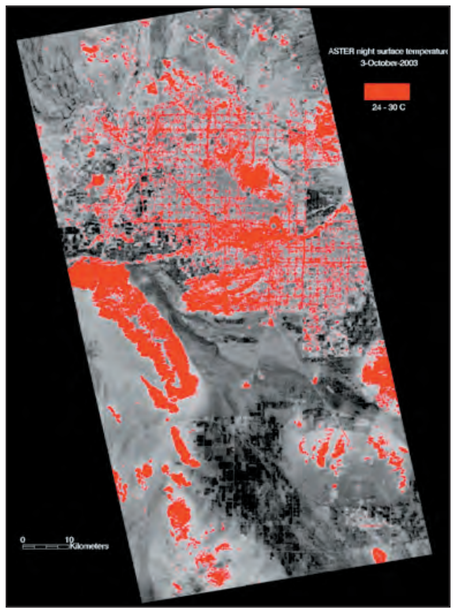


Figure 1-49. The role of materials to the UHI. On the left, is a satellite image from 10/3/2003 at 10 pm of the three-county region with yellow depicting the hottest surface temperature. On the right, is the same image showing the top 20% of surface temperatures in red. The role of pavements and buildings in the urban area is significant. (Source: Arizona State University)

Contributing Factors

The climate within cities is quite complex, with many factors contributing to its behavior within an urban area. Oke et al. (1997) summarized the most critical factors that differentiate urban areas from natural land cover and lead to elevated temperatures within urban centers.

Canyon Geometry – Buildings form "canyons" that tend to trap thermal energy near the bottom surface.
Thermal Properties – The materials, concrete, asphalt, roofs, and walls tend to be denser and absorb and retain more thermal energy than natural surface cover.

Anthropogenic Heat – Heat released from the combustion of fuels, electrical energy used for lighting and driving motors, and human and animal biological metabolism can elevate the temperature in dense urban areas.

The Urban Greenhouse Effect – Warmer air and air pollution within cities acts as a microgreenhouse effect, preventing heat from radiating from the warmed surfaces.

The Effective Reflectivity (Albedo) – The total reflectivity of a city is reduced due to the trapping of short-wave radiation by its building canyons.

Reduction of Evaporating Surfaces – As a city expands, natural vegetation is removed at a greater rate than it is replaced. This loss of moisture can adversely affect temperatures within the city.

Reduced Turbulent Transfer of Heat – In some areas of the city, wind patterns can actually be blocked, causing pockets with little wind flow and mixing. This reduced mixing of air greatly reduces the heat released from streets.

The images in Figure 1-50 and Figure 1-51 were taken using an infrared camera from a helicopter at 3 and 10 pm during Summers 2006 and 2008. The images show the contrasting surface temperatures found at night within different urbanized areas of Phoenix. Areas adjacent to tall buildings have lower sky-view factors, reducing the ability of heat to dissipate, and are made of dense concrete, which lead to their increased temperatures after sunset. These are just a few examples of the thermal complexity within urban settings.

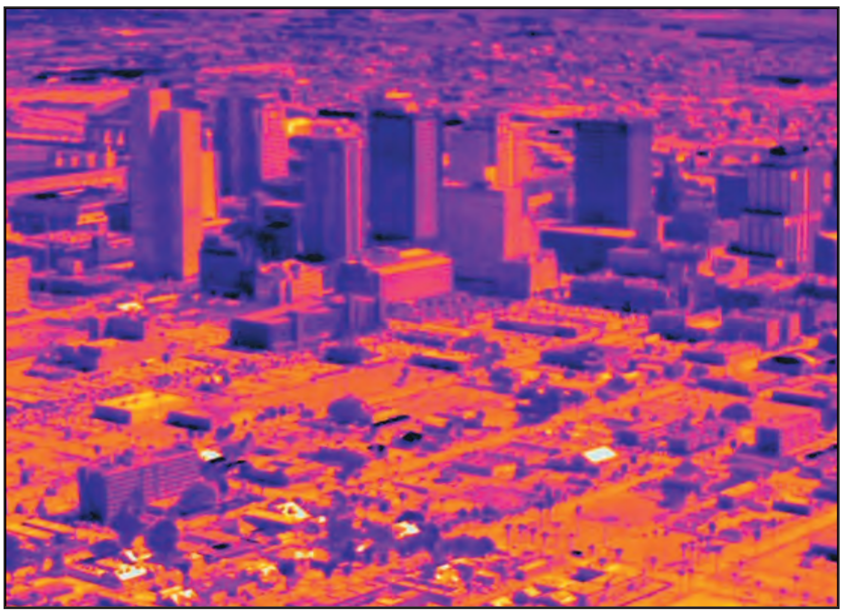


Figure 1-50. Handheld infrared thermographic image of downtown Phoenix, Arizona at 3pm on April 4, 2008. (Source: Arizona State University).

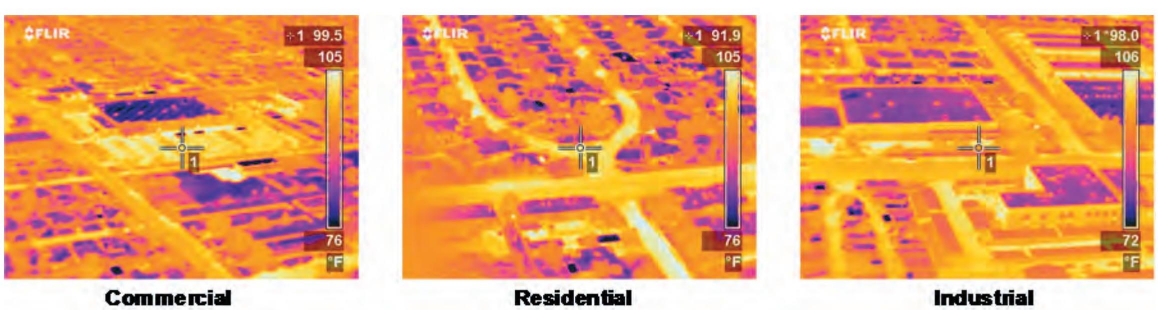


Figure 1-51. Helicopter infrared imagery of typical Phoenix land uses showing the role of pavements. Yellow is warmest, purple shows coolest temperatures, images taken at approximately 10pm July 2006. (Source: National Center of Excellence on SMART Innovations).

Urban Surface Energy Balance

"Understanding the nature of energy partitioning at the surface of cities is prerequisite to gaining proper insight and ability to model their climatic environment" (Roberts et al. 2003).

According to a study that compiled the results of several studies in various urban centers around the globe, the **urban surface energy balance (USEB)** is expressed theoretically as follows;

$$QI + QF = QH + QE + \Delta QS + \Delta QA$$

Where QI is net all-wave solar radiation, QF is the anthropogenic heat flux (car exhaust, light bulbs, etc), QH is the sensible heat flux, QE is the latent heat flux, ΔQs is the net storage flux, and ΔQA is the net horizontal heat advection (Roberts et al. 2003). The ΔQs, the term representing urban energy storage flux, is of the greatest relevance to the urban environment because it is shown to account for over half of the daytime net radiation at highly urbanized sites, including St. Louis and Mexico City (Ching 1985). ΔQs is dependant on both the materials and geometries of the urban surface and nocturnal heat energy release is thought to be the major variable in the **hysteresis lag** effect that creates the UHI (Roberts et al. 2003). Though ΔQs is agreed to be the most critical term in the USEB, it is significantly understudied. The complexity and three-dimensional aspect of the urban surface makes it a difficult challenge to accurately measure.

Researchers at Arizona State University (ASU) and other universities are working on improving the methods and input variables required to model the UHI formation and its impacts. With accurate modeling capabilities, city officials may someday be able to understand the broader impacts and benefits of policy decisions regarding UHI mitigation and energy use.

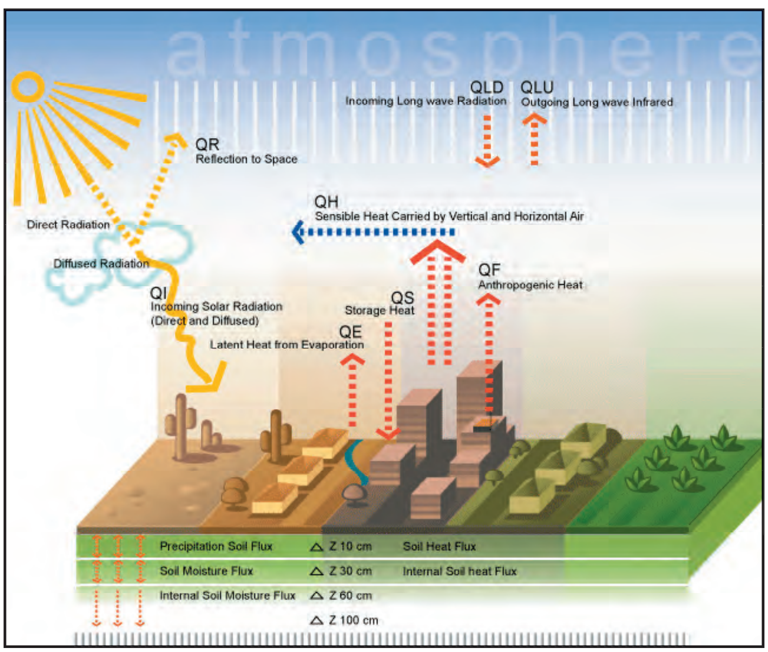


Figure 1-52. Urban surface energy balance fluxes (Golden 2004).

Impacts of Urban Heat Islands

The UHI can have several impacts on the three imperatives of sustainable development: environment, economic, and social well being. The most prevalent impacts of elevated temperatures include air quality, thermal comfort, energy consumption, water use and loss, tourism and business, agriculture production, vehicle efficiency, and weather patterns (Figure 1-53).

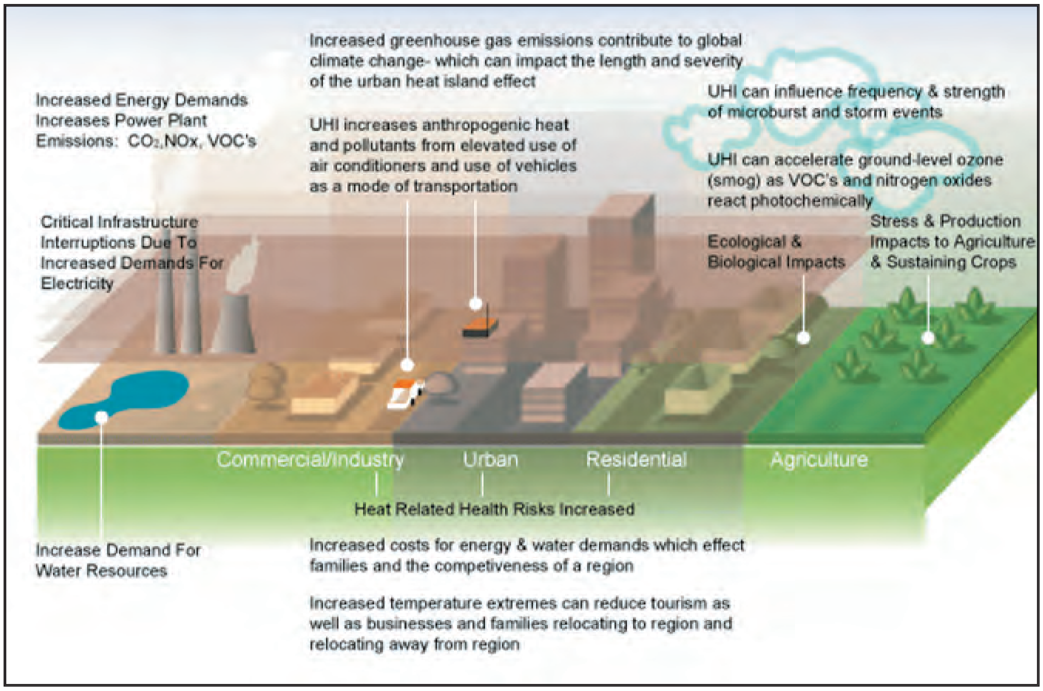


Figure 1-53. Impacts from the UHI effect. (Golden 2004).

Air Quality and Urban Heat Islands

When increased surface and ambient air temperatures combine with ultraviolet radiation and a mixture of nitrous oxides (NOx) and volatile organic compounds (VOCs) the result is the formation of ground level ozone. Urban centers in arid and semiarid regions with congested traffic often deal with the rapid formation of smog as ambient temperatures rise (EPA 2001). The elevated air temperatures within urban centers can also lead residents to run air conditioning systems at higher rates and for longer periods of time, increasing the demand for energy production. The power plants supplying the power required for these cooling systems often emit aerosolized compounds that can contribute to smog formation. The plot in Figure 1-54 shows this correlation between energy demand and smog generation as average afternoon temperatures increase.

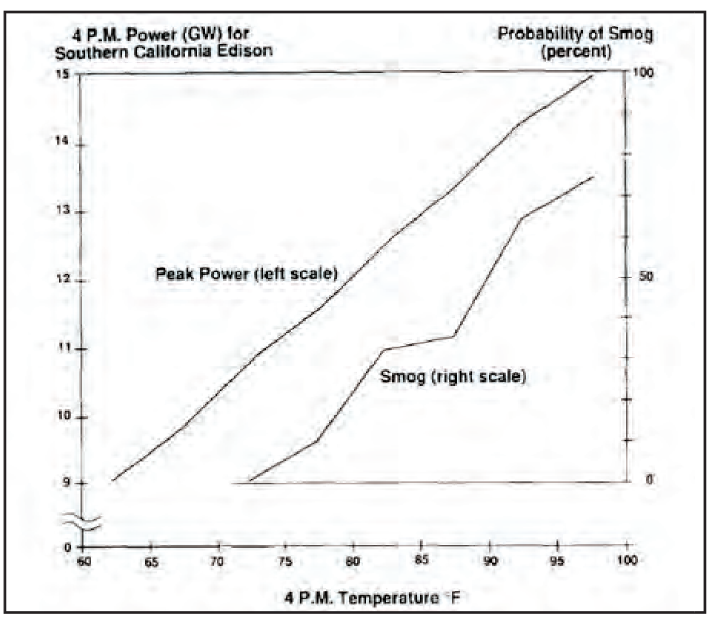


Figure 1-54. Energy consumption and smog production vs. afternoon temperatures in Los Angeles. (Source: US EPA).

Energy and Urban Heat Islands

UHI also increases the consumption of electricity and the risk of a major disturbance in energy delivery due to the UHI-induced increase in mechanical cooling needs. Commercial and residential buildings use 65.2% of total US electricity and 36% of total US primary energy. Research in the Phoenix area has directly related the continued increase in electricity consumption dating from 1948, due to urban climate change. Architectural energy modeling conducted at ASU concluded that a typical residence in Phoenix (using conservative 2002 construction technologies) would experience an increase from 7,888 annual kWh in 1950 to 8,873 kWh in 2004 when accounting for the urban-climate change during that same period. Additionally, in US cities with populations over 100,000, peak-utility loads increased 1.5-2.% for every 1°F (0.6°C) increase in summertime temperatures (EPA 1992).

A Lawrence Berkeley National Laboratory (LBNL) and Department of Energy (DOE) study in Los Angeles concluded that about 1-1.5 Gigawatts of power are used to compensate for these increases in urban-climate temperatures. This amount is equivalent to the combined power used annually by 400,000 average US homes. This increased power needs cost the Los Angeles ratepayers about $100,000 per hour and about $100 million per year. On a national basis, the cost avoidance for electricity and the associated emissions was estimated at $5B/year. The increase of fossil fuels burned, water consumption, water discharges, air emissions, and waste generation at the power plants also acts upon the system.

Economics and Urban Heat Islands

Research has indicated that if UHI mitigation strategies could realize a 1.8°F to 3.6°F decrease in average temperature in urban settings, the annual energy savings could reach $26 million for three demonstration US cities (LBNL 2000). In areas of high-solar capacity, such as the desert Southwest, modeling the adaptation of renewables such as photovoltaics as a mitigation strategy merits consideration

Water and Urban Heat Islands

Up to 40 gallons (140 liters) of water is required to produce 1kWh of electricity from a coal plant and 54 gallons (205 liters) for nuclear-powered plants. Approximately 408 billion gallons per day were withdrawn for all uses in the US during 2000. Fresh groundwater withdrawals (83.3 Bgal/d) during 2000 were 14% higher than in 1985. Approximately 195 Bgal/d, or 48%, of all freshwater and saline-water withdrawals for 2000, were used for thermoelectric power. Most of this water was derived from surface water and used for once-through cooling at power plants.

Alteration of water temperature in urban stormwater runoff, from contact with increased surface temperature of pavements can play a significant role in the chemical and biological processes that support water quality. In urbanized watersheds, nonpoint source runoff is considered to be a major general source of many pollutants, and the percentage of impervious surface area has been documented to be an important factor in determining receiving stream water quality as defined by ecological indicators such as benthic macroinvertebrate community composition and fish density and abundance. Water-resource protection at the local level is increasingly complicated, largely due to the importance of nonpoint source pollution, or polluted runoff. This diffuse form of pollution, now the nation's leading threat to water quality, results from contaminants that are washed off the surface of the land by stormwater and are carried either directly or indirectly into waterways or groundwater.

Excessive Heat Events and the Urban Heat Island

One of the most significant impacts from the UHI effect relate to human health. During extended periods of excessively high temperatures, called **heatwaves**, the UHI can make it difficult for citizens to escape the heat at night. During August 2003, one of the largest fatal disasters occurred in one of the most developed regions in the world.
Between 22,000 and 35,000 people died across developed Europe as a result of excessive heatwaves. Heat-related illnesses kill more people in the US than hurricanes, tornadoes, earthquakes, and floods combined. In France in 2003, most of the 14,800 deaths occurred in the urban region of Paris. Similarly, in Chicago in 1995, heatwaves killed 739 people. The victims

of heatwaves are usually already in compromised physical states such as the elderly or young. In addition, the homeless and impoverished are often susceptible to heat stress due to lack of air conditioning, water availability, and health services.

Phoenix has an average of 89 days per year of greater than 100oF (37.8°C) and has experienced 143 days of greater than 100°F (37.8°C) temperatures as recently as 1989 (National Weather Service 2008). The region also has the potential of reaching extremely hazardous temperatures as high as 122°F (50 °C) in 1990 and 121oF (49.4°C) in 1995 (Golden 2004). Figure 1-55 includes a bar graph showing the numbers of deaths in Arizona related to heat over a 10-year period.

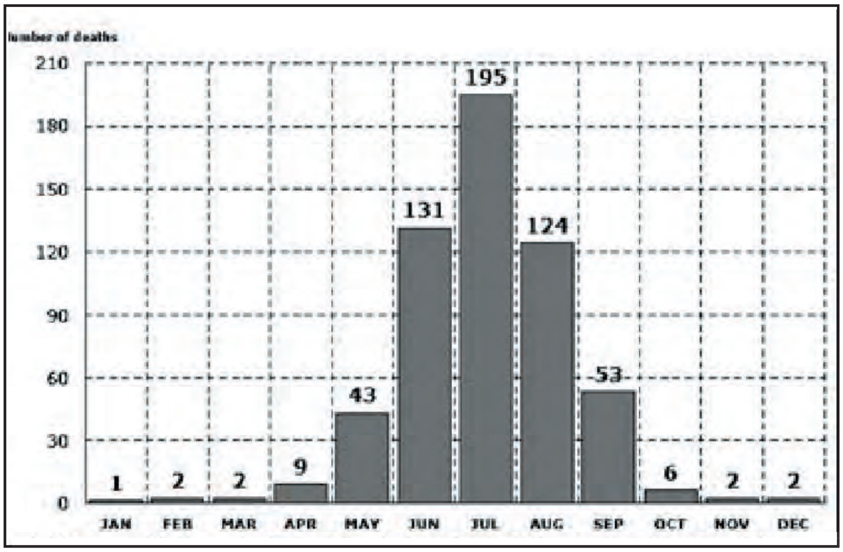


Figure 1-55. Deaths from exposure to excessive climatic heat occurring in Arizona from 1992-2002 Source: AZ Department of Health Services

Transportation in Urban Areas

Transporting individuals, goods, and services from one structure to another is a daily occurrence to accommodate commerce, social interaction, and public safety. Transportation in urban areas presents a challenging combination of the environmental, social, and economic concerns within the urban environment. Energy use for transportation is the fastest growing energy sector in the world. Most of this increased demand for motor vehicles will be in urban areas. Adversely, this

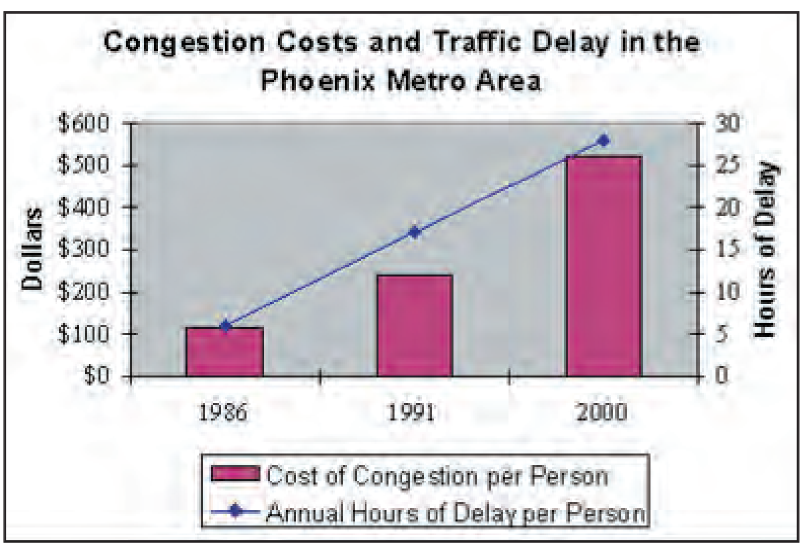


Figure 1-56. Congestion costs and traffic delays per person per year in the Phoenix area from 1986-2000. Source: Texas Transportation Institute and US EPA

added mobility comes at an environmental cost. Motor vehicles are the primary cause of traffic congestion and air pollution in cities. In cities similar to Phoenix, the distances between residential areas and the business and industrial sectors make owning and driving a motor vehicle appealing and even essential. In turn, this need, creates a cycle of social inequities by limiting the mobility and access to jobs for those that can not afford vehicles. Although bus transportation is available, due to spatial layout, it is not always easily accessible and requires long trip times. In developed countries like the US, 75% of all car trips are less than 10 km (6.23 miles) with the typical car emitting almost 5 tons of CO_2 a year (Climate Change Canada 2003)

Traffic congestion has become a major problem in the Phoenix area. Research by the Texas Transportation Institute examined the cost of congestion per person. Figure 1 56 shows that the annual cost of congestion for Phoenicians has grown by $408 per person from 1986 to 2000, which equates to an average of 28 hours of delay annually per person: a 367% increase! To describe this in more graphic terms, the average driver in Phoenix today loses about three days of work time a year sitting in traffic compared to a driver in 1986. This trend has major quality of life implications for Valley residents.

summary

The region surrounding Phoenix, Arizona has experienced a rapid growth in population and resulting urbanized areas in recent decades. Many people are drawn to the area for a better quality of life – seeking a lower cost of living, pleasant year round weather, and economic and educational opportunities. Citizens are beginning to realize that this growth comes at a cost, and if unchecked, may result in a decrease in the quality of life that originally brought them here. The transformation from rural to urban provides many benefits and opportunities for residents, but it also places new pressure on the ecological and infrastructure systems on which we rely. The resulting stress can have severe and irreversible consequences that will ultimately impact our way of life.

A new train of thought is beginning to take hold globally that seeks to mend the disconnect between the natural and built environment. It acknowledges the importance of economic development while also accepting the limits of the earth's ecosystems, and understands that the actions we take today can negatively or positively affect future generations and their quality of life. This new paradigm is referred to as Sustainable Development and this idea aims to balance the three over-arching objectives of economic, environmental, and social prosperity.

In this chapter we explored several key urban sustainability issues related to the rapid growth in the Phoenix Region – including energy generation and use, water quality and quantity, transportation, air quality, waste generation, noise pollution, and local climate change. The most important aspects of each issue are summarized below.

Energy

The historical and projected energy generation and consumption patterns of the region are on an unsustainable trajectory due to the over reliance on non-renewable energy sources for electrical power and transportation. The primary source of electrical energy is from coal burning power plants, which release the green house gas carbon dioxide (CO_2). Our buildings are not as efficient as they could be, wasting energy on artificial light and air conditioning poorly insulated spaces. And while many suggest solar energy as the obvious savior for our state's energy needs, it still remains economically out of reach.

The gasoline on which our daily commutes depend is derived from locations far outside of the state, and our reliance on personal automobiles will likely continue into the future due to the spread out nature of the city and the lack of a robust public transportation system. Several measures are underway to increase accessibility, speed, and safety of public transportation in the Valley. The Valley's first light rail system is due to open in 2008 and the public bus networks are also continuing to grow. Even with these additions, we are still far from having a system comparable to many of the nation's prominent metropolitan areas.

Water

Water quality and quantity will always be a concern in a dry desert region. The early landowners foresaw this limit to growth and constructed a network of canals and dams to control and deliver water from the northern fringes of the state.

These measures may have bought us time but the limits of this supply is inevitable and demands an immediate and drastic shift in the way we use, allocate, and reuse water within the state.

Emissions

Since the 1970s, harmful air and water emission concentrations in the Valley have been steadily declining thanks to regulations and programs set forth by the Arizona Department of Environmental Quality and the Environmental Protection Agency. Nevertheless, air emissions from automobiles and construction have kept ground level Ozone (O_3) and Particulate Matter (PM) concentrations at the higher end of the acceptable levels. Naturally occurring water contaminants such as Arsenic (As) and historical chemical releases from industrial facilities remain a threat to underground water resources in rural and urban areas of Arizona.

Waste

The amount of solid waste continues to increase with population, but the relative percentage of waste that is diverted or recycled has been helping to slow this trend. Curbside recycling began in the early 1990s in Arizona and has had positive results, but there remains plenty of room for improvement. Public awareness, convenience, incentives and regulation are key components of managing and reducing waste as we move forward.

Urban Climate

The expansion of urban areas in the region have lead to the removal of vegetation and the construction of countless new roads, parking lots and buildings made of dense and often dark materials. These engineered materials capture and store the sun's energy more readily than natural materials, resulting in warmer air temperatures at night. This phenomenon is known as the Urban Heat Island (UHI) effect and impacts the amount of energy and water we use, the amount of smog in the air, and our overall enjoyment and comfort within the city. This phenomenon occurs in nearly all urban areas, and the magnitude of the Phoenix UHI is particularly severe. The average night time low in Phoenix has increased by 8ºF over the last 50 years (Brazel 2000). Research is being conducted to help reduce these effects, and in the following chapter, Urban Heat Island Mitigation, we provide detailed information about the latest materials and design strategies that planners and designers can use to help mitigate urban heat island effects within cities.

Moving Forward

The topics discussed in this chapter were focused on the environmental problems of urbanized regions. There are, of course, many equally important economic and social problems that our region continues to struggle with. Issues of immigration, the housing market, health care, drug abuse, crime, education and employment affect us all and require our constant diligence and attention. Many governmental and non-governmental organizations have been working for decades to address these issues. Sustainable development can be the uniting ideal that brings these efforts into a single trajectory, forming a powerful force as we progress into the future.

Our intention in writing this guidebook was not to provide solutions for all of the world's problems but rather to focus on the ones that are within the realm of city planners, architects and engineers. And in providing an overview of the most pressing issues, we can hope that future development in the region will be guided by the principles and ideals of sustainable development in the Phoenix region.

Additional Resources

- **World Business Council for Sustainable Development:**
  www.wbcsd.org/templates/TemplateWBCSD5/layout.asp?MenuID=1
- **US EPA:** National Risk Management Research Lab's Life-Cycle Assessment:
  www.epa.gov/ORD/NRMRL/lcaccess/index.html
- **ISO Standards:** www.iso.ch/iso/en/CatalogueListPage.CatalogueList?ICS1=13&ICS2=020&ICS3=10
- **UN Life Cycle Initiative:** http://lcinitiative.unep.fr
- **Life Cycle Assessment for Cities:** www.gdrc.org/uem/lca/lca-for-citie.html
- **Portland Cement Association:** www.cement.org/buildings/sustainable_lca.asp
- **National Center of Excellence on SMART Innovations for Urban Climate and Energy:** www.asuSMART.com
- **EPA Energy Star:** www.energystar.gov/index.cfm?fuseaction=find_a_product
- **US Green Building Council:** www.usgbc.org
- **Green Roofs:** www.greenroofs.com
- **National Asphalt Pavement Association:** www.hotmix.org
- **American Concrete Pavement Association:** www.pavement.com
- **Lawrence Berkeley National Lab:** http://eetd.lbl.gov/heatisland
- **DOE's Home Energy Saver:** http://hes.lbl.gov
- **eQUEST:** http://doe2.com/equest/index.html
- **DOE2 Energy Model:** http://doe2.com/DOE2/index.html
- **Air Explorer:** www.epa.gov/airexplorer
- **AirWeb:** Protecting Air Quality: www2.nature.nps.gov/air
- **Arizona Department of Environmental Quality:** www.azdeq.gov
- **Earth 911:** Making Every Day Earth Day: www.earth911.org
- **Earth's Biggest Environment Search Engine:** www.webdirectory.com
- **Environmental Protection Agency:** www.epa.gov
- **EPA** – Air and Radiation: www.epa.gov/oar/oaqps
- **EPA's** – AIRNow: www.airnow.gov
- **EPA's Air Quality Database:** www.epa.gov/air/data/index.html

Software

- **Athena LCA Software:** www.athenasmi.ca
- **Boustead Consulting Database and Software**
- **ECO-it:** Eco-Indicator Tool for environmentally friendly design - PRé Consultants
- **EDIP** - Environmental design of industrial products - Danish EPA
- **EIOLCA** - Economic Input-Output LCA at Carnegie Mellon University
- **GaBi** - Product Family (Ganzheitlichen Bilanzierung - holistic balancing) - Five Winds KCL-ECO 3.0 - KCL LCA software
- LCAiT - CIT EkoLogik (Chalmers Industriteknik)
- **SimaPro 7 for Windows** - PRé Consultants
- **Tools for Environmental Analysis and Management (TEAM)** - Ecobalance, Inc.
- **Umberto** - Advanced software tool for Life Cycle Assessment - Institut für Umweltinformatik
- **Building Life-Cycle Cost (BLCC) Program, version 5.2-04** - Economic analysis tool developed by the National Institute of Standards and Technology for the DOE Federal Energy Management Program.
- **Energy-10** - Cost-estimating program of the Sustainable Buildings Industry Council
- **The Tri-Services Parametric Estimating System (TPES)** contained in the National Institute of Building Sciences (NIBS) Construction Criteria Base developed models of facility types by determining critical cost parameters (i.e., number of floors, area and volume, perimeter length) and using these values to predict the costs of a wide range of

building systems, subsystems, and assemblies. The TPES models can be adapted to facilities beyond those included in the base- modeling system by using SuccessEstimator, a software package available from US Cost.

References

ADEQ, 2000. The Status of Water Quality in Arizona, Clean Water Act Section 305(b) Report 2000. ADEQ Environmental Quality Report EQR-00-03.

ADEQ, 2002. Groundwater Protection in Arizona: An Assessment of Groundwater Quality and the Effectiveness of Groundwater Programs. A.R.S. §49-249.

ADWR, 2002. ADWR Website: Arizona's Water Supplies and Water Demands. http://www.adwr.state.az.us/AZWaterInfo/statewide/supplyde.html

ADEQ, 2006. Air Quality Annual Report, A.R.S. 49-424.10.

Allenby, B.R. 1999. Industrial Ecology: Policy Framework and Implementation. Upper Saddle River, NJ: Prentice Hall.

Arnfeld, A.J., Herbert, J.M. and Johnson, G.T. (1999). *Urban Canyon Heat Source and Sink Strength Variations: A Simulation-Based Sensitivity Study,* Congress of Biometerology and International Conference on Urban Climate, WMO: Sydney

Arwood, J. (2006). Solar Power is Sizzling Hot. *Tech Connect Magazine*, 2, 36 - 40

Baker, L. et. al. (2002). "Urbanization and Warming of Phoenix (Arizona, USA): Impacts, feedbacks and mitigation." *Urban Ecosystems*, 6:183-203

Baker, L. , Brazel, Anthony, J., Westerhoff, P. (2004). Environmental Consequences of Rapid Urbanization in Warm, Arid Lands: Case Study of Phoenix, Arizona, the Sustainable City III, Advances in Architecture Series, WIT Press, Boston.

Balling, R.C., Brazel, S.W., (1989). Time and space characteristics of the Phoenix urban heat island. *Journal of the Arizona-Nevada Academy of Science*, 21, pp. 75-81.

Bartone, Carl, "Annotated Outline of a Report on Strategic Options for Managing the Urban Environment" Washington DC: World Bank, 1991.

Baruska, T. and W. McClure, 2007. The Built Environment: A Collaborative Inquiry Into Design and Planning,

Bass, B., Krayenhoff, S. & Martilli, A. (2002). *Mitigating the Urban Heat Island with Green Roof Infrastructure*. Urban Heat Island Summit: Toronto.

Brazel, A., Selover, N., Vose, R., and Heisler, G. (2000). The tale of two climates-Baltimore and Phoenix urban LTER sites. *Climate Research*. Vol. 15: 123-135, 2000.

Brazel, A. J., Gober, P., Lee, S., Grossman-Clarke, S., Zehnder, J. and Hedquist, B. (2007) Dynamics and determinants of urban heat island change (1990-2004) with Phoenix, Arizona USA. *Climate Research* 33:2 , pp. 171-182.

Bretz, S., Akbari, H. (1997). Long-term Performance of High-Albedo Roof Coatings. Energy and Buildings – Special Issue on

Urban Heat Islands and Cool Communities, 25(2), pp. 159-167.

Bruntland, H.G. (1987). Our Common Future, WCED. New York: Oxford University Press.

Carson, Rachel L. (1962). *Silent Spring 40th Anniversary Edition*. First Mariner Books edition 2002.

Ching, J. K. S. (1985). "Urban-scale variations of turbulence parameters and fluxes." Bound.-Layer Meteor., 33 (4), 335-361.

Decker, E. H., Elliott, S., Smith, F., Blake, D. and F. S. Rowland (2000). Energy and Material Flow Through the Urban Ecosystem.. *Energy Environment*. 25:685-740.

Energy Information Administration (2007). Annual Energy Review. US Dept of Energy, Washington, D.C. <www.eia.doe.gov/emeu/aer/contents.html>

Erlich, Paul R. (1968). *The Population Bomb*. New York: Ballantine Books.

Ewing, R.. *Pedestrian and Transit Friendly Design: A Primer for Smart Growth*. June 1999. Smart Growth Network.

Feely, T. J., Hoffman, J., and B. Carney (2005). Power plant water management—A Department of Energy/National Energy Technology Laboratory R&D Initiative.

Golden, J., Brazel, A., Salmond, J., and D. Laws (2006). Energy and Water Sustainability - The Role of Urban Climnate Change from Metropolitan Infrastructure. Engineering for Sustainable Development Vol. No. 1, pp. 55-70.

Golden, J. (2004). "The Built Environment Induced Urban-Heat-Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity." Environmental Sciences, 2003/2004, Vol. 1, No. 4, pp. 321–349

Godish, T. (1989). Indoor Pollution Control. Lewis Publishers. Chelsea, Michigan.

Graf, Charles G., 1986. VOC's in Arizona.s Groundwater; A Status Report. Proceedings of the Focus Conference on Southwestern Groundwater Issues, National Water Well Association, Oct. 20-21, 1986.

Grimmond, C.S.B and Oke, T.R. (1999). Aerodynamic properties of urban areas derived from analysis of surface form. *Journal of Applied Meteorology*, 38, 1262-1292.

Hall, J., and H. Vredenburg (2004). "The Challenges of Innovating for Sustainable Development". MIT Sloan Management Review.

Herzog, H.J., Drake, E.M., and E.E. Adams (1997). CO2 Capture, Reuse and Storage Technologies for Mitigating Global Climate Change. DOE Order No. DE-AF22-96PCO1257. Cambridge: MIT.

Heisenberg, W. (1927). Uber den anschaulichen Inhalt der quantentheoretischen Kinematick und Mechanik, in *Zeitschrift fur Physik,* pp. 172-198, volume 43.

Howard-Grenville, Jennifer A. (2001). Institutional Evolution. The Case of the Semiconductor Industry Voluntary PFC Emissions Reduction Agreements. *Organizations, Policy and Natural Environment: Institutional and Strategic Perspectives.* Palo Alto: Stanford University Press.

Idso, C. D., Balling, R.C. (2001). An Intensive Two-Week Study of an Urban CO2 Dome. *Atmospheric Research* Vol. 35, No. 6, pp. 995-1000.

IPCC (2001). *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu (eds). Cambridge: Cambridge University Press.

Lee, Yok-shiu, "Myths of Environmental Management and the Urban Poor" in *Mega-City Growth and the Future. Tokyo*: United Nations University, 1994.

Leitman, Josef, *Rapid Urban Environmental Assessment. Volume I: Methodology and Preliminary Findings*.. UMP Discussion Paper 14. Washington DC: World Bank.

McGranahan, G. et. al. (2002). *The Citizens at Risk: From Urban Sanitation to Sustainable Cities.* Earth Scan, p17.

McMichael A.J., Butler, C., and Ahern M.J. (2003) Environment as a *Global Public Good for Healeh in ed. Beaglehole, R., Drager, N. and Smith, R., Global Public Goods for Health*, World Health Organisation and United Nations Development Programme Collaboration, Oxford University Press.

National Strategies for Sustainable Development 2007. "World Conservation Strategy: Living Resource Conservation for Sustainable Development". NSSD.net. Retrieved on August 2, 2007.

National Weather Service (2007). Historical data for central Arizona <www.nws.noaa.gov> (December 10, 2007)

Oke, T.R. (1982) "The energetic basis of the urban heat island." Quarterly Journal of Royal Meteorological Society. 108, 1–24.

Oke, T.R. (1987). *Boundary Layer Climates 2nd edition*. Routledge. London.

Oke, T.R. (1997). Urban Environments. The Surface Climates of Canada. McGill-Queen's University Oress, Montreal, 303-327.

Parker, D.S., Barkaszi, S.F. & Sonne, J.K. (1994). *Phase II: Measured Cooling Energy Savings from Reflective Roof Coatings Applied to Florida Residences*, FSEC-CR-111-94, Florida Solar Energy Center, Cape Canaveral, FL..

Pielke, R.A., Avissar, R. (1990). Influence of landscape structure on local and regional climate. *Landscape Ecology*, 4, 133-135.

Price, L., Michaelis, L., Worrell, E., and Khrushch, M. (1998). Sectoral Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions. *Mitigation and Adaptation Strategies for Global Change*. 3: 263-319.

Roberts, S., T.R. Oke, J.A Voogt, C.S.B., Grimmond, and A. Lemonsu (2003). "Energy Storage in a European City Center." Fifth International Conference on Urban Climate, September, 2003 - geo.uni.lodz.pl.

Robertson, F.M., 1975. Hexavalent Chromium in the Groundwater in Paradise Valley, Arizona. Groundwater, Vol. 13, No. 6, pp 516-527.

Robertson, F.M., 1986. Occurrence and Solubility Controls of Trace Elements in Groundwater in Alluvial Basins in Arizona. American Water Resources Association Monograph Series No. 7, pp. 69-80.

Roseland, M. (1997). Dimension of the eco-city, *Cities*, 14 (4), pp. 197-202.

Rosenfeld, A., H. Akbari, S. Bretz, B. Fishman, D. Kurn, D. Sailor, H. Taha (1995). "Mitigation of urban heat islands: materials, utility programs, updates." Energy and Buildings, 22 (3), pp. 255-265.

Sailor, D.J. and Pavlova, A. (2003). Air Conditioning Market Saturation and Long Term Response of Residential Cooling Energy Demand to Climate Change. *Energy – the International Journal*, 28 99), 941-951.

Samules, R. (2002). *Urban Heat Islands.* Submission to House of Representatives Standing Committee on Environment and Heritage Sustainable Cities 2025 Inquiry. Sydney, Australia.

Santamouris, M. (2000). Energy and Climate in the Urban Built Environment. London: James & James Ltd.

Schmidli, R. J. (1996). Climate of Phoenix, Arizona: An Abridged On-Line Version of NOAA Technical Memorandum NWS WR-177. Weather Service Forecast Office Phoenix, Arizona. < http://geography.asu.edu/cerveny/phxwx.htm> (February 8, 2006)

Scharff, D., Burke, D., Villeneuve, M. and L. Leigh (2002). Industrial Water Use 1996. Environmental Economics Branch, Environment Canada. Minister of Public Works and Government Services Canada. Catalogue No. En40-669/2002E.

SOS (1995). *The State of the Southern Oxidants Study: Policy-Relevant Findings in Ozone Pollution Research 1984-1994.* Southern Oxidants Study: Raleigh, NC, 94 pp.

Taha, H., Sailor, D., & Akbari, H. (1992). High-albedo Materials for Reducing Building cooling Energy Use. *Lawrence Berkeley National Laboratory Report* No. 312721 UC-350: 71

Taha, H. (1997). Modeling the Impacts of Increased Urban Vegetation on the Ozone Air Quality in the South Coast Air Basin. *Atmospheric Environment* 30: 3423-3430.

Ting, M., Koomey, J. (2001). *Preliminary Evaluation of the Lifecycle Costs and Market Barriers of Reflective Pavements.* Lawrence Berkeley National Laboratory, LBNL-45864, Berkeley.

United NAtions (2005) Millennium Ecosystems Assessment Report. Island Press.

United Nations (2002) *World Urbanization Prospects* – The 2001 Revision Data Table and Highlights. Department of Economic and Social Affairs.

United Nations. (1987). "Report of the World Commission on Environment and Development." General Assembly Resolution 42/187, 11 December 1987. Retrieved: 2007-04-12

United Nations Division for Sustainable Development. Documents: Sustainable Development Issues Retrieved: 2007-05-12

US Census 2000, http://www.census.gov/population/cen2000/phc-t3/tab03.pdf

US DOE (1999). U.S. Department of Energy, Energy Information Administration, (2000). Annual steam-electric plant operation and design data.

US DOE (2000). Energy Information Administration (EIA), Electric Power Annual 1999 Volume I & II. DOE/EIA-0348(99)/1.

US EPA (1992). Cooling Our Communities - A Guidebook on tree planting and Light-Colored Structures, Socument So. 22p-2001, US EPA, Washington DC.

US EPA (2000). *The Urban Environment: Phoenix, Arizona. Environmental Protection Agency.* <epa.gov/urban/phx/index.htm> Accessed August, 2007

US EPA (2001). *Our Built and Natural Environments: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality.* US Environmental Protection Agency. January, 2001

Wackernagel, M. and Rees, W. (1996) Our Ecological Footprint: Reducing Human Impact on the Earth, New Society Publishers. BC, Canada.

Wackernagel, M., Onisto, L. Linares, A.C. et. al., (1997) Ecological footprints on nations: how much nature do they use? How much nature do they have? International Council for Local Environmental Initiatives, Toronto Commissioned by the Earth Council.

Weng, W., Taylor P.A., (2003). On modeling the 1-D atmospheric boundary layer. *Boundary-Layer Meteorology.* 107, 371-400.

WGA (2006). *Clean Energy, a Strong Economy and a Healthy Environment.* Western Governors' Association. Denver, CO. June, 2006

Wilson, Richard P., 1991. *Summary of Groundwater Conditions in Arizona*. USGS Water-Resources Investigations Report 90-4179. Tucson.

World Health Organization (1996). *Climate Change and Human Health.* McMichael, A., et al. (eds). Geneva.

World Resources 1996-97: The urban environment. World Resources Institute, United Nations Environment Programme, United Nations Development Programme, and the World Bank.

CHAPTER 2:

URBAN HEAT ISLAND MITIGATION

Chapter 2 Table of Contents

Introduction

Phoenix and surrounding Valley cities form one of the largest metropolitan areas in the US. Population growth has increased exponentially over the last decade, forcing the expansion of urban infrastructure into areas that were once agricultural or native desert. This alteration of land cover has resulted in an average nighttime air temperature increase of nearly 8°F (4.4°C) over the last 50 years. (Golden 2004), This phenomenon is referred to as the **Urban Heat Island (UHI)** effect, and it is increasing at a dramatic rate. The Phoenix area has long been known for its pleasant winters; as the region develops, it is becoming known for its inescapably hot summer nights.

The UHI effect is the result of changes to the urban surface. As urban sprawl expands, new construction eliminates agricultural crop fields, native vegetation, and soil to make way for buildings with exposed roofing and streets with dark, dense pavement. The cooling process of evapotranspiration is lost with the removal of vegetation, and the dark engineered materials absorb and retain the sun's intense energy during the day. Surface temperatures of these engineered materials can reach daytime temperatures of over 160°F (71°C) and gradually release energy stored during the day into the ambient air at night.

Increased air temperature in cities affects the amount of energy and water used in buildings and homes, changes weather patterns, increases the formation rate of smog, and affect our bodies, causing discomfort and heat related illness or even death.

This chapter of the guidebook focuses on what can be done immediately to address these problems. Affordable materials and design strategies are currently available to reshape the face of cities and reduce UHI. An overview of each mitigating strategy is presented, along with associated benefits, general costs, and suggestions for successful, citywide implementation.

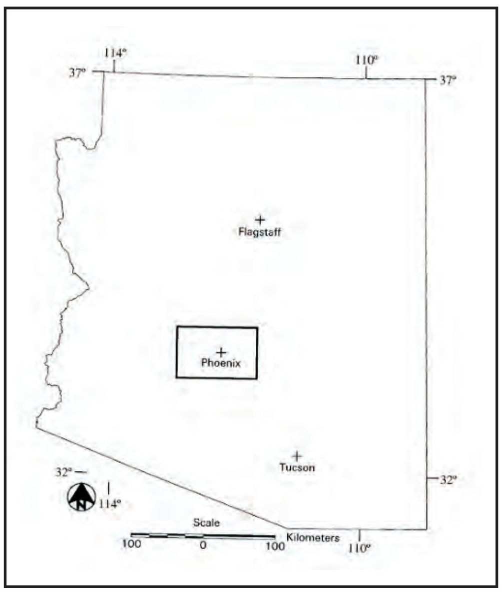


Figure 2-1. The Phoenix Region, Arizona, USA.

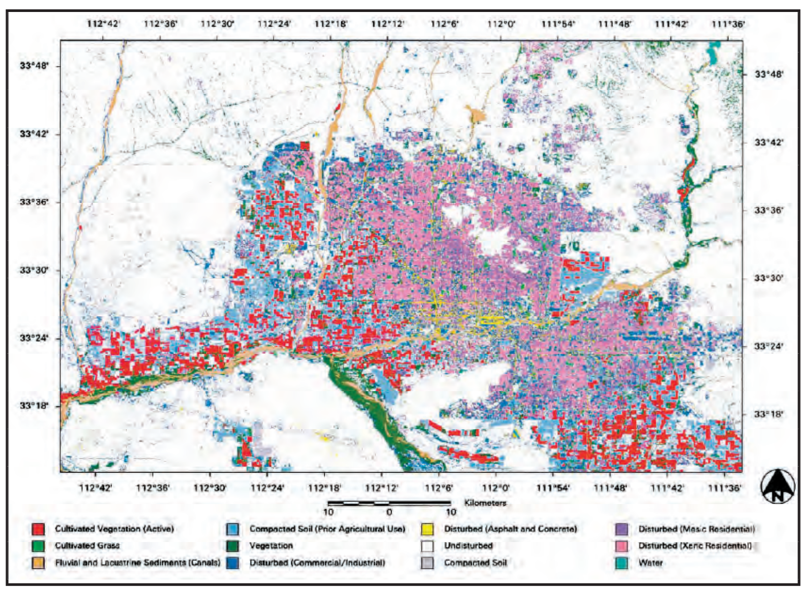


Figure 2-2. Land-cover classifications within the Phoenix Region. (Stefanov 2001)

Land in Transition

The land cover of the Phoenix Region, as defined in Figure 2-1, has been shaped and reshaped by natural processes over millions of years. For the first time in its history, it is being reshaped by the hands of man. The materials we use to build our cities and enhance our quality of life create a unique dynamic between the energy of the sun and the urban surface. To determine the root causes of the UHI in the Phoenix Region, it is important to accurately quantify the constituents of the urban surface area. A recent study conducted by researchers at Arizona State University did just that. The results, presented in Figure 2-2, indicate

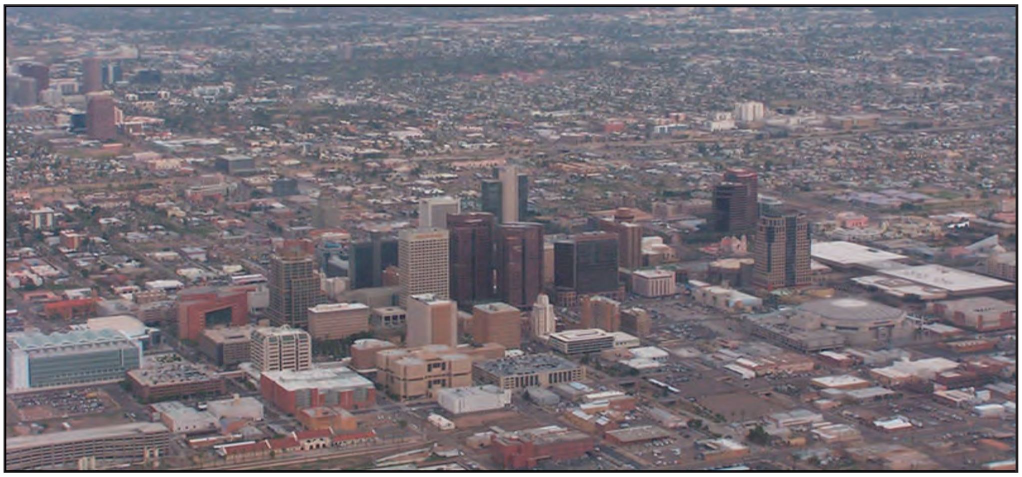


Figure 2-3. Aerial view of Phoenix area, showing pavement-intensive development.

that there are several types of land cover that must be considered.

Grouping man-made surfaces together reveals that the urban surface generally consists of the following categories: pavements (parking lots, streets, sidewalks, and driveways), roofs, vegetated landscape (trees and grass), and undisturbed soil. Different cities

(a)

(b)

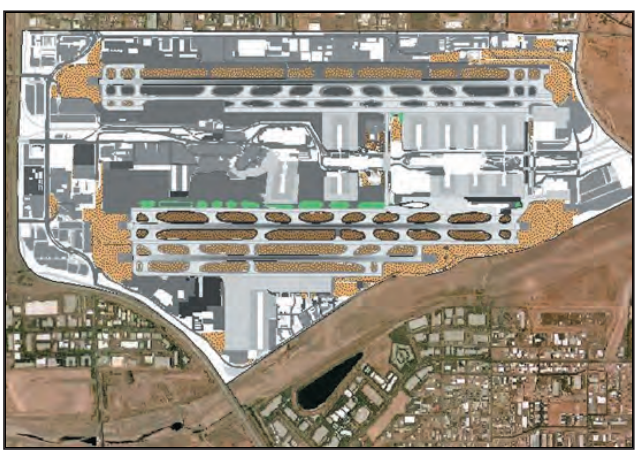


Figure 2-4. GIS image of (a) landscape and bare soil; (b) paved areas within Sky Harbor Airport. (Carlson 2006)

(a)

(b)

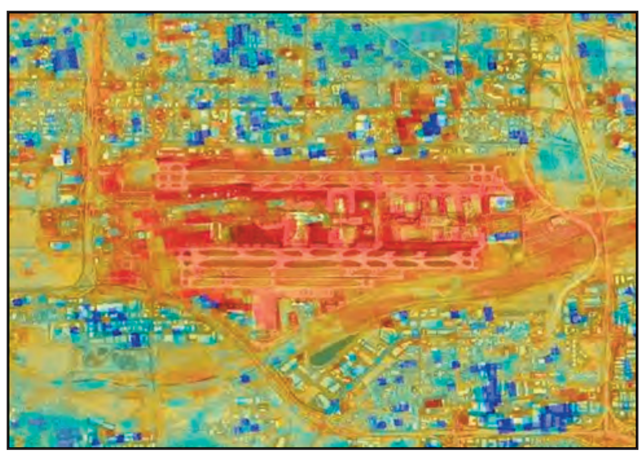


Figure 2-5. (a) Aerial image of Sky Harbor Airport and surrounding areas; (b) ASTER infrared image of same area at 10:00 p.m. on June 7, 2004. Source: National Center of Excellence, Arizona State University.

have different percentages of each type of surface material. High density metropolitan areas such as New York City and Chicago typically have more roofs than pavements and sparse vegetation within their central districts. In a lower density metropolitan area such as Phoenix, pavement comprises nearly half of the developed land cover. This is a direct result of the automobile-centric lifestyle of most Phoenicians.

In some areas, pavements comprise the majority of urban surface cover. In developments such as airports, the runways, long-term parking areas, and aircraft aprons combine to form a sea of pavement that dwarfs the building footprint. Nearly 75% of the Sky Harbor International Airport area is covered in various pavement types, as shown in Figure 2-4. This is common to airports nationwide and presents a unique challenge for airport officials. Sky Harbor International Airport is actively involved in efforts to address the UHI, with policies being implemented for pavement renovations in non-aircraft movement areas around the airport.

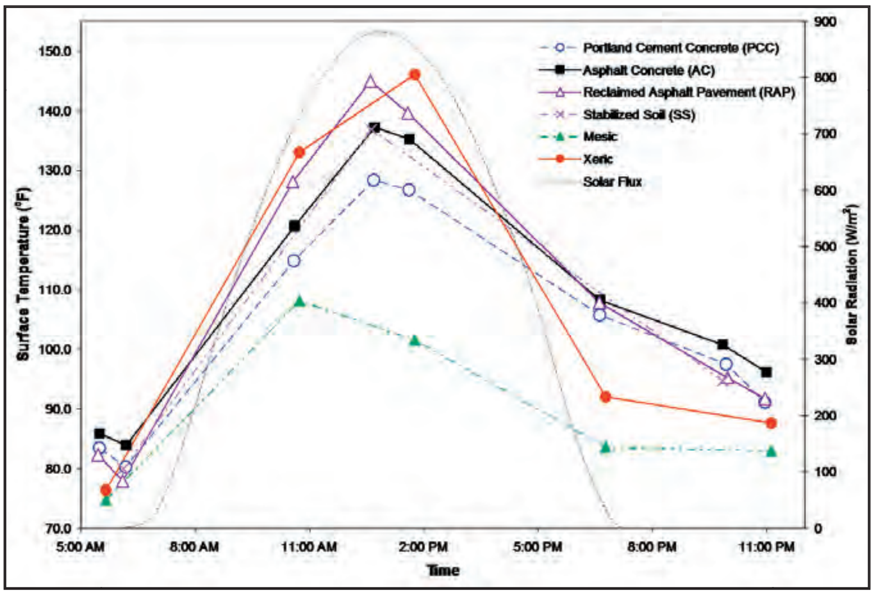


Figure 2-6. Average surface temperatures of six different surface materials during September 15, 2005 at Sky Harbor International Airport. (Carlson 2006)

Thermal Performance of Urban Materials

The thermal interactions within an urban environment is very complex. Surfaces made of the same material located at different areas within the same city can behave quite differently. This is a result of the microclimatic influences of the surrounding environment. Likewise, two different materials at the same location, influenced by identical conditions, can have widely different thermal behaviors. This is a function of the materials' intrinsic properties. It is important to understand both the environmental influences and the inherent material properties of urban construction materials to discern what contributes to their surface temperatures, and in order to understand why different materials are recommended in different circumstances to mitigate the urban heat island effect.

ENVIRONMENTAL INFLUENCES

Sky View Factor

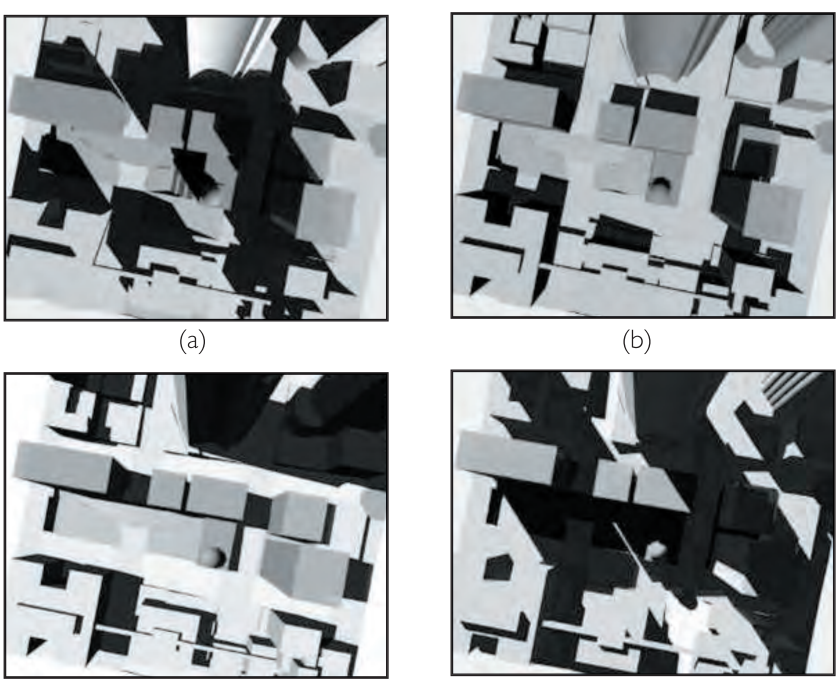
The **sky view factor (SVF)** of a surface is the percentage of open sky that is in direct view from the surface (Figure 2-7). SVF ranges from 0 to 1, where 1 is a surface with hemispheric view of the sky with no interference from other structures. Some flat roofs can have an SVF near 1. Pavements, on the other hand, can have much lower SVF due to the trees, buildings, and other objects that typically surround them. SVF influences the ability of a surface to release stored thermal energy into the sky. Surfaces emit radiation to the sky both day and night. The smaller the sky view factor, the less the surface can cool through radiation

Figure 2-7. Two views from different surfaces that have similar sky view factors resulting from completely different surroundings, one an urban canopy and the other a forest. Photo courtesy of the National Center of Excellence, Arizona State University

heat transfer. Heat transfer through radiation is preferable to other means of heat transfer in UHI mitigation because radiation will generally not heat the air above the surface as much as convection and conduction heat transfer will. Air does not readily absorb long wave radiation (thermal radiation), and therefore a large percentage of heat leaving a surface in the form of thermal radiation will pass through ground level air and dissipates through the upper layers of the atmosphere.

Solar Access

The solar access of a surface describes the time and duration that a surface is directly affected by solar energy. This value varies



(a) (b) (c) (d)

Figure 2-8. A computer generated shadow analysis of downtown Seattle, WA., showing different surfaces have more exposure over the course of the day. (a) June, 9:00am; (b) June, 12:00pm; (c) June, 3:00pm; (d) June, 6:00pm. Source: Seattle Municipal Civic Master Plan (1999).

by season and time of day. Surfaces that are surrounded by tall buildings may only receive direct solar radiation for a few hours at midday during the summer, and not at all during other times of the year. This can be determined with a shading analysis tool as shown in Figure 2-8.

Wind

As cool air moves over a surface, it picks up thermal energy and thereby reduces the temperature of the surface. Wind direction and speed results from differences in air pressure caused by temperature differentials and geometries within urban areas. Wind can also be created by man-made equipment such as passing automobiles, airplanes, or ventilation exhaust units. Wind dispersion is one of the most important and complex elements of UHI analyses. Surfaces located in narrow building canyons can be sheltered from strong seasonal winds, while at other times, the wind speeds can be intensified, depending upon the direction of prevailing winds. Surface temperatures of pavements are greatly influenced by the speed and frequency of traffic driving across them. It is common that the surface temperatures of highway shoulders (no traffic) far exceed the temperatures of center lanes with high traffic volumes.

Moisture

The amount of moisture within, below, and above urban surfaces can greatly affect their thermal behavior. As water is heated by solar energy from a liquid to a vapor, it is then pulled away by passing air currents, taking heat energy with it and cooling the surface. This phenomenon, evaporation, is how vegetation and the human body keep cool. Moisture content within soils and pavement surfaces greatly alters their thermal transport properties making modeling these properties more complex in moist conditions.

Humidity

The relative humidity of ambient air can have a significant effect on evaporation rates at the surface of plants, soils, and even human skin. Generally, evaporative cooling methods are most effective in drier climates. This is why different cooling strategies must be evaluated appropriately in different regions of the country; something that works well in Phoenix may not be ideal for the humid climate of New Orleans.

THERMOPHYSICAL PROPERTIES

Analyzing the thermal behavior of urban materials may be more understandable with a brief description of the thermophysical properties of matter. There are two distinct categories of these properties: those related to transport of energy through a

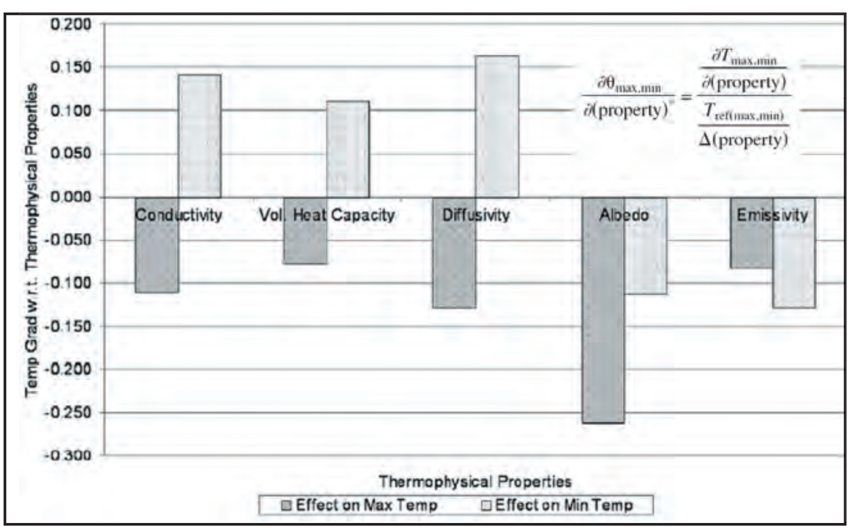


Figure 2-9. The effect of different thermal properties on the maximum and minimum temperatures of surfaces. A negative temperature gradient correlates to a decrease in temperature. Source: (Gui el. al. 2006).

system, and those related to the thermodynamic, or equilibrium state, of a system (Incropera and DeWitt 1996).

Transport of energy through a system, also referred to as heat transfer, occurs in three ways: radiation, conduction, and convection. Transport properties relating to radiation heat transfer such as albedo and emissivity will be discussed in more detail below, along with the rate coefficients that govern conduction and convection heat transfer.

Thermodynamic properties differ from transport properties in that they are concerned with the equilibrium state of a system. These properties include density and specific heat, which are the basis of volumetric heat capacity and thermal diffusivity. These properties and terms are discussed in detail below (Figure 2-9).

Albedo

Albedo is the term given to the amount of solar energy that is reflected by a surface. The higher the albedo of a surface, the less solar energy it will absorb. Albedo is the first line of defense a surface has against incoming solar radiation. It is regarded as the most important factor in the mitigation of the urban heat island effect in urban centers (Rosenfeld et al. 1995). The value of albedo can range from 0 (perfect absorber) to 1 (perfect reflector). Albedo is the ratio of solar radiation that reflects off of a surface divided by the total incoming radiation. For this reason, albedo is also given as a percentage (e.g., an albedo of 0.75 indicates that 75% of the solar radiation that hits the surface is reflected). Very often, high albedo is related to lighter shades of color but a more complex analysis is required to determine the true albedo of a given surface. Because solar energy is comprised of 10% ultraviolet, 40% visible, and 50% infrared wavelengths, a large portion of the solar energy cannot be seen. Color, to the naked eye, is only the visible energy that is reflected by a surface. To accurately determine albedo, one must use a sensor that also detects light in the infrared region. Error! Reference source not found. Figure 2-10 and Figure 2-11 show typical albedo ranges for common urban surfaces.

Figure 2-10. A typical urban area, with roof and wall albedo ranges indicated on the different surfaces.
Source: National Center of Excellence, Arizona State University

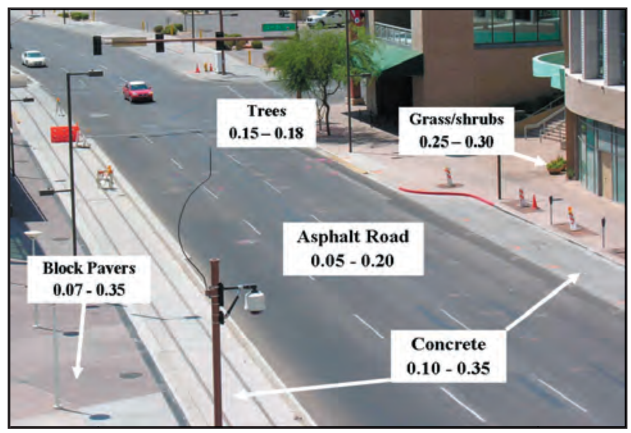


Figure 2-11. A typical urban area showing various ground-level-material albedo ranges.
Source: National Center of Excellence, Arizona State University.

Emittance

A portion of the thermal energy contained within any surface is constantly being emitted as radiation back into the atmosphere. The property that indicates a surface's ability to emit radiation is referred to as its **thermal emittance**, which can range in value from 0 (non-emitter) to 1 (perfect emitter). Most natural and construction materials have relatively high emittance values, as shown in Figure 2-12.

The infrared emittance of a surface greatly depends on the surface material and its finish. For instance, a polished copper surface will have a very low emittance level close to 0.06, while rough surfaces such as concrete and asphalt have an emittance level above 0.90.

Convection Coefficient

Convection heat transfer describes energy transfer due to random molecular motion (conduction) and bulk fluid motion (Incropera and DeWitt 1996). This kind of heat transfer occurs between a surface and the ambient air that passes over it. The proportionality constant, convective heat-transfer coefficient, is dependant on surface characteristics and environmental conditions, including surface roughness, air velocity (wind), and the type of fluid motion (turbulent vs. laminar) of the air above the surface. Therefore, the convection coefficient assigned to a specific material depends on these conditions. However, it is possible to gauge which surfaces will be more efficient at transferring heat through convection due to certain characteristics (such as surface porosity) that increase the surface area and mixing of air over the surface.

Density

Density is widely used in thermal analysis. It is the measure of mass per volume of a substance. Generally, materials with higher density will transfer and store more solar energy than lower density materials.

Specific Heat

Specific heat is also used in determining the thermal behavior of surface materials. It is typically defined as the amount of heat energy required to raise the temperature of one gram of a substance by 1.8°C. It is not useful for comparative purposes until it is combined with density to form the volumetric heat capacity.

Volumetric Heat Capacity

When the density and specific heat of a substance are multiplied together, they equal the **volumetric heat capacity** of the substance (Incropera and DeWitt 1996b). The volumetric heat capacity quantifies the ability of a material to store thermal energy.

Thermal Diffusivity

The ratio of thermal conductivity to the volumetric heat capacity is an important factor in heat transfer analysis. This property, termed **thermal diffusivity,** measures the ability of a material to conduct heat relative to its ability to store heat energy. The thermal diffusivity enables one to estimate how a material will behave under certain conditions. For instance, a material having a very large diffusivity will respond more quickly to thermal changes than a material of small diffusivity. The smaller the thermal diffusivity the longer it will take to reach an equilibrium state.

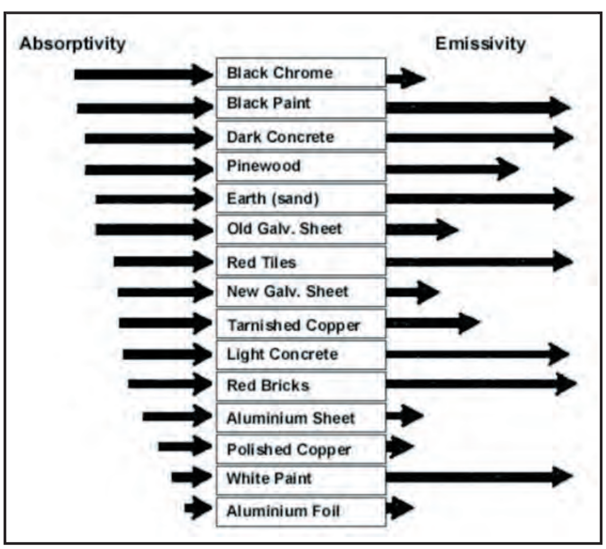


Figure 2-12. A visual representation of the magnitudes of absorptivity and emissivity for common building materials. Source: Lawrence Berkeley National Laboratory.

Porosity

The **porosity** of a material is defined as the ratio of the volume of pores in a substance to its total volume (Somayaji 2001). This term is widely used when discussing groundwater transport through soils. The same concept can be applied to porous pavements, which are becoming more common in various applications including innovative storm water management in parking lots and sidewalks. Porosity is an important design consideration when permeability is desired.

Permeability

Permeability is commonly defined as the ability of a surface material to allow fluids such as rainwater to move through it. The majority of conventional pavement designs undergo compaction during construction to significantly limit the transport of water through them. The more porous a pavement is, generally, the more permeable it is.

Permeability is also an important factor when considering surface energy fluxes. Permeable areas such as exposed soil and grass landscaping are often cooler during the day because of their ability to transform incident solar radiation into latent heat (Taha 1997). **Latent** heat is the energy that drives evaporation at the surface of leaves and moist soils. Latent heat does not raise the temperature of the fluid but is responsible for the phase transition from liquid to a vapor. Non-permeable and dry pavements lack this ability, thereby increasing the thermal energy that becomes stored in the material.

UHI Mitigation Strategies

Urban-heat-island mitigation strategies can be grouped into three categories:

- Roofs
- Paving
- Urban Forestry

As mentioned previously, pavements and building roofs form more than half of the urban surface in the Phoenix metropolitan area. By providing cool alternatives for these two surface material categories, decision makers can have a significant effect on their communities. Trees are also an important asset in mitigating adverse urban air temperatures. While trees are not usually thought of as a technology, it is important that cities assess their tree populations, or lack thereof. The following three sections will delve into each of these key mitigation strategies and provide lists of commercially available and affordable alternatives to conventional materials and designs.

ROOFING

Buildings make up a significant portion of land cover, and cooling their interiors is often the greatest source of energy demand in an urban area. In the US, over one-sixth of the total electricity consumed is for air conditioning alone. Nearly 15% of Phoenix's land cover is comprised of buildings, from flat roofs of multi-story skyscrapers in the central business district to the pitched roofs of residential neighborhoods (Bhardwaj 2006). The surfaces of traditional roof systems using modified bitumen and dark asphalt shingles can reach temperatures of 150°F (65.5°C) to 180°F (82°C) during the sweltering Arizona summers. These extreme temperatures can have major economic and environmental impacts on a metropolitan area.

The large temperature swings that these roofing materials undergo can cause premature aging, resulting in cracking and curling that require regular maintenance or replacement. In addition, their elevated temperatures affect the solar heat gain of the interior itself, forcing the mechanical cooling equipment to run longer to maintain a comfortable indoor environment. Finally, the elevated surfaces transfer heat to the air passing over the roof, thereby contributing to the urban-heat island effect.

The good news is that these elevated roof temperatures can be reduced dramatically using readily available and extensively proven roofing alternatives. These roof systems, referred to here as cool roofs, can cut peak summer roof temperatures by 60°F (33°C), will have longer operational lifetimes than conventional roofs, and can result in huge energy savings for building owners.

This section of the guidebook will focus on different cool roofing technologies that are currently available and in use around the country. We begin by defining and quantifying the different types of buildings and roof types in Phoenix and other major urban areas. This is followed by a review of the various cool roofing solutions, along with relative costs, applications, material properties, and benefits. Finally, suggestions for implementing cool roofing in existing and future building construction and retrofits in the Phoenix region are provided.

Figure 2-13. Roofing in Phoenix, Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

Roofing in the Valley of the Sun

Phoenix and its surrounding communities are similar in design to other modern metropolitan areas built after the advent of the automobile, with a relatively small urban core surrounded by an expansive area of low-rise (one or two-story) buildings (see Figure 2-13). Buildings of similar design and function can be grouped and categorized as either residential, commercial, office, industrial, or public buildings. While nearly 15% of Phoenix's total land area is covered by buildings, this percentage can vary greatly by neighborhood and is changing rapidly as local cities expand and 'infill' of new buildings in older areas is done. Surface classification of Houston, Texas, revealed that nearly 50% of its building surface areas were residential. In this study, we assumed the same percentage applies to Phoenix due to the large number of single-family homes built in the Valley over the last 10 years. The US Census Bureau recorded 11,403 new permits for single-family homes (out of 11,836 total residential building permits) in Maricopa County in 2006 alone. This equates to 2.14 billion in total construction dollars in the Valley each year.

Common Roofing Applications and Materials

Roof designs can be described as steep or low sloped depending upon the pitch of the roof. Steep slope indicates an elevation change of more than four inches per foot; low slope roofs are those with less pitch. Zero slope or flat roofs fall under the low slope category. In 2001 the National Roofing Contractors Association's (NRCA) Annual Market Survey showed that 63% of all roofing in the U.S. was low slope, as shown in Figure 2-14. Of the low sloped roofs installed, 62% involved re-roofing, with 25% and 15% for new construction and maintenance, respectively. With the rapid housing development in Phoenix in the last five years, it is expected that new construction may have a larger percentage of the market than these national figures present. Re-roofing and new roof construction projects are perfect opportunities to apply energy efficient roofing materials and designs.

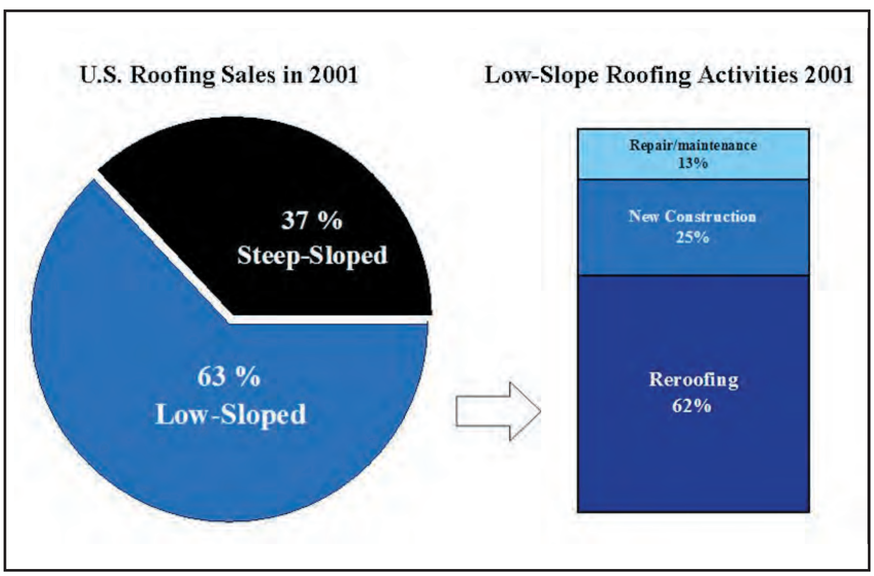


Figure 2-14. Roofing sales in the United States by type, and breakdown of all low-slope roofing activities in 2001. Source: NRCA (2002).

Many products are available for low slope roofs. Roofing materials used for single family residential buildings historically have consisted of asphalt shingles, but recent trends in Arizona favor concrete tiles as shown in Figure 2-15.

Figure 2-15. Concrete-tiled roofs in the Valley of the Sun. Photos courtesy of National Center of Excellence, Arizona State University.

Nearly 80% of commercial and industrial low slope buildings in the U.S. use one the following roofing materials: EPDM, modified bitumen, or built-up roof (BUR). The percentages for all roofing materials are given in Figure 2-16.

These results are from the NRCA's 2004 survey of the roof construction field. Figure 2-17 indicates that steep slope buildings use predominately architectural metal or fiberglass asphalt shingles. A brief description of each of these common roofing materials and information on their thermal performance are provided on the following page.

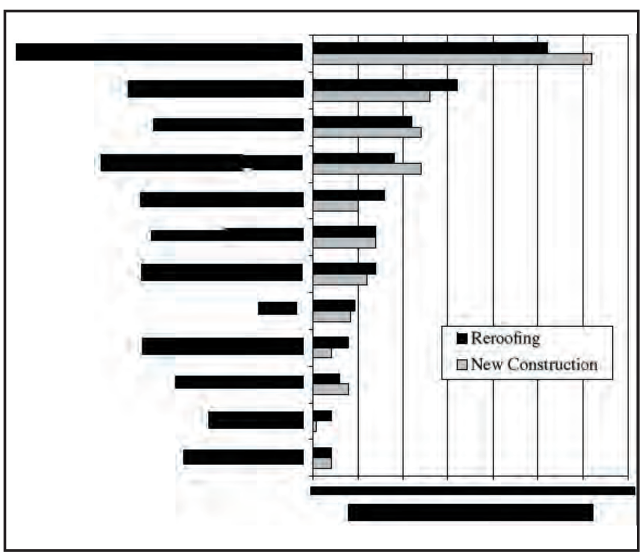


Figure 2-16. Percent of new construction and reroofing by material type in the US for low-slope roofs 2004. *Built-up membranes using modified bitumen cap sheets are considered modified-bitumen roof systems.
Source: NRCA (2005).

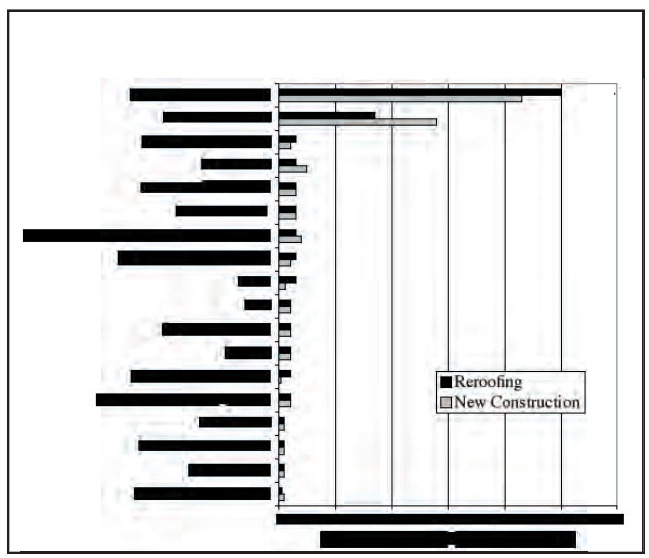


Figure 2-17. Percent new construction and reproofing by material type in the US for steep-slope roofs in 2004.
*Built-up membranes using modified bitumen cap sheets are considered modified-bitumen roof systems.
Data Source: NRCA (2005).

Asphalt Shingles

Asphalt shingles are the most popular type of residential roof material in consideration of cost (as low as $0.80 per square foot installed), ease of installation and the availability of a wide range of colors (Figure 2-18). There are two types of asphalt shingles - glass fiber and organic. Organic shingles consist of paper saturated with asphalt and coated with adhesive asphalt in which ceramic granules are embedded. Organic shingles are heavier and more durable than glass fiber shingles due to 40% more asphalt content.

Glass fiber shingles are reinforced with a glass fiber mat, which is coated with asphalt and mineral fillers to create a waterproof barrier. Ceramic granules are embedded into adhesive asphalt on one side of the mat. The roofing granules are typically 1 mm diameter grains of crushed granite, coated with an inorganic silicate material. The coatings help to give the granules their desired color.

The granules of both type of shingles provide the color and give protection from the sun's ultra violet (UV) rays, otherwise the asphalt would deteriorate very quickly. Glass fiber shingles are by far the most common roof material in the U.S. The average lifespan of asphalt shingles depends upon the climate. In Phoenix, for example, asphalt shingles rated for 20 years may actually last less than 14 fourteen years because of the intense summer sun (Figure 2-18).

Figure 2-18. Common asphalt shingles up close. Photo courtesy of National Center of Excellence, Arizona State University.

EPDM

Ethylene Propylene Diene Monomer (EPDM) is a terpolymer product, consisting of three distinct monomers. EPDM is a single-ply (layered) thermoset (heat cured) material. Thermosetting can occur at the manufacturing plant (vulcanization) and delivered in rolls, or the material can come unvulcanized in a bucket and be applied to the roof, with the natural weather conditions finishing the curing process (Figure 2-19 and Figure 2-20).

EPDM membranes range from 0.030-inch (0.8-mm) thick to 0.100-in (2.5-mm) thick, and have been used in the US since the 1960's. EPDM is cheaper, easier to install, and less messy than older roofing methods. The sheets can be fastened to the roof using water or solvent-based adhesives, either using mechanical fasteners or loose-laid. Sheets are then covered with a ballast of round river rock (application weight 1,000-12,000 pounds per 100 sq ft) or concrete pavers (20 lbs per sq ft).

Figure 2-19. A fully adhered EPDM roof surface.
Source: Kozlowski Co. (http://www.kozlowskico.com/)

Figure 2-20. Image of a ballasted, loose EPDM roof.
Source: NRCA

Figure 2-21. Modified bitumen on commercial, low-slope buildings.Photos courtesy of National Center of Excellence, Arizona State University.

(a) (b)

Figure 2-22. (a) Example of a modified-bitumen roll.;
(b) Application of modified bitumen roll.
Source: www.derbigumus.com.

Modified Bitumen

Modified Bitumen (MB) uses asphalt with specific modifiers mixed in to give it plastic or rubber-like properties. Common modifiers include atactic polypropylene (APP) and styrene butadiene styrene (SBS). MB comes in meter wide rolls. Once the rolls are placed, a torch or hot bitumen is used to rapidly heat the material to bond it to the surface. Following the melting and adhesion process, the BM sheets are typically covered with mineral granules such as aluminum, copper, or an aggregate such as gravel or slag to protect them from UV degradation. Figure 2-21, and Figure 2-22 illustrate different MB roofs.

Built-Up Roof (BUR)

Built-up roof (BUR) is one of the oldest and most reliable roofing methods, dating back to the 1840s. BUR is comprised of layers of roof felts laminated together with a waterproofing bitumen such as asphalt, coal tar, or lap cement. The layers can be made of any combination of saturated felt, coated felt, polyester felt, or like fabrics. The top layer is usually covered by asphalt, some type of aggregate, emulsion, or granule surfaced cap sheet. The service life of BUR can vary greatly due to factors like climate, foot traffic, materials used, construction quality, and roof slope. Under ideal conditions, a three ply BUR can last 15 years and a five ply may last 25 years.

Architectural Metal

Metal roofing has become increasing popular over the last decade due to its long life, relatively light weight, recyclability, and variety of forms and colors. Most metal roofs are made of steel. Stainless steel, aluminum, copper, and zinc alloys can also be used, but are very expensive. A steel roof is typically protected from rusting or corrosion with a zinc coating or epoxy primer and then a baked-on acrylic. Highly durable paints and its extensive formability enable metal roofing to resemble many other kinds of roofing materials, such as shingles and clay tiles. Metal systems are best suited and most popular for steep sloped roofs of residential and commercial buildings because of their aesthetic appeal and low maintenance. Properly constructed metal roofing systems are rated to last for over fifty years before full replacement is required.

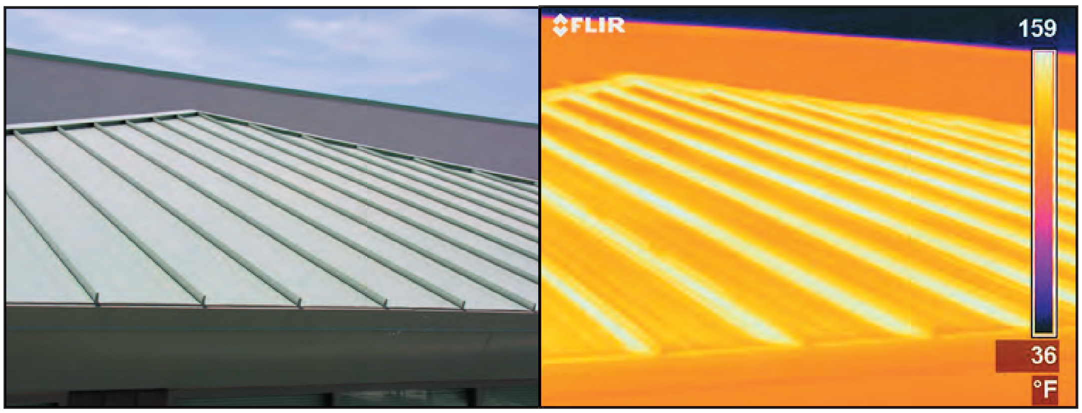


Figure 2-23. Metal panels on a steep-slope commercial structure can have high surface temperatures during the day. Photos courtesy of National Center of Excellence, Arizona State University.

Thermal Performance of Conventional Roofing Materials

To better understand the thermal performance of the materials that are commonly being used on roofs in Arizona and nationally, researchers at the Oakridge and Lawrence Berkeley National Laboratories conducted extensive research into the properties of common roofing materials as part of a decade-long project for the U.S. Department of Energy and the U.S. Environmental Protection Agency. They summarized their findings and presented average values for the following four categories:

1) *Solar Reflectance* – the fraction of incident solar energy that is reflected by a surface. The values were measured in accordance with ASTM Standards E903 and E892 using a spectrophotometer.

2) *Infrared Emittance* – a surface property ranging from 0 to 1 that indicates the ability of a hot material to shed heat in the form of radiation.

3) *Temperature Rise* – the maximum roof temperature rise above ambient air temperature is calculated using the equation on the following page.

$$T_{max} = \frac{(1\text{-}R)I_0\text{-}h_r(T_{air} - T_{sky})}{h_c+h_r}$$

Where...
R = *albedo (reflectance)*
I_o = *solar flux = 1kW per square meter of roof (assumed)*
h_r = *heat transfer coefficient for radiative cooling* = $6.1 Wm^{-2}°C^{-1}\varepsilon$
Where ε = thermal emittance of the surface
T_{air} = ambient air temperature
T_{sky} = sky temperature, assumed to be 10°C lower than ambient
So, $T_{air} - T_{sky}$ = 10°C
h_c = convection heat transfer coefficient = $12.4\ Wm^{-2}°C^{-1}$ (assumed)
(Berdahl 2000)

Figure 2-24. Temperature response of roofs, pavements, and walls during an average summer day in Phoenix. Photos courtesy of National Center of Excellence, Arizona State University

4) *Solar Reflective Index (SRI)* – a measure of the surface's ability to reflect solar heat. Each material is compared to a standard black (albedo 0.05, emittance 0.90) which represents an SRI = 0, and where a standard white (albedo 0.80, emittance 0.90) is equivalent to SRI = 100. It is calculated that a standard black will have a temperature rise of 90°F (50°C) in full sun, while under the same conditions, standard white has a temperature rise of only 14.6°F (8°C). The maximum calculated surface temperature is then used to estimate the SRI as interpolated between black and white. Using this procedure for estimating SRI, some very hot materials will have negative SRI values and ultra-cool materials will have SRIs greater than 100.

According to research conducted at Lawrence Berkeley's National Lab (LBNL), the solar reflectance of commercial asphalt shingles is very low (i.e. absorbs heat). Table 2-1 shows that even the premium white shingles only reflect about 30% of sun's energy. Paul Berdahl, the author of the LBNL study, believes that the low reflectance is the result of several factors including the limited pigment applied to the granules. It is also believed that the roughness of the shingle surface increases the solar absorption, as light does not reflect uniformly when striking a non-planar surface. In the case of some of these products, a large portion of the black asphalt is still exposed and absorbs nearly 95% of the incident energy. All of these factors cause the surface of asphalt shingles to heat up to temperatures that are over 60°F (33°C) warmer than the ambient air (i.e. low SRI).

Solar Reflectance and thermal performance of asphalt shingles.

Product Name	Solar Reflectance	Infrared Emittance	Temperature Rise Above Ambient Air Temperature (°F)	Solar Reflectance Index (SRI)	Reference Facility
White	0.21	0.91	68	21	LBNL
ISP K-711 White	0.36	0.91	55	40	LBNL
Antique Silver	0.2	0.91	69	19	LBNL
Gray	0.08	0.91	79	4	LBNL
Light Brown	0.19	0.91	70	18	LBNL
Medium Light Brown	0.1	0.91	77	7	LBNL
Medium Brown	0.12	0.91	76	9	LBNL
Dark Brown	0.08	0.91	79	4	LBNL
Green	0.19	0.91	70	18	LBNL
ISP K-711 White	0.31	0.91	59	34	FSEC
Shasta White	0.26	0.91	64	27	FSEC
Generic White	0.25	0.91	64	26	FSEC
Generic Grey	0.22	0.91	67	22	FSEC
Aspen Gray	0.18	0.91	71	17	FSEC
Ocean Gray	0.12	0.91	76	9	FSEC
Beachwood Sand	0.2	0.91	69	19	FSEC
Autumn Brown	0.1	0.91	77	7	FSEC
Surf Green	0.16	0.91	72	14	FSEC
Onyx Black	0.03	0.91	83	-2	FSEC
Island Brown	0.09	0.91	78	6	FSEC

LBNL - Lawrence Berkely National Lab, Berkeley, California
FSEC - Florida Solar Energy Center, Cocoa, Florida

Table 2-1. Solar reflectance and thermal performance of asphalt shingles. SOurce: LBNL, 2000.

Solar Reflectance and thermal performance of Roofing Membranes

Product Name	Solar Reflectance	Infrared Emittance	Temperature Rise Above Ambient Air Temperature (°F)	Solar Reflectance Index (SRI)	Reference Facility
Sarnafil White	0.83	0.92	11	104	LBNL
Trocal Roofing Systems, White	0.83	0.9	11	104	LBNL
T-EPDM	0.81	0.92	13	102	FSEC
Ecology Roof	0.8	0.9	14	100	LBNL
Stevens Hi-Turf EP white	0.78	0.9	16	97	LBNL
Carlisle Syntec System Brite-Ply	0.77	0.9	17	96	LBNL
Trocal Roofing Systems, White	0.77	0.9	17	96	LBNL
Hypalon	0.76	0.91	18	95	FSEC
Hypsam Roofing Systems, Hyload	0.75	0.9	19	93	LBNL
White EPDM	0.69	0.87	25	84	FSEC
White-coated gravel on BUR	0.65	0.9	28	79	Reagan
Sarnafil Blue	0.61	0.92	32	73	LBNL
Sarnafil Beige	0.43	0.92	49	49	LBNL
Light Gravel on BUR Roof	0.34	0.9	57	37	Reagan
Firestone SBS Bitumen on White	0.26	0.92	63	28	FSEC
White Granular Surface Bitumen	0.26	0.92	63	28	FSEC
Grey EPDM	0.23	0.87	68	21	FSEC
Darke Gravel on BUR Roof	0.12	0.9	76	9	Reagan
Black EPDM	0.06	0.86	83	-1	FSEC
Smooth Bitumen	0.06	0.86	83	-1	FSEC

LBNL - Lawrence Berkely National Lab, Berkeley, California
FSEC - Florida Solar Energy Center, Cocoa, Florida

Reagan - Reagan, J.A. and D.M. Acklam; "Solar Reflectivity of Common Building Materials and its Influence on the Roof Heat Gain of Typical Southwestern USA Residences." Energy and Buildings, 2 (1979) 237-248.

Table 2-2. General Solar performance characteristics of Roofing Membranes. Source: LBNL, 2000

The thermal performance of several types of common roof membranes is provided in Table 2-2. including single ply materials EPDM and Modified Bitumen and the multiple ply Built Up Roof systems. The solar reflectance of these surfaces depends on the type and color of the base polymer and the granule materials applied to the top surface. It is clear that the surface using bitumen based materials performed the worst due to the dark color of the material. T-EPDE performed the best, primarily because of the bright white color of the rubber membrane.

Metal roofs made from galvanized steel, aluminum, or copper usually have good reflectance properties; however, they can reach high daytime temperatures due to their low emittance. This problem is often mitigated by applying thin polymer coatings over the surface during manufacturing. Table 2-3 provides examples of typical values for bare galvanized steel, aluminum, and two metal surfaces that have been treated with white polymer coatings.

Solar Reflectance and thermal performance of Metal Roofs

Product Name	Solar Reflectance	Infrared Emittance	Temperature Rise Above Ambient Air Temperature (°F)	Solar Reflectance Index (SRI)	Reference Facility
Atlanta Metal Products Kynar Snow White	0.67	0.85	28	82	FSEC
MBCI Siliconized Polyester White	0.59	0.85	37	71	FSEC
Aluminum	0.061	0.25	48	56	FSEC
New, bare galvanized steel	0.61	0.04	55	46	FSEC

LBNL - Lawrence Berkely National Lab, Berkeley, California
FSEC - Florida Solar Energy Center, Cocoa, Florida

Table 2-3. Solar reflectance and thermal performance of metal roofing. Source: LBNL, 2000

A wide variety of roofing tile colors are being used in new developments in the southwestern US. Many of the more popular styles mimic the deep oranges and reds of the clay tiles found in Spain and Italy.

Table 2-4 shows that even though these tiles can be highly emissive, their limited reflectivity results in peak temperatures of 60 to 70°F above that of ambient air.

Solar Reflectance and thermal performance of Roofing Tiles

Product Name	Solar Reflectance	Infrared Emittance	Temperature Rise Above Ambient Air Temperature (°F)	Solar Reflectance Index (SRI)	Reference Facility
concrete tile, off-white coating	0.74	0.9	20	92	LBNL
white concrete tile	0.73	0.9	21	90	FSEC
concrete tile, light beige coating	0.63	0.9	30	76	LBNL
concrete tile, pink & gray coating	0.53	0.9	40	63	LBNL
concrete tile, light brown coating	0.42	0.9	50	48	LBNL
concrete tile, pale bluish purpose	0.41	0.9	51	46	LBNL
red clay tile	0.33	0.9	58	36	FSEC
fiber cement, earth brown color	0.26	0.9	64	27	LBNL
unpainted cement tile	0.25	0.9	65	25	FSEC
fiber cement , pewter gray color	0.25	0.9	65	25	LBNL
red concrete tile	0.18	0.91	71	17	FSEC

LBNL - Lawrence Berkely National Lab, Berkeley, California
FSEC - Florida Solar Energy Center, Cocoa, Florida

Table 2-4. Solar reflectance characteristics of roof tiles. Source: LBNL, 2000

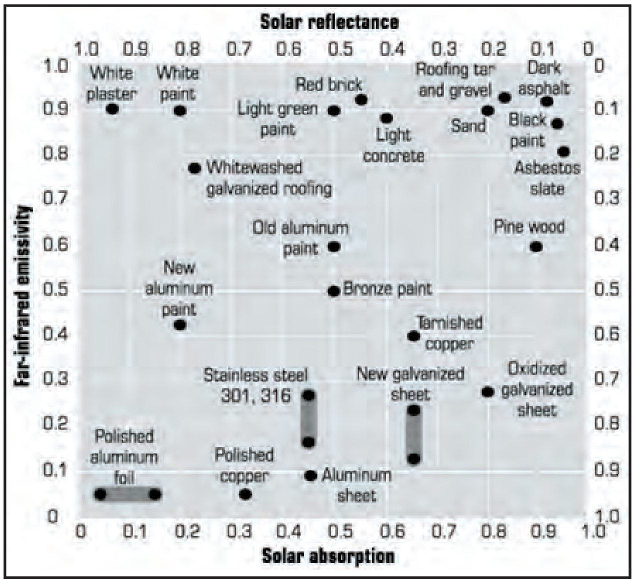


Figure 2-25. Spectral characteristics of common building materials. Source: Florida Solar Energy Center

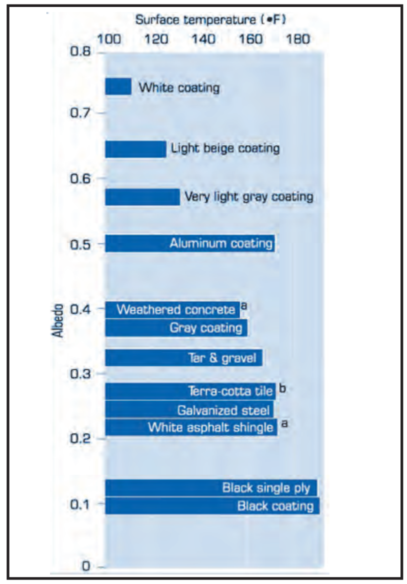


Figure 2-26. Surface temperatures and corresponding albedos of different roofing materials. Source: Lawrence Berkeley National Lab.

Principles of Cool Roofing

Cool roofs to maximize one or more of the following basic principles (Figure 2-29):

1) REFLECT as much solar energy as possible. The less energy that penetrates the surface, the lower the surface temperature will be.

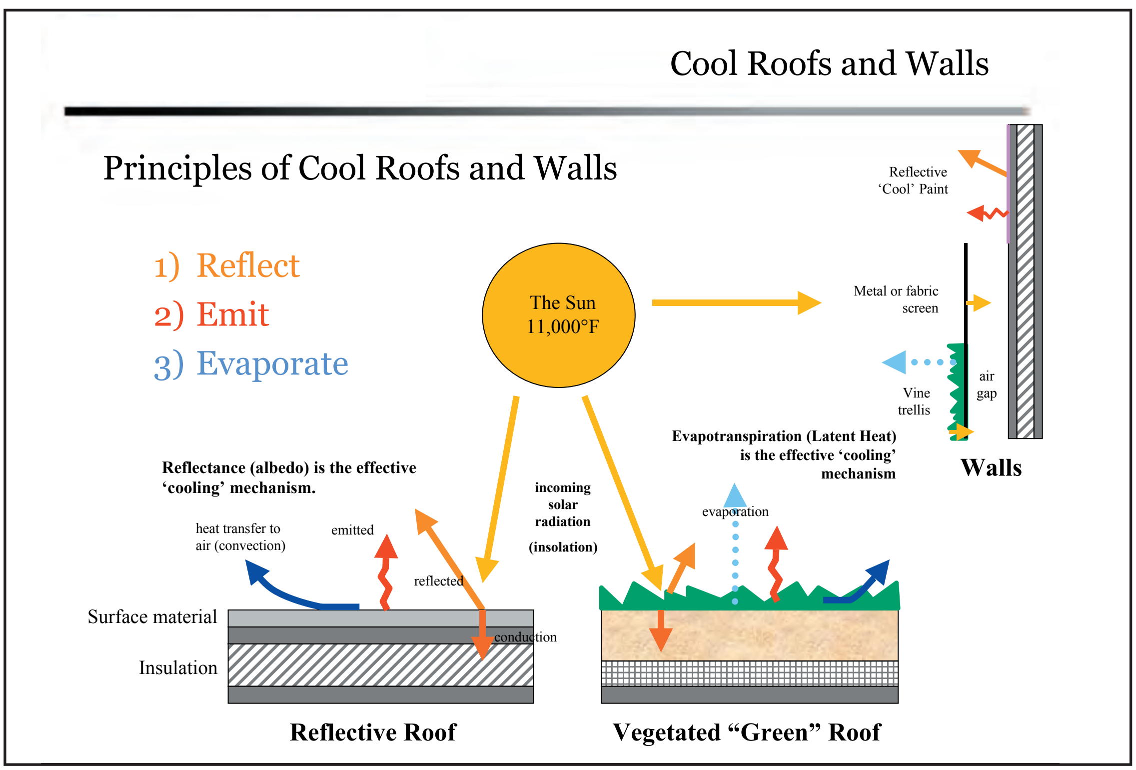


Figure 2-27. Principles of cool roofs and walls. Illustration: J. Carlson, National Center of Excellence, Arizona State University (2007).

2) **EMIT** absorbed energy as quickly as possible. The closer the thermal emittance is to 1, the better the surface will release heat. Because air is virtually transparent to long wave radiation, energy emitted into the night sky in the form of radiation will not be transferred to the ambient air above the surface. This can have a positive influence on the urban heat island effect.
3) **EVAPORATE** moisture to cool the air and roof surfaces. Evapotranspiration at the surface of vegetation, soil, and water bodies converts incident solar radiation energy from the sun into latent heat as it transforms from a liquid to a vapor.

Question: What determines whether a roof is a 'cool roof' or not?

There are several public and government entities that have asked this question. They established the following criteria for what constitutes a 'cool roof.'

Figure 2-28. Energy Star® Logo

- ***EPA's Energy Star® program*** has established an initial albedo for low-slope roofing of 0.65, for steep slope roofing of 0.25, and an aged (three-year) albedo for low slope roofing of 0.50 and steep-slope roofing of 0.15.
  Website: http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_product

- ***The American Society of Heating, Refrigerating and Air-Conditioning Engineers*** (ASHRAE) have included specifications for cool roofs into the standard ASHRAE 90.1- 2004 They have established an albedo of 0.70 and emittance of 0.75.
  Website: http://www.ashrae.org/

- ***Georgia White Roof Legislation:*** The Georgia White Roof Amendment has adopted the criteria established by ASHRAE 90.1. Cool Communities program in Atlanta.
  Website: http://www.coolcommunities.org

- ***California's Cool Roof Program:*** The State of California has developed a Cool Roofs Program with established criteria of Initial Solar Reflectance and Emittance for low slope roofing of 0.65 or greater and 0.80 or greater, respectively; or a Minimum SRI of 75 using ASTM1980. Steep roof criteria to meet EPA Energy Star and high profiled tiles are to have initial albedo of 0.40 or greater and emittance of 0.80 or greater, or an SRI 41 using ASTM 1980.
  Web site: http://www.consumerenergycenter.org/coolroof

- ***LEED® Program:*** U.S. Green Building Council's Leadership in Energy & Environmental Design (LEED) program offers credits in the category of "Sustainable Site/Urban Heat Island Effect." One credit is achievable if the building uses a roof with both high solar reflectance and high emissivity. The requirement states: "Use Energy Star Roof compliant, high reflectance and high emissivity roofing (initial albedo of at least 0.65, three year aged albedo of at least 0.50 when tested in accordance with ASTM E 903, and emittance of at least 0.90 when tested in accordance with ASTM E 408) for a minimum of 75% of the roof surface; OR, install a green roof for at least 50% of the roof area."
  Web site: http://www.usgbc.org/LEED/LEED_main.asp

Question: How is the reflectivity and emittance of a roof or product measured?

There are standardized test methods for determining the solar reflectance and emittance of a product in the field or laboratory. The test methods are available from the **American Standard for Testing and Materials (ASTM).** The test methods for solar reflectance are ASTM E 903, ASTM E 1175, and ASTM E 1918. To get a rough measurement of reflectivity of large surfaces in the field, the standard ASTM 1918 can be used. Thermal emissivity is measured using ASTM E 408, ASTM C 835, and ASTM C 1371. Calculating solar reflectance index (SRI) is described in ASTM 1980.

Question: How can I be sure that a roofing product will meet the cool roof requirements without measuring it?

The **Cool Roof Rating Council (CRRC)** is an independent and unbiased organization that has developed protocols and procedures for testing products for Solar Reflectance and Emittance. Any product that has gone through the structured and rigorous testing requirements defined by the CRRC will have the CRRC label (see Figure 2-29) on the product packaging. The CRRC label alone may not indicate that the product is a 'cool roofing' product. The EnergyStar® label verifies that the radiative properties measured by the CRRC for this product meet the cool roofing requirements as defined by the EnergyStar® requirements. The CRRC also serves as a library for data from tests performed by CRRC-accredited laboratories on the wide range of materials submitted by manufacturers. Find out more at http://coolroofs.org.

Figure 2-29. The Cool Roof Rating Council Label.

<u>Cool Roofing Technologies</u>

Cool roofing products have been used to reduce energy consumption for several decades, and new products are being developed all the time. The products that have been most successful are those that easily adapt to use with the most common roof types. Other, less conventional products may be even more effective, but due to lack of contractor experience, higher initial cost, and lower availability, they have not been as rapidly adopted by the roofing industry. There are five categories of cool roofing technologies for use in both new construction and re-roofing applications. This section describes each technology and explains when it is best used, what's 'cool' about it, and its cost compared to other roofing materials.

Cool Liquid-Applied Coatings

Liquid coatings are the most versatile cool roof technology as they can be applied to the top surface of the roof covering or membrane of either new or existing roofs. Titanium dioxide and zinc oxide are mixed into acrylic polymer to create durable, bright white coatings, and this pure white coating can achieve initial reflectance values of 75-80% and emittance of 0.90. For those not desiring a bright white look, other colored pigments can be added, but any additional color will result in a decrease in reflectivity depending on the hue. These coatings generally have a thickness of 15-20 mils (mil = 0.001 in), and can be applied to almost any roof surface regardless of slope and material - built-up roofs, spray applied polyurethane foam, modified bitumen, or metal. Figure 2-30 below compares the maximum surface temperature of a low slope roof before and after treatment with a commercially available cool roofing coating product. These liquid applied coatings offer affordability and ease of application for improving the performance of existing roof materials, and there are a wide variety commercially available. Check for the **Energy Star® Certified Label** when looking for products that meet the minimum Solar Reflective Index values.

Figure 2-30. Cool roofing on a commercial low sloped roof. The surface temperature was reduced by 85°F after the roof was treated with a liquid applied cool roofing product. Images courtesy of Hydro-Stop, Inc.

Figure 2-31. Liquid-applied cool-roof coating (product Mirror Seal™) on a low-slope, residential roof in Guadalupe, Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

Figure 2-32. Walls also present an opportunity to use reflective coatings. This example shows how a simple layer of reflective paint (represented by a dark purple) can dramatically affect the surface temperature of a brick wall. Photos courtesy of National Center of Excellence, Arizona State University.

New liquid applied cool wall coatings are also becoming available from large paint manufacturers. The paints come in a variety of colors while still reflecting infrared radiation. The temperature of a wall can be greatly reduced with the simple application of a reflective coating.

Cool Prefabricated Membranes

Many of the single ply membrane materials already in use, such as **Ethylene Propylene Diene Monomer Rubber (EPDM)**, **Polyvinyl Chloride (PVC), Copolymer Alloys**, and **Thermoplastic PolyOlefin (TPO)**, are naturally white and opaque. These membranes are typically over 45 mil thick and can be rolled out and attached to roofs, providing an initial reflectance of 0.75 to 0.85 and an infrared emittance of 0.80. With any highly reflective surface, it is vital that the roof be adequately sloped to drain precipitation and remove dust from the surfaces during rain events.

Other, darker membranes, such as modified bitumen and prefabricated asphalt rubber sheets, can be made more reflective by adding other materials to the surface during manufacture. Generally, metallic foils, mineral granules, and other proprietary materials can be embedded on the top surface to achieve improved reflectivity. While there is a limit to the effectiveness of coated mineral granules, typically only achieving reflectance of 25%, a metallic foil-embedded fabric can improve reflectance values to 85%, and a white coating applied to the flakes can achieve an emittance of 0.80.

Figure 2-33. Cool-roof, PVC, single-ply membrane applied to a roof. Photo courtesy of Honolulu Roofing Company.

Cool Metal Panel Roof Systems

Metal roofs are prefabricated, allowing for reflective, high-emittance treatments to be added during the manufacturing process. The metal sheets can be formed and installed in a variety of configurations depending upon the desired style and slope of the roof. Special reflective coatings are usually baked on to ensure surface durability. Innovations in the metal treatment process have developed colored surface treatments that reflect more energy in the invisible near-infrared range than in the visible spectrum. This results in a colored metal roofing system that stays cooler than conventional surfaces of the same color. These reflective panels can achieve solar reflectance of 0.15 to 0.70. The additional benefit of using steel is that it can last over fifty years, costs nearly the same as tile, is less messy than liquid applied roofing products, and is 98% recyclable after deconstruction.

Figure 2-34. A cool metal roof. Photo courtesy of the BASF Company

Emerging Products for Tiles and Shingles

New products are continually emerging in the cool roof industry. Most of these products are suitable for steep slope roof applications. Concrete and clay tile products, coated or tinted with light colored pigments with reflectance values greater than 0.40, are among these new products (Figure 2-35). While asphalt shingles are still the dominant roofing material for steep sloped residential construction, new metallic coated shingles are starting to become more available. The limited use of these products for steep sloped residential roofs is a result of several factors: limited awareness of homeowners, lack of government incentives, and, until recently, the lack of a LEED™ Certification for Homes, all resulting in limited demand. This trend is likely to change as homeowners become more aware of climate change and energy use.

Figure 2-35. Reflective roof tiles.Source: Sacramento Bee, Sacramento, California

Vegetated/Green/Brown Roof Systems

Vegetated roof systems, also referred to as green roofs, date back to ancient times. The combined cooling effect of evapotranspiration, the insulating ability of earthen materials, and the aesthetic appeal make vegetated roof systems an increasingly popular solution for managing storm water and mitigating UHI effects in densely built urban areas. The term "brown roofs" applies to vegetated roof systems in arid climates where vegetation is quite different in appearance from the lusher foliage found on green roofs in wetter areas such as the Midwest or Northwestern U.S.

A typical vegetated roof includes the following components (starting from the structural roof surface and moving upward):

- *Waterproofing/roofing membrane* – made of any one of the roof membranes discussed above (liquid applied, polymeric rubber; hot applied, rubberized asphalt; prefabricated, single ply membrane; or multiple ply, modified bitumen membrane)
- *Insulation medium* – typically an extruded, polystyrene insulation
- *Supporting structure* – metal structure to support the load of growing medium, vegetation, and sometimes foot traffic
- *Waterproofing membrane* – to prevent water from reaching the roof after passing through the growing medium
- *Drainage medium* – a prefabricated, polymeric drainage panel or gravel fill material
- *Filtration medium* – this could be any combination of root-barrier geotextiles, drainage mats, aeration products, and water retention mediums
- *Growing medium* – may be traditional planting soil or engineered lightweight growing mediums.
- *Vegetation* – grasses, shrubs, cacti, bushes, or even trees, depending upon whether the roof is an intensive or extensive system

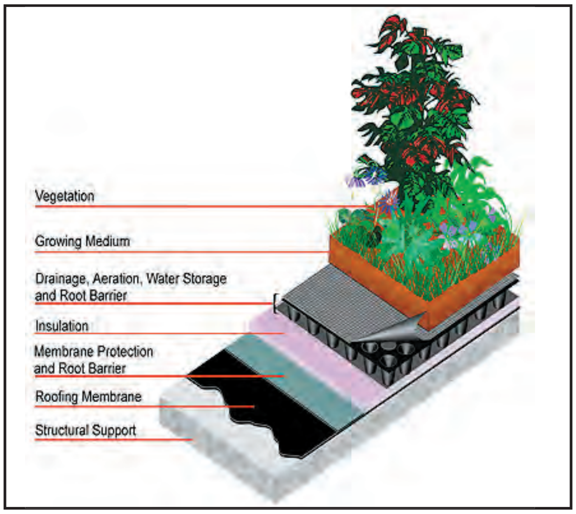


Figure 2-36. Cross- section of green roof assembly. Source: US EPA

Extensive vs. Intensive Green Roof Systems

When designing a green roof it is important to consider climate conditions, level of maintenance required, and water availability. Roofs that employ durable, self-propagating, and small native plants can often be constructed with thin growing medium layers (4-6"), which after the initial growing stage can thrive on the rainfall in the area. These designs are referred to as **extensive greens roofs,** and typically require less maintenance and structural support due to the reduced water needs and weight of the growing medium.

Figure 2-37. Modular, extensive green roof being constructed on a sloped residential home in Pinon, Arizona. Source: www.greenroofs.com.

Figure 2-38. Example of plant types used in extensive green roofs. Photo courtesy of National Center of Excellence, Arizona State University.

Intensive green roofs are quite different. These systems require at least twice the growing medium layer depth (6-12" depth), constant pruning and watering, and are only suitable for low sloped roofs. However, intensive green roofs can support a greater diversity of plants, offer more shade for roof visitors, and provide valuable habitat for nesting birds and other urban wildlife. Most intensive green roofs are designed to simulate parks and encourage visitor interaction and enjoyment. In some cases, intensive green roofs can function as urban farms, growing edible plants for the pleasure and consumption of building occupants.

Figure 2-39. An intensive green roof on Chicago's City Hall. The infrared image on the right shows the dramatic temperature difference between a normal built-up roof and a green roof under identical conditions. The air temperature was around 85oF. Photos courtesy of National Center of Excellence at Arizona State University and Department of the Environment, City of Chicago

Vegetated roofs have additional benefits beyond reducing the surface and air temperature around buildings. They can also improve water quality and reduce the rate of stormwater runoff, thereby limiting the risks of flooding around a building perimeter. The growing medium and filtration in vegetated roof system captures and filters the rainwater before releasing the unneeded portion to either irrigation storage tanks or to the surface below. A four inch deep green roof can retain as much as an inch of rainfall before it begins to release unused rainwater through the drainage medium. During this process, pollutants are broken down by microorganisms in the soil and heavy metals are retained. The rainwater passing through the layered system slows the discharge, which can prevent sudden surges into ground level retention areas, allowing infiltration to occur slowly and preventing overflow and flooding.

In addition to these environmental benefits, green roofs are considered attractive areas where people can enjoy interaction with vegetation. Green roofs can be designed with walking and sitting areas and can improve the marketability of a property. Studies have also shown that the color, sound, and appearance of vegetation and wildlife can reduce stress and improve worker productivity. These benefits can be realized when building occupants view a green roof from a location above or at the same level as the roof.

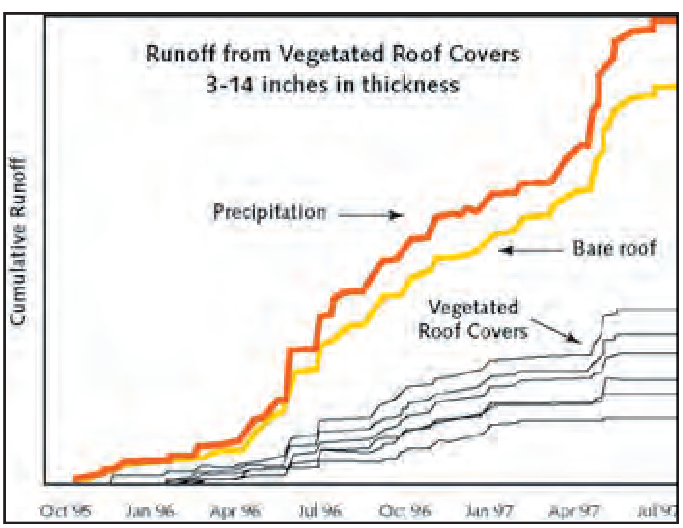


Figure 2-39. Plot of cumulative runoff over time using various types of roofing materials. Source: Whole Building Design Guide, www.wbdg.org.

Comparing Cool Roof Options

is a complete analysis of comparing the application, attributes, costs, and typical lifespan of many cool roofing product options.

Cool Roofing Technology	Slope	Uses	Solar Reflectance	Emissivity	Installed Cost* (p sq/ft)	Lifecycle
Liquid Applied Coatings						
White	Low/steep	Coating	75-80%	0.87	$1.25 - $1.50	15-35 yrs
Colors	Low/steep	Coating	25-85%	0.87	$1.25 - $1.50	15-35 yrs
Aluminum-asphalt	Low/steep	Coating	50%	0.40	$0.50 - $0.75	10-15 yrs
Prefabricated Membranes						
Single-ply (white)	Low/steep	New construction/ Reroofing	75-80%	0.80	$1.65 - $1.85	7-10 yrs
Modified bitumen (M foil/white)	Low/steep	New construction/ Reroofing	25%	80% 0.80	$1.50 - $1.80	5 -7 yrs
Metal Panel Roof Systems						
Metal Panel System (white)	Steep	New construction/ Reroofing	50%	0.60	$4.50 - $7.00	7-10 yrs
Green Roof/Garden Roof Systems						
Greem Roof System	Low	New construction/ Reroofing	N/A	N/A	$15.00 - $25.00	7-10 yrs
Specialty Products Systems						
Clay tiles (white)	Steep	New construction	40%	0.85	$6.00 - $8.00	7-10 yrs
Concrete tiles (white)	Steep	New construction	40%	0.85	$6.00 - $8.00	
Metallic tile (white)	Steep	New construction	40%	0.85	$5.00 - $7.00	5 -7 yrs

* Costs for roofing and reroofing are highly variable due to buildings characteristics. Cost values are only meant to show the order of magnitude perspective of thes conducted by the Houston Advanced Research Center (Hitchcock, 2004).

Table 2-5. Comparison of cool roofing options.

Economic Benefits of Cool Roofing

The ability of cool roofs to reduce urban temperatures is clear, but building owners may need more incentive to implement these technologies. Cool roofs will actually pay for themselves over a relatively short period of time. Cool roofing retrofits are proven to benefit building owners directly through energy savings and reduced maintenance costs. This section takes a closer look at the benefits in detail and shows that cool roofing makes economic and environmental sense for building owners, tenants, and the community as a whole.

Energy Savings and Peak Demand

Heat transfer through the roof of a building can increase the air temperature inside, resulting in an increased demand for cooling. Electrical energy demand for cooling makes up 11% of the total electricity consumed in the United States, and this percentage is even greater in hot, arid climates such as Phoenix. Research studies of individual buildings equipped with sensor networks were monitored before and after implementing cool roofing technologies. These studies produced by Lawrence Berkeley National Laboratory, the Florida Solar Energy Center, and others, showed energy savings of 20-30% when cool roofs were implemented. In terms of air temperature around a building, a decrease of 3-7°F can lead to a 10% reduction in air conditioning requirements. A study in Houston, Texas showed that cool roofing technologies, if implemented on just office and retail buildings, could result in $9-18 million savings annually (Konopacki and Akbari, 2002). An even greater energy savings could be realized by the Phoenix region if cool roofing technologies were implemented in similar facilities. To learn more about how much energy can be saved for a particular building, go to EnergyStar®'s cool roof energy savings calculator at: http://roofcalc.cadmusdev.com/default.aspx.

This calculator uses the general design and location of a building to compare potential energy savings using different types of conventional and cool roofing technologies.

Peak energy demand in the Phoenix region occurs during the hottest part of summer days. This is when cool roofing could be most beneficial. By maintaining roof temperatures closer to ambient air conditions, energy use within the individual building is reduced. This reduction in cooling requirements can help reduce regional peak energy demand during the afternoon. Replicating this energy reduction over the entire Phoenix area would add up to huge savings for the City as energy is charged at the premium rate during peak hours. Cool roof strategies result in savings for the building owner, but also reduce the need for additional energy generation facilities to increase capacity, reducing air quality impacts, and save tax payers money.

Occupant Comfort

Cool roofs can limit the temperature swings within buildings that cause discomfort for occupants. Many facilities such as warehouses, storage areas, and older buildings have limited air conditioning and/or insulation. Cool roofing technologies can have their greatest effect on these types of buildings and improve the productivity of workers.

In addition to increasing comfort inside a building, reduced roof temperatures can reduce the local air temperature that surrounds a building. Buildings behave like heat islands, and reduction of roof temperatures can have a positive affect on the ambient air outside of the building.

Maintenance Costs

Lowered roof surface temperatures can affect the lifetime of the HVAC equipment and of the roof itself. By reducing cooling demand, cool roofs reduce the number of operating cycles of the cooling HVAC equipment. While this is difficult to quantify, it is likely that the fewer hours an air conditioning system is in operation, the less often the equipment will need repairs and the longer it will last..

Solar radiation, especially ultraviolet radiation, and high temperatures are the leading causes of roof material failure. As the daily temperature cycles, incident radiation degrades the surfaces, causing them to become brittle and crack as shown in Figure 2-40. By lowering the amplitude of these temperature cycles cool roof coatings can extend the life of roofing materials by several years. In the case of green roofs, the system completely isolates the roofing membrane from the weathering elements and the temperature is held relatively constant under the protection of the mass of the green roof, both during the summer and winter months.

Figure 2-40. Examples of deteriorating asphalt shingle roofs on residential homes in Phoenix. Photos courtesy of National Center of Excellence, Arizona State University.

<u>Roofing Action Plan</u>

The cool roofing technologies described in the previous sections are commercially available and have proven their benefits over the last decade. They are not standard practice in the Phoenix region, possibly because of limited public and government awareness of them. This section of the report proposes actions and strategies for implementing cool roofing in the Phoenix region. These strategies are based on similar cool roofing plans that have been successful in California, Georgia, Florida, and Texas, demonstrating that local governments can plan successfully to address this key component of UHI mitigation. In order to be effective, region wide cool roofing implementation plans must:

- *Target buildings that have the highest potential for utilizing existing cool roofing technologies;*
- *Provide information on cool roofing to the key decision makers, including building owners, contractors, and public officials;*
- *Establish new municipal codes and regulations that specify cool roofing requirements and adopt existing energy code provisions;*
- *Provide economic incentives for cool roofing;*
- *Create visible demonstration projects through public partnerships and leadership; and*
- *Increase public awareness.*

This section provides detailed examples of each of these components. Incorporating these components into city action plans will have immediate impact on energy consumption and UHI formation in the Valley. Phoenix and its surrounding neighbors have a great opportunity to become leaders in UHI mitigation and provide a role model for other urban centers located in hot, arid regions.

Target Surfaces

An effective development plan must focus its attention on specific targets. A target must possess the greatest potential for positive change. In the case of roofing it is important to select roofing types that are:

- *a large percentage of the total number of roofs*
- *frequently being constructed or re-roofed*
- *receptive to cost effective and commercially available cool roofing solutions*
- *under the jurisdiction of building codes and municipal guidelines*

Roofing surfaces in the Phoenix region account for 15% or more of the total developed area. The roofs are divided into two categories: steep sloped roofing and flat or low slope roofs. As discussed previously, cool roofing solutions are commercially available for both sloped and flat roofs. However, it is clear that flat roofs are more suited to the majority of cool roofing technologies. And in terms of contractor experience and availability, there are a significant number of cool roof technologies already being used on flat roofs in the Phoenix region. Many of these white reflective roofs were installed over the last two decades to reduce cooling demands of buildings. Yet, there are still many surfaces that are not using cool roofing products which could benefit from incentives and public awareness campaigns.

The majority of roof surface area in Phoenix is on residential homes. Ninety percent of these are sloped; only 10% of residential buildings, mostly multi-family units, have flat roofs. Most flat roofs are on commercial, retail, public, and office buildings comprising about 40% of the total roofing area in the Phoenix region. The average useful life of a roof material ranges from ten to thirty years. In Phoenix, however, flat roofs are expected to last for only ten years before requiring replacement or significant repair. Residential sloped roofs usually last longer, depending on the quality of construction and materials. Asphalt shingles can require replacing every 10 years, while tile roofs can last twenty or more years without routine maintenance. Metal roofs that are adequately coated with anti-rusting agents can have lifetimes of more than 30 or 40 years.

Given the availability of suitable cool roofing technologies, the relatively frequent re-roofing requirements, and potential energy savings, low sloped roofs present the best opportunity for implementing cool roofing technologies in the Phoenix region. Low slope roofs are therefore the main target for initial implementation of a cool roofing strategy. As cool roofing technologies for sloped roofs become available for residential applications, it is essential that homes with sloped roofs are added to the plan. With the rate of re-roofing projects in the Valley, within ten years nearly two -thirds of all flat roofing in the Valley could be cool roofing if the recommendations in this guide are implemented. According to studies of similar regions, this would increase the average roofing albedo of the Valley by nearly 70%. Table 2-6 shows the relative percentages of roof area, their recorded average albedo, and the projected albedos after a ten year plan to use cool roofing on all new and re-roofing projects in the Houston area.

Land/Use Land Cover	Projected Roof Area	% of All Roof Area	Current Albedo	Targeted Roof Area*	New Albedo **
Residential	5,189	53.7	0.15	519	0.65
Commercial/Service	69	6.9	0.20	536	0.70
Industrial	642	6.6	0.20	514	0.70
Transportation/Communications	136	1.4	0.20	109	0.70
Industrial and Commercial	571	5.9	0.20	457	0.70
Mixed Urban or Built-Up Land	394	4.1	0.20	315	0.70
Other Mixed Urban or Built-Up Land	2,056	21.3	0.20	1645	0.70
Total	**9,657**	**100%**	**0.17avg**	**4094**	**0.36**

**Targeted Roof Area includes 10% of existing and future residential buildings with low slope roofs and 80% of all existing and future commercial, office, and public buildings over the next 10 years.*

*** New Albedo is an increase of 0.50 for the albedo for all targeted roof areas. The total (0.36) is the projected overall albedo average fo roofing, which doubles the existing albedo levels for the Houston area.*

Table 2-6. Projected roof and albedo change over a 10-year period in Houston, Texas.

Providing Information to Building Owners and Managers

Building owners and managers are the most important decision makers when it comes to roofing choices. New guidelines are needed that include information on common practices, commercially available materials and suppliers, and technical support for the installation of cool roof options. While this guidebook provides an introduction to the variety of materials and the benefits of cool roofing, product summaries, and links to local suppliers, more detailed technical support from independent consultants and roofing specialists is necessary to implement cool roofing plans successfully. In addition to written materials, business and professional organizations should conduct workshops, seminars, and product demonstrations for building owners, managers, and roofing companies. This would ensure that all stakeholders and decision makers are adequately informed about the benefits and availability of cool roofing technologies.

Changing Codes

Municipal codes are established to maintain quality, safety, functionality, and consistency of buildings. Incorporating cool roofing requirements into these codes would be the most effective way to ensure that they are implemented in construction. Changing building codes is not an easy process and requires the support of trade, business, and community leaders. Considerable time and effort is involved in changes to codes and this should be considered only when the community stakeholders are sufficiently informed about the benefits and methods for implementing cooling roofing.

Economic Incentives

The rate at which cool roofing is installed can be increased by providing economic incentives to end users. The State of California developed a project that offered incentives ranging from $0.15 to $25 per square foot of roofing for installing reflective roofing materials. They estimated that 20 megawatts of peak energy demand was offset for every 60 million square feet of cool roofing. Utilities can also offer incentives for demand -side management. In Austin, Texas, the local utility, Austin Energy, provides a similar rebate of $0.10 per square foot of cool roofing constructed. Other incentives could include property tax deductions as part of a state energy program where the local jurisdiction could be reimbursed by the State to make up for lost tax revenue.

Widespread Use of Energy Code Provisions: ASHRAE 90.1

The Energy Standard for Buildings, Except Low-Rise Residential Buildings (ASHRAE 90.1), produced by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), has provisions that allow the reduction of insulation within roof assembly when cool roofing is used. The roof must have a reflectance of 0.70 and a thermal emittance of 0.75. Potential insulation reductions of 14-23% are possible under this energy standard, depending upon the climate conditions in which the building is located. Architects, builders, engineers, developers, and building owners need to be reminded that this provision exists and that they should take advantage of it. Several cool roofing technologies cost nearly the same as standard roofing material and offer opportunities to save in other areas of building construction under well established energy standards such as this one.

Creating Visible Public Partnerships and Leadership

The best way to publicize the availability and utility of cool roofs is to conduct demonstration projects on highly visible public buildings. Buildings belonging to school districts, community colleges, and public universities; transportation centers; and hospitals are potential candidates. Taking a leadership role and setting an example can bring positive attention to these institutions and help promote knowledge and awareness of cool roofing to the general public.

Increasing Public Awareness

Public awareness of cool roofing technologies is essential for change. Citizens must be knowledgeable about changes in building codes, homeowner's association guidelines, and other restrictions that may have an impact on them. In addition, economic incentives such as tax credits or rebates have to be clearly defined and understood by building owners in order to be used effectively. One strategy to increase awareness is to publish case studies, news stories, and video documentaries about cool roof projects in the Phoenix area. The benefits of each project, cost savings, and interviews with the building owners are important components to include. Consistent, persuasive public information is vital to promote the adoption of cool roofing practices and other urban heat island mitigation strategies.

Steps Toward Implementation

- Form a Cool Roof Steering Committee of various agencies and stakeholders to oversee the implementation of heat island mitigation measures for cool roofing actions.
- Work with the City of Phoenix to set goals and implement cool roofing projects, including the identification of cool roofing opportunities in City owned buildings. Similar actions are needed with school districts, school buildings, and other local governments.
- Work with the Arizona Department of Environmental Quality (ADEQ) to develop a strategy for including cool roofing in the State's air quality plan.
- Work with appropriate officials to ensure that the state energy code includes explicit provisions for reflective roofing and green roofing technologies.

- Working with the ADEQ and EPA, develop specific, credible methods of mitigating the heat island effect to help ensure compliance with the Clean Air Act and Clean Water Act.
- Work with the Maricopa Association of Governments (MAG), other planning organizations, and cities within Maricopa County to incorporate heat island mitigation measures such as cool roofing into community planning and development activities.
- Establish a roofing baseline for measuring progress in achieving cool roofing goals that helps establish a means of verifying air quality credit.
- Work with the Steering Committee to design and launch a cool roofing education, training, and outreach program for state and local agencies, building owners, building mangers, and roofing industry companies and organizations.

Adapted from HARC (2004)

PAVEMENTS

The economic vitality and quality of life within an urban area are often related to the quality of its transportation system. Nearly half of the developed area in the Phoenix region is dedicated to transportation and is paved with dark, dense, and impervious materials that are the most significant contributors to urban heat island formation. Paved surfaces include the networks of highways, roads, parking lots, driveways, and sidewalks that provide for the movement of people, goods, and services and are vital to the economic success of the region. According to the Bureau of Transportation Statistics (BTS), the United States spends about 11% of its annual budget on transportation and these systems account for nearly 16% of U.S. Gross Domestic Product

Figure 2-41. Transitioning surfaces from desert to engineered surfaces such as parking lots.

(BTS, 2006). Recent advances in pavement design have resulted in "cool paving" materials and designs that can significantly reduce heat absorption and retention of surfaces. This section of the guidebook focuses on cool paving technologies that are currently available for new construction, maintenance, and reconstruction projects throughout the region. Here we define and quantify each pavement type for the Phoenix region, review cool paving solutions and their relative costs and benefits, and suggest how to incorporate cool paving in current and future development projects.

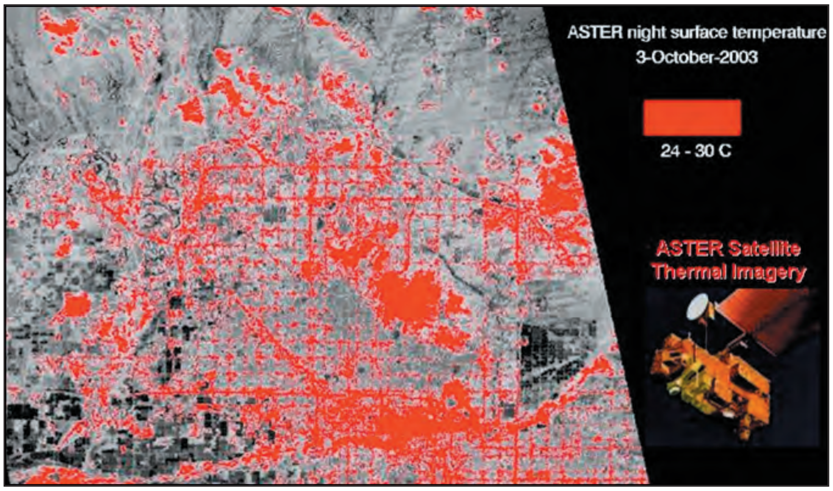


Figure 2-42. ASTER satellite image of surface temperature in the Phoenix metropolitan area at night. The warmest 20% is highlighted in red. Image courtesy of Arizona State University.

Paving Applications

Paved surfaces can be categorized by their functional characteristics. These include location, number and size of vehicles that traverse the pavement, and the distance and speeds that will be traveled upon it. For the purposes of this guidebook, pavement applications are grouped into seven categories: Highways, Arterials, Collectors, Local Roads, Parking Lots, Sidewalks, and Driveways. Engineering requirements can vary greatly among these categories, and performance requirements will dictate which cool paving solution is most appropriate for each application. Defining categories also helps decision makers target the pavements that are likely to be replaced or reconstructed most frequently. Figure 2-43 highlights the spatial relationships among the four different types of road networks.

Figure 2-43. Four basic roads categories in a typical urban area. Source: Google Earth.

Highways

Highways are the conduits that carry vehicular traffic across regions. They can range from rural, two lane roads to multi-lane pavements in major metropolitan areas. They must be designed to support nearly constant loads, ranging in size from motorcycles to large commercial shipping vehicles with six or more axles that exert over 25 tons of force on the pavement.

Speed limits on highways are the fastest in an urban area, up to 75 mph. To support these loads, highways are often made of engineered materials several feet thick. The surface typically consists of rigid or flexible pavement that is supported by layers of base and sub-base materials. Figure 2-44 shows a typical multi-lane highway near Phoenix, Arizona.

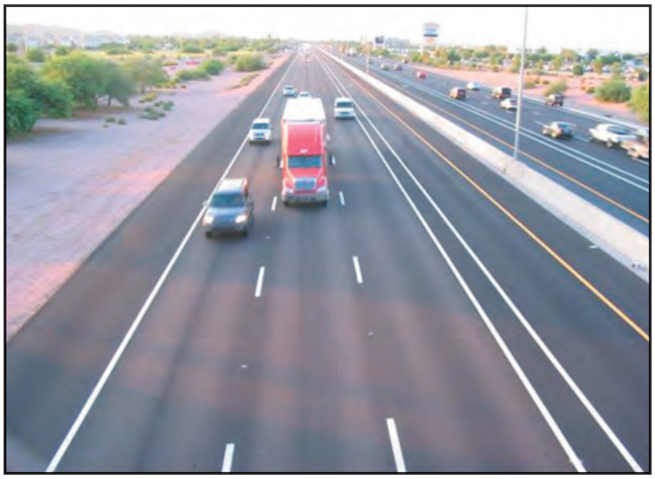


Figure 2-44. Multi-lane highway in Phoenix, Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

Arterials

Arterials are roads that connect directly to major population centers. They link to highways and serve as the major distributors of urban traffic within a city. Arterials can be two to six lanes across and are typically made of flexible pavements with substantial base support materials. These roads can stretch the entire length of metropolitan areas, connecting multiple urban centers. Arterials vary greatly in capacity and traffic volume. Some two lane arterials are traveled by 10,000 vehicles a day, while six lane arterials often have 75,000 vehicles per day. Arterials have lower speed limits (30-45 mph) than highways and are integrated with traffic controls systems such as stoplights at major intersections. Figure 2-45 shows an arterial street in Phoenix.

Figure 2-45. An arterial street and adjoining sidewalk in Phoenix. Photo courtesy of National Center of Excellence, Arizona State University.

Collectors

Collectors link arterials to provide a balance between mobility and direct access to land within residential, industrial, and commercial areas. They typically have fewer than four lanes made of flexible pavement, with sidewalks located on either side. Speed limits range from 25-35 mph, and the roads can handle from 5,000-10,000 vehicles, depending upon the number of lanes.

Figure 2-46. Parking lot outside of a major commercial facility in Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

Local Roads

Local roads are the roads that run through residential neighborhoods. These streets are typically constructed of full depth, flexible pavement and can have rounded curbs and sidewalks on both sides. Speeds are typically between 20 and 30 mph and the roads usually serve fewer than 5,000 vehicles per day.

Parking Lots

Vehicle **parking lots** are typically constructed of flexible pavement several inches thick. Parking lot speed limits are usually 5 to 15 mph, and the number of vehicle spaces can vary greatly depending upon the type of facility the lot serves. Figure 2-46 includes a typical parking lot; this one is located at a shopping mall in Tempe, Arizona.

Most commercial parking lots are constructed of 4 to 6 inches of flexible pavement, such as hot mix asphalt, over a crushed aggregate base. Figure 2-47 shows the cross section of a parking lot located in Tempe, Arizona.

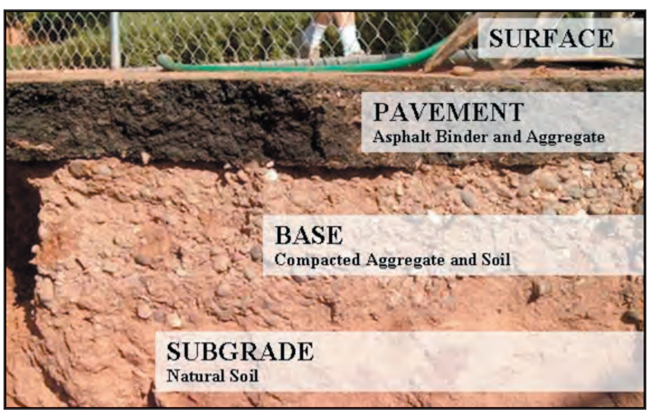


Figure 2-47. Cross-section of an asphalt parking lot located in Tempe, Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

Sidewalks

Sidewalks are paved surfaces for pedestrian and bicycle traffic. They can be found along major arterials, connectors, and local roads, or in any location where a permanent path is desired. In most cases sidewalks are made of a thin layer of concrete or block pavers. They can often reach temperature of 150°F (65°C) during the day as shown in Figure 2-48.

Figure 2-48. Visible and infrared images of pedestrians walking over pavements with temperatures of over 150°F. Images were taken in July 2006 with a peak air temperature of 100°F. Photos courtesy of National Center of Excellence, Arizona State University.

Driveways

Driveways provide vehicular access to buildings or parking facilities. Traffic volumes can vary greatly and structural design is dependant on the size of the vehicles to be accommodated. A commercial driveway leading to a loading dock will be much thicker than a residential driveway connected to a house.

Paving in the Phoenix Region

Phoenix and its surrounding cities are one of the most pavement rich areas in the country and rapid growth adds many more miles of new roads, highways, and parking lots every year. Landcover studies performed in other cities have shown that nearly half of all pavements in urban regions are designated for parking. For example, in Houston nearly 217 square miles of pavement is for parking, while 125 square miles is roads (Rose et al. 2003). Parking lots cover 15% of the total land area for the entire Houston region. Preliminary findings of landcover studies at ASU show that parking lots in Phoenix account for closer to 18% of the total land cover. That is more area than all of the building roofs combined. Research is currently underway at ASU to accurately quantify types and surface area of pavements in the Phoenix region.

Eighty-four percent of all roads in the US are constructed of **asphalt concrete (AC)**. The second most common paving material is **Portland cement concrete (PCC)**. In Phoenix, the majority of streets are made of asphalt concrete and the highways are typically constructed of PCC. Over the last decade, rubberized asphalt has become widely used for major arterials and as a highway overlay on top of PCC. Rubberized asphalt is simply that, crumb rubber (mostly from used tires) mixed with conventional asphalt concrete. The result is a flexible pavement that is on average four decibels quieter than asphalt or concrete pavements. The Arizona Department of Transportation (ADOT) first used rubberized asphalt in 1964, and in 1989, Phoenix began its use and continues to use it more than any other city in the world. According to ADOT, the benefits of using rubberized asphalt are that it fills in cracks in the existing pavement during repairs, it is more durable and skid-resistant, and it reduces traffic noise and provides a smooth, quiet ride. However, the albedo of rubberized asphalt is especially low. Conventional and rubberized asphalt albedo can range from 0.20 to as low as 0.04 when brand new. Over time, with traffic wear and degradation caused by ultraviolet radiation, asphalt pavement becomes lighter. PCC, on the other hand, starts out with a 0.40 albedo and over time it loses its reflectivity, becoming darker (albedo = 0.25) due to tire deposits and grime build up. The lower albedo of both of these conventional paving materials can result in surface temperatures that far exceed the ambient air temperature. Figure 2-49 shows an example of the difference between surface temperatures of asphalt and concrete in Rio Verde, Arizona on a 95°F afternoon.

(a)
(b)

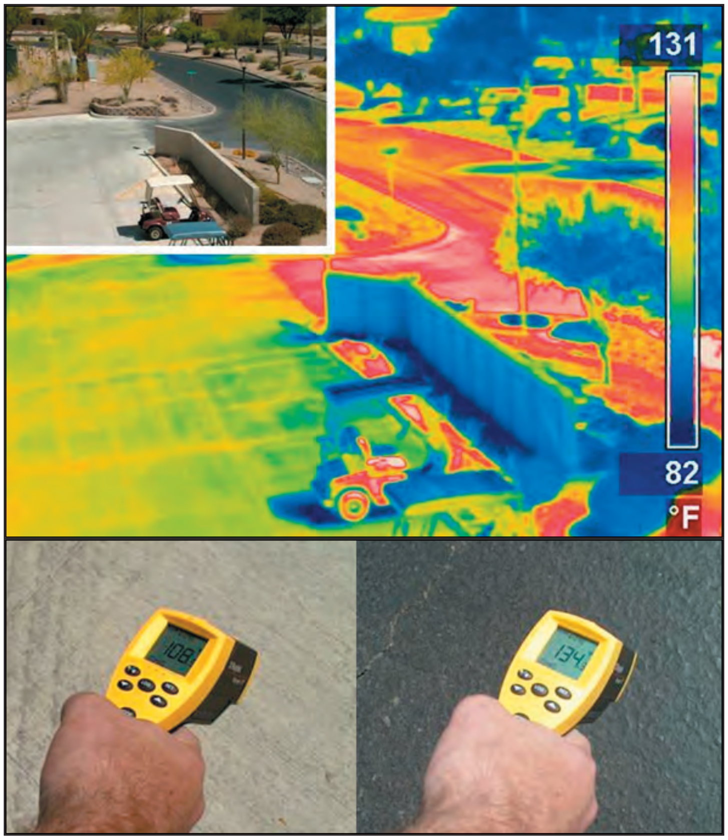


Figure 2-49. (a) Visible and infrared image of concrete parking next to new asphalt sealed road located at Rio Verde, Arizona, during June 2006 (ambient air temperature 90°F); (b) Hand held thermometers verify this temperature difference on the ground. Photos courtesy of National Center of Excellence, Arizona State University.

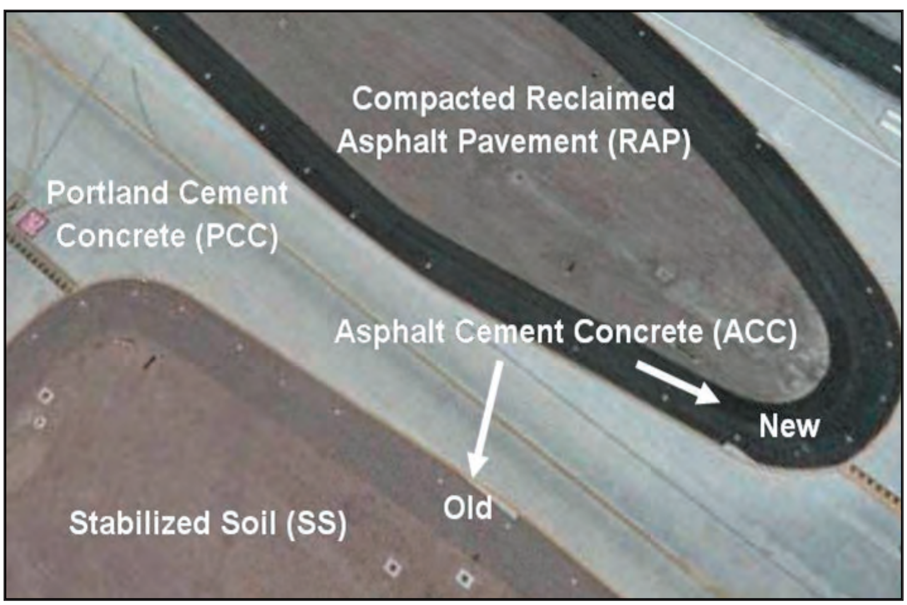


Figure 2-50. Example of pavement material variations on the south airfield at Sky Harbor International Airport in Phoenix. Asphalt cement concrete can vary from 0.05 to 0.15 albedo, depending on its age.
Source: Sanborn.

The low thermal performance of both of these conventional materials has contributed to urban heat island formation in Phoenix. Completely replacing all pavements with new material is not economically feasible. Asphalt is the most inexpensive paving option in the country, accounting for its domination in the paving materials market. Both asphalt concrete and Portland cement concrete are appreciated for their strength, durability, and longevity under the demanding loads and harsh environments to which roads are subjected. Luckily, new modifications to these existing paving materials can greatly improve their thermal performance while still taking advantage of their well established ability to meet structural and durability requirements. The cool paving materials and surface treatments presented here are rooted in the conventional materials of asphalt and concrete. For this reason, they can be easily adopted in pavement projects and construction without requiring a lot of redesign by engineers, planners, and contractors.

Principles of Cool Paving Technologies

Cool pavements are pavements that absorb less solar energy than conventional paving materials under identical environmental conditions. Although there is no industry standard established yet for what constitutes a cool pavement, there are several key elements that indicate the potential for a surface to absorb less energy. These four elements are essential to cool pavement materials and designs.

Reduce Direct Solar Exposure

Perhaps the simplest but most effective means of reducing the amount of solar energy absorbed by pavements is to prevent the sun from reaching it in the first place. This can be accomplished in several ways, dependent upon the pavement application and function. Consideration of the location of the sun during different seasons is very important to maximize shading. Certain paved surfaces such as parking lots, sidewalks, and driveways are easier to shade than roads and highways, for obvious reasons.

Parking shade structures are commonly used to shade automobiles; however, they are also beneficial for reducing the heat

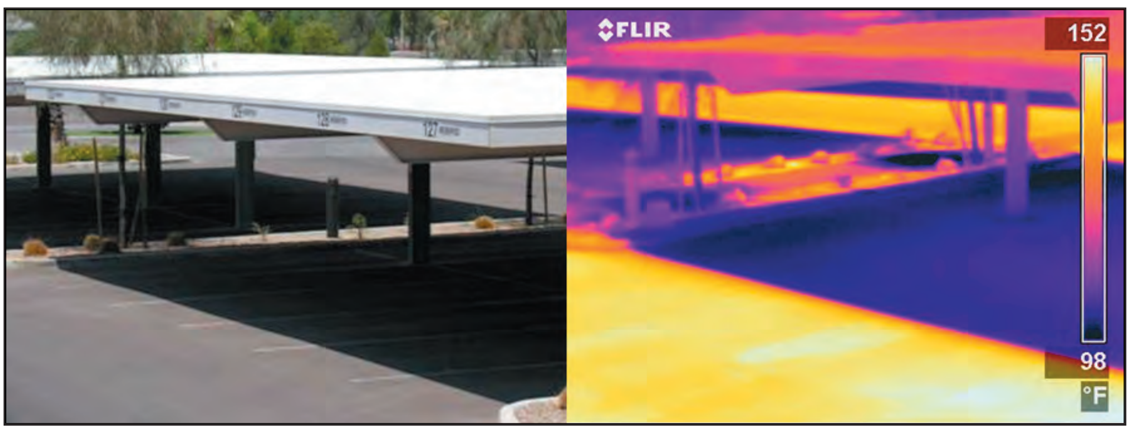


Figure 2-52. Shade parking canopy. Photos courtesy of National Center of Excellence, Arizona State University.

Figure 2-53. Solar shading canopies reduce temperatures, increase pavement life, and produce power for lighting and building. This lot, located in San Diego, California, provides parking for 186 vehicles while generating 235 kilowatts of electrical power. Photo courtesy of Kyocera Solar, Inc.

absorbed by pavements. Structures such as metal awnings, stretched fabric, and tree canopies block direct thermal rays of the sun. Metal structures are most effective if they are designed with gaps that allow hot air to rise and pass through them. While metal canopies can often reach high temperatures during the day, their thin structure retains less energy and their large sky view helps to release the energy quickly after sunset. A study conducted at ASU showed that photovoltaic paneling systems can provide shade while generating electrical power for onsite uses such as lighting at night. (Golden and Carlson 2006).

When funding permits, constructing parking areas below ground is highly recommended. This completely isolates the parking area from the sun's energy while also increasing the amount of area above ground that can be used for vegetated landscape walking areas or additional building space.

Figure 2-53. Example of underground parking in a commercial shopping center. Photo courtesy of Tunnerl-Spangler-Walsh & Associates.

When choosing vegetated shading like vine canopies and trees, it is important to choose species that will require little maintenance (trimming, watering) while providing adequate shading during the summer months. The following section on urban forestry provides more information on native species and their effectiveness for shading in the Phoenix bioclimatic region.

The US Green Building Council's LEED™ rating system recognizes shade as an effective means of mitigating the urban heat island effect in parking lots. LEED™ credits can be awarded for constructing 50% of the parking surfaces underground, shading with structures, or covering by growing tree canopy within five years of construction completion) (LEED™ NC Version 2.2 Reference).

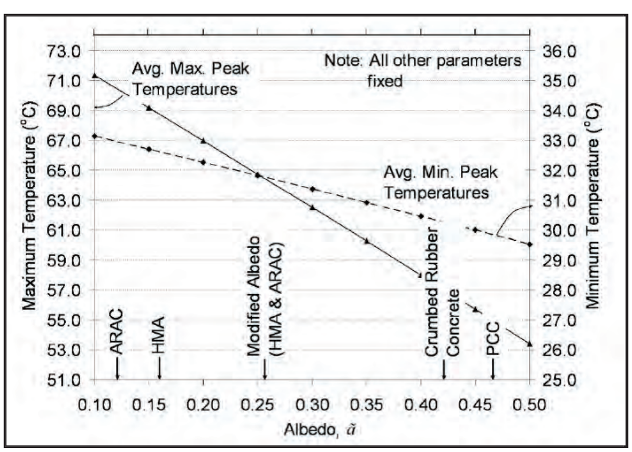


Figure 2-54. Pavement temperatures versus albedo. Source : Gui et al. (2006).

Increase Surface Reflectance and Emittance

If direct sun exposure is unavoidable, the next best opportunity to limit the heat gain of pavements is by reflecting it. Albedo is the ratio of solar energy reflected by a surface to the amount striking the surface. Increasing the albedo of surface pavements has been shown to reduce the surface temperature and heat retention of pavement more than any other material property. In fact, a 10% increase in albedo of a pavement reduced the surface temperature by 7.2°F (4°C) (Pomerantz et al., 2000). A decrease in surface temperature can also greatly reduce the temperature gradient within a pavement. This gradient differential causes stresses within the pavement layers that can result in cracking and greatly reduces the pavement life. Solar reflectance has never been included in pavement requirements before, but is recommended.

Very few material have even close to 100% solar reflectivity (albedo=1); therefore, all materials absorb some energy. A portion of the absorbed energy is emitted as radiation to cooler surfaces and the sky while the rest is transferred to the ambient air through convection. Concrete, asphalt, soil, and rock are high emitters, with emittance values of 0.90 and higher.

A common misconception about high albedo pavement surfaces is that glare from the surface will affect driver visibility during the day and at night. This is not the case, as pavements like concrete are diffusive, reflecting light equally in all directions. This is the opposite of a metallic surface, which is specular and reflects light at angles. Only when pavement surfaces are wet is glare a problem, which has little to do with the albedo. Glare on wet surfaces can be reduced by increasing porosity on asphalt pavements and by tining concrete surfaces. Studies comparing reflective surfaces at night show high albedo actually increases safety and visibility for drivers by reflecting more of the headlight glare towards pedestrians or other objects in the road.

Figure 2-55. A high albedo surface under direct sunlight, showing diffuse reflection.

Increase Porosity

Porosity is a measure of air in a material. Surface materials with higher porosity will have lower thermal conductivities and volumetric heat capacities because air is a poor heat conductor and has very low density. An increase in porosity can significantly reduce the amount of energy that can be stored in a surface. Like soil and decomposed granite landscaping, the surface of porous materials can get hot during the day, but the heat is only stored in the top few inches. After sunset, the energy stored in this top layer is released rapidly due to the surface characteristics of porous materials. The surface of some types of porous pavement is very rough, and those cavities help cool the surface by allowing more surface area to radiate, transfering heat to air that passes across it.. A secondary benefit of porosity is retention of storm water. The more porous a material, the more likely the air

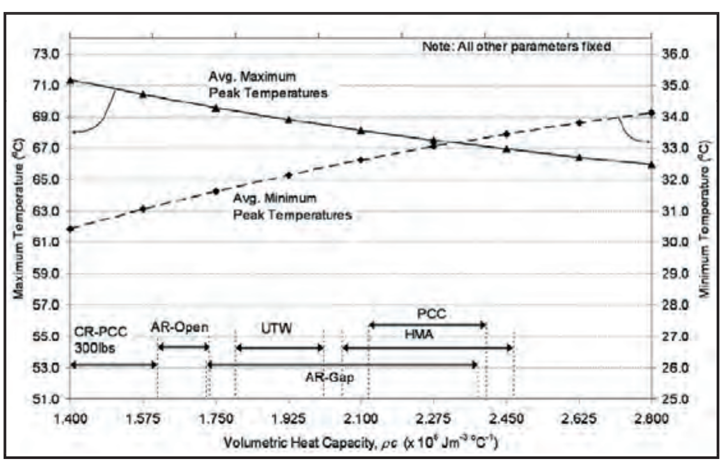


Figure 2-56. Insert plot of density versus pavement maximum and minimum temperatures. Source: Gui et. al, (2006).

spaces will interconnect. This interconnection creates channels that allow water and air to pass through the structure, making it permeable. Water can then be retained on site to benefit the vegetation and trees that surround a parking lot. One downside of surface roughness is that reflectivity is reduced, as smooth surfaces reflect more effectively.

Increase Evapotranspiration

Surface pavements that retain moisture stay cool by means of evapotranspiration. Similar to vegetated surfaces and soil, if a moist surface is heated by the sun, part of its thermal energy is expended in converting liquid into vapor. As this vapor leaves the pavement surface, it takes away heat and cools it similarly to the way skin sweats. Only a few pavement types do this effectively and they will be discussed below.

Cool Paving Materials

The cool paving materials described in this section maximize one or more of the three beneficial characteristics described above: increase albedo, increase porosity, or increase evapotranspiration. While none of the materials is extremely effective at all three, they are the best options currently available. With further research and investment in alternative products, this list will grow and change.

Pavements are comprised of two primary components, a binder and aggregates. Binder is the glue that holds the pavement together, either made of asphalt, Portland cement concrete, or emulsified polymers. Specific binders are chosen for different climate conditions. For instance, an asphalt binder used in the cold regions of Canada performs very differently from those used in climates like Arizona. The aggregate is usually crushed rock, which provides the strength, durability, and friction of the pavement. The type of rock used typically depends on whatever is available in the local area. Aggregate size can range from over one inch in diameter to fine sand, depending on the type of pavement and its application. The albedo of the pavement depends on the albedo of the binder and aggregates. In the case of asphalt, nearly 75% of an asphalt pavement is dependant on the albedo of the aggregate that is exposed at the surface (Pomerantz et al. 2000). Surface properties of pavements change over time due to the effects of weather and maintenance methods. Asphalt gets lighter over time, while concrete becomes darker.

Portland Cement Concrete

Particles that form a bond when mixed with water are referred to as hydraulic cements. The most common of these in the construction industry is Portland cement. Portland cement is made by mixing calcareous (lime coated) materials with argillaceous (clay) materials (Brantley and Brantley 1996). The raw materials of lime, silica, aluminum oxide and iron oxide are mixed in specific proportions. The mixture is then sent to a kiln, where temperatures close to 2700°F (1482°C) drive a chemical process that produces hard pellets of a material referred to as clinker which are ground into Portland cement powder.

Portland cement, when mixed with fine and coarse aggregate, air, and water is the basis of Portland cement concrete (PCC).

Figure 2-57. Portland cement concrete parking lot in Tempe, Arizona. Photo courtesy of National Center of Excellence, Arizona State University.

PCC is initially very plastic, perfect for casting or molding, which solidifies by a chemical reaction (Brantley and Brantley 1996). Portland concrete provides engineers with a low cost, easy to place, strong, and durable material.

New roads made of PCC are usually eight inches thick and can have lifetimes of over 35 years. PCC surfaces similar to the parking lot shown in Figure 2-57 typically have an initial reflectance of 0.35 to 0.40 when new, but over time, dirt, grease, and tire residues can lower its albedo to less than 0.25. By using lighter colored cement, aggregate, and sand, PCC can attain initial albedos of 0.40 to 0.80.

White Cement

White cement is made using the same process as PCC, but kaolin is substituted for ordinary clay. (The iron oxide in clay is responsible for the gray color of PCC.) Because solar reflectance is not usually specified in engineering requirements, white cement use is uncommon and currently nearly twice the price of normal cement. Because albedos of 0.80 are possible with the use of white cement, it is desirable that cement suppliers find new methods or additives for increasing the albedo of their products.

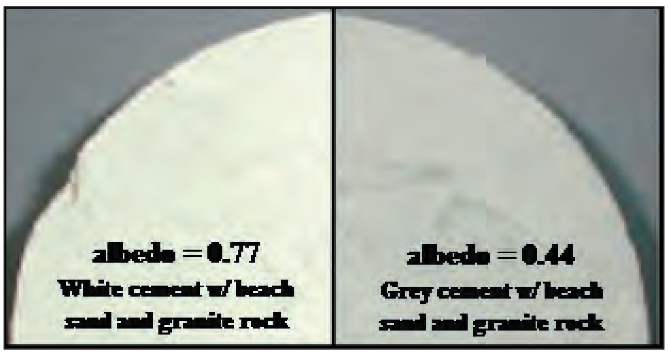


Figure 2-58. Albedos of white and grey cement with identical aggregate proportions. Source: Levinson and Akbari (2001).

White Topping

White topping is an industry term for a 4-to-8-inch layer of conventional Portland cement concrete laid over new or existing asphalt pavement. The name is misleading because the surface is gray, not white, in color. Because it is made of cement concrete, the surface radiative properties are the same as those of cement, with albedo ranging from 0.25 to 0.40.

Ultra thin white topping is a fiber reinforced cement concrete layer only 2-to-4-inches thick. It is particularly useful for dealing with intersection crosswalks that have elevated surface temperatures impacting pedestrian traffic. Because of high surface temperatures and continuous loads from braking vehicles, asphalt pavements at intersections suffer from rutting, shoving, and cracking. White topping creates a cooler surface and ambient temperature, increases pavement strength, and reduces life cycle costs.

Figure 2-59. A thin white topping project in Phoenix: (a) grinding down the existing asphalt base, and (b) curing the final surface. Photos courtesy of National Center of Excellence, Arizona State University.

Interlocking Block Pavers

Block pavers are made of precast concrete and come in a variety of shapes, designs, and colors. The albedo of these pavers varies greatly, but the lighter the color, the higher the albedo. The strength of block pavers is derived from their interlocking design. Each block is support by the pavers surrounding it, and the load is distributed horizontally. Block pavers are typically used in low traffic areas such as parking lots, turn lanes, and driveways. Some designs are made to be permeable with open joints that allow water to pass through while still maintaining tight wall-to-wall contact. Some cities use block pavers to fill in utility cuts because they can be dug up and replaced in a relatively short period of time and are considered more aesthetically pleasing than conventional repair materials.

Figure 2-60. High albedo, interlocking block pavers. Photo courtesy of LCRA Service Center, Austin, Texas.

Asphalt Cement Concrete (ACC)

Asphalt is a black or dark brown residue from the petroleum distillation process. Consisting of hydrocarbons and their derivatives, asphalt is used for many applications that require durable, weather resistant characteristics. One such application is asphalt cement, which is used in the construction of flexible, high grade pavements. Asphalt cement, when used as a binder mixed with aggregates such as gravel, sand, and crushed stone, is referred to as asphalt cement concrete (ACC). Since the turn of the century, ACC has been the most commonly used paving material for roads, parking lots, and highways.

The majority of ACC used for roads and parking lots is "hot mix asphalt" (HMA), produced by mixing aggregates and asphalt cement at elevated temperatures in either a batch or drum mix asphalt plant (US Army Corps of Engineers 2000). HMA is typically divided into three different mix types; dense graded, gap graded, and open graded. These names correspond to the size gradation of the aggregates in the mix.

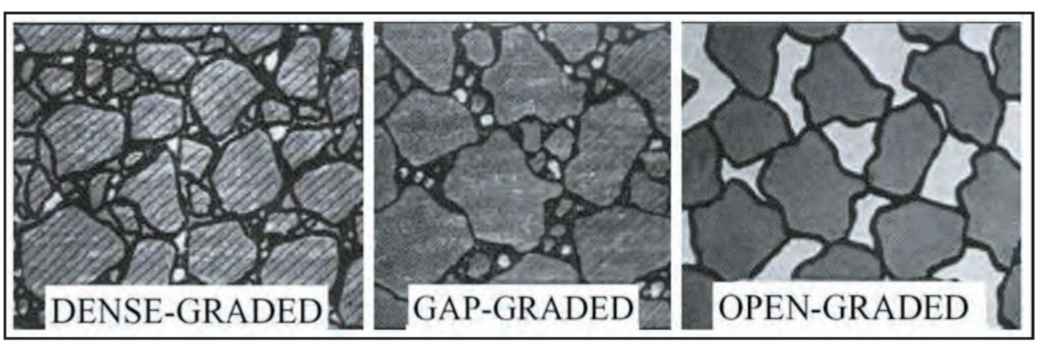


Figure 2-61. Cross section of three aggregate types found in hot mix asphalt. Source: National Asphalt Pavement Association.

Newly constructed asphalt can be one of the hottest surfaces in an urban setting, often reaching temperatures of 160°F (72°C) during summer days, due to its very dark, non-reflective surface (albedo=0.04). As asphalt ages, its albedo increases; however, it rarely exceeds 0.15 before being resealed with a dark asphalt sealant. Asphalt concrete is not considered a cool paving material, but adjustments in its mix design could greatly improve its thermal performance.

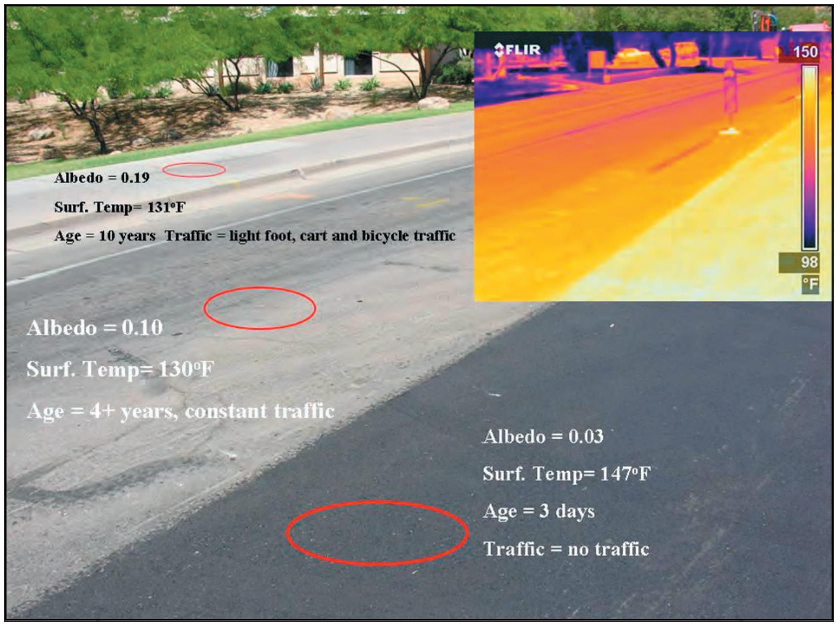


Figure 2-62. New and old asphalt surfaces in the Valley. Courtesy of National Center of Excellence, Arizona State University.

Cool Asphalt Concrete

Cool asphalt paving is constructed using lighter colored aggregates and sand. Changing the color of the binder is difficult and costly, but changing the aggregate is relatively easy. And because nearly 75% of an asphalt surface is made of exposed aggregate, a 30-40% increase in the aggregate albedo will result in a pavement surface that is 10-30% more reflective. As the asphalt binder ages, the surface will become lighter. Because the aggregates that contribute to surface reflectance are only at the surface, only the last lift (layer) of asphalt needs to incorporate the lighter colored aggregates. This reduces the supply problem for lighter colored aggregates in areas where they are less available or more costly.

Figure 2-63. A road made of asphalt concrete with reflective aggregates. Courtesy of the Asphalt Pavement Alliance.

Cool Asphalt Resurfacing and Coatings

Aged or damaged asphalt pavements are usually maintained with chip seal or slurry seal. These thin layer (< 0.5 inches) treatments help to rejuvenate roads and parking lots and are the best options for increasing asphalt surface reflectivity.

Gritting

Gritting is a type of chip sealing that spreads small, uniform aggregate over a freshly laid layer of hot, emulsified asphalt. It is used mainly on low traffic roads to increase skid resistance and the useful life of pavement. By using highly reflective aggregates it is possible to raise the pavement surface albedo significantly. The top layer of the gritted surface is exposed shortly after construction due to normal traffic wear and weathering effects. Although the aggregate is usually coated before it is laid down, it is possible to apply uncoated aggregate to the surface. This will produce immediate results, although the adhesion of the aggregate may be reduced if not compacted immediately after placement. Gritting is usually applied to older surfaces but it can also be used on new overlays to increase the albedo of the conventional pavement underneath.

Figure 2-64. Gritting requires a spreading truck to deposit reflective aggregate to hot asphalt emulsion.
Source: Asphalt Pavement Alliance.

Slurry Seal

Slurry seal consists of a mixture of emulsified asphalt, aggregate, water, and specified additives. Slurry seals are applied over existing pavements to reduce oxidation, seal surface cracks, and stop raveling and loss of materials from the underlying pavement. Slurry seal also makes surfaces impermeable to air and water and can improve skid resistance by increasing the surface roughness. The aggregates used in slurry seals are very small, and if made of a high albedo material, can dramatically increase the surface reflectivity. The only limitation to slurry seals for cool pavement purposes is that they are well mixed to thoroughly coat the aggregate, creating a smooth, dark final surface. With time and wear the aggregate will be exposed, making the increased reflectivity a delayed result. Gritting offers a more immediate benefit over slurry seals because their aggregates are exposed directly during construction.

Figure 2-65. New technologies such as shot-blasting are being developed to lighten asphalt pavement immediately after construction. This technique abraded the surface binder. Photo courtesy of the Asphalt Pavement Alliance.

Tinted Asphalt Binder

Originally developed for decorative purposes, light colored seal coats have a major potential for increasing the albedo of new and existing asphalt pavements for roads and parking lots. Traditionally, seal coats were applied to existing parking lots to improve the appearance, limit ultraviolet degradation, and reduce moisture damage. However, light colored seal coats also result in lower surface temperatures, which increase the life of the pavement underneath.

Figure 3-73. Example of a light colored synthetic binder using reflective aggregate. Photo courtesy of the Asphalt Pavement Alliance.

Reflective asphalt coatings are not yet widely available. Several pilot projects may be required in the Phoenix area before contractors begin to make this product commonly available and economically competitive with conventional surface treatments.

Crumb Rubber Friction Course (CRFC)

Recycled crumb rubber added to asphalt friction coarse pavements results in a unique flexible pavement material widely used in urban regions to reduce highway noise by up to 6 decibels. A **crumb rubber friction course** is placed in a 1-to-2-inch thick overlay of standard 12-14 inch structural Portland cement concrete pavement . These kinds of pavement designs have initially proven to reduce surface temperatures at night more than conventional Portland cement concrete pavements (Belshe 2006). This phenomenon is attributed to the porosity of the top friction course in comparison to conventional PCC mix. There are up to

18% air voids in CRFC pavement, and combined with the higher convection generated by automobiles traveling at high speeds on freeways, the pavement's porosity helps to reduce pavement temperature at night. However, the lower albedo of the black rubber tire and asphalt mix tends to elevate daytime temperatures in comparison to PCC. Additionally, an asphalt friction course may not function appropriately in some slower speed applications as it has less resistance to deformation due to its lower viscosity compared to traditional hot-mix asphalt. It can be used on arterial streets but is not recommended for parking lots or residential streets.

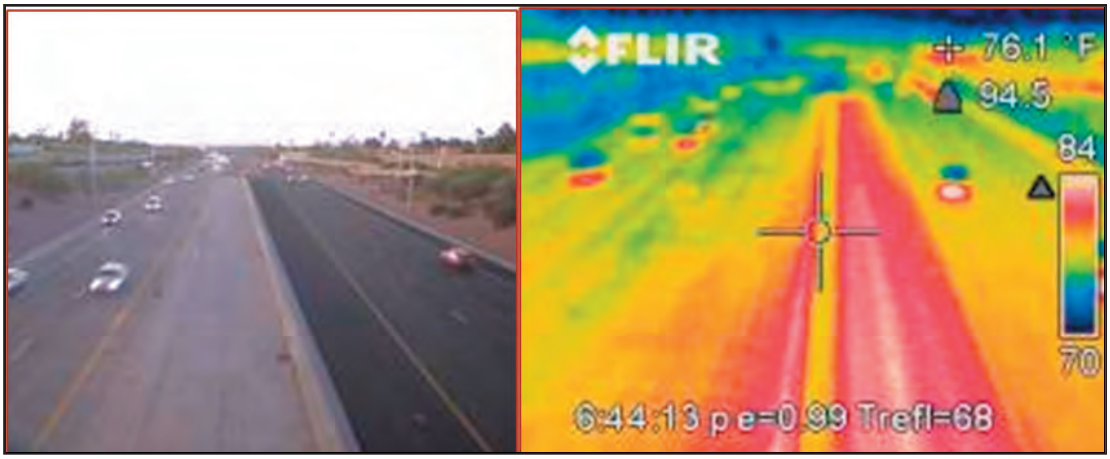


Figure 2-67. Despite its low albedo, crumb-rubber friction course overlays may stay at the same temperatures as Portland-cement concrete in areas of high traffic volume due to convection at the surface. Areas without traffic, such as the highway shoulder in this image, still reach comparatively warmer temperatures during the day. Images courtesy of National Center of Excellence, Arizona State University.

Open Grid and Permeable Pavements

Open grid and **permeable pavements** are unique alternatives to conventional PCC and ACC designs for parking lots and low traffic roads. There are a number of benefits associated with both types of pavements. Open grid pavements have large openings (50% of the total area) which can be filled with material such as soil or gravel. In some instances the soil is vegetated with grass. Open grid pavements are suited for low speed, low volume areas such as parking lots, long term parking areas, and fire truck access areas near buildings. Open grid systems provide an alternative to conventional pavement that is cooler, more natural looking, and permeable, yet strong and durable enough to support vehicles. A variety of the open grid pavements are shown in Figure 2-68. The USGBC's LEED™ Rating systems recognizes open grid pavements for their ability to help mitigate Urban Heat Islands. In LEED™ Sustainable Site Credit 7.1 building designers can achieve one point for using an open grid system for over 50% of the project's parking lot area.

Permeable concrete pavements include **Portland Cement Pervious Concrete (PCPC)** and **Porous Asphalt Concrete (PAC)**. Often referred to as 'no-fines' concretes, permeable concrete pavements use less binder and uniform aggregate (rock) sizes to create a network of interconnected voids that allow for water and air to readily penetrate the surface. These pavements are an ideal solution for non-roof storm water management. If designed and constructed correctly, PCPC and PAC pavements can serve as retention basins, eliminating all or part of the additional land typically required for storm water retention areas on the property. Pollutants such as hydrocarbons and heavy metals are washed into the pavement and infiltrates the subgrade where natural microbial activity in the soil filter and degrade them thereby improving groundwater recharge rates and quality. The minimum required permeability for subgrade soils under permeable pavement is 0.5in/hour. In areas where of clayey soil it is recommended to provide a back up drainage area in case of heavy rainfalls. The air voids in permeable concrete pavements also help to reduce the heat transfer and energy stored by these materials, however, the overall benefit to UHI reduction is not fully understood yet. Most testing of this material has explored its ability to reduce storm water runoff and its ability to percolate

Figure 2-68. Open grid pavements come in a variety of designs and provide a cooler alternative for parking lots and other hardscapes.

(a) (b)

Figure 2-69. Examples of an open grid parking areas comprised of stabilized granite: (a) East Valley Transit Facility, and (b) a residential complex in Tempe, Arizona. Photos courtesy of National Center of Excellence, Arizona State University.

water to the soil below the pavement. A recent study at ASU tested several pervious concrete pavers and found that their temperatures ranged from 5.4ºF to 9ºF (3°-5°C) cooler than impervious concrete of equal thickness and albedo. With moisture present, pervious concrete was 18º-27ºF (10º-15°C) cooler during the day than impervious concrete (Asaeda 2001). Additional research is underway to quantify this reduction under typical Phoenix region climate conditions in several pilot permeable parking lots. The observed reduction in surface temperatures at night is believed to be the combined result of several factors, including evapotranspiration at the surface, high percentage of air voids and surface roughness increasing heat loss through convection.

Figure 2-70. Pervious concrete parking lot outside of the Nelson Fine Arts Center at Arizona State University.
Photo courtesy of National Center of Excellence, Arizona State University.

Along with a reduction in heat storage, permeable pavements can help reduce microclimates by improving the health of parking lot shade trees. Trees planted in locations adjacent to impervious concrete often suffer high mortality because their roots are deprived of moisture and oxygen, elevated soil temperatures, and the tree root balls are compressed. Preliminary findings suggest that these problems can be mitigated with permeable concrete pavements. Using permeable pavements around the base of trees can increase the longevity and canopy size of trees that provide vital shade for hardscapes, parked vehicles, and pedestrians. When used in combination with high albedo pavements, using permeable concrete pavements can be a great design strategy for improving the microclimate and stormwater management of parking lots. An example of this hybrid type design is shown in Figure 2-71.

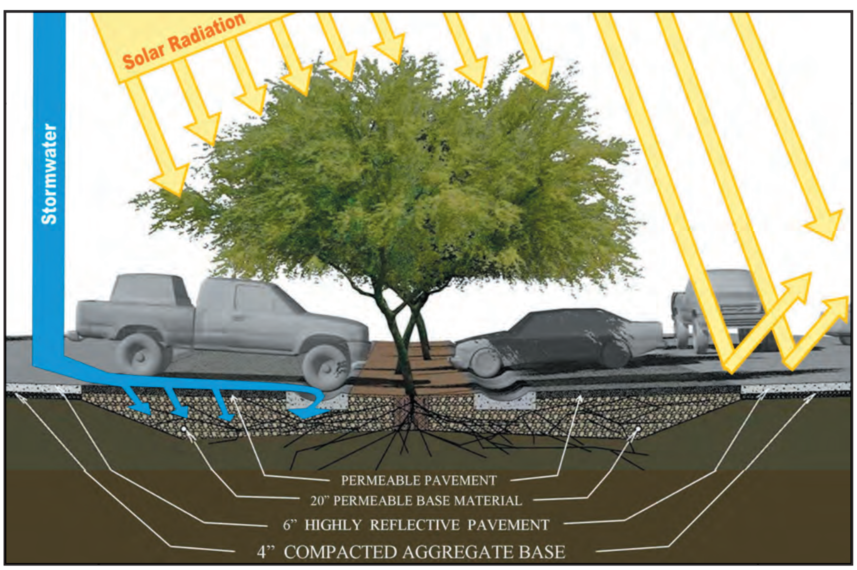


Figure 2-71. A sample design for integrating tree shade with permeable and cool pavements in parking lots.
Illustration courtesy of National Center of Excellence and College of Design, Arizona State University.

While PCPC and PAC are highly encouraged to meet the stormwater requirements for LEED™ they are not recognized as pavement strategies for UHI mitigation by the USGBC. However, with more research results and modification to the designs they may be accepted for this credit in the future. Table 2-7 compares the key cool pavement technologies in terms of application, use, solar reflectivity, cost per square foot, and expected useful life.

Comparing Cool Paving Options

While cool asphalt concrete is the cheapest of all paving solutions in terms of upfront costs, installed cost does not consider the additional expense required to maintain and replace the pavement at the end of its useful lifetime. Cement concrete can last up to 35 years and asphalt concrete is only rated for ten years in most situations. Long term costing can level the playing field for materials with high initial costs but significantly longer anticipated operational lives.

Cool Paving Technology	Application	Uses	Solar Reflectance	Installed Cost (per sq/ft)	Lifecycle
Portland Cement Concrete					
Portland Cement Concrete	Highways, arterials, intersections, parking lots, driveways, sidewalks.	New construction	New: 35% - 45% Old: 25% - 35%	$3 - $4.50	15-35 yrs
White cement	Highways, arterials, intersections, parking lots, driveways, sidewalks.	New/resurfacing	New: 60%	> $4.50**	15-35 yrs
White topping	Arterials, intersections.	New/resurfacing	25 - 45%	$1.50 - $2.50	10-15 yrs
Concrete Pavers	Roads, driveways, sidewalks, parking stalls.	New construction	30%	$1.5 - $3.00	10-15 yrs
Asphalt Concrete					
Cool Asphalt - White aggregate	Highways, arterials, connectors, local roads, parking lots.	New construction	10 - 15%	$1.00 - $1.50	7-10 yrs
Asphalt Surfacing **- White aggregate (gritting)** **- Light colored seal coats**	Arterials, connectors, local roads, parking lots.	Resurfacing and Maintenance	20%*	$0.09 - $0.14	5 -7 yrs
Cool Seal Coat (light colors)	Parking lots.	Resurfacing and Maintenance	15%*	$0.25 - $75	3 - 7 yrs
Permeable Pavements					
Pervious Concrete	Local roads, driveways, parking lots.	New construction	15%	$5.00 - $6.25	15 - 20 yrs
Porous Asphalt - Light aggregate	Local roads, driveways, parking lots.	New construction	10%	$2.00 - $2.50	7 - 10 yrs

Adapted from I. Gartland, Cool Alternative Paving Materials and Techniques, http://energy.ca.gov/coolcommunity/strategy/coolpave.html
* Estimation of reflectance. Vary widely with construction technique, aggregate type, etc.
** Price will be greater than regular concrete due to the lack of demand and supplier availability at this time.

Table 2-7. Cool paving technology applications, use, benefits, cost, and life expectancy.
Source: Houston Advanced Research Center, 2004.

Environmental and Economic Benefits of Cool Paving

Cool paving technologies can help to reduce air temperatures within cities by reducing the amount of solar energy absorbed by transportation infrastructure. Other benefits of cool paving may not be as apparent. Direct economic and environmental benefits include increased pavement life, greater nighttime visibility, and improved stormwater management. Indirect benefits include decreased smog formation, reduced energy and water demand, and fewer heat related illnesses.

Reduced Smog Formation

Smog in cities is formed when volatile organic compounds (VOC) from gasoline automobile exhaust are subjected to ultraviolet rays from the sun. As with all chemical reactions, the rate of reaction and formation of smog is directly related to the air temperature in which it occurs. And because conventional paving heats the near surface air at the same height as tailpipe exhaust, smog formation is significantly increased. Studies conducted in Los Angeles indicate that air temperatures at the surface level correlate with smog concentrations and incidence of illnesses related to air pollution (Akbari 1991).

Durability and Increased Lifetime of Pavements

The leading cause of pavement degradation in Phoenix is thermal stress. When pavement surface temperatures heat and cool throughout a daily cycle, the pavement is stressed between the top and bottom surfaces. This daily cyclical stress can eventually crack and warp the pavement. The time it takes for a surface to crack is directly related to the magnitude of the temperature swings to which it is subjected. It is not uncommon to observe surface temperatures of 85°F (30°C) for low albedo pavement at 5:00 a.m. rising to 160°F (70°C) at 1:00 p.m., and then falling back to 85°F (30°C) the following morning.

Surface temperature swings of 75°F (42°C) result in major stresses that take their toll over time. The constant heating of pavement surfaces and the penetration of UV radiation degrades the oils and resins in the binder, causing the pavement to become brittle and crack or unravel. Finally, at 160°F (70°C), asphalt binder becomes soft and the pavement will actually deform under heavy traffic loads caused by braking or turning, resulting in permanent deformations such as rutting or shoving. When this type of failure occurs, the pavement becomes unsafe and needs to be replaced. In some intersections within Phoenix, pavement lanes are replaced every three years due to rutting and shoving.

By lowering surface temperatures of asphalt concrete with the cool asphalt techniques described above, the lifetime of these surfaces can be increased by several years, thus reducing the amount of money required for maintenance, repair, and removal of thermally stressed pavements. This savings alone can offset the upfront costs associated with alternative pavement designs (Pomerantz et al. 2000).

Nighttime Safety

High albedo pavements are meant to reflect solar energy. An added benefit is that they generally reflect visible light from artificial light sources such as street lamps and sidewalk lampposts. By reflecting more visible light, these surfaces increase the amount of light in an area, improving nighttime visibility in urban areas and on the road. Studies indicate that pedestrian and driver safety is increased at night in areas with high albedo surfaces. The reflected light from a high albedo pavement provides greater illumination of a pedestrian or object in the road than does the light of street lamps and automobile headlights over a dark surface.

Some city planners have expressed concern that white pedestrian crosswalk striping in the road is not as visible to drivers when high albedo pavements are used. This concern is not valid because the crosswalk striping is not meant for drivers to see but rather for the pedestrian's awareness (Ziedman 2005). Brightly colored yellow crosswalk signs perpendicular to the pavement surface inform drivers about crosswalk areas.

Lighting Demand

An additional benefit of higher albedo pavements at night is the decreased need for energy for road and sidewalk lighting. Increasing the amount of light reflected from driving and walking surfaces allows low energy lighting systems like light emitting diodes (LED) to be used and the spacing between lights can be increased, requiring fewer light fixtures for the same area. One study showed that a road with asphalt paving required 39 light fixtures per mile to meet required roadway lighting levels, but when the same road was repaved with a more reflective concrete, only 27 light fixtures were needed per mile to meet the requirement. This decrease in lighting of 31% equated to a financial savings of $24,000 per mile on construction, $576 per mile per year on maintenance, and $600 per mile per year on energy bills (Stark, 1984). Unfortunately, transportation designers do not take into consideration the type of road material being used for a project when determining how many light fixtures are required per mile along roadways, but typically use worst case scenarios associated with new asphalt for lighting calculation purposes. This is a huge cost savings opportunity, but will require a change in current design practices.

Stormwater Runoff

When it rains, natural surfaces slow the movement of water and much of it permeates the soil, benefiting vegetation and recharging aquifers. In highly urbanized areas, much of the land is covered with impermeable surfaces, and water that falls on these surfaces is either channeled into subgrade retention basins, sent through sewers to wastewater treatment facilities, or flows into nearby streams and bodies of water. Urban storm water contains automobile residues, landscaping pesticides, suspended solids, and other pollutants. These contaminates become concentrated in storm water collection areas and take a heavy toll on biological systems and municipal wastewater treatment facilities. Permeable pavement technologies help to capture and retain this stormwater runoff, preventing pollutants from leaving parking lots and driveways and concentrating in retention basins or sewers. This captured rainwater filters through soils, recharging underground aquifers, and improves the health of adjacent vegetation. These benefits are in addition to the evapotranspiration process that cools the surface due to stored moisture within the pavement.

Paving Action Plan

There are several ways to reduce the contribution of pavements to UHI formation within the Phoenix region. City governments must set forth a plan to address this key component of UHI mitigation. Many urban centers in the U.S., including Houston, Austin, Philadelphia, Sacramento, and several other California cities, have already begun to adopt cool paving practices. Of all of the metropolitan areas in the United States, Phoenix and its surrounding areas would benefit most from direct and immediate action to address the UHI effect. In order to be effective, regionwide cool paving implementation plans must:

- *Target the surfaces of greatest potential benefit for installation of cool pavements during the next ten years.*
- *Educate key decision makers, including building owners and contractors, about local government requirements.*
- *Establish new codes and regulations for construction and maintenance procedures that incorporate cool paving strategies.*
- *Provide incentives to adopt these new paving techniques and strategies. Phoenix has the potential to become the leader in proactive UHI mitigation in the nation. The region could serve as an example of best practices for urban centers that are developing in hot, arid regions around the world.*

Target Surfaces

It is important that city administrators focus their attention on the pavement surfaces that present immediate opportunity for change. Many surfaces within an urban area, such as residential streets, sidewalks, and driveways, do not change very often. However, surfaces like older parking areas are resurfaced frequently, every five to ten years. The rapidly growing Phoenix region adds new pavements in residential and commercial areas every year. These new construction projects are great opportunities to immediately adopt cool paving for both streets and parking lots. Highways are also resurfaced continually and their shoulder sections present an opportunity to use high albedo treatments, as they are rarely under traffic loads.

Parking Lots: Resurfacing and New Construction

The first component of a cool paving implementation plan should address parking lots. Nearly 50% of all paved surfaces in the Phoenix region are parking lots, and they are resurfaced often, are subjected to medium traffic loads, and are more easily shaded than roads or highways. Constructing new or resurfacing parking lots with cool paving materials will have a significant effect on the UHI formation in the region. The benefits of high albedo will also improve the useful life of the lots and reduce the maintenance costs associated with thermal stresses.

Road Expansion: New Streets in Residential and Commercial Areas.

New road construction in the Phoenix region is another great opportunity to implement cool paving. Residential and commercial streets are rarely resurfaced and can remain unchanged for 15 to 35 years depending on the traffic volume. New road development in Phoenix will continue to flourish in the region, adding over 10% of the current roadway surface area in the next 10 years. This growth presents an unprecedented opportunity for cool paving implementation over the next decade.

Highways: Resurfacing and Shoulders

Highways seem to always be under construction in the Phoenix region. The harsh desert conditions and increasingly heavy traffic volumes necessitates resurfacing these pavements every 10-15 years. Most highway surfaces are now being covered with

1 inch Crumb Rubber Friction Coarse described earlier. The rubberized asphalt creates a very low albedo (0.04) surface when brand new. By using white aggregate cool asphalt techniques, these CRFC high-performance roads can stay cool while serving as an insulation layer over the large concrete mass underneath.

Resurfacing highway shoulders may present an even greater opportunity for UHI mitigation than resurfacing the lanes. Highway shoulders, nearly the width of an additional lane on each side of the highway, are continually exposed to solar radiation and are not cooled by traffic movement, causing them to become the hottest pavement surfaces in an urban area. Because the shoulders are only used in emergency situations, their engineering performance and durability can be much lower than that of the lanes. The highway shoulders can be constructed of white cement, cool asphalt, or resurfaced with a cool sealcoat to take advantage of an additional opportunity to reduce the urban heat island effect.

The Power to Make it Happen

Informing key decision makers (legislators, city officials, architects, engineers, planners, building owners, and cool paving suppliers) about cool paving options, their benefits and costs, is essential to successful implementation of a UHI mitigation plan. State officials responsible for implementing the Federal Clean Air Act and Clean Water Act need to be made aware that cool paving, along with other UHI mitigation strategies, can help them attain compliance. These same officials could develop a regulatory framework that recognize cool paving and provides incentives or credits for using cool paving throughout the region.

Education and information distribution is also needed at the local level. Community leaders and city officials need to become knowledgeable about the impacts of and options available for cool paving in their areas. Local governments can take an active role in creating change by following these suggestions:

- *Sponsor pilot and demonstration projects.*
- *Adopt cool paving as part of public works options for addressing air and water quality issues.*
- *Add solar reflectivity to performance standards for paving materials.*
- *Add cool paving to maintenance plans for pavements.*

Adapted from Hitchcock (2004)

Trade and professional organizations in the Phoenix region can distribute information on the options, benefits, and costs of cool paving technologies to their members. These organizations can develop online information specific to their industries, including cool paving construction techniques, issues, and case studies. Cool paving workshops, certification courses, and demonstration projects will help increase awareness and create a base network of professionals who are familiar with cool paving designs and construction techniques.

Incentives and Regulations

Use of new paving technologies is often discouraged by their higher initial cost over conventional materials. Private property owners usually are concerned only about short term costs, and using cool paving materials can cut into their immediate return on investment. Governments should take a life cycle cost approach to paving projects by incorporating operational lifetime, maintenance costs, and environmental regulation compliance. Economic incentives can be an effective way to overcome the barriers to implementing cool paving technologies. Some incentive programs that have been implemented in other cities are:

- *Incentive payments, in the form of direct rebates, given to building owners and developers based on the square footage of temperature reduction of materials used for the roads and parking lots*;
- *Small property tax advantage for new or resurfaced parking lots that use cool paving*;

- Reduction of sales tax on installation of reflective paving;
- Reduc*tion of utility related fees where it can be demonstrated that cool paving reduces energy consumption or provides water management benefits; and*
- *Pervious pavements counted as retention basins, reducing the amount of land required to meet storm water regulations.*

Adapted from Hitchcock (2004)

Adjustments to building regulations may also be used to encourage cool paving. Green building rating systems such as the US Green Building Council's LEED^{TM} Certification already incorporate and award points based on cool paving technologies and materials for parking lots. These points are part of the Sustainable Sites Credit section, and one of the lead drivers in the rapid adoption of cool paving technologies in new commercial construction projects nationwide.

URBAN FORESTRY

Planting vegetation is one of the simplest and most cost effective ways to cool the Phoenix region. Trees, shrubs, and vines naturally cool the air, shade surfaces from direct sunlight, improve air quality, and enhance the aesthetics of urban areas. The direct energy savings from the shade provided for individual buildings is surprisingly high, and the collective cooling effect of an urban forest can have an even greater influence on energy savings for the entire community.

While the cooling benefits of urban forests are the main focus of this section, it is difficult to ignore the many other benefits of vegetation, including increased property value, noise abatement, storm water management, and soil stabilization. Another advantage of investing in trees is that these benefits will only increase with time as the trees mature. That's definitely one thing you can't say about roofing, pavements, and HVAC technologies.

Many people assume that increasing vegetation in the desert strains the region's limited water resources. This is a very important point, so a regional tree planting plan should include only species that are native or can adapt to the local climate conditions. New grey water and rain water collection practices can offset the potable water used for landscape watering. The reduction in energy use that urban forests can provide significantly outweighs the amount of water required to support them.

While Phoenix has many mature landscaped neighborhoods that date back to the mid-twentieth century, new developments are quite different and comparably bare. As native desert is transformed into master planned communities, there are opportunities to conserve the native vegetation. By limiting the destruction of mature desert trees during initial site preparation, communities can conserve the character of the desert and limit the impact of development on wildlife diversity.

This section of the guidebook focuses on urban forestry in the Phoenix region, assessing current forestry practices and discussing the benefits of vegetation, including the economic benefits. Strategies are presented for reforestation and conservation, and suggestions are provided to help governments, private companies, and citizens implement effective urban forestry programs in their communities.

Trees and Vegetation in the Phoenix Region

An **urban forest** is defined as the whole community of trees and other vegetation found within city limits, a collective greenscape that provides environmental, economic, and social benefits for today and into the future. There has never been an inventory of the total number of trees in the Phoenix region. Studies using remote sensing satellites to measure the amount of vegetation in the region indicate that vegetation accounts for about 13% of the total land cover in Phoenix. Older neighborhoods with flood irrigation often have yards full of thick grass and large, broad-leafed, deciduous trees. This mesic landscaping resembles the yards found in the Midwest, where many of the early settlers in Phoenix originated. In the 1950s, water resources seemed bountiful and using lush landscaping to keep cool was perfectly acceptable for large, single-level homes. Most of the trees and vegetation were not drought tolerant and required large amounts of water and maintenance to survive the harsh Arizona summers.

As the city grew, flood irrigation was no longer used and new master planned communities began to use sprinkler systems to water grass yards. Since the 1990s, residential landscaping practices have increasingly incorporated native and drought tolerant plants. Decomposed granite, aloe, yucca, cacti, mesquite, and palo verde trees have become popular, low maintenance options for new homeowners in the suburbs. Many yards are designed with a mix of both desert and lush landscaping, resembling green golf courses surrounded by desert. This style is referred to as 'oasis' landscaping. The majority landscaping practices have been based on aesthetic considerations rather than on those of energy and water conservation, or urban heat island mitigation.

Benefits of Forestry in Urban Areas

The benefits of vegetation are quite remarkable given the low cost and ease of planting. While the UHI mitigation effect of vegetation is dependent on factors such as density, shape, dimensions, and placement, benefits can be realized from almost any tree.

Trees, shrubs, vines, and groundcover plants affect urban climate and energy use in two ways. Direct effects modify the way a building interacts with its surroundings, and include the shading and shielding effect of vegetation surrounding a building. Direct effects occur on a building-by-building basis, and vary greatly depending on the location, size, and density of the trees. Indirect effects are those that change the surrounding environmental conditions, such as air temperature or humidity. The cooling effect of trees on ambient air temperature is an example of an indirect effect of trees. Indirect effects of trees are felt beyond the nearest building and can be aggregated over a large area, benefiting an entire neighborhood or even city.

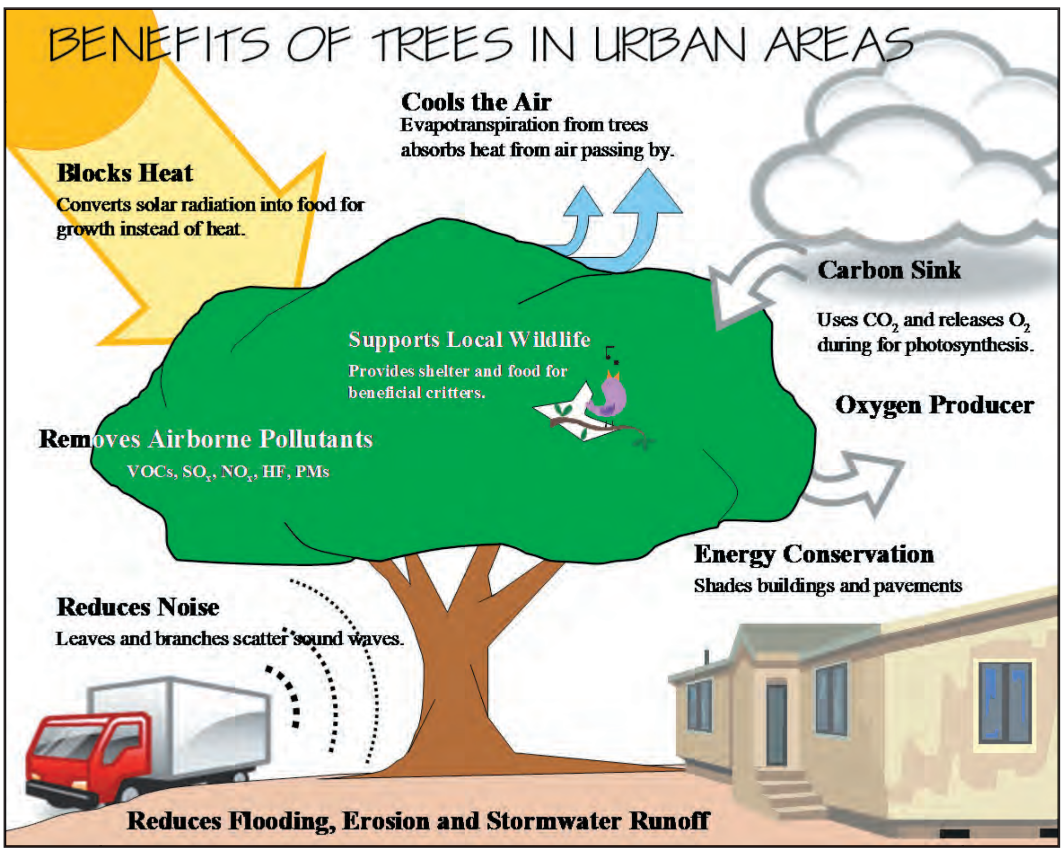


Figure 2-72. The benefits of urban forestry. Source: National Center of Excellence, Arizona State University.

Shading Urban Surfaces

Trees can be very effective in blocking the sun's energy from reaching building facades and pavements. The amount of shading is dependant on species, which defines tree shape and density of foliage. For example, a broad leafed tree can block 95% of incoming radiation, but a deciduous tree will generally block less than 50% over the course of a year. It is important to understand which species will perform the best over time and during different seasons.

Shade from trees reduces cooling energy demand because it:

- prevents direct solar radiation from entering through windows;
- prevents walls, windows, and roofs from getting hot and transferring heat inside; and
- keeps the soil around a building cool, providing a "heat sink" for the building.

In fact, the shading from vegetation is more effective than Venetian blinds, tinting, or reflective coatings on glass for keeping building interiors cool. A study in Florida estimated that trees and shrubs planted near a residential home can reduce air conditioning costs by 40% (Parker 1983). The study showed that the most effective locations for trees were in front of windows and near the air conditioner. A 10% increase in air conditioner efficiency was observed when the unit was shaded.

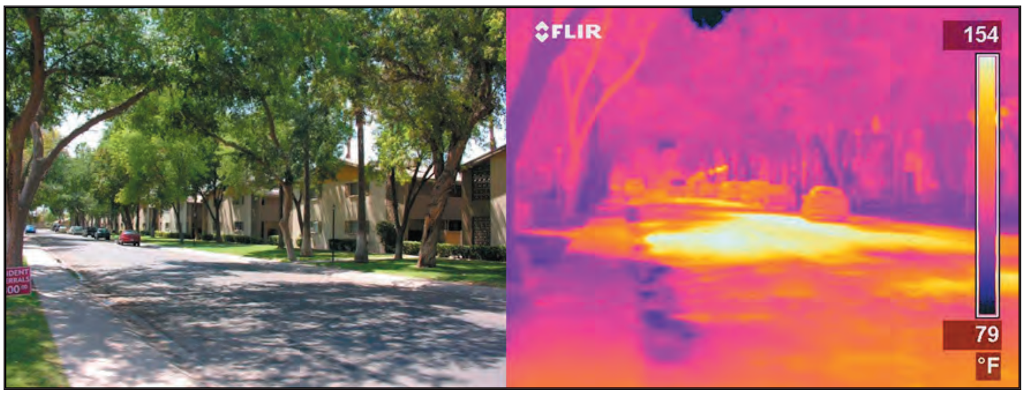


Figure 2-73. Example of street shaded by a thick tree canopy. Photos courtesy of National Center of Excellence, Arizona State University.

While shading in the summer is extremely beneficial, shading during the winter can increase the heating demand in a home when shade prevents the sun from warming the building. A deciduous tree that loses its leaves in the winter will often allow 65% of the solar energy through to the house, which reduces this impact. Despite this fact, and given the mild winters of the Phoenix region, the benefits of shading in the summer far outweigh its drawbacks, as evidenced in Table 2-8.
Table 2-8 Simulated annual energy savings from trees for various metropolitan areas. All savings are in $/100 m2.
Source: Taha et al. (1996)

Location	*Poorly Insulated Residence*		*Moderate Insulated Residence*		*Poorly Insulated Office*		*Moderately Insulated Office*	
	Direct	*Indirect*	*Indirect*	*Direct*	*Indirect*	*Direct*	*Indirect*	*Direct*
Atlanta	5	2	3	1	3	2	2	2
Chicago	3	2	1	0.5	1	1	2	1
Los Angeles	12	8	7	5	6	12	4	10
Fort Worth	6	6	5	4	4	5	2	4
Houston	10	6	6	4	3	5	3	3
Miami	9	3	6	3	3	2	2	2
New York City	3	2	2	1	3	3	2	2
Philidelphia	-5	0	-7	0	2	1	1	1
Phoenix	27	8	16	5	9	5	6	4
Washington, DC	3	2	1	1	3	1	2	1

Table 2-8. Simulated annual energy savings from trees for various metropolitan areas. All savings are in $/100. Source: Taha et al. (1996)

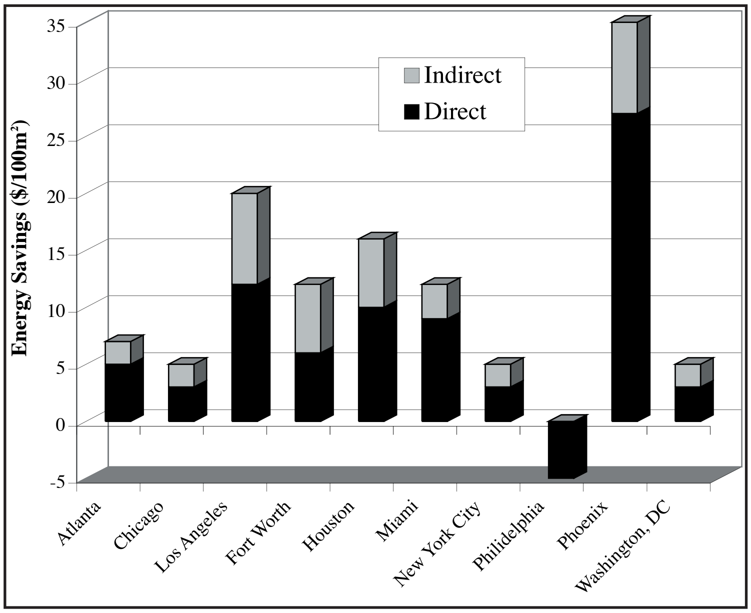


Figure 2-74. Combined indirect and direct effects on energy savings, using trees around a poorly insulated residence. The results indicate that trees provide significantly greater economic benefit in Phoenix than in most other cities in the US. Data source: Taha et al. (1996).

Another affect of trees around a building is on wind speeds. While reducing winter wind speed is a proven benefit for colder regions, it has a negative effect during the summer. Winds that typically help to cool buildings during the summer are reduced by trees. However, the shading benefits are still more influential on energy use in a desert region, overall.

To fully appreciate the benefits of the direct effect of trees, it is important to consider both the positive and negative impacts that shading and wind shielding have on energy consumption in buildings. While actual energy savings depend on the design and efficiency of the buildings in question, in a study that used computer simulations to estimate the net effects for an older home (pre -1973) located in different climatic conditions, results showed energy savings for both cooling and heating in Phoenix. Phoenix may benefit more from trees than any other major city in the US. That finding alone is incentive to make trees a regular part of good energy policy in Phoenix.

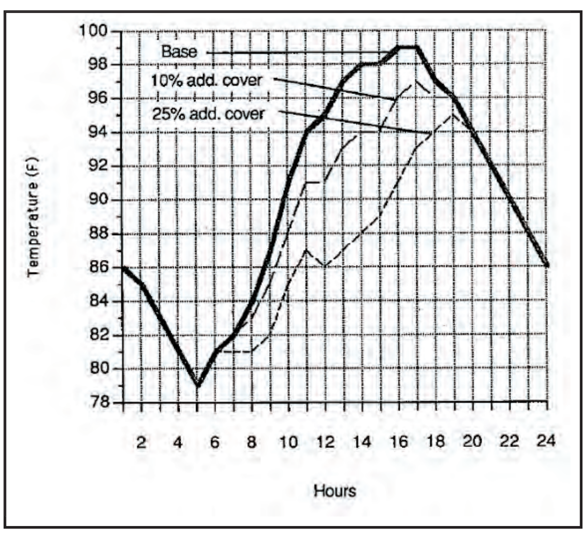


Figure 2-75. Predicted temperature reductions for City of Phoenix from tree-coverage increases of 10% (equivalent to one tree added per house) and 25% (three trees per house). Source: Huang et al. (1987).

Cooling the Air

The most important indirect effect of trees is their ability to cool the air around them. This cooling phenomenon is the result of evapotranspiration, the process by which plants release moisture as water vapor. Evapotranspiration uses up energy from solar radiation or warm air thus decreasing air temperature. Some large trees are known to transpire as much as 100 gallons a day, a cooling effect equivalent to running five air conditioners for 20 hours. A cooling effect of this magnitude can only be realized in a hot, arid climate, but not in humid climates where there is already a great deal of moisture in the air.

Evapotranspiration and shading are a powerful combination and can reduce air temperatures by 9°F (5°C) or more. In areas with mature trees, air temperatures during the day can be 3-6°F (2-3.3°C) lower than nearby, newer neighborhoods with less vegetation. Studies have shown that the cool air leaving tree canopies can rise to heights five times the height of the trees. The complex nature of heat and fluid transfer in urban areas makes modeling the effects of evapotranspiration difficult. Simulations developed at the LBNL and at ASU have been used to predict the temperature effects of changing the relative percentages and types of land cover in the Phoenix area (Bhardwaj 2006). The simulations predict that increasing the tree cover in Phoenix by 25% would result in a 10°F decrease in daytime temperatures (Huang et al. 1987). Figure 2-75 shows the results from this simulation for a 24-hour period.

Improving Air Quality

Trees can improve the air quality in several, not so obvious ways. As trees have direct and indirect effects on energy use in buildings, so are there direct and indirect ways that trees help to improve air quality. The following list summarizes how trees improve air quality within urban environments.

- *Trees absorb green house gases* such as carbon dioxide (CO_2) for metabolic needs, and release oxygen (O_2) as waste.
- *Particulate matter attaches to tree leaves* through a process called dry deposition. This removes nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM), and ozone (O_3) from the air.
- *Trees lower air temperature,* which in turn slows the chemical formation rate of ozone. Ozone is a major component of smog and is comprised of several ingredients:
    - o NOx – produced by high temperature vehicles and power plants
    - o VOCs – volatile organic compounds which evaporate from fuels
    - o Solar radiation – activates reactions; therefore, smog is a daytime phenomenon and can reach its peak in the afternoon when the solar flux is most pronounced.
    - o High temperatures – increases formation rate; the lower the temperature within urban areas, the less ozone is formed.
- *Trees reduce energy and electricity demand* in buildings and cities. This in turn reduces emissions from power plants during peak hours. Fewer emissions mean less ozone and smog formation.

It is important to point out that VOCs are also a natural emission (biogenic) of photosynthesis and other metabolic reactions in plants. Forests are actually major sources of VOCs; however, these releases are neither as toxic to humans nor as difficult to break down. Isoprene and monoterpenes are two types of VOCs that contribute to ozone formation. Isoprenes are produced during the day, but in hot temperatures their release is greatly reduced. Most researchers agree that the beneficial effects of trees for reducing urban temperature outweigh the negative effects of VOC release.

Providing Natural Storm-Water Management

Vegetation is naturally designed to intercept falling raindrops and slow the descent of rainwater to the ground. This has a major influence on runoff, flooding, and erosion during times of intense rainfall. In areas dominated by impervious concrete, asphalt, and rooftops where this moderating effect is not present, fast flowing runoff can cut through unprotected soils, causing soil erosion and water pollution in streams and waterways. The American Forestry Association estimates that a city with 30% tree coverage has over four times the amount of leaf surface area than the surface area of all paved and building surfaces combined. This can result in a significant reduction in peak flood flows, and thus reduce the need for constructed floodways and storm sewers, resulting in savings on construction costs for the city.

Mental and Physical Benefits of Vegetation

The link access to nature, positive human emotions, and feelings of relaxation have long been described by poets and naturalists. Recent studies have been able to empirically document these subjective assumptions through academic surveys and physiological monitoring systems. One study found that images of natural colors and landscapes produce more relaxed brainwave signals and positive survey responses than did images of urban settings (Ulrich 1981). Other studies have shown that workplaces that provide open outdoor spaces and areas where trees and vegetation are in view of employees show an increase in productivity and job satisfaction.

Trees can also reduce noise levels in urban areas. Their leaves, twigs, and branches break up and absorb the high frequency city sounds that can cause irritation for residents. A line of trees 100 feet long and 50 feet tall can reduce highway noise by about 50% (6 -10 decibels). The sound of leaves rustling in the wind and birds singing can also have a soothing effect on the observer.

In addition to benefits to humans, trees and vegetation provide homes, protection, and food for urban wildlife. They can help restore or maintain the natural biodiversity that existed prior to heavy urban development.

Urban areas can create character and a sense of pride by incorporating trees unique to their climate and region. Trees placed along traffic corridors can also improve the image of the city to visitors and reduce the stress of drivers during their daily commutes. The proven benefit of trees and vegetation to the mental and physical health of citizens is a very important and often overlooked aspect of trees in urban areas.

<u>Urban Forestry Strategies</u>

Phoenix region urban heat island is largely caused by its lack of vegetation. What once was an area of bountiful desert bristling with Sonoran Desert shrubs and shade trees is now a mix of concrete, asphalt, walls, and roofs, with manicured vegetation sprinkled about. Estimates indicate that tree canopy accounts for less than 13% of land cover in the developed areas of Phoenix. This lack of vegetation exposes pavements to the intense sun and greatly reduces evapotranspiration rates that would otherwise help to balance the net energy of the urban surface. This section of the guidebook offers urban forestry strategies that are appropriate for the region and provide the greatest benefit for reducing energy use and cooling the region as a whole. The components of a citywide urban forestry program can be grouped into two categories, reforestation and conservation.

REFORESTATION

Reforestation is the restocking of areas depleted of vegetation with native tree stock. Urban reforestation is simply the act of maximizing the native vegetation coverage within a developed area. In order to develop a successful urban reforestation program, it is important to include the following components:

- *Quantify and Monitor – Establish a baseline for the total number of trees currently in an area and track the number of trees planted and destroyed each year. This will help set citywide goals and provide the data necessary to verify plan progress.*

- *Target Specific Areas – Identify locations that would benefit the most from increased tree coverage.*

- *Select Appropriate Species – Use only plants that are native to the region and provide the desired shading effect. This will save on water and maintenance.*

- *Optimize Placement – Place trees to produce the greatest savings in energy and water use.*

- *Build Upon Successful Landscaping Practices – Integrate urban reforestation strategies into existing landscaping practices and policies if the community already encourages low water use, native plants.*

Current Landscaping Activities in the Phoenix Region

The Phoenix region has historically benefited from an abundance of water availability for landscaping and irrigation. Most of this water originates from hundreds of miles away and its delivery to Phoenix is made possible by a series of manmade waterways and political agreements that were established in the mid-twentieth century. However, with the rapid influx of population, construction, and expansion of city boundaries, many of the Valley's water resources are beginning to be strained. While Phoenix, by many estimates, will likely have plenty of water to meet the demand for the next 100 years, other cities in Arizona may not be so fortunate. Gilbert, Tucson, Casa Grande, and Flagstaff are among those that have limited water supplies and are beginning to rethink the way that water is used by their residents. Since the late 1990s, many of these cities have organized educational campaigns and developed ordinances that address landscaping. They often mandate that all new developments must use xeric (low water) landscaping, and that areas such as golf courses and manmade lakes must use reclaimed water from wastewater treatment plants. In areas that have existing mesic (water intensive) landscaping, residents are encouraged to use more efficient irrigation techniques. A reforestation plan would build upon these practices and require quantification, tracking, and maintenance.

To date, there has not been a thorough inventory of the urban forest in the Phoenix area. An initial study would establish a baseline for the city and would improve the accuracy of models used for predicting the benefits of increased canopy coverage within the city. Once a baseline is established, future planting and destruction should be monitored. A report documenting the status of the urban forest in Phoenix should become part of the City's annual Sustainability Report.

Target Locations

Every building owner and citizen can benefit from the planting of new trees. However, a reforestation plan should target locations with the greatest potential for success and overall impact on the Valley.

- *Residential Property* -- Homes are by far the largest single land use category in the Phoenix region. If each homeowner planted one or more trees, the area's urban forest would increase by over a million trees. Families are also likely to care for their own personal landscaping, which would reduce the financial burden of cities. Home owners also have the most to gain in terms of energy savings and property value increases. Strategies should seek to get homeowners and residential developers engaged and committed to future urban reforestation activities.

- *Commercial and Office Developments* -- Commercial properties make up the second largest land use category and offer a great opportunity for planting trees. Some property owners may reject the idea, while others will embrace it. Tenants usually prefer attractive landscaping and may be willing to pay more for space with a large tree population.

- *Public Properties* -- Government offices, schools, highways, bus stops, streets, and other easements are among the many forms of public properties. Working with the Arizona Department of Transportation, cities can specify that trees be included along major streets and highways. Long term strategies are needed to ensure the success and expansion of tree planting on public grounds.

Encouraging tree planting will be most effective if each type of location is targeted with unique methods and strategies. Different incentives, ordinances, and educational efforts may be effective depending on the type of property to be landscaped.

Tree Planting in a Hot, Arid Climate Region

Planting trees in a hot, arid climate region can have an immediate positive effect on the urban climate. The cooling effect of vegetation can actually create microclimates in which urbanized areas are cooler during the day than the surrounding desert areas. This is commonly referred to as the "oasis effect." The Phoenix region has small pockets and corridors that experience this phenomenon. Those areas are usually heavily watered parks, golf courses or greenbelts, and comprise a small percentage of the entire developed area. These "oasis" areas do experience cooler air temperatures day and night but require large amounts of water, a resource that our region cannot afford to waste. In addition to their water hungry habits, golf courses require continual maintenance and do not directly help to reduce energy demand in buildings.

Planting trees and other vegetation in a hot, arid climate requires knowledge of the appropriate species and optimal planting locations that maximize benefits while minimizing maintenance.

Selecting the Best Plants for the Phoenix Region

A healthy urban forest must be diverse and consist of plant species that are native or adapted to the regional climate and ecosystems. Water is a limited resource in nearly all areas of the United States and especially in the Southwest. Water can be the primary expense of maintaining a landscape. In fact, the savings in air conditioning costs that large, deciduous trees and grass yards provide can be counteracted by expensive summer water bills. Through the careful selection of plants, the amount of moisture needed to support an urban forest can be greatly reduced. Plants convert minerals and water into nutrients through photosynthesis. This requires plants to absorb water through their roots and transfer it throughout their systems. When leaves get hot, they transpire moisture through their leaves. Plants native to hot dry regions have evolved methods to reduce water loss from their leaves. Some of these plants use small leaves to prevent moisture loss, while others have leaves that are covered with a waxy or felt-like coating. Additional differences in the cellular and internal structure configurations help drought tolerant plants to survive in harsh desert environs.

Xeriscaping is a landscaping practice that minimizes the amount of water required to support plant life. Xeriscaping (derived by combining the Greek work for "dry," xeri, with "landscape") has become popular among gardeners, landscapers, and urban planners seeking sustainable approaches to planting in a desert climate. Water conservation is important to the long term sustainability of the Phoenix region, and xeriscaping programs have been developed in many cities to encourage property owners to landscape with drought tolerant plants. Some might believe that xeriscaping greatly restricts the variety and freedom needed to create attractive and interesting landscapes, but the opposite is true. There are thousands of drought tolerant trees, shrubs, vines, and groundcovers that require little water while providing beauty and diversity in the landscape., In his book, Landscaping with Native Plants of the Southwest, George Oxford Miller recommends the following plants for dry climates. Please refer to the book for more details about and pictures of these and other native desert plants.

<u>TREES</u>

Acacia farnesiana, huisache
Acacia greggii, catclaw acacia
Arbutus arizonica, Arizona madrone
Celtis laevigata var: reticulate, netleaf hackberry
Cercis canadensis var. mexicana, Mexican redbud
Chilopsis linearis, desert willow
Cupressus arizonica, Arizona cypress
Ebenopsis ebano, Texas ebony
Fraxinus cuspidate, fragrant ash
Fraxinus greggii, Gregg ash
Fraxinus velutina, Arizona ash
Juglans major, Arizona walnut
Juglans microcarpa, little walnut
Juniperus species, junipers
Leucaena retusa, goldenball leadtree
Olneya tesota, desert ironwood
Parkinsonia florida, blue palo verde
Parkinsonia hybrid, Desert Museum palo verde
Parkinsonia microphylla, foothills palo verde
Pinus edulis, New Mexico pinyon pine
Prosopis glandulosa, mesquite
Prosopis velutina, velvet mesquite
Prunus serotina var. rufula and var. virens, southwestern black cherry
Quercus arizonica, Arizona white oak
Quercus emoryi, Emory oak
Quercus grisea, gray oak
Quercus hypoleucoides, silverleaf oak
Quercus oblongifolia, Mexican blue oak
Quercus pungens, sandpaper oak
Quercus turbinella, shrub live oak
Rhus lanceolata, prairie flameleaf sumac
Robinia neomexicana, New Mexico locust
Sambucus nigra subsp. canadensis, Mexican elder
Sapindus saponana, soapberry
Ungnadia speciosa, Mexican buckeye

SHRUBS

Acacia constricta, white-thorn acacia
Agave species, century plants
Aloysis gratissima, bee brush
Amorphia fruticosa, false indigo
Anisacanthus quadrifidus var. wrightii, flame anisacanthus
Anisacanthus thurberi, desert honeysuckle
Artemisia filifolia, sand sagebrush
Artemisia tridentata, big sagebrush
Baccharis sarothroides, desert broom
Bouvardia ternifolia, scarlet bouvardia
Buddleja marrubifolia, woolly butterflybush
Caesalpinia gilliesii, desert bird of paradise
Calliandra conferta, fairy duster
Ceanothus greggii, desert ceanothus
Celtis pallida, desert hackberry
Cercocarpus montanus, mountain mahogany
Choisya dumosa, starleaf Mexican orange
Chrysactinia mexicana, damianita
Dalea Formosa, feather dalea
Dalea frutescens, black dalea
Dasylirion species, sotols
Dononaea viscosa, hopbush
Echinocereus species, hedgehog cacti
Encelia farinosa, brittle bush
Ephedra species, joint firs
Ericameria laricifolia, larchleaf goldenweed
Ericameria nauseosa, chamisa
Fallugia paradoxa, Apache plume
Fendlera rupicola, cliff fendlerbush
Ferocactus species, barrel cacti
Foresteria pubescens var. pubescens, desert olive
Fouquieria splendens, ocotillo
Garrya wrightii, silktassel
Hesperaloe parviflora, red yucca
Justicia californica, chuparosa
Justicia canadicans, jacobinia
Krascheninnikovia lanata, winterfat
Larrea tridentata, creosote bush
Leucophyllum frutescens, Texas ranger
Lycium species, wolfberry
Mahonia species, barberries
Mamillaria vivipara, pincushion cactus
Mimosa dysocarpa, velvet pod mimosa
Nolina species, beargrass
Opuntia species, cholla or prickly pear
Pachycereus schottii, senita cactus
Parthenium argentatum, guayule
Parthenium incanum, mariola
Psorothamnus scoparius, broom dalea
Purshia stansburiana, Mexican cliffrose
Rhus microphylla, little-leaf sumac
Rhus virens, evergreen sumac
Salvia greggii, autumn sage
Senna wislizeni, shrubby senna
Simmondsia chinesis, jojoba
Sophora secundiflora, Texas mountain laurel
Stenocereus therberi, organ-pipe cactus
Tecoma stans, yellow trumpet flower
Vauquelinia californica, Arizona rosewood
Viguiera stenoloba, skeleton-leaf goldeneye
Yucca species

VINES

Campsis radicans, trumpet creeper
Clematis ligusticifolia, western virgin's bower
Maurandya antirrhiniflora, snapdragon vine
Parthenocissus quinquefolia, thicket creeper

GROUNDCOVERS

Artemisia ludoviciana, white sagebrush
Dalea greggii, Gregg dalea
Glandularia goodingii, Goodding's verbena
Muhlenbergia rigens, deer grass
Phyla species, frogfruit
Sedum species, stonecrop

Shading for Buildings and Occupants

The building envelope, consisting of the roof, walls, doors, and windows, provides a buffer between the outdoors and the interior environment. Vegetation can act as an additional buffer, reducing the energy required to maintain comfortable temperatures within a climate controlled building. Trees, shrubs, vines, and groundcovers form a protective shell around these surfaces, preventing direct sunlight and reflected heat from reaching the building's façade and transferring heat through the wall. The shade and increased humidity from plants also reduce air temperature during the summer and provide protection from cold winds in winter.

The natural cycle of deciduous trees make them a perfect choice for both summer and winter energy savings. During the spring and summer when the sun's intensity is at its peak, the leaves of trees are fully spread, capturing the sun's energy and converting it into nourishing food for growth and reproduction. These leaves often block over 80% of incoming energy. This results in natural shading that also allows rising warm air to pass into the ambient air, maintaining a cool, dark area underneath the tree. In winter, plants begin to slow their metabolism in preparation for shorter days and limited sunlight. Deciduous trees practice the survival mechanism of shedding their leaves when the temperature drops. The once deep leaf shade becomes a series of branches, allowing the winter sun to penetrate and warm the building. This natural cycle is automatic, providing a benefit year round. Even evergreens can be a benefit year round, providing shade in the summer and blocking chilly winds in the winter.

Figure 2-76. Looking up from under a mesquite tree during summer. Photo courtesy of National Center of Excellence, Arizona State University.

Placing a tree in the correct location will greatly improve its ability to decrease energy demand. The first priority is to shade windows to prevent direct sunlight from entering the building. Forty percent of building solar heat gain is through windows, and conventional blinds on the inside do not prevent this. By placing a tree, tall shrub, vine covered trellis, or arbor in front of windows, building owners can block direct sunlight while providing privacy and allowing in soft light. Using vegetation in front of windows will also help to cool the air coming in when windows are open.

The exterior walls on a building are vulnerable to heat penetration no matter how well they are insulated. This added heat forces the air conditioning system to compensate, resulting in increased utility bills and decreased equipment lifetime. The summer sun attacks the east wall in the morning, the south wall nearly all day, and the west wall in the afternoon. Walls can be shaded by trees planted about 15-20 feet away. The optimal location for trees is on the west side of a building. To shade exteriors while still allowing air circulation around the building, be sure to choose trees that do not have low hanging limbs. Native trees such as the walnut, ironwood, New Mexico locust, and huisache are recommended by George Miller as substitutes for the traditional ashes, maples, and oaks. Of course, a mature tree will provide greater benefit than a young one. For this reason it is important to emphasize the need to conserve existing trees. If more light is desired, a tree such as the desert willow, mesquite, or palo verde let light through while blocking the majority of solar radiation. Walls can also be shielded by vines climbing on trellises or arbors clinging directly to a masonry wall. There is some risk of the vines penetrating roof shingles or mortar, which can cause deterioration and expensive damage to the building exterior. A trellis or arbor with climbing vines set off of the wall acts to block the sun's rays while creating an air space that resists the transfer of heat to the building.

The roof of a building, if shaded by a large tree, can reduce the interior building temperature by eight to ten degrees. Often, air conditioning units are placed on roofs or alongside houses in direct sunlight. Providing shade for an air conditioning unit can increase its efficiency dramatically.

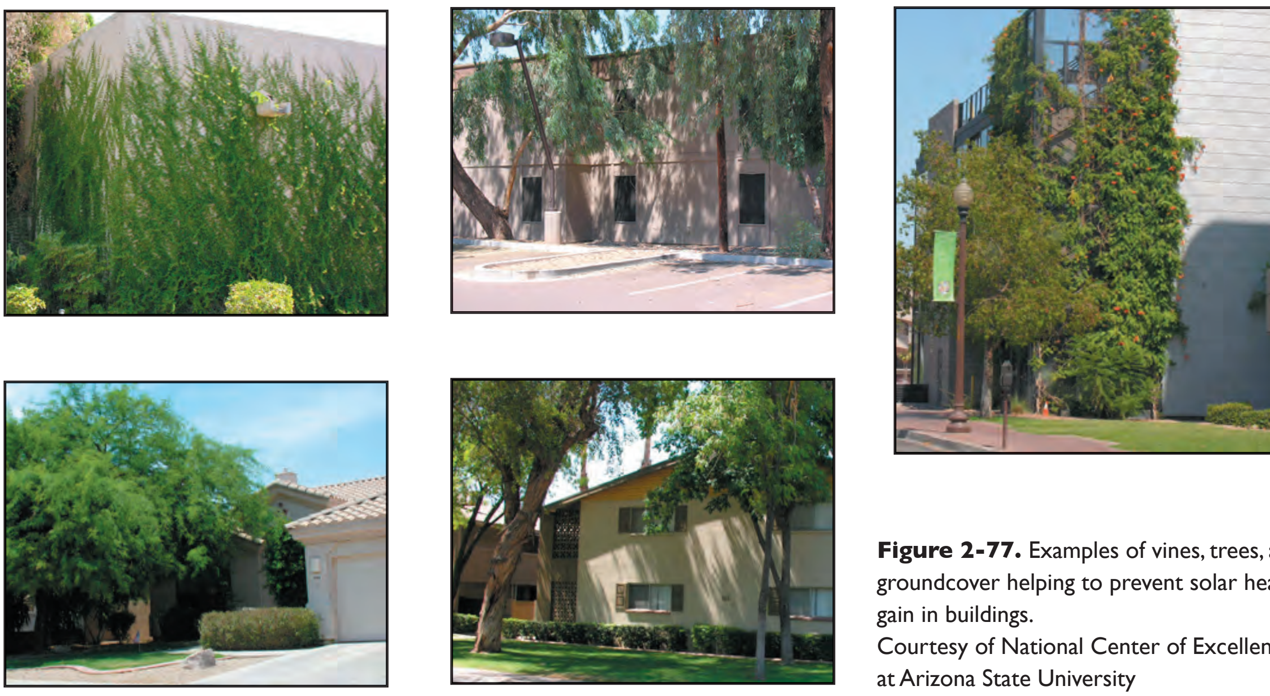


Figure 2-77. Examples of vines, trees, and groundcover helping to prevent solar heat gain in buildings.
Courtesy of National Center of Excellence at Arizona State University

Paved driveways, patios, and rock gardens reflect the sun's rays and emit heat energy, which can heat building facades and make outdoor areas around a building uncomfortable. Small shrubs and groundcover help to prevent the heating of landscape rock, similar to what occurs in the natural desert. Patios and driveways should be shaded with tall shrubs, arbors, or shade trees to mitigate build up of stored heat. Air temperature above different groundcovers can be up to fifteen degrees cooler than air temperature at the same height above rock or paved surfaces (Miller 2007).

The Arizona State Energy Code and local government landscape ordinances should be changed to encourage use of trees and other shading devices to reduce energy use in buildings and mitigate the urban heat island. For example, Los Angeles' Landscape Ordinance No. 170, 978 states that, "A minimum of one tree, or equivalent, shall be required per each 25 feet of exposure."

Shading Pavements and Hardscapes

Exposed pavements and hardscapes absorb solar radiation during the day, reaching temperatures of over 160°F in some cases. The heat energy is then released slowly to the night sky, resulting in elevated nighttime air temperatures, especially around extensively paved areas such as parking lots, airports, and highways. Shade trees can provide a first line of defense against the sun by protecting paved surfaces from direct sunlight.

Trees placed along roads and parking lots provide benefits that complement pavement structure. These benefits include capturing runoff and improving water quality through natural infiltration. Planting shade trees along sidewalks and within parking lots can improve the comfort level of those using the areas. Shade trees can also enhance the appearance of buildings and thus increase their desirability and property value.

Optimal Planting Locations for Building Energy Use and UHI Mitigation

- Plant shade trees, tall shrubs, vine trellises, or arbors near the south, west, and southwestern corners of buildings.
- Shade windows to block direct sunlight from entering the building.
- Shade air conditioning units to improve efficiency.
- Use shrubs and groundcover plants to prevent solar energy from heating up landscaping rocks that can reflect or emit radiation and increase the thermal loads of buildings.
- Plant shade trees next to the street or between the sidewalk and the street.
- Plant trees in parking lots to shade pavements and cars.

CONSERVATION

Conservation forestry refers to the protection of existing trees in and around developed areas. Millions of dollars could be saved every year if fewer trees and native vegetation were destroyed during development and land transactions. Phoenix does not have a tree conservation program, although many cities have tree ordinances to protect street trees, historic trees, and even some trees on private property. While these are very important conservation measures, the majority of vegetation loss in the Phoenix region occurs at its fringes where new developments replaces native desert and agricultural land. A common practice in Maricopa County is to completely clear and grade land prior to development. This also occurs when land is improved for sale. Developers will argue that this type of practice is more economical and the savings are passed on to the future property owner. While this may be true in terms of dollars, the hidden economic and environmental costs resulting from the loss of vegetation, permeability, biodiversity, and connection to the natural environment should be considered. Recent trends in luxury home communities in northern Scottsdale indicate that owners appreciate the natural beauty of the Sonoran Desert and will pay more to live in communities that are integrated with native desert. When vegetation loss or cannot be avoided, ordinances must require that reforestation efforts replace a large percentage of plants following the clearing and development process.

Education also plays an important role in forest conservation. Governmental planning departments, professional trade organizations, and conservation groups can provide instructional seminars and literature to land clearing contractors and developers about low impact methods that minimize the destruction of native desert vegetation during land development.

Making Urban Forestry a Priority in the Valley

Many cities around the country, including Sacramento, Chicago, Houston, San Francisco, and Austin, have adopted aggressive, citywide reforestation plans to ensure the future of trees and vegetation in their cities. It is time that the government and citizens of the Phoenix region begin to consider the importance of trees in urban areas.

A successful urban reforestation plan requires the involvement and cooperation of several groups within the community. Newly planted trees must be properly maintained and watered for the first two to three years in order for the tree to survive to become self sufficient. City and county governments are typically unable to take on major new tree maintenance programs due to competing budgetary priorities. Similarly, local botanical, nonprofit organizations can offer only limited volunteer time and funding to provide the necessary care and maintenance. That is why it very important to find ways to involve businesses and homeowners. Property owners must be made aware of the many financial benefits of tree planting, including increased property values, decreased energy use, increased outdoor shade, and the general enjoyment of their property. The value of trees varies according to personal preferences; however, the environmental and economic values may be the most persuasive for motivating increased urban reforestation in the region. A study conducted by American Forests in 2001 developed a rough estimate of the economic value of trees. The Houston Advanced Research Center used the estimate to project the return on investment per tree. They estimated an 11.4% return on investment for their reforestation plan. While this estimate may uncertain, it is safe to assume that the energy savings benefit per tree would be greater in the Phoenix region.

The Center for Urban Forest Research, a part of the USDA Forest Service, conducted a similar analysis of the benefits of trees in the Southwest. They published their findings in the "Desert Southwest Community Tree Guide." The results of their quantitative study show that the combined average economic benefit increases as a tree matures.

Size	Annual Benefit (per tree)
Small	$14 - $18
Medium	$25 - $30
Large	$37 - $43

Table 2-9. Estimated annual economic benefit per tree in the southwest US. Based on the combined savings from pollution, erosion control, shading, and air cooling effects of trees, as presented by the USDA Center for Urban Forest Research. Source: McPherson 2004

Partnerships, Initiatives, and Education

Planting millions of new trees in an urbanized region requires a considerable amount of effort and coordination of resources. To accomplish the actions and strategies discussed earlier will require a multitude of new partnerships, initiatives, and education efforts.

New partnerships between public and private organizations can result in new business growth that contributes to the economic health of the region. One example of this type of partnership involves the supply of appropriate trees. The quantity of trees that would be needed for a massive urban forestry program may far exceed the capacity of existing nurseries to provide. An entrepreneurial approach to this supply chain dilemma could be the solution to such a shortage of trees, or an integrated effort within the network of Maricopa County nurseries could solve the problem.

Sources of funding could also come from public organizations such as water, electricity, gas, and municipal utilities. As part of energy conservation programs and peak load reduction, utilities such as APS and SRP could offer incentives or offsets for building owners who plant additional trees in strategic locations on their properties to reduce cooling demand and shade pavements.

Regional tree initiatives led by advocacy groups, nonprofit organizations, local foundations, and governmental organizations are also needed. These advocates could promote tree planting and maintenance activities to the top of their local government agendas, devise new ways to achieve tree anting goals, and create educational and outreach events. Experienced organizations could assist by providing leadership and coordination for managing private and public funds.

Educational programs, materials, and events will be needed to involve the community and to develop generational connections between children, their parents, and grandparents. Some reforestation plans suggest developing regional seedling distribution programs for elementary schools to teach children about tree planting, tree care, and other basics that will follow them throughout their lives.

Steps Towards Implementation

- *Create an inventory of all trees in the Phoenix region, characterized by land use, location, type, and age, if possible.*
- *Change the energy code to include specific provisions for shade trees.*
- *Encourage expanded public policies for trees.*
- *Lower tree prices and increase availability of native and desert adapted trees within the region.*
- *Institute a Regional Trees Initiative that includes tree advocates, homeowners, businesses, and schoolchildren.*
- *Implement a targeted program for office and retail development.*
- *Expand landscape set -asides for local, state, and federal roadway projects.*
- *Institute tree incentives and programs for parking area improvements.*
- *Expand private and public support for existing tree organizations.*
- *Create a Regional Tree Conservation Partnership of major public conservation agencies, aimed at outlying and developing areas and tree conservation on private lands.*
- *Target education, training, and awareness programs to large tract property owners, construction contractors, and land clearing companies and staff.*
- *Enlist regional leadership, particularly in outlying counties, from among elected officials and community leaders, to support tree protection and conservation.*
- *Create and fund a public-private partnership to expand the tree market in the region and tree planting activities in the private sector.*

Adapted from HARC (2004)

Further Information about Urban Forestry in the Phoenix Region

Phoenix Urban Forestry, City of Phoenix Parks and Recreation Department.,
1802 W Encanto Blvd., Phoenix, AZ 85007. (602) 495-3763; www.phoenix.gov/FORESTRY/#URBAN

Arizona Community Tree Council, John Eisenhower, President,
1110 W Washington St., #100, Phoenix, AZ 85007. (602)-542-6191; www.aztrees.org

Arizona State Land Department, Ron Romatzke, Urban Forester,
1616 W Adams, Phoenix, AZ 85007. (602) 542-2518; www.land.state.az.us/programs/natural

University of Arizona Cooperative Extension Service,
4341 E Broadway, Phoenix, AZ 85040. (602) 470-8086; ag.arizona.edu/maricopa/garden/
The National Arbor Day Foundation,
100 Arbor Ave., Nebraska City, NE 68410. www.arborday.org Treetures 1-800-863-7175; www.treetures.com

National Tree Trust,
1120 G St., NW, Suite 770, Washington, D.C. 20005. 1-800-846-8733
International Society of Arboriculture, P.O. Box 3129, Champaign, IL 61826-3129. www.isa-arbor.com

Additional Resources

- U.S. Environmental Protection Agency (EPA) on Urban Heat Island
  http://www.epa.gov/heatisland/
- National Center of Excellence on SMART Innovations for Urban Climate + Energy
  Arizona State University
  http://asusmart.com/urbanclimate.php
- Cool Roof Rating Council (CRRC)
  http://www.coolroofs.org/
- Lawrence Berkeley National Laboratory (LBNL) Urban Heat Island Group
  http://eetd.lbl.gov/HeatIsland/
- NASA Earth Observatory: The Earth's Big Cities, Urban Heat Islands
  http://eobglossary.gsfc.nasa.gov/Study/GreenRoof/index.html
- American Concrete Paving Association (ACPA)
  http://www.cement.org http://www.pavement.com/chaplinks/chapters/chapmap.html).
- National Asphalt Paving Association
  http://www.hotmix.org
  http://www.hotmix.org/view_article. php?ID=63
- Asphalt Paving Alliance
  http://www.asphaltalliance.com/
- The Portland Cement Association
  http://www.pavement.com
- FHWA's Office of Pavement Technology
  http://www.fhwa.dot.gov/pavement/ about.htm
- FHWA's Office of Planning, Environment, and Realty
  http://www.fhwa.dot.gov/hep/index.htm
- AASHTO Center for Environmental Excellence
  http://environment.transportation.org/
- Consortium for the Study of Rapidly Urbanizing Regions, Arizona State University
  http://ces.asu.edu/csrur/index.htm
- Houston Advanced Research Council (HARC)
  http://www.harc.edu/harc/Projects/CoolHouston/HeatIsland

References

Akbari, H., Rose, L. and Taha, H. (1999). "Characterizing the Fabric of the Urban Environment: A case study of Sacramento, California." Lawrence Berkeley National Laboratory, US Department of Energy. LBNL-44688.

Asaeda T., Vu, T.C., Wake, A. (1996) "Heat storage of pavement and its effect on the lower atmosphere. " Atmospheric Env., 30 (3): 413

Belshe, M., Kaloush, K., Golden, J., Phelan, P. (2007). "AR-ACFC Overlays as a Pavement Preservation Strategy for PCCP". Journal of the Transportation Research Board, CD-ROM, Washington, D.C., January 2007 – National Academies Press.

Bhardwaj, R., Phelan, P.E., Golden, J., Kaloush, K. (2006). An Urban Energy Balance for the Phoenix, Arizona, USA Metropolitan Area. Proceedings of 2006 ASME International Mechanical Engineering Congress and Exposition. November 5-10, 2006, Chicago, Illinois, USA

Brantley, L. and Brantley, R. (1996). Construction Materials. In Frederick, M., Loftin, M., and Ricketts, J., editors, Standard Handbook for Civil Engineers. McGraw-Hill. New York. 5.2, 5.9, 5.6

Brazel, A., Selover, N., Vose, R. & Heiser, G. (2000). "The Tale of Two Climates-Baltimore and Phoenix Urban LTER Sites." Climate Res., 15, 123-135

Brazel, A. J., Gober, P., Lee, S., Grossman-Clarke, S., Zehnder, J. and Hedquist, B. (2007) Dynamics and determinants of urban heat island change (1990-2004) with Phoenix, Arizona USA. Climate Research 33:2 , pp. 171-182.

Bureau of Transportation Statistics (2006).

California Department of Transportation 2003. "I-15 Devore Project." <http://www.dot.ca.gov/dist8/i15devore/project%20photos/I-15Devore_project_photos.htm> (November 15th, 2005)

Carlson, J. (2006). Quantifying the diurnal thermal variability of urban surface pavements in a hot climate region. Thesis (M.S.) Arizona State University

Çengel, Y. (2003). Heat Transfer; A Practical Approach, Second Edition. McGraw Hill, Boston, pp. 563-569.

Celestian, S. and Martin, C. (2003). "Leaf physiology of four landscape trees in response to commercial parking lot location." Central Arizona Phoenix – Long Term Ecological Research. NSF.

Florida Solar Energy Center, < http://www.fsec.ucf.edu/> Accessed August, 2007.

Golden, J. (2004). "The Built Environment Induced Urban-Heat-Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity." Environmental Sciences, 2003/2004, Vol. 1, No. 4, pp. 321–349

Golden, J., Carlson, J., Kaloush, K., Phelan, P. (2007). "A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures." Solar Energy, 81 (7) 872-883

Gui, J., Phelan, P., Kaloush, K., Golden, J. (2007). "Impact of Pavement Thermophysical Properties on Surface Temperatures." ASCE Journal of Materials in Civil Engineering., Volume 19, Issue 8, pp. 683-690

Hitchcock, D. (2004). "Cool Houston! A Plan for Cooling the Region." Houston Advanced Research Center (HARC), The Woodlands, Texas.

Houston Advanced Research Center (HARC) < http://www.harc.edu/>

Huang, Y.J., H. Akbari, and H.G. Taha, and A.H. Rosenfeld. (1986). "The Potential of Vegetation in Reducing Summer Cooling Loads in Residential Buildings." LBL Report 21291, Berkeley, CA: Lawrence Berkeley Laboratory

Incropera, F. and D. DeWitt, (1996). Fundamental of Heat and Mass Transfer; Fourth Edition. John Wiley and Sons.

LBNL (Lawrence Berkeley National Laboratory). Urban Heat Island Group. <http://eetd.lbl.gov/HeatIsland/>

Levinson, R. and H. Akbari,(2001) "Effects of Composition and Exposure on the Solar Reflectance of Portland Cement Concrete," Heat Island Group, Lawrence Berkeley National Laboratory.

Konopaki, S., Akbari, H., (2002). Energy savings for heat-island reduction strategies in Chicago and Houston. LBNL-49638

McPherson, G., Simpson, J., Peper, P., Maco, S., Xiao, Q., & Mulrean, E., (2004). Desert Southwest Community Trees Guide: "Benefits, Costs, and Strategic Planting." Center for Urban Forest Research.

McMichael, A.J., Butler, C., & Ahern, M.J. (2002). "Environment as a global public good for health." In R. Beaglehole, N. Drager, & R. Smith (Eds.), Global public goods for health, World Health Organization and United Nations Development Programme Collaboration. Oxford: Oxford University Press.

Miller, G. O. (2007) Landscaping with native plants of the Southwest. Voyageur Press.

NRCA (2005). National Roofing Contractors Association <http://www.nrca.net/> November 2007

Parker, J. H. (1983). Landscaping to Reduce the Energy Used in Cooling Buildings. Journal of Forestry 81(2):82-83

Pomerantz, M., Pon, B., Akbari, H., S.C. Chang (2000) The Effect of Pavement Temperatures on Air Temperatures in Large Cities. LBNL-43442

Roberts, S., T.R. Oke, J.A Voogt, C.S.B., Grimmond, and A. Lemonsu (2003). "Energy Storage in a European City Center." Fifth International Conference on Urban Climate, September, 2003 - geo.uni.lodz.pl

Rose, S.L., Akbari, H., and H. Taha. (2003). "Characterizing the Fabric of Urban Environment: A case study of Metropolitan Houston, Texas". Lawrence Berkeley National Laboratory report LBNL-51448.

Rosenfeld, A., H. Akbari, S. Bretz, B. Fishman, D. Kurn, D. Sailor, & H. Taha (1995). "Mitigation of urban heat islands: materials, utility programs, updates." Energy and Buildings, 22 (3), pp. 255-265

Rosenfeld, A.H. Akbari, J.J. Romm, M. Pomerantz, "Cool Communities: Strategies for Heat Island Mitigation and Smog Reduction," Energy and Buildings 28 (1998) pp. 51-62

Sailor, D., L. Kalkstein and E. Wong (2002) The Potential of Urban Heat Island Mitigation to Alleviate Heat-Related Mortality:

Methodological Overview and Preliminary Modeling Results for Philidelphia, Fourth Symposium on the Urban Environment, May 20, 2002.

Seattle Municipal Civic Center Master Plan 1999. Solar Access Study < http://www.seattle.gov/fleetsfacilities/civiccenter/masterplan/default.htm> Accessed: October 2007

Somayaji, S. (2001). Civil Engineering Materials, Second Edition. Prentice Hall. New Jersey. pp. 52, 383, 449.

Stefanov, W., Ramsey, M. and Christensen, P. (2001). Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers. Remote Sensing of Environment. 77, 173-185

Taha, H. 1996. Modeling the impacts of increased urban vegetation on the ozone air quality in the South Coast Air Basin. Atms. Environ., 30, 3434-3430

Taha, H. (1997). "Urban climates and heat islands; albedo, evapotranspiration, and anthropogenic heat". Energy and the Environment, 25 (2), pp. 99-103

Ulrich, R.S. 1981. "Natural Versus Urban Scenes: Some: Psychophysiological Effects." Environment and Behavior. 13:53-556

US Environmental Protection Agency "Cooling our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing,", January 1992, 22P-2001

US Army Corps of Engineers, (2000). Hot-Mix Asphalt Paving. Library of Congress catalog card number LC 00-135314. Federal Aviation Administration, AC 150/5370-14A, pp. 3, 5, 125.

Ziedman, K. (2005) "Roadway Reflectivity and Visibility." Report prepared for Granit Rock Company, Watsonville, CA.

CHAPTER 3:

DESIGN FOR CLIMATE AND ENERGY

Chapter 3 Table of Contents

Introduction

Buildings and their support systems are the centerpiece of urban life. They shelter us from the harsh natural elements, provide access to water and food, power our appliances, provide light after the sun goes down, collect and dispose of our wastes, and offer privacy and sense of personal safety. We sleep, eat, bathe, work and play within them. Their location determines the length of our daily commutes, and depending on their organization and functional diversity, they can either induce or hinder human interaction and a sense of community. Their facades create a city's visual character and serve as major landmarks for visitors and tourists. They also depend on us for regular maintenance; forming a unique relationship between humans and the built environment.

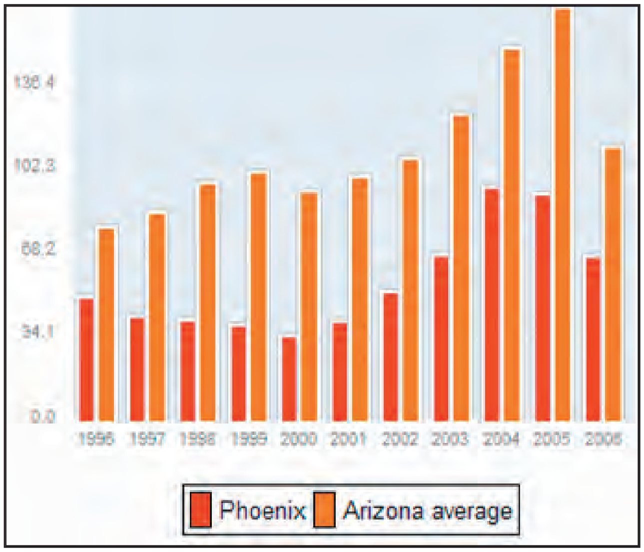
The average American spends over 90% of their lives indoors and yet we are often unaware of the energy and resources used in the construction and operation of buildings. Buildings form a large portion of the total environmental impact in the United States. Even though they only contribute to 12% of land use, buildings demand a significant amount of natural resources, generate solid and liquid wastes and are responsible for nearly half of the atmospheric emissions released in the United States. Their contribution to the economy is also very important. According to the Department of Energy's Building Energy Databook the construction market for commercial, residential and industrial buildings comprises 14.2% of the $10 trillion U.S. GDP.

There are many different types of buildings in an urban area, each having different program requirements and energy use patterns.

A building's energy consumption is the largest portion of its environmental impact (Levin 1997). 42% of the U.S. energy consumption and 68% of its electricity is consumed in buildings every year (WBDG 2005). Over the past two decades many improvements to energy efficiency have been incorporated into new buildings. However, according to the US energy information agency, a large majority of the existing buildings that are more than a decade old do not meet current energy efficiency construction standards (EIA 1991). It is necessary to perform energy analysis of existing buildings to determine if energy retrofits or improvements are necessary. Investing to improve the energy efficiency of buildings can provide immediate and relatively predictable cost savings resulting from lower energy bills (Krarti 2000). This section of the guidebook will take a closer look at many of the strategies that can be incorporated into new and existing structures that can reduce energy, water and material use in buildings with particular attention to solutions for the Phoenix regional climate.

TYPES OF BUILDINGS

Buildings are generally grouped into three major categories; residential, commercial and industrial. The categories are based on the predominate activities that occur within them.



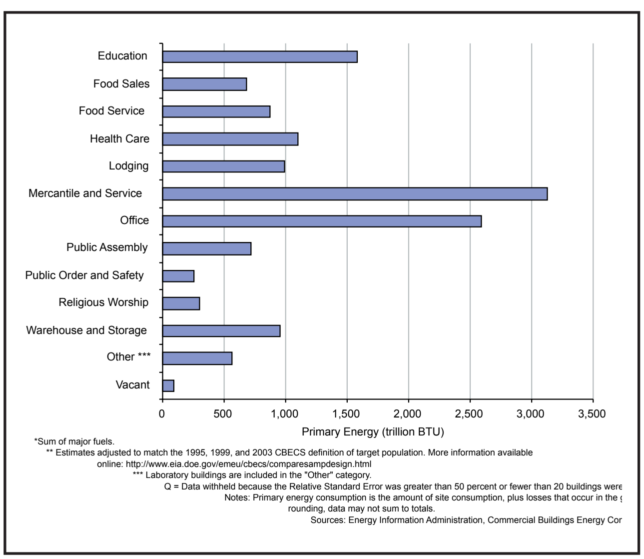
Residential permits per 10,000 residents in the Phoenix and Arizona from 1996 to 2006. Source: National Association of Home Builders.

Residential

Residential buildings are structures in which humans live and are often referred to as houses. Housing can support the needs of a single family or provide shelter and living space for thousands of people. They can range in size from one-room wood-framed, masonry, or adobe dwellings to multi-million dollar sky scrapers. Three story residential buildings are considered low-rise while anything larger is classified as high-rise. The majority of housing in the Phoenix area is low-rise though recent trends have seen a growing number of high-rise residential structures as the population growth continues to drive demand.

Commercial

Commercial buildings provide shelter for business establishments and other organizations that provide services. This includes traditional service businesses, such as retail and wholesale stores, hotels, restaurants, offices and hospitals. It also includes institutional facilities such as public schools, correctional facilities, and religious and fraternal organizations. Commercial buildings are generally owned by corporations or investments institutions and have the greatest potential for adopting and benefiting from high-performance strategies. The majority of LEED™ certified buildings in the U.S. are commercial buildings. The graph below indicates office and mercantile buildings consume the greatest amount of primary energy of all the commercial buildings.



Primary energy consumption by major commercial building type in the U.S. in 2003. Source: Energy Information Agency.

Industrial

Industrial buildings are those that provide for the goods-producing industries including manufacturing, agriculture, mining, forestry, fisheries, and construction. Industrial buildings generally consume more energy, water and raw materials than most buildings due to the demands of large industrial equipment such as motors, presses, conveyors, ovens, compressors and pumps. Industrial buildings also have unusual schedules sometimes having several worker shifts a day requiring the building systems to operate nearly 24 hours a day.

Evaluating the Environmental Impact of Buildings

The recent sustainable development movement has been gaining strength and evolving for nearly two decades. This has resulted in significant shift in the planning and delivery of buildings that include alternatives to the energy and resource hungry methods of past generations. A major turning point in the United States was the founding of the **U.S. Green Building Council (USGBC)** in 1993 which brought about a newfound commitment to high-performance building practices within government and the building industry. For five years the USGBC task force developed a standard to evaluate a building's resource efficiency and environmental impact. This standard, released in 1998, was aptly named **Leadership in Energy and Environmental Design (LEED),** and helped to remove ambiguity in the loosely interpreted concepts associated with sustainability and green building at the time. LEED™ gained wide acceptance in both the private and public sectors causing an exponential shift in the construction industry in U.S. Since 1998, the number of LEED™ certified new buildings has doubled every year resulting in 121 buildings in 2004 and over 694 in 2006. At this rate, within 10 years, the majority of new construction will be in high-performance and green buildings. While these numbers represent LEED™ for New Construction (LEED-NC), the USGBC has also released LEED™ standards that address Existing Buildings (EB), Commercial Interiors (CI), a building's Core and Shell (CS), Homes (H) and most recently Neighborhood Development (ND). Although other building assessment standards do exist, LEED™ is now the most widely accepted standard and predominates the U.S. Other countries including Spain, Canada, and China are considering adopting LEED-based approaches to green building. The wide acceptance of LEED™ can be attributed to the consensus based method employed by its authors when developing the standard often involving the collective minds of hundreds of design and construction professionals from all sectors of the building industry.

The Arizona Biodesign Institute at Arizona State University's Tempe Campus is the first building in Arizona to achieve LEED™ Platinum Certification for new construction.

This section provides a general overview of sustainable design as it applies to buildings. There is no intention to circumvent the LEED™ Rating System as they offer a level of detail that is out of the scope of this guidebook. It is our intention to provide a concise and general introduction to buildings types, core principles and benefits of high-performance buildings, the accepted design strategies for achieving improved performance and several additional resources for further reading. Particular attention is given to the strategies that are of most importance to the Phoenix region, including passive solar design, building envelope and water use and conservation.

Fundamentals of Sustainable Building Design

Principles

Design, can been summarized as "the intentional shaping of matter, energy, and process to meet a perceived end or desire" (S. Ryn and S. Cowan 1995). Following the Industrial Revolution, the built environment has lacked the diversity and creativity of the natural landscape that which is replaces. The buildings were built with the sole purpose of functioning to meet a human centered need and often conforming to simple models and templates that were replicated regardless of the climatic and cultural differences between locations. Human-designed and engineered landscapes consisting of unrecyclable and toxic products produced by wasteful industrial processes replaced the natural landscape that once existed. This human-centric design paradigm greatly improved the quality of life for many however it neglected the fragility of natural resources and the associated impacts to human and ecological systems resulting in many of the environmental problems that our society faces today. The concept of

'ecological design' also referred to as **'green'** design seeks to amend this disconnect between urban design and nature. Instead of urban designs that destroy the native landscape, designers would develop solutions that allow human-created structures to coexist in a symbiotic way with the native landscape. This can be achieved through designs that mimic the behavior of natural systems and are harmless in their production, use and disposal. This design ideal faces many barriers due to the legacy of infrastructure, products and process that have been created and ingrained into society over the past century.

Sustainable Design broadens the scope of 'green' design and extends it to address the Triple Bottom Line: environmental impacts, social consequences and economic performance. The Conseil International du Batiment (CIB), an international construction research agency, defined the goal of sustainable design and construction in 1994 as "creating and operating a healthy built environment based on resource efficiency and ecological design." CIB developed these Seven Principles of Sustainable Design and Construction;

1. Reduce Resource Consumption
2. Reuse Resources
3. Use Recyclable Resources
4. Protect Natural Systems
5. Eliminate Toxics
6. Apply Life-Cycle Costing
7. Focus on Quality

These principles were meant to inform decision making through each phase of the design and construction of projects. They apply to the entire building life cycle from the initial planning phase to the design, construction and eventual disposal/deconstruction of the built environment. Though simple, these principles apply to everything that is used to create and operate the built environment from the land, minerals, water, energy and ecosystems.

Benefits

Sustainable design and construction requires that all players from the building owner to the facility operator must be aware of these principles in order for the project to be successful. An often effective means of creating a successful project is to be sure that all key players in the building process are aware of the benefits of sustainable design and construction. The broad range of economic, environmental and social issues that sustainable design addresses enable just about everyone to find a benefit that they can agree with. Table 1 was developed by the Federal Energy Management Program (FEMP) to provide an overview of the potential benefits of Sustainable Design.

	Economic	Societal	Environmental
Project Siting	Reduced costs for site preparation, parking lots, roads.	Improved aesthetics, more transportation options for employees.	Land preservation, reduced resources use, protection of ecological resources, soil and water conservation, restoration of brownfields, reduced energy use, less air pollution.
Water Efficiency	Lower first cost, reduced annual water and wastewater costs.	Preservation of water resources for future generations and for agricultural and recreation uses; fewer wastewater treatment plants.	Lower portable water use and reduced discharge to waterways; less strain on aquatic ecosystems in water shortage areas; preservation of water resources for wildlife and agriculture.

	Economic	Societal	Environmental
Energy Efficiency	Lower first costs, lower fuel and electricity costs, reduced peak power demand, and reduced demand for new energy infrastructure.	Improved comfort conditions for occupants, fewer new power plants and transmission lines.	Lower electricity and fossil fuel use, less air pollution and fewer carbon dioxide emissions, lowered impacts from fossil fuel production and distribution.
Materials and Resources	Decreased first cost for reused and recycled materials, lower waste disposal costs, reduced replacement costs for durable materials, reduction of need for new landfills.	Fewer landfills, greater markets for environmentally preferable products, decreased traffic due to the use of local/regional materials.	Reduced strain on landfills, reduced use of virgin resources, better managed forests, lower transportation energy pollution, and increase in recycling markets.
Indoor Environmental Quality	Higher productivity, lower incidence of absenteeism, reduced staff turnover, lower insurance costs, and reduced litigation.	Reduced adverse health impacts, improved occupant comfort and satisfaction, better individual productivity.	Better indoor air quality, including reduced emissions of volatile organic compounds, carbon dioxide, and carbon monoxide.
Commissioning: Operations and Maintenance	Lower energy costs, reduced occupant/owner complaints, longer building and equipment lifetimes.	Improved occupant productivity, satisfaction, health and safety.	Lower energy consumption, reduced air pollution and other emissions.

Table 1. Benefits of Sustainable Design (Source: Federal Energy Management Program, 2003)

Barriers

Listed below are some of the most significant barriers are often faced for accomplishing authentic 'green' design in State agencies. Following the description of each barrier is a list of suggested actions for overcoming the barrier.

ARCHITECTS AND ENGINEERS LACK KNOWLEDGE AND TRAINING IN GREEN DESIGN, AND THERE IS A STEEP LEARNING CURVE.

- Obtain training in green design through workshops and conferences offered by groups like the U.S. Green Building Council.
- Participate in LEED™ training workshops and encourage design staff to become LEED™ Accredited Professionals.
- Obtain knowledge about green design by reading various publications such as Environmental Building News and Environmental Design and Construction magazine and using green design tools such as the Green Building Advisor and GreenSpec6.
- Encourage and reward professionals who develop expertise in high performance building design.
- Prioritize green design and select design team members with appropriate experience and commitment.

IN-HOUSE DESIGN STAFF IS ALREADY OVERWORKED AND THERE IS NO TIME TO LEARN ABOUT OR IMPLEMENT GREEN DESIGN.

- Obtain a top-level commitment to green design which requires "finding the time" to make green design a priority.
- Move in-house staff in the direction of green design, incrementally, as workload permits.
- Hire consultants to provide green design services which in-house staff does not have time for.
- Find ways to ease workload to allow for organizational growth and change.
- Add staff hired to work specifically on introducing green design into projects and implementing a culture change within the department.

FAST TRACK PROJECTS MAKE IT IMPOSSIBLE TO FIND THE TIME TO IMPLEMENT GREEN DESIGN.

- Find ways of slowing the pace of projects so that an integrated design process may occur - otherwise, designs will be less than optimal and potential life cycle savings will be lost.
- Hire consultants to provide green design services which in-house staff does not have time for.

FUNDING IS INSUFFICIENT TO COVER THE INCREMENTAL COST OF GREEN DESIGN.

- Seek dedicated green design funding for expensive green design measures from organizations.
- Seek design synergisms to reduce or eliminate increases in project first cost.
- Incorporate green technologies and design elements into building retrofit projects and finance them as part of larger energy conservation performance contracts.
- Use creative financing like that used in performance contracting to pay for green design premium costs in new construction.

GREEN DESIGN OR SPECIFIC GREEN MEASURES ARE PERCEIVED AS TOO RISKY FROM A COST, OPERATION, OR MAINTENANCE PERSPECTIVE.

- Recognize that well-managed green building designs are often delivered at no or low additional first cost.
- Make sure expectations and performance targets are realistic and relate them to the level of sophistication of operating staff and other resources.
- Bring operators on board during design and train them during commissioning.

CAPITAL AND OPERATING BUDGETS ARE DISCONNECTED, MAKING IT DIFFICULT OR IMPOSSIBLE TO USE FUTURE OPERATING SAVINGS STREAMS TO OFFSET ADDITIONAL PREMIUM "FIRST COSTS" FOR GREEN DESIGN AND HIGHER EFFICIENCY.

- Ensure all projects are examined from a life-cycle costing perspective.
- Develop budgetary mechanisms to bring extra funds to cover the costs of energy efficient or green design measures that pay for themselves and will reduce the life cycle costs of the building.
- Consider revolving funds which use energy savings as a mechanism for funding premium costs of green design.

CAPITAL PROJECTS ARE CONCEIVED, MANAGED, AND BUDGETED IN ISOLATION FROM OTHER PROJECTS, MAKING IT DIFFICULT TO OBTAIN THE ECONOMIES AND SYNERGIES OF INTEGRATED DESIGN.

- Establish mechanisms to ensure comprehensive asset management which requires capital project planning on a "whole building" and "whole campus" basis.
- Review capital asset management reports prior to funding new projects to ensure integrated design opportunities are optimized.

The Design Process

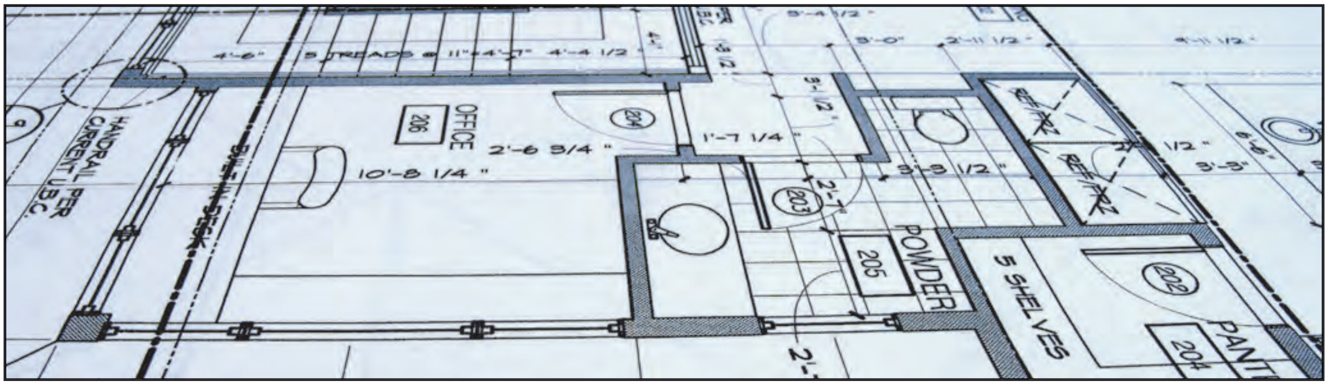
The design processes and strategies presented in the guidebook are intended to serve as a valuable resource for assisting government personnel, consultants and the general public in implementing sustainable design concepts into city construction and renovation projects. It serves not to replace the existing works such as LEED™ Rating System developed by the of the US Green Building Council but rather to augment these management systems by providing a concise summary of key concepts and up to date information pertaining to materials and technologies that are locally applicable in the Southwest Desert Region.

Team Development

High-performance, sustainable, building design is accomplished through an integrated collaborative approach amongst many design disciplines. Linking the experience and expertise of professionals in landscaping, hydrology, civil, electrical, mechanical, architectural, interior design and plumbing from the onset of the project to its completion is vital to its success. Implementing a team approach can result in creating effective design solutions that achieve multiple benefits that would have otherwise been over looked.

There are several computer building energy modeling software tools such as the **Department of Energy's DOE 2.1E, eQuest,**™ **Energy Plus,** and **Virtual Environment**™ that can be used to accurately predict the benefits of various design scenarios and combinations. These models need to be used early in the design process to be most effective. By inputting detailed building design information, climate data and mechanical system information different outcomes can be assessed and optimized for the most cost-effective combination of strategies of each particular project.

Often the most important step of any high performance design is to form an enthusiastic team of all stakeholders of the final project. With a team in place and in full communication, agreed upon project goals and a means of achieving them can be established.



Technical Strategies

The following strategies listed in this section cover the entire building process from site selection, building design, selection of materials and building operation. The strategies are purposefully concise in order to provide a quick overview of a large body of knowledge. Many of the strategies were taken from different design guidelines and adapted for use by a more general audience. The strategies have been grouped into four main categories;

- **SITE SELECTION AND DESIGN**
- **PASSIVE SOLAR DESIGN**
- **MECHANICAL AND ELECTRICAL SYSTEMS**
- **WATER MANAGEMENT AND CONSERVATION**
- **BUILDING LIGHTING, EQUIPMENT, ENERGY, MANAGEMENT, AND UTILITIES**
- **MATERIAL AND PRODUCT SELECTION**

How to Use This Section

This part of the Guidebook has been developed as an easy-to-use reference guide. Each section contains multiple numbered subsections that provide a bulleted checklist of the more significant components of appropriate building design relating to desert climate and energy use. Where available, links to Phoenix regional resources are also provided. These will generally include overviews and contacts of local or state government programs relating to the topic.

Site Selection and Design

Buildings and outdoor living spaces are greatly affected by the physical features of the site, as well as the local microclimate that surrounds it. By taking advantage of the inherent site features a building or outdoor area can greatly be enhanced for optimal human comfort without a significant dependence on mechanical or electrical systems. If planned according to the strategies presented here, heating and cooling loads can be minimized, resulting in significant decreases in energy consumption and operational costs. In most cases small changes in the project's orientation, configuration made during the initial planning stages can make a huge difference later on. The following design strategies will aid project teams when they are developing different site designs for their project.

SELECTING APPROPRIATE SITES

1. AVOID DEVELOPMENT OF INAPPROPRIATE SITES AND REDUCE THE ENVIRONMENTAL IMPACTS FROM THE LOCATION OF A BUILDING ON A SITE.

- ***Select sites without sensitive natural features and restricted land uses.*** Avoid prime farmland, wetlands, parkland, land in a floodplain, endangered species habitats, etc.
- Consider reuse of existing building space whenever possible.

2. DIRECT DEVELOPMENT TO URBAN AREAS. USE URBAN AREAS WITH EXISTING INFRASTRUCTURE, PROTECT GREENFIELDS AND PRESERVE HABITAT AND NATURAL RESOURCES.

- Give preference to urban and urbanized sites during the site selection process.
- ***Site the building near mass transit*** whenever possible, minimizing transportation impacts.
- ***Centrally locate sites*** to encourage walking and/or the use of bikes.
- ***Joint use of facilities.*** Program for building use by community or other appropriate organizations. Consider integrating building function with a variety of uses, to improve community integration, increase security, and achieve other benefits.

3. CONSIDER BROWNFIELD REDEVELOPMENT. REHABILITATE PREVIOUSLY UTILIZED AND/OR DAMAGED SITES WITH SUSPECTED OR CONFIRMED ENVIRONMENTAL CONTAMINATION, THEREBY REDUCING PRESSURE ON DEVELOPED LAND.

- ***Give preference to brownfields sites*** during the site selection process.
- Develop and implement a site remediation plan using strategies such as pump-and-treat, bioreactors, land farming and in-situ remediation.

Additional Resources

City of Phoenix Brownfield Program (602) 256-5669
http://phoenix.gov/BROWNFLD/brownfld.html

Arizona Department of Environmental Quality Brownfield Program: (602) 771-4401
http://www.azdeq.gov/environ/waste/cleanup/brownfields.html

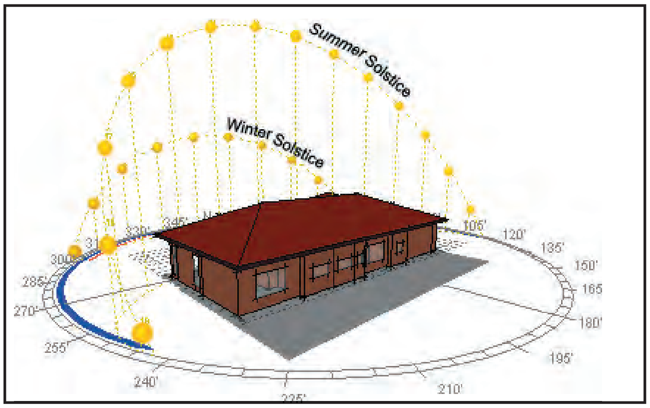
Chase Field in Phoenix is home of the Arizona Diamondbacks and exemplifies a highly successful Brownfield redevelopment project.

SUSTAINABLE SITE ANALYSIS AND DEVELOPMENT

4. EVALUATE THE SITE TO DETERMINE HOW BEST TO CONSERVE AND RESTORE ECOLOGICAL HABITATS AND SUPPORT BUILDING ENERGY AND RESOURCE EFFICIENCY.

- ***Inventory and analyze*** microclimate characteristics, surface and underground hydrology, flora and fauna biodiversity, existing air quality and ground level wind patterns and man-made landscapes.
- ***Map habitat corridors and stimulate healthy microclimates.*** Explore opportunities to connect surrounding open space with proposed green space on the site.
- ***Map sun and shade patterns*** associated with new construction. Design landscaping features to take advantage of sun/shade for plants.
- ***Examine opportunities to minimize disruption to existing hydrological features*** such as creeks, streams, ponds, lakes and/or wetlands.
- ***Test soil and groundwater*** to determine pollution levels, depth to water table, soil-bearing capacity, and what types of fertilizers or soil amendments may be required for planting.
- ***Examine opportunities to restore the surface cover of impacted areas*** where existing topsoil is fertile and contains nutrients that support plant life, filters contaminants, and neutralizes and binds many air and water pollutants.
- ***Map natural hazard zones*** with exposure to high winds and storms, floods, unstable soils, steep slopes, earthquake fault

lines, former (buried) water features, etc.
- Design building, parking, and roadways to complement existing site contours by limiting cut and infill.

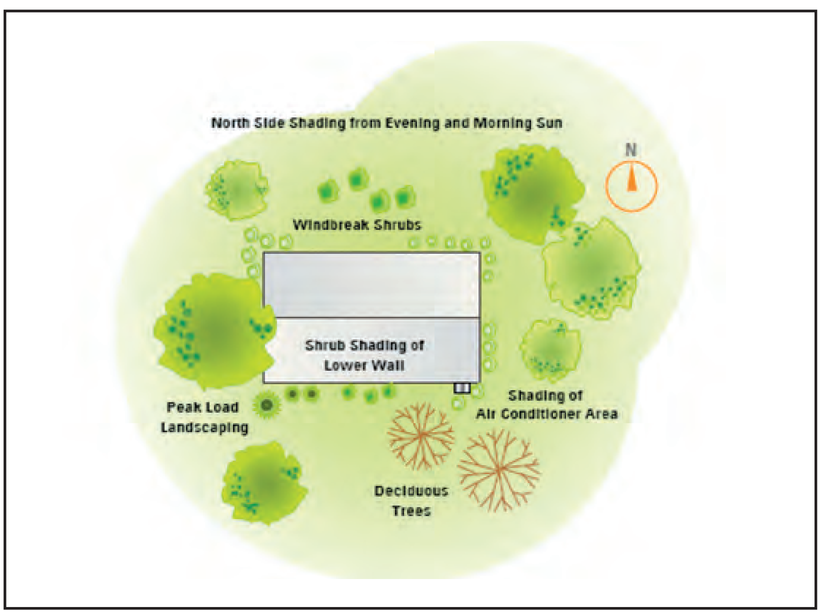


Building orientation with respect to the sun's seasonal patterns is one of the most important aspects of energy efficient design.

SITE DESIGN

5. CREATE IMPORTANT BUILDING AND SITE SYNERGIES

- *Complement the building with site features* that minimize negative environmental impacts and restore natural systems.
- *Organize building mass, orientation and outdoor spaces* to provide efficient access, service, and recreational areas with multiple functions in addition to visual value. For example, rooftops can be used as gardens and for water collection; outdoor water features can be used for ambient evaporative cooling and as recreational space where people can gather.
- *Use earth forms, plantings, drainage, water detention systems, and soils* to support the functions of the building and site (e.g., screening, windbreaks, etc.).
- *Coordinate landscape design with building envelope.* Orient building, windows, and outdoor spaces to take advantage of light, airflows, and interesting views.
- *Use deciduous shade trees and exterior structures* such as arbors and trellises, louvers, overhangs and light shelves to reduce cooling load of the building.



Strategically placed vegetation can significantly reduce energy demand during the summer and winter months.

6. REDUCE POLLUTION AND LAND DEVELOPMENT IMPACTS FROM AUTOMOBILE USE BY ENCOURAGING ALTERNATIVE TRANSPORTATION.

- *Survey future building occupants* to identify transportation needs and facilitate car-pooling.
- *Provide bus stop seating areas* that are covered and wind-sheltered, or provide waiting areas within enclosed building lobby where appropriate.

Locating building near and provided for access to mass transit systems such as city bus lines is an important strategy for reducing regional energy.

7. PROMOTE BICYCLING FOR LOCAL TRANSPORTATION TO REDUCE POLLUTION AND LAND DEVELOPMENT IMPACTS FROM AUTOMOBILE USE.

- *Encourage bicycle or pedestrian access with site design features* such as attractive landscape elements, walking and cycling paths, public squares, and public seating.
- *Provide bicycle amenities for building occupants,* such as centrally located, secure bicycle racks and shower/changing facilities.
- *Work with the larger community* to make bicycling safe and convenient.

8. PROVIDE CREATIVE PARKING SOLUTIONS TO REDUCE POLLUTION AND LAND DEVELOPMENT IMPACTS FROM AUTOMOBILE USE, ESPECIALLY SINGLE OCCUPANCY VEHICLES.

- *Provide preferred site parking* for hybrid and alternative fuel vehicle owners, and vehicles used for carpools or vanpools.
- *Minimize parking lot/garage size.* Consider sharing parking facilities with adjacent buildings. Excess parking spaces encourage increased automobile use, contribute to urban heat island effects, and can increase pollution from stormwater runoff.

9. PROTECT OR RESTORE OPEN SPACE, HABITATS AND BIODIVERSITY TO REDUCE SITE DISTURBANCE.

- *Limit "greenfield" site disturbance* (including earthwork/clearing of vegetation) to no more than:
  - 40 feet beyond the building perimeter (where the building perimeter includes adjacent paved areas and parking)
  - 5 feet beyond primary roadway curbs, walkways and main utility branch trenches
  - 25 feet beyond constructed areas with permeable surfaces.
- *On previously developed sites restore a minimum of 50% of the site area* (excluding the building footprint) by replacing impervious surfaces with native or adaptive vegetation.

A well planned building design can meet the functional requirements while minimizes the total building footprint.

10. MINIMIZE THE AREA OF THE DEVELOPMENT FOOTPRINT IN ORDER TO REDUCE SITE DISTURBANCE. CONSERVE EXISTING NATURAL AREAS TO PROVIDE HABITAT AND PROMOTE BIODIVERSITY.

- *Design the building with a minimal footprint* to minimize site disruption. Strategies include stacking the building program, tuck-under parking and sharing facilities with neighbors.
- *Designate an open space area* adjacent to the building, equal to or greater than the size of the building footprint (for areas with no local zoning requirements).
- *Avoid negative impacts on adjacent facilities or open area properties*. Typical impacts include reflected glare, waste heat, light spill, noise from cooling towers, air handling equipment, and generators, as well as the shading of adjacent green space or buildings, and gusty winds at grade from wind tunnels created by new structures.
- *Cluster underground utilities running in conduits*, such as telephone, cable, electric, water, wastewater.
- *Locate underground utilities in fire lanes,* as appropriate, to minimize site disturbance. (Separate sewer/water and high temperature piping as required.)

11. REDUCE OR ELIMINATE STORMWATER RUNOFF TO LIMIT DISRUPTION AND POLLUTION OF NATURAL WATER FLOWS.

Permeable pavements can reduce stormwater runoff from parking lots.

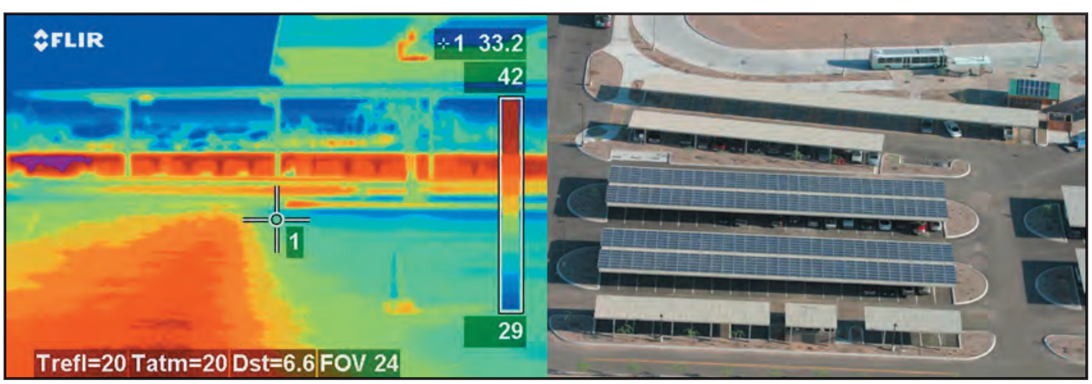
- *Maintain natural stormwater flows* by designing the project site to promote infiltration.
- *Specify garden roofs and pervious paving* to minimize impervious surfaces. Pervious paving includes such materials as pervious concrete, porous asphalt, GravelPaveTM, and open grid pavements. More information on these materials can be found in the following chapter.
- *Reuse stormwater* for non-potable uses such as landscape irrigation, and exterior site washing. Establish with the appropriate regulatory body that no adverse health effects would be associated with this water reuse. Underground cistern storage is preferable.
- *Prevent non-point source pollution* by planting watershed buffers, allowing infiltration via porous surfaces, and minimizing paved parking areas.
- *Design roads and parking lots without curbs,* or with curb cuts and openings, that drain to stormwater treatment and infiltration features.
- *Minimize paved areas for sidewalks, roadways, and parking lots* to the extent practicable to minimize stormwater runoff and also meet the needs of the building program.

12. TREAT STORMWATER ON SITE. LIMIT CONTAMINATION OF NATURAL WATER FLOWS BY ELIMINATING CONTAMINANTS AND INCREASING ON-SITE INFILTRATION.

- *Provide on-site stormwater treatment systems* to remove suspended solids and phosphorus, and other contaminants.
- *Consider natural treatment systems* such as constructed wetlands, vegetated filter strips and bioswales to promote infiltration and "bio-remediate" the site's stormwater flows. Such natural features remove gasoline, oil, grease, herbicides, fertilizers, etc., and reduce the need for constructed drainage channels and stormwater piping.
- *Provide grading and drainage* via vegetated buffers to reduce the need for artificially constructed drainage channels and stormwater piping.

13. LANDSCAPE AND PAVE TO REDUCE "HEAT ISLAND EFFECT"

- *Provide shade within five years* on at least 30% of the site's non-roof impervious surfaces.
- *Utilize light colored paving* (high-albedo materials) or open grid pavement for the site's impervious surfaces, including parking lots, walkways, plazas, etc.
- Overhead photovoltaic covering offers another method to reduce the urban heat island effect while generating a renewable energy source.



The Joint City of Phoenix – SRP Pecos Park-n-Ride facility utilizes photovoltaic panels to generate a renewable energy source while mitigating the Urban Heat Island through shading of high thermal storage pavements.

14. UTILIZE SUSTAINABLE LANDSCAPE PRACTICES TO PROMOTE THE CONSERVATION AND RESTORATION OF EXISTING BIOLOGICAL AND WATER RESOURCES, INCLUDING SPECIES DIVERSITY, SOIL FERTILITY, AND AERATION.

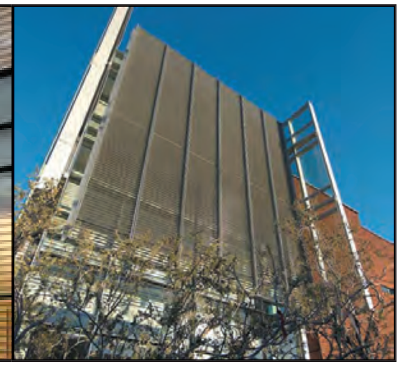
- ***Emphasize plant diversity.*** Select plants native or adapted to the region and microclimate. Consider those that grow together naturally, and are self-sustaining (i.e., can reseed and spread without much maintenance).Avoid invasive plant species and those that threaten local native ecosystems.
- Reduce the use of plant species that require frequent maintenance.
- ***Avoid plants that require chemical treatment, especially pesticides.*** Use plant combinations and maintenance methods that do not require chemicals.
- ***Avoid allergy-causing plantings*** adjacent to building openings such as air intakes, entries or operable windows.
- *Use plants that contribute nitrogen to the soil* (clover, honey locusts, black locusts, and legumes) to reduce dependence on fertilizers.
- ***Promote large common root systems.*** Cluster rather than scatter site plantings to provide adequate root space for plants, especially street trees, and to help protect other plants from wind, sun, and reflected heat, and prevent erosion. Wherever possible, locate trees so that rooting zones of more than one tree can be combined. Create larger planting islands.
- ***Salvage native plants*** to be replanted on the site (or elsewhere) to preserve biodiversity.

15. REDUCE WATER USE FOR PLANT IRRIGATION

- ***Use plants that do not require irrigation*** or that have water requirements that can be provided by natural precipitation patterns.
- ***Reduce irrigation inefficiency*** by developing "planting zones" based on water use requirements. Clearly identify such areas on site plan drawings.
- ***Consider drip irrigation where irrigation*** is necessary, or other water efficient irrigation systems. Avoid misting sprinklers, which waste water.

16. IMPROVE SOIL QUALITY.

- ***Analyze planting soil*** to identify contamination and determine if remediation is needed.
- ***Implement soil remediation measures*** as needed for the site such as introducing earthworms if they are sparse, adding organic matter and microorganisms to break down pollutants, and removing toxic materials.
- ***Use mulch*** to conserve soil moisture, restore soil fertility, and reduce need for fertilizers.
- ***Provide space and bins*** for composting landscape materials.



Passive Solar Design

Passive solar design refers to design techniques that maximize the beneficial aspects of solar energy while minimizing the negative effects. Passive solar design affects the building's shape, orientation, glazing, thermal mass and many other static features of the building. This does not include the generation of electrical energy but it can include the using solar energy to heat water and drive the movement of air through natural, non-mechanical means.

SITING AND MASSING CONSIDERATIONS

17. OPTIMIZE SITE PLACEMENT AND BUILDING FORM TO REDUCE ENERGY LOADS.

Earth sheltered homes are able to achieve a greater energy performance.

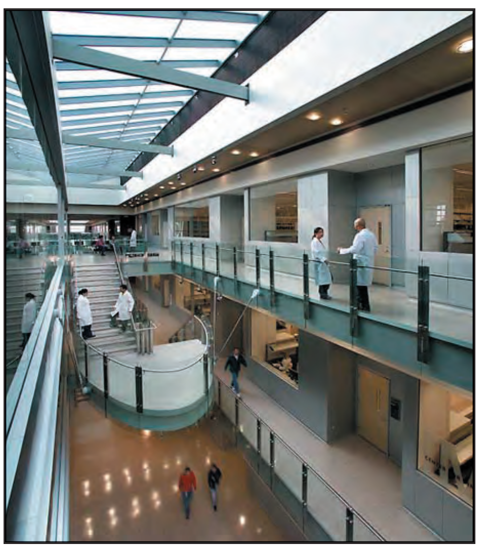
- ***Utilize topography.*** On hilly sites, utilize or modify existing topography to obtain the insulating effect of earth through berming, and other manipulations of the section.
- ***Utilize/control wind on site***. Whenever possible, orient buildings to protect entrances and minimize infiltration from prevailing winter winds. During other seasons, take advantage of non-winter air movement by utilizing prevailing winds for natural ventilation.
- Trees. Review location of existing and proposed deciduous and evergreen trees on site. Where feasible, locate buildings so that deciduous trees block summer sun to the south and west, and evergreens block winter wind.
- Building Form/Massing. Maximize solar opportunities by elongating the building structure on its east-west axis. This orientation will allow use of sun-controlled natural daylight and winter solar gain, while minimizing summer heat gains and resulting cooling loads on the east and west facades of the building.
- Avoid use of large glass atria or large glazed surfaces that cannot be justified from a programmatic perspective or by operating savings returns (e.g., from passive solar heating).

INTERIOR LAYOUT/SPATIAL DESIGN

The layout of program spaces within buildings is often overlooked when considering energy use reduction. Well planned layouts can take advantage of passive solar heating and cooling. This in turn can result in the reduction in size of mechanical systems. The following strategies address the most important consideration in optimal spatial design within buildings.

18. ORGANIZE PROGRAMMED SPACES FOR MAXIMUM ENERGY AND RESOURCE EFFICIENCY AS WELL AS COMFORT.

- *Program the facility for efficient use of built areas* (multi-functional spaces and appropriate net-to-gross). Avoid adding non-productive square footage to the building.
- *Group similar program functions* to concentrate heating/cooling and simplify HVAC zoning loads.
- *Utilize public areas and circulation zones as thermal collectors and buffers.* Such spaces tolerate a wider range of temperatures and greater temperature swings than continuously occupied spaces.
- *Design building layout to utilize natural systems.* Arrange occupied spaces for daylighting and natural ventilation whenever possible. Locate open occupied spaces adjacent to exterior windows and use borrowed light for interior offices. Utilize low partitions adjacent to window walls to enhance daylight penetration to interior areas.
- Provide well-lit, pleasant, secure stairwells/staircases to encourage the use of stairs instead of elevators.
- *Combine water-use zones for plumbing* to decrease heating and pumping requirements and reduce construction costs.



Open atriums utilize natural light and are conducive to interaction between building occupants.

19. UTILIZE PASSIVE SOLAR HEATING TO REDUCE FOSSIL FUEL ENERGY USE.

- *Design for direct solar gain for appropriate space types.* Direct solar gain should be considered for all south-facing spaces where critical visual activities are not typically conducted, including public spaces such as atria, food courts, circulation areas, etc.
- *Utilize sunspaces* where programmatically appropriate.
- *Consider mass walls.* Consider the use of interior south-facing opaque mass walls exposed to direct sunlight in the interior of a passive solar space or as a trombe wall to provide thermal storage during the day and passive heating at night. Consider different design solutions for storing heat in the building structure or materials.

- Perform computer energy modeling to determine if a passive solar configuration saves energy in a cost-effective manner. Issues to be explored in this analysis include:
  - determining whether energy gains from passive solar heating will exceed energy loss due to additional fenestrations.
  - investigating the effect of south-facing glass with low U-value but high solar heat coefficient.
  - assessing the effectiveness of thermal mass.

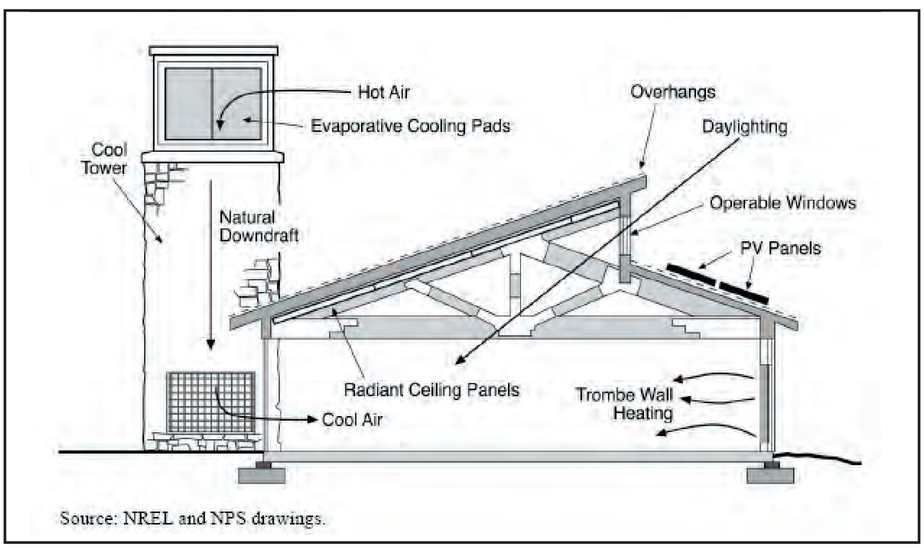
Passive Cooling and Natural Ventilation

20. EVALUATE THE POTENTIAL OF THERMAL MASS FOR BOTH EXISTING AND NEW BUILDINGS.

- *Moderate interior temperatures* where appropriate through the use of sufficient thermal mass. Consider different design solutions for storing cooling in the building structure or materials.
- *Balance solar heat gain properties of glass* by selecting high performance glass. Consider different types according to orientation and consider specifying appropriate solar heat gain coefficients and visible transmittances to reduce unwanted solar gain cooling loads.
- *Balance solar heat gain properties of glass* with the effectiveness of other solar controls such as shading devices.
- *Use shading devices.* Consider shading to let in natural light but exclude heat and glare and control contrast ratios. Shading strategies include vertical fins on east and west fenestration, overhangs or lightshelves on south fenestration, as well as arcades, trees, "brise-soleils," and deep window insets.

21. NATURALLY VENTILATE THE FACILITY TO THE EXTENT POSSIBLE IN APPROPRIATE BUILDING TYPES, BUILDING ZONES AND/OR LOCATIONS.

Natural ventilation, unlike mechanically forced ventilation, uses the natural forces of wind and buoyancy to deliver fresh air into buildings. Fresh air is required in buildings to alleviate odors, to provide oxygen for respiration, and to increase thermal comfort. At interior air velocities of 160 feet per minute (fpm), the perceived interior temperature can be reduced by as much as 5°F.



Natural ventilation design utilizes natural wind patterns, air temperature differences and buoyancy to create currents within buildings. This example of a cooling tower is from the visitors center in Zion National Park, Utah.

- ***Consider natural ventilation strategies*** in design of HVAC and exterior window and wall openings to reduce reliance on mechanical ventilation at least during swing seasons. Take local air quality and prevailing winds into consideration.
- ***Design for cross ventilation.*** Develop other ventilation strategies where appropriate for the interior building space and its function. These include cross ventilation through narrow floor plates, solar chimneys or other types of stack ventilation.
- Consider providing operable windows with appropriate HVAC interlocks or occupant annunciation systems to avoid HVAC operation and energy loss when windows are open.
- ***Carefully balance the deficits of operable windows,*** which may compromise the efficiency and maintenance of central systems, with the psychological benefits of operable windows.
- ***Consider fan-powered night ventilation*** in lieu of operable windows. Employ computer modeling to decide on the period for nighttime ventilation. In many situations, one or two hours of fan operation would be sufficient; longer run times may be ineffective and can waste energy. Night ventilation must be enthalpy-controlled, to avoid introducing excessive humidity in the building.
- ***Utilize stack effect for cooling*** through high vent reliefs on stairwells, and other high outlets where smoke evacuation will not be compromised.

Additional References

How Natural Ventilation Works by Steven J. Hoff and Jay D. Harmon. Ames, IA: Department of Agricultural and Biosystems Engineering, Iowa State University, November 1994.

Inside Out, Design Procedures for Passive Environmental Technologies by G.Z. Brown, B. Haglund, J. Loveland, J. Reynolds, and M. Ubbelohde. New York, NY: John Wiley & Sons, Inc., 1992. ISBN: 0471898740.

Passive Building Design: A Handbook of Natural Climatic Control by Narenda Bansal, Narenda, Gerd Hauser, and Gernot Minke. The Netherlands: Elsevier Science BV, 1994. ISBN: 044481745X.

Sky lights help bring natural light down to living spaces.

DAYLIGHT/SUN CONTROL

Nearly 40% of a buildings electric energy demand is due to the use of artificial lighting. Controlled daylighting should be incorporated into the building as the preferred source of illumination as often as possible. The optimal times for daylighting also correspond to the hours of peak energy use for cooling. Reducing the electric lighting can help mitigate peak loads during the day. The following techniques can greatly enhance the daylighting potential in new and existing buildings.

22. OPTIMIZE USE OF DAYLIGHT IN NEW AND RENOVATED FACILITIES.

- ***Configure the fenestration system to achieve a minimum daylight factor of 2 percent*** (excluding all direct sunlight penetration) for most occupied spaces that are contiguous to an exterior wall, day lit atrium wall or roof, as a starting point in the design. Windows located below 30" and above 7'6" do not qualify for this calculation.
- ***Consider glare-protection strategies that minimize the time when interior-shading devices must be drawn*** (e.g., light shelves per 2.2.g.), and if vertical shading devices on the exterior are unacceptable for east and west orientations (e.g., due to first cost, views or aesthetics).
- ***Achieve a line of sight to vision glazing for regularly occupied spaces,*** creating views and connecting indoors and outdoors. Exceptions would include copy rooms, storage areas, mechanical, laundry and other low occupancy support areas.
- ***Consider computer modeling*** of daylight spaces and design features to ensure that daylight spaces will be comfortable areas (with no glare) and that energy gains in terms of avoided electric lighting costs are greater than the energy costs from increased cooling loads. The heating load may decrease for south or even east-facing fenestration, or may be higher for other orientations. Enhance the favorable effect of glazed areas with glass selection, daylight harvesting systems and coordination with HVAC controls. When evaluating additional energy loads caused by daylighting features, include the impact of additional square footage and increased surface area caused by spacious design elements like atria. Seek design improvements to mitigate these loads so that daylighting and solar features reduce the energy load of the building, and do not add to it by creating additional space.

23. ORIENT BUILDING TO OPTIMIZE DAYLIGHT.

- ***Create an elongated massing allowing for daylighting*** using north-facing and south-facing glass. An east-west elongated building with an appropriate overhang will permit effective daylighting while increasing winter solar gain through south glass, and reducing the direct penetration of summer sun.
- ***Avoid exposed, eastern- and western-facing glass*** because of the large variation in light levels throughout the day and greater solar gains in the warmer months, resulting in increased cooling requirements. Eastern exposures are less problematic than the western ones in terms of heating and cooling costs.
- ***Consider north facing glazing*** for occupants requiring more uniform levels of diffuse daylight.

24. SHAPE FORM TO GUIDE DAYLIGHT.

- ***Incorporate courtyards*** or other daylight-enhancing techniques to bring light into interior spaces.
- ***Evaluate such design elements*** to ensure that they do not add to building heating and cooling loads. Make design improvements as necessary to mitigate these loads.
- ***Place and size glazing apertures appropriately.*** Maximize daylight through location and size of windows, roof monitors and skylights, and through use of glazing systems and shading devices appropriate to building orientation and space use.
- ***Design to avoid glare by using top lighting*** such as monitors in the roof or ceiling plane that allow a greater quantity and more even distribution of daylight within spaces. Flat, bubble and low-slope skylights have a negative heat balance, but provide glare-free light with light-deflecting devices installed underneath them.
- ***Consider high clerestory windows*** (often preferable to skylights) to provide deep daylight penetration especially for space types needing useable wall space.
- ***Consider light pipe technology*** for top lighting in areas with relatively deep roof cavities to transmit natural light to deep interior spaces not reachable by other means.
- ***Consider the use of interior and/or exterior light shelves,*** especially on south-facing windows, and on appropriate east or west facades for deeper daylight penetration. Light shelves avoid solar gain and glare of directbeam penetration and may eliminate need for use of mini-blinds on south facades. Some type of room darkening might be required in certain space types with audio-visual uses.
- Provide exterior shading devices (overhangs, vertical fins, projecting light shelves, etc.) where solar gain and direct light are undesirable.

25. PROVIDE DAYLIGHTING CONTROLS

- ***Design appropriate daylight harvesting controls.*** Review alternatives for reducing electric lighting use through daylight harvesting. Continuous daylight dimming has broad occupant acceptance, especially if, in individual spaces, it is coupled with a manual dimmer that allows for adjustment for maximum intensity of the artificial light from lamps. On/off or three-stage controls are appropriate for spaces with transitory occupancy (e.g., corridors) and where the glazed areas are large, so that the change from one light level to another rarely occurs. Manual dimming and switching lights on and off is typically done by occupants to enhance visual comfort rather than save energy.
- Wire luminaries, where practicable, in parallel to the window walls, so they can be dimmed or turned off row by row.

Additional Resources

Advanced Building Web Site.
http://www.advancedbuildings.org/main_t_lighting_daylighting_controls.htm

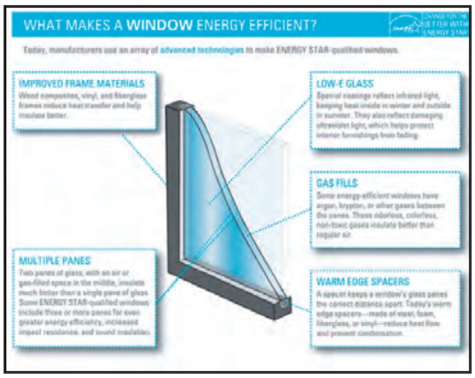
Lighting Controls Association.
http://www.aboutlightingcontrols.org/education/papers/daylighting.shtml

BUILDING ENVELOPE

A buildings exterior, commonly referred to as its envelope, separates the internal environment from the often harsh outdoor conditions. The envelope includes the walls, roof, foundations, doors, and windows of the building. Proper selection of these assemblies for these features will provide good thermal and moisture control while enhancing reductions in energy use. Natural energy can also be optimized by a well planned envelope the use of daylighting and passive solar techniques.

26. OPTIMIZE WINDOW FRAME PERFORMANCE.

- ***Provide thermal break*** in metal window frames for best thermal performance and to minimize condensation.
- Consider security issues and water intrusion in glazing and design details.
- Provide high performance, durable weather stripping to minimize infiltration.
- ***Consider wood windows frames*** that provide a natural thermal break where appropriate in new construction (e.g. residential), and in window replacement on historic buildings.
- ***Consider "pultruded" fiberglass window frames,*** which are insulated and are higher performance than wood or metal, for appropriate applications.



Energy efficient windows such as above depicted by Energy Star can provide substantial reductions on mechanical HVAC systems: Courtesy of Energy Star.gov

27. SELECT GLAZING FOR OPTIMAL PERFORMANCE

- ***Select appropriate high performance energy characteristics.*** Consider U-value, solar heat gain coefficient, and visible light transmittance.
  - Note: Each of these performance characteristics are testing and labeled on manufactured windows in accordance with standards of the National Fenestration Rating Council.
- ***Optimize glazing by orientation using energy modeling.*** Glass on south, east and west facades should be highly protective against solar heat gain, except glazing that is protected by shading devices, or south-facing glazing being utilized for passive solar heating.
- ***Consider specifying glazing with high visible light transmittance and high shading coefficients*** on north walls where glare is much less of a problem. Glass on north facades can be clear or lightly tinted.
- ***Consider fritted, and spectrally selective glazing*** tuned to use and orientation on south, east or west elevations.
- ***Select appropriate color.*** Tinted glass for south, east, and west orientations should be in the blue/green family, which is ideal for daylit buildings since they have a high coolness index (visible light transmittance divided by solar heat gain coefficient).

Additional Resources

American Council on Energy Efficient Economy
http://www.aceee.org/consumerguide/windows.htm

Efficient Windows Collaborative
http://www.efficientwindows.org/lowe.cfm

State of Arizona Energy Office
http://www.azcommerce.com/Energy/

28. PROVIDE EFFECTIVE INSULATION TO MINIMIZE HEATING, COOLING AND ENERGY USE LOADS.

Cellulose chips (left) and fiberglass (right) are two types of insulation commonly used.

- ***Optimally insulate the building shell*** (walls, roof, basements/foundation). Utilize computer modeling to determine cost-effectiveness of adding insulation beyond code requirements.
- ***Avoid thermal bridging*** in metal-framed assemblies through exterior wall, roof, and floor details and components.
- ***Avoid irregular exterior building shapes or soffits,*** which increase surface area, resulting in unwanted heat loss. Compensate for extra surface area with additional insulation.

Additional Resources

National Insulation Association
http://www.eere.energy.gov/consumer/your_home/insulation_airsealing/index.cfm/mytopic=11510

29. CONTROL AIR AND MOISTURE IN THE BUILDING ENVELOPE.

- ***Detail the building envelope*** to minimize infiltration and to prevent moisture build-up within the walls due to condensation. In humidified spaces that have masonry walls, do not place the insulation on the winter-cold surface of the concrete masonry wythe. If the insulation must be placed on the winter-cold surface of the masonry wythe, examine potential moisture condensation (dewpoint position).
- Ensure that all internal sources of humidity are properly ventilated.

30. REDUCE "HEAT-ISLANDS" FOR ALL BUILDINGS AND ROOF REPLACEMENTS.

- ***Install new or replace existing roofs with high albedo roofs***. Use highly reflective ENERGY STAR™ compliant and high emissivity roofing for the greatest amount of roof surface.
- Consider installing new or replacing existing roofs with vegetated roofs. Review combinations of high albedo and vegetated.

Additional References

US EPA and DOE Energy Star Program:
http://www.energystar.gov/

Cool Roof Rating Council
http://www.coolroofs.org/

Mechanical and Electrical Systems

Mechanical and electrical systems are the life pulse of buildings. These systems provide the heating and cooling of water and air, the delivery and disposal of water and waste and provide access to power that drive appliances and artificial light. Providing these comforts of modern life demands considerable energy in the form of electrical and natural gas. With careful attention to design, these systems can work in concert with the building's layout, orientation, envelope features, lighting strategies, electrical equipment, and site characteristics to reduce energy demand. Efficient design requires appropriate equipment sizing, efficient electrical device selection, and power distribution systems that incorporate renewable energy. There are several new strategies that can be utilized in existing and new design. These are generally categorized into two groups; those strategies that apply to the Mechanical Systems; energy sources, building processes, heating, ventilation and air conditioning (HVAC) systems, and those that focus on the Electrical Systems including power delivery systems, equipment loads and lighting.

ENERGY SOURCES

Best design practices must first address load reduction, then capitalize on solar heating, natural ventilation, daylight use, and other renewable strategies. Systems designers should explore renewable energy sources before resorting to conventional fossil fuel technologies. The benefits, in addition to the reduction of atmospheric pollution, include decreasing the State's expenditures on imported fuel and power while augmenting investments in local jobs and materials related to renewable energy sources.

31. REDUCE USE OF CONVENTIONAL FUEL SOURCES.

Georgetown University Intercultural Center in Washington DC exemplifies a roof integrated PV system. Photo courtesy of Georgetown University

- Minimize heating, cooling, lighting and other energy loads.
- Minimize electric space or water heating.
- ***Maximize use of passive solar heating and cooling*** in the design of new facilities and additions. Investigate passive solar technologies with the architect for heating portions of buildings such as lobbies, corridors, gymnasiums, cafeteria and

other public areas. Consider the use of external shading of windows (particularly those on the south, west and east facades) to reduce summer solar gain.

- *Maximize day lighting* in conjunction with reduction of electric lighting.
- Consider building-integrated photovoltaic systems.
- *Consider Ground Source Heat Pump (GSHP) systems* where subsurface conditions allow and where cost effective and practical from a maintenance and operation perspective.
- *Consider ground cooling or cooling to a body of water as alternative to cooling towers,* and ensure that this type of cooling will not have adverse environmental effects. In making the determination, consider
  - reduction in chemical treatment due to elimination of cooling tower
  - increase in cooling equipment efficiency with associated reduction in emissions
  - increase in ground water or water body temperature, which is a problem if the increase is likely to be significant
  - whether the subsurface water or the surface water body is polluted.
- *Consider use of combined heat and power* and distributed generation, e.g. micro turbines.
- *Encourage the use of purchased Green Power.* Use grid-source, renewable energy technologies such as wind energy produced on grid-connected wind farms.
- *Investigate cleaner forms of hydrocarbon-based distributed generation systems,* such as natural gas powered fuel cells and micro-turbines, particularly when waste heat is recovered.

HEATING, VENTILATING AND AIR CONDITIONING (HVAC) SYSTEMS

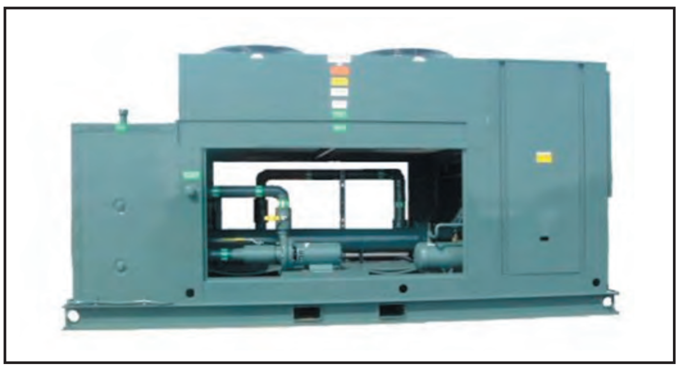
The following general approaches to use of Heating, Ventilating and Air Conditioning (HVAC) systems are recommended for new buildings, additions, and major rehabilitations of existing buildings to ensure an integrated approach to building and systems design for optimal energy efficiency and indoor air quality.

32. OPTIMIZE HVAC SYSTEMS THROUGH DESIGN INTEGRATION

Properly installed and maintained HVAC systems reduce operational costs and energy demand.

- *Design the architectural features* (orientation, exposure, height, neighboring structures, present and future landscaping, performance of the building envelope, daylighting) in concert with selecting appropriate HVAC alternatives and sizing systems. Use acceptable computer modeling for all system choices.
- *Assess the interaction* between the HVAC equipment and other related systems such as lighting, office equipment, fire protection, security, etc. in order to optimize design and energy efficiency.
- *Use separately zoned HVAC systems* to serve areas with different users, loads, orientations, and hours of operation.
- Keep computer server rooms on separate cooling systems when rooms require continuous cooling.
- *Locate thermostats or other sensors* to cover areas of similar load (similar occupancy and similar solar exposures).
- *Design for "diversity of use"* assuming that not all spaces will be used at all times or with full occupancy or at full load.

- ***Consider distributed air-handling mechanical rooms*** to reduce the size and complexity of ductwork systems. Special attention should be paid to noise control.
- ***Evaluate the potential use of heat-wheels by performing a cost-effective analysis.*** Heat wheels area more energy efficient than glycol loops, but cost more and require additional space. Care should be taken to select systems appropriate for use in contaminated air streams such as laboratories.
- ***Evaluate heat recovery with glycol loops by performing a cost-effective analysis.*** Ideally, the glycol loops should have a summer bypass, so, during periods when the temperature differential is small (and sensible heat recovery is very inefficient), the heat recovery coil is bypassed; thus avoiding unnecessary increase in the fan energy.
- ***Isolate building air intakes,*** placing them upwind and away from building exhaust air, loading dock, or parking lot vehicular exhaust air, as well as away from adjacent roadways, sewer vents, cooling tower spray, combustion gases, sanitary vents, trash storage areas and other sources of undesirable air contaminants.
- ***Locate and design air intakes*** for the best air supply source for the HVAC system and in favorable direction for full airside economizer mode operation, as well as for minimizing snow intake in areas where this occurs.
- ***Avoid use of ceiling plenums*** as return air ducts.
- ***Provide low-leak outside air dampers,*** which utilize separate dampers for minimum outside air and main outside air functions in order to accurately control minimum outside air intake quantities. Do not use main outside air damper to set minimum fresh air level.
- Provide modulating dampers to ensure minimum outside air.
- Implement demand control ventilation.
- ***Avoid rooftop units*** that preclude other roof top uses and add maintenance difficulty, which may result in inefficient operation. Always install air-handling units in accessible locations where they can be maintained.



COOLING EQUIPMENT OPTIMIZATION

With building loads minimized, designers should select cooling systems and equipment based on meeting those loads at maximum efficiency.

33. MAXIMIZE COOLING EQUIPMENT EFFICIENCY

- ***Select electric chillers that operate at high efficiency*** at full and anticipated part loads. Model overall chiller efficiency based on seasonal ton-hours at likely load profile (not just peak load). Consider variable speed drive chillers in this investigation.
- ***Consider alternative cooling technologies,*** e.g. passive cooling and natural ventilation, natural gas-fired absorption or engine driven chillers with heat recovery or cogeneration, ground source heat pumps, etc.
- ***Select high efficiency cooling towers,*** generally draw-through style. Provide variable speed drives on all cooling tower fans.
- Control the cooling tower operation with wetbulb reset instead of constant temperature.

- ***Consider thermal energy storage*** (e.g. ice storage) as a means to avoid peak loads for cooling, especially if equipment sizes can be reduced. Example; district cooling using ice storage at Chase Field in Phoenix, Arizona. http://www.apses.com/content/northwind/press_releases/media20000516.asp
- ***Consider water-cooled vs. air-cooled*** condensers on a systems efficiency basis. Also consider maintenance issues (for cooling towers and cost of chemical treatment, water, and maintaining additional equipment). For water-cooled condensers, consider heat rejection to ground (open loop or standing column if water table is less that 50ft deep, or closed loop) or to adjacent water body.
- ***Consider winter free-cooling*** from air economizers that can reduce district chilled water use and cost.
- ***Consider enthalpy heat recovery*** in conjunction with a reduction in the size of the chiller plant.
- Consider enthalpy-based economizers vs. sensible heat only.
- ***Consider desiccant dehumidification.*** Address indoor air quality issues and operational lifecycle costs.
- Provide variable speed drives on chillers and chilled water pumps.

34. "RIGHT SIZE" COOLING EQUIPMENT

- ***Avoid over sizing chillers*** or other cooling equipment more that recommended by ASHRAE.
- ***Consider chillers of different sizes*** that could allow for more efficient part-load operation of the system, or chillers with variable speed drives.
- *Segregate spaces that need cooling from spaces that do not need it,* thus providing cooling only where required. Downsize cooling equipment accordingly.
- If an increase in cooling load is possible in the future, provide space in the central plant for another chiller, if and when it becomes necessary. Avoid purchasing and additional chiller now, since future chillers will be more energy efficient and more environmentally friendly. If you must purchase the additional capacity by significantly over sizing one of the chillers for the current facility, provide that chiller with variable speed drive.

DISTRIBUTION SYSTEM OPTIMIZATION

35. OPTIMIZE DISTRIBUTION SYSTEM

- ***Use premium efficiency motors for fans and pumps*** to reduce operating costs and energy consumption.
- ***Use variable air volume (VAV) systems*** to reduce operating energy cost of main air handling units unless analysis clearly indicates that an alternative system would be more cost-effective over the life cycle. Note that because of typical over sizing for AHU's, a VAV system may even reduce that peak kW demand by the fan.
- Use variable speed drives to vary air and water volumes in order to reduce fan and pump energy requirements.
- Consider displacement-cooling methods to reduce cooling loads.
- ***Consider the use of under-floor air distribution systems*** in applications where this design produces efficiency, occupancy controllability, reliability, and renovation ease and cost benefits sufficient to justify added costs.
- ***Design energy efficient ductwork,*** minimizing duct runs, duct velocity and duct resistance in order to reduce horsepower requirements and energy use.
- Locate ductwork to avoid exposure to building skin or outside temperatures.
- ***Avoid three-way by-pass valves*** in order to reduce needless pumping.
- ***Consider Direct Digital Controls to the VAV boxes,*** especially if the boxes have reheat coils. Minimize the reheat by increasing the air temperature when most boxes are in the reheat mode.
- Design for supply water temperature reset in heating and cooling loops.
- Find ways to insure high temperature deltas on chilled water loops.
- ***Install flow or BTU meters*** to analyze distribution loads.

36. OPTIMIZE USE OF SENSORS

- ***Consider providing a thermostat*** in every room (with digital readout and the ability for occupants to adjust temperature within a limited range consistent with temperature policy).
- ***Locate sensors proximate to occupants*** for readings of temperature and carbon dioxide.

DOMESTIC HOT WATER

37. OPTIMIZE HOT WATER SYSTEM

- Utilize low-flow water fixtures.
- ***Utilize energy efficient water heaters.*** Consider condensing water heaters to maximize efficiency. Consider retrofitting large, non-condensing DHW heaters with oxygen trim control.
- Do not oversize water heaters or hot water tanks.
- ***Utilize heat recovery methods*** when available, to provide service or domestic hot water.
- ***Consider utilizing point-of-use water heaters*** for small loads and where hot water demand is spread out with a building.
- Consider solar water heating.
- ***Consider alternatives to re-circulating hot water systems*** or employ and automatic control for re-circulating hot water systems to reduce temperature or cycle pumps off during hours of non-use.

Building Lighting, Equipment, Energy Management, and Utilities

Lighting design begins with daylighting. Why light interior spaces with electricity if better quality lighting can be provided by sunlight? Electric lighting should be designed to maximize savings from daylighting. Because lamp, ballast and light fixture efficiencies keep improving each year, it is possible to design high quality lighting systems with lower and lower wattage densities. More efficient plug load and hard-wired equipment is also now available, in part due to the Energy Star program. Building process utilities – like steam, compressed air, and purified water - can also be provided more efficiently. On-site co-generation of electricity can offer efficiency advantages. Electricity can also be provided from renewable sources with the purchase of grid-supplied "green power" or the on-site generation of electricity from building integrated photovoltaic solar electric panels.

ENERGY EFFICIENT LIGHTING

38. UTILIZE ENERGY EFFICIENT INTERIOR LIGHTING

- ***Select the most energy efficient lamps, ballasts and fixtures*** to achieve low lighting densities (e.g. 1.0 watt per square foot or less in offices). Current lighting technology makes it possible to achieve footcandle thresholds with lighting wattage densities approaching 0.6 watts per square foot.
- ***Use lamps with a high color-rendering index*** (CRI) for indoor use. The 841 series T-8 lamps are the current energy standard; these have a CRI of 82 and color temperature of 4100 K.
- Incandescent lights should not be used except when required in historic structures.
- ***Use compact fluorescent lights*** in all "high hat" can-type fixture applications. High CRI, dimming, compact fluorescent lamps are available.

Compact fluorescent bulbs are part of a new generation of energy efficient lighting.

- Use T-5 lamps only where cost effective and where their higher lumen output can be utilized without creating glare. (T-5 fixtures may be appropriate for high bay lighting.)
- ***Select fluorescent fixtures on the basis of efficiency.*** Consider reflectorizedfixtures (with fewer lamps) to maximize fixture efficiency. Consider high efficiency lenses to improve fixture efficiency. Avoid inefficient parabolic and paracube fixtures.
- ***Consider indirect or direct/indirect fixtures*** only if the watts per square foot efficiency is comparable to or lower than what would be achieved with direct fixtures.
- ***Utilize task lighting*** to permit reduced ambient lighting and lower lighting power density (watts per square foot).
- Select LED (light emitting diode) exit lights.
- Strictly minimize any decorative electric lighting.

39. USE LIGHTING CONTROLS TO REDUCE LIGHTING "BURN HOURS"/HOURS OF OPERATION.

- Provide multi-zone and multi-level switching for multiple use spaces.
- Incorporate time clock or energy management system controls, or infrared, ultrasonic or combination occupancy motion detectors in spaces where cost-effective.
- ***Properly zone lighting circuits and switches*** to optimize energy efficient operation including perimeter zones using photocell control, dimming controls and daylight harvesting.

40. PROVIDE ENERGY EFFICIENT OUTDOOR LIGHTING

- ***Use energy efficient high-pressure sodium fixtures*** to illuminate streets, parking lots, and walkways to achieve foot-candle thresholds.
- Strictly minimize any outdoor decorative lighting.
- ***Eliminate light trespass from building site*** by using energy efficient fixtures which direct light downward. Also consider cut-off luminaires, low-reflectance surfaces, etc., to prevent light trespass.
- ***Meet IESNA standards.*** Provide outdoor light levels and uniformity ratios that meet or are lower than those recommended by the Illuminating Engineering Society of North America (IESNA) Recommended Practice Manual: Lighting for Exterior Environments (RP-33-99).

ENERGY EFFICIENT EQUIPMENT

41. SELECT ENERGY EFFICIENT EQUIPMENT AND LOAD-CONSUMING DEVICES.

- ***Specify only energy efficient plug load equipment*** for office, lab, kitchen, food service, vending, etc. Specify Energy Star label when available and /or equipment with built-in timers or power management features set as default to maximize likelihood of use.
- Purchase liquid display (LCD) low wattage flat screens in lieu of conventional CRT monitors for computers.
- Use premium efficiency motors and controls.
- ***Use variable speed drives to control all motors 5 hp. or greater*** that run for extended hours and where reduced, variable flow is possible.
- ***Identify and use energy efficient alternatives*** for all other energy using equipment in building, e.g. elevators, compressors, and motors.

42. UTILIZE EFFICIENT POWER DISTRIBUTION SYSTEMS.

- Distribute electricity at high voltage, consistent with safety and other applicable codes.
- *Consider utilizing direct current* (DC) from photovoltaic systems, fuel cells, or other sources in lieu of conversion to alternative current (AC). DC may be appropriate for certain applications such as discrete lighting circuits or computer equipment.
- *Avoid electromagnetic pollution/exposure.* Locate high voltage and high current electrical feeders, panel boards, transformers or motors away from occupants/personnel. Provide electromagnetic interference (EMI) shielding if necessary.

ENERGY LOAD MANAGEMENT

43. PROVIDE APPROPRIATE ENERGY MANAGEMENT

Digital energy meters and control systems.

- Use direct digital control energy management systems.
- ***Provide building automation systems*** with the following characteristics:
  - Computerized monitoring and control of all major HVAC systems and equipment, capable of implementing full range of energy conservation and efficiency strategies. These should include setback strategies for when spaces are unoccupied.
  - Energy consumption monitoring and trend logging through hourly graphs to follow the effect of operational changes and monthly graphs to analyze historical data.
  - Load tracking and load anticipation capability to optimize system response to building pickup and power demand level.
  - Load shedding and demand control through scheduled equipment cycling.
  - Local controllers able to manage equipment operation independently and gather data for reporting.
  - Appropriate interconnection with central energy management systems if available.
- ***Employ all appropriate peak-shaving strategies*** to reduce demand and flatten load profile when electricity is most costly.
- ***Consider shifting electric power consumption*** by utilizing thermal storage system in conjunction with a conventional chiller system.
- ***Provide equipment controls*** for vending machine, water cooler and other refrigeration loads.

44. IMPROVE STRATEGIES FOR CONTROLLING HVAC AND VENTILATION

- ***Operate based on need.*** Do not air condition all spaces. Do not air condition spaces when not in use.
- Eliminate or strictly minimize simultaneous heating and cooling. Design for zero reheating during the cooling season.
- ***Turn off non-essential electric equipment*** during peak hours to limit electric demand.

- ***Install CO2 sensors and implement demand control ventilation*** to allow for the reduction of outside ventilation air in large spaces with variable occupancy. Verify that recommendations are consistent with code requirements.
- ***Provide supply air temperature reset controls*** for air distribution systems based on space occupancy. (Use appropriate control algorithms on VAV systems to avoid losing fan horsepower savings.)

45. PROVIDE FOR ONGOING ACCOUNTABILITY AND OPTIMIZATION OF BUILDING ENERGY AND WATER CONSUMPTION PERFORMANCE OVER TIME.

- ***Develop a measurement and verification plan*** to enable continuous optimization of building energy performance by installing continuous metering equipment for appropriate end-uses specified.

ELECTRICAL POWER SYSTEMS

46. PROVIDE THE MOST EFFICIENT SOURCES OF POWER

- Avoid electric space and water heating.
- ***Evaluate the cost-effectiveness in existing facilities*** of converting electric space and/or water heating to natural gas or some other energy source.
- Explore cogeneration and distributed power generation applications.
- Explore renewable energy sources and technologies.
- Explore the use of gas-fired micro-turbines or fuel cells.
- ***Improve power factor*** by specifying appropriate equipment.
- Use high-efficiency and K-Rated transformers to serve non-linear equipment.
- ***Avoid electromagnetic radiation exposure.*** Locate high voltage and high current electrical feeders, panel boards, transformers or motors away from campus occupants and school personnel. Provide electromagnetic interferences (EMI) shielding.
- ***Install adequate metering*** to monitor electric loads.

Water Management and Conservation

All new design should conserve water and protect water quality. There are many energy and environmental costs associated with wasting potable water. Sustainable design measures conserve water by increasing fixture efficiency and by avoiding technologies that waste water. With proper design, landscaping can be accomplished in a water efficient manner. Harvested storm water or recycled tap water (gray water) can provide irrigation when required.

WATER EFFICIENCY

47. CREATE WATER EFFICIENT LANDSCAPING. LIMIT OR ELIMINATE THE USE OF POTABLE WATER FOR LANDSCAPE IRRIGATION.

- *Perform a soil/climate analysis.* Determine appropriate landscape types and design the landscape with indigenous plants to reduce or eliminate irrigation requirements.
- *Eliminate permanent irrigation systems* through exclusive use of indigenous plant materials, allowing for temporary "quick couple" systems during the establishment period or extreme drought.
- Consider high-efficiency irrigation systems such as drip irrigation or soaker hoses.
- *Collect and use rainwater* or gray water for landscape irrigation, urban gardening, and site washing purposes.

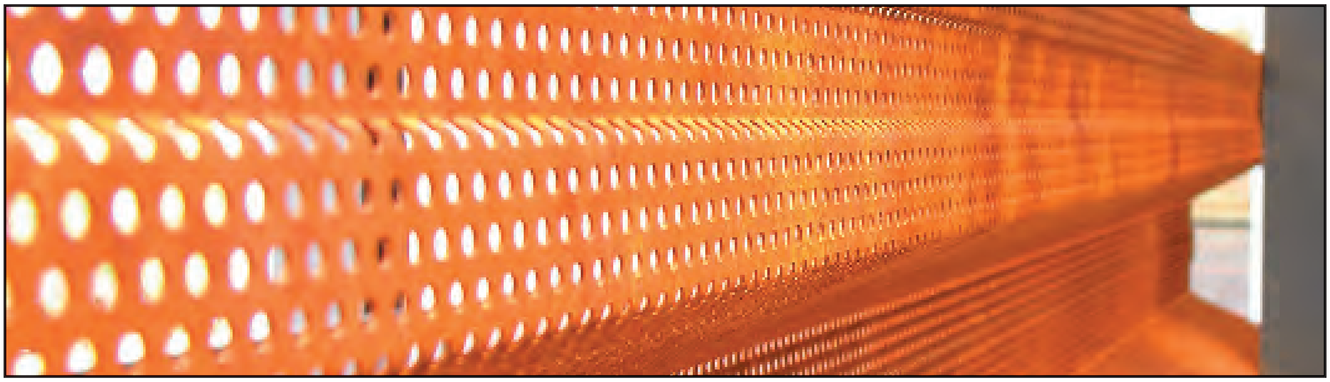
48. IMPLEMENT WATER USE REDUCTION STRATEGIES TO CONSERVE WATER. MAXIMIZE WATER EFFICIENCY WITHIN BUILDINGS TO REDUCE THE BURDEN ON MUNICIPAL WATER SUPPLY AND WASTEWATER SYSTEMS.

- Estimate the potable and non-potable water needs for the building.
- *Use high-efficiency fixtures* or dry fixtures. Consider the use of low flow toilets and urinals (increasingly available), waterless urinals, and/or composting toilets.
- *Consider occupant sensors* to reduce the potable water demand for lavatories.
- *Consider reusing stormwater and gray water* for non-potable applications such as toilet and urinal flushing, mechanical systems, and custodial uses.
- Consider use of automatic, usually spring loaded shut-off controls on sinks to lower water usage.
- *Improve water efficiency of HVAC equipment.* Do not utilize "one pass" cooling units that use potable water and discharge it to a drain.
- *Improve water efficiency of water-cooled cooling towers*. Provide metering for both the makeup and the blowdown rate. Use a water analysis program to monitor water quality and to minimize blowdown rate.
- *Consider ozonation for laundering systems and cooling tower make-up* water. Using ozone in lukewarm water reduces the need for detergents and bleaches in hot water and reduces energy use of laundering.
- Use only horizontal axis Energy Star compliant clothes washers.

Rainwater is collected from the roof and stored in drums to be used for watering plants outside a home in Guadalupe, Arizona.

49. USE INNOVATIVE WASTEWATER TECHNOLOGIES. REDUCE GENERATION OF WASTEWATER AND POTABLE WATER DEMAND, WHILE INCREASING LOCAL AQUIFER RECHARGE.

- *Consider reusing stormwater or gray water* for sewage conveyance by installing a dual plumbing system for gray water use.
- *For taller buildings, consider a black water* system in lieu of gray water. The black water system will have a lower first cost, and its water saving features are more advanced.
- *Consider roof water harvesting.* Avoid lead, copper, or terne roofing, which can contaminate water sources.
- *Recover groundwater.* Use excess groundwater from sump pumps to provide a source of recycled water.
- *Consider a solar-aquatic installation* or artificial wetlands to treat wastewater on site to tertiary standards.



Materials and Product Selection

There are many considerations required when selecting the appropriate materials and products used for high performance buildings. While traditional selection criteria such as cost, durability, performance and aesthetics remain very important in these buildings, sustainable design requires consideration of environmental and health issues related to their manufacture, installation and disposal. Methods for evaluating products for their environmental and health performance are often controversial and are still evolving. There are a growing number of regulated certification programs that provide evaluation and labeling for different sustainability criteria. As the evaluation methods have been improving the demand for materials and products has also rapidly grown. There are now a large number of building products with improved environmental characteristics and this is steadily increasing. It is important that design professionals have a working knowledge of the key environmental and health related criteria associated with different material types.

Environmentally preferable materials are those that are reused; recycled; low in embodied energy; renewable; sustainably harvested; non-toxic in production, use and disposal; and local (to reduce transportation impacts). Carefully selected materials can significantly reduce the environmental impact of new construction. In addition, planning recycling collection spaces and strategies for building occupants in the original design can reduce material waste over the life cycle of the building.

WASTE PREVENTION

50. CONSIDER RENOVATING EXISTING BUILDINGS INSTEAD OF NEW CONSTRUCTION TO EXTEND LIFE OF EXISTING BUILDING STOCK, CONSERVE CULTURAL RESOURCES, AND REDUCE NEW BUILDING ENVIRONMENTAL IMPACTS.

- ***Consider reuse of existing buildings,*** including structure, shell and non-shell elements, and upgrading outdated components such as windows, mechanical, electrical and plumbing systems.
- ***Remove elements that pose contamination risk*** to building occupants, and upgrade outdated components.
- Quantify the extent of anticipated building reuse.

51. USE MATERIALS EFFICIENTLY AND PREVENT WASTE.

- ***Maximize resource conservation through efficient space design.*** Explore options for smaller buildings that still meet program through tight net-to-gross, compact form and use of multi-purpose spaces.
- ***Consolidate program uses wherever possible,*** and co-locate communal spaces to reduce building area.
- ***Design to accommodate future needs*** and anticipate future retrofit requirements.
- Reduce material used and waste generated through efficient design and detailing.
- ***Design for disassembly and reuse of materials*** where possible, particularly for applications that are likely to change frequently.

- Eliminate unnecessary finishes in areas where not required.
- ***Design using modular sizing of spaces and materials*** (as an organizing concept) to the extent practicable.
- ***Select products for durability,*** reducing replacement costs, occupant disruption and waste disposal.
- ***Consider use of moveable partition systems*** and/or raised-floors systems to reduce churn costs and material waste.

52. REUSE MATERIALS. USE SALVAGED, REFURBISHED OR REUSED MATERIALS AS PART OF BUILDING MATERIALS PALETTE.

- ***Establish a project goal*** for the incorporation of salvaged, refurbished or reused materials into the building design.
- ***Identify materials and suppliers*** that can achieve the project goal.
- ***Retain nonstructural elements*** such as roofing material, and portions of interior walls, doors, flooring, and ceiling systems, when doing major renovation of an existing building.
- ***Consider salvaged materials*** such as beams and posts, floor coverings, paneling, doors and frames, cabinetry and furniture, brick and decorative items.
- ***Do not reuse materials and/or systems that contain toxins (***e.g. lead, asbestos) and/or are not efficient (e.g. single-pane windows).

53. PROMOTE STORAGE AND COLLECTION OF RECYCLABLES.

- ***Provide a dedicated recycling area, appropriately sized and easily*** *accessible* to serve the entire building for separation, collection and storage of materials including (at a minimum) paper, cardboard, glass, plastics, and metals. Provide appropriate access for collection vehicles.
- ***Provide areas on each floor or in each major department*** for recycling collection stations consistent with facilities recycling program.
- ***Consider employing cardboard balers, aluminum can crushers, recycling chutes*** and other waste management technologies to further enhance the recycling program.
- Provide easy to understand graphics and/or text for each material.

54. DIVERT CONSTRUCTION AND DEMOLITION DEBRIS FROM LANDFILLS BY RECOVERING USABLE RESOURCES.

- ***Develop quantifiable waste management goals*** to redirect recoverable and recyclable materials back to secondary waste handlers.
- Research local waste recycling market.
- ***Develop appropriate specification language and details*** for the required Construction and Demolition Waste

MATERIALS FOR REDUCED ENVIRONMENTAL IMPACTS

55. GIVE PREFERENCE TO MATERIALS WITH LIFE-CYCLE ANALYSES INDICATING AVOIDED OR REDUCED ENVIRONMENTAL DAMAGE.

- Avoid materials that may cause environmental damage in their manufacture, use or disposal.
- ***Give preference to materials with low-embodied energy,*** where other performance criteria have been satisfied. Products with higher embodied energy involve more air emissions and pollution.

56. USE MATERIALS MANUFACTURED AND/OR HARVESTED REGIONALLY (WITHIN A RADIUS OF 500 MILES).

- ***Establish a project goal*** for the incorporation of locally manufactured materials into the building design and identify local materials suppliers that can achieve this goal.
- Establish which of those materials are also locally harvested.

57. SELECT MATERIALS WITH RECYCLED CONTENT. CONSIDER BOTH POST-CONSUMER AND POST-INDUSTRIAL RECYCLED CONTENT.

- Note: Recycled content materials shall be defined in accordance with the Federal Trade Commission document, Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e).
- ***Establish a project goal*** for the incorporation of recycled content materials into the building design and identify material suppliers that can achieve this goal.
- Conform to the most current consensus product standards for given product types and resource efficient materials. These standards have been developed by government agencies, environmental certification services, or trade organizations for environmentally preferable material selection.
- Consider alternative materials to plywood, such as composite boards, which use milling by-products, recycled paper, wood scraps, and/or agricultural waste.
- Consider composite products made from recycled materials, such as wood and plastic. It is important to use wood from sources that practice sustainable forest management.

Management Plan for the Contractor (General or Prime Contractor or Construction Manager) to implement.

58. USE CERTIFIED WOOD TO REDUCE NEGATIVE ENVIRONMENTAL IMPACTS ON FORESTS.

- *Specify Forest Stewardship Council (FSC) certified wood materials* including but not limited to structural and general dimensional framing, mill-work, flooring, finishes, furnishings, and non-rented temporary construction applications such as bracing, concrete form work, and pedestrian barriers.
- Establish a project goal for the incorporation of FSC-certified wood products into the building design.
- *Identify material suppliers* that can achieve this goal.
- *Reduce the use of large timbers* by utilizing assemblies that require smaller pieces of wood, and by using glue-laminated beams and other types of prefabrication.

59. USE RAPIDLY RENEWABLE BUILDING MATERIALS (MADE FROM PLANTS THAT ARE TYPICALLY HARVESTED WITHIN A 10-YEAR OR SHORT CYCLE) FOR THE MAXIMUM AMOUNT OF BUILDING MATERIALS AND PRODUCTS USE IN THE PROJECT.

- *Establish a project goal* for the incorporation of rapidly renewable materials into the building design and identify material suppliers that can achieve the project goal.
- *Consider rapidly renewable materials* such as linoleum, cork or bamboo flooring, poplar Oriented Straw Board (OSB), straw board or wheat grass for cabinetry materials, and others.
- *Consider the source of the material,* with its effect on embodied energy, (e.g. bamboo from Asia, cork from Europe) and the toxicity of binders in the product (e.g. some bamboo flooring contains ureaformaldehyde binders).

ASSESSMENT OF MATERIALS

60. PROVIDE COORDINATED IMPLEMENTATION OF ENVIRONMENTALLY PREFERABLE MATERIALS DURING DESIGN AND CONSTRUCTION.

- *Develop specification criteria.* Provide specification criteria for environmentally preferable materials selection and for their appropriate methods of installation. Criteria can be developed from product consensus standards and from additional materials guidelines.
- *Conform to the most current consensus product standards* for low-emitting and resource efficient materials. These standards have been developed by government agencies, environmental certification services, or trade organizations for environmentally preferable material selection.
- *Identify material suppliers* that can achieve these goals.
- *Research manufacturer or third-party certification*. Check for third party certification for manufacturer claims.

- ***Quantify the total percentage*** of salvaged, recycled content, local and regional, rapidly renewable, sustainably harvested, low-embodied energy, and non-toxic low-emitting materials that are installed during construction.
- Provide documentation and manufacturers' certifications.

61. CONSIDER LIFE CYCLE COSTS IN PRODUCT AND ASSEMBLY SELECTION

Consider life cycle cost when selecting products. Durable, low maintenance products are often less expensive over time than other products that require frequent replacement. "Life Cycle Cost" typically the amortized annual cost of a product, including capital costs, installation costs, operating costs, maintenance costs, and disposal costs discounted over the lifetime of the product. Also consider environmental and health issues associated with product manufacture, use and disposal.

Additional Resources

- US Green Building Council
  http://www.usgbc.org/

- Arizona Green Building Council
  http://chapters.usgbc.org/Arizona/

- Whole Building Design Guide
  http://www.wbdg.org/

- US Department of Energy: Office of Energy Efficiency and Renewable Energy
  http://www.eere.energy.gov/buildings/highperformance/

References

Energy Information Administration (1991) Annual Energy Outlook. US Department of Energy. <http://www.eia.doe.gov/>

Kibert, C. (2005). Sustainable Construction: Green Building Design and Delivery. New Jersey. John Wiley & Sons.

Krarti, M. (2000) Energy Audit of Building Systems: An Engineering Approach. CRC Press.

UB High Performance Building Guidelines (2004). University of Buffalo, The State University of New York.

USGBC (2006). LEED New Construction v2.2 Reference Guide. United States Green Building Council. Washington, DC.

Van Der Ryn, Sim, and Stuart Cowan (1996). Ecological Design. Washington, DC. Island Press.

WBDG (2005) Whole Building Design Guide. National Institute of Building Sciences. <http://www.wbdg.org/index.php>

CHAPTER 4:

SYSTEMS, MATERIALS AND TECHNOLOGIES

Chapter 4 Table of Contents

Product Categories

Table of Contents Continued

Table of Contents Continued

Table of Contents Continued

Product Categories

- ALTERNATIVE PAVEMENTS
- PASSIVE SOLAR DESIGN
- BUILDING ENVELOPE: THERMAL AND MOISTURE PROTECTION
- BUILDING ENVELOPE: OPENINGS
- ELECTRIC AND NATURAL LIGHTING
- HEATING AND COOLING SYSTEMS
- ONSITE ENERGY GENERATION
- WATER USE AND CONSERVATION
- VENTILATION AND INDOOR ENVIRONMENTAL QUALITY
- BUILDING AUTOMATION
- SERVICES

ALTERNATIVE PAVEMENTS

- PERVIOUS CONCRETE
- OPEN-JOINTED CONCRETE PAVERS
- OPEN-CELLED PAVERS
- GROUND COVER SUPPORT STRUCTURES
- STABILIZED GRADED AGGREGATE

Pervious Concrete

Applications

Parking Lots, Residential Streets, Sidewalks, Basketball and Tennis Courts

Definition

Pervious concrete is a special type of concrete that allows water and air to pass through it.

Description

Often referred to as 'no-fines' concrete, pervious concrete consists of;

- Portland Cement
- Coarse aggregate (stone)
- Water
- Admixtures

If mixed and formed according to specification, the resultant pavement will contain 15-25% void space with the concrete. The void spaces interconnect to form channels that allow water and air to pass through the pavement structure.

Benefits

- Prevents standing water from forming on pavement surface.
- Functions as a dry detention pond.
- Reduces capacity requirements for drainage facilities and discharge basins.
- Eliminates water pollution through natural biological processes.
- Recharges ground water aquifers.
- Improves the health of trees by improving the root system access to air and water.
- Absorbs and stores less heat than conventional pavements for UHI mitigation.

Limitations

- Durability under heavy traffic loads resulting in raveling.
- Maintenance issues associated with clogging.
- Limited experience among local contractors.
- Hazardous liquid spills difficult to clean up.

Typical Design Section

- 6" inches of pervious concrete
- 6" layer of clean aggregate provides structural support and temporary storage for water passing through the pavement.
- Non-woven filter fabric is placed below the aggregate to prevent migration of soil into the void spaces.
- A moisture barrier sheet is also desired at the junction between pervious and conventional pavement.

Maintenance

- Silts, clays, or heavy organic materials may clog pavement and reduce permeability. In most cases however, even at 99% clogging, permeation rates of 2-7inch/hour are observed.
- Cleaning and inspecting every two years to ensure functionality as per specifications Cleaning methods include high pressure rinsing and vacuuming.

Additional Considerations

- Infiltration rates of native soil need to be at least 0.5 inch/hour.
- Grade should have 0% slope.
- An under drain below pervious pavement may be necessary for less permeable soils. Overflow structure and connection to storm sewer is required to handle instances of abnormally heavy rains.

LEED Credits

Pervious concrete is recognized by the LEED program. Pervious concrete may contribute LEED points in the following areas;

- Stormwater Management. By allowing water to soak through and infiltrate, pervious paving reduces stormwater flow and pollutant loads. Contributes to LEED Credit SS 6.
- Minimize Site Disturbance. By integrating paving and drainage, less site area may need to be used to manage stormwater, allowing a more compact site development footprint. May contribute to LEED Credit SS 5.

First Costs

- In the Phoenix Metropolitan area as of 2006, pricing is at approximately $5/ft2 for a 6" pervious concrete parking lot. This price includes the 4" aggregate base layer.
- Integrating a stormwater pond and a parking lot into one unit can result in a large cost savings as compared to the conventional designs that include storm water drains and storm water sewer piping etc.

Life-Cycle Cost Considerations

There are additional costs associated with washing and inspecting the pavement throughout its lifetime. Many pervious concrete pavements have been in use for over twenty years before requiring replacement. The life of the pavement greatly depends on the quality of its initial construction as well as regular maintenance procedures.

Codes and Specifications that Apply

Pervious concrete, when used as part of a water management strategy may help to meet requirements for several City of Phoenix codes including;

- Chapter 32A GRADING AND DRAINAGE
- Chapter 32C STORMWATER QUALITY PROTECTION

A specification for pervious concrete is currently under development for the Southwestern United States. Several regions have already developed specifications for several states in the southeastern and northwestern regions.

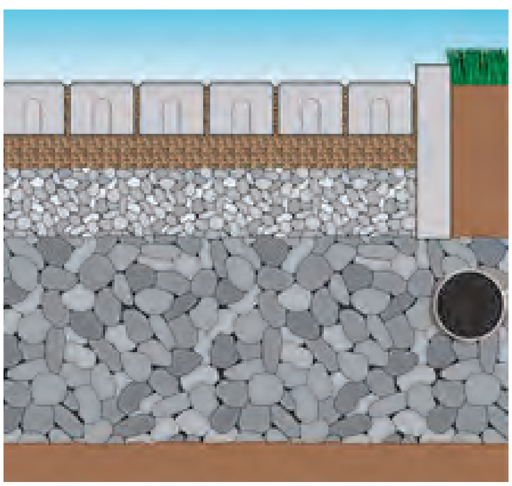
Example Regional Contractors

CEMEX Inc.
Website: www.cemexusa.com
Phoenix Area Phone (602) 416-2652

Rinker Materials
701 N. 44th St.
Phoenix, AZ 85008
Website: www.rinker.com
Phoenix Area Phone: (602) 220-5000

Progressive Concrete Inc.
2136 W. Melinda Ln
Phoenix, AZ 85027
Website: ProgressiveConcrete.com
Phone: 623-582-2274

Additional Resources and Case Studies
http://www.concretethinker.com
http://www.concreteparking.org/pervious/pervious%20success%20stories.htm



Open-Jointed Concrete Pavers

Definition

Interlocking Pavers with inherent voids between blocks.

Applications

Sidewalks, driveways, terraces, roads, and small parking lots.

Description

Describe the functionality of material or technology. List the major components and describe their role in the overall system.

Benefits

- Permeability and reflectivity can mitigate urban heat island effect.
- Allows water and air to transfer through surface for healthy tree growth.
- Applicable for slow to medium speed traffic.
- Comparable in strength to Portland cement concrete and asphalts pavements.
- Aesthetics. Available in varying colors, shapes and sizes.
- No cure time. Immediately drivable.
- Long operational lifespan.
- Reduced costs of utility cuts repair.
- Contributes to LEED® Certification.

Limitations

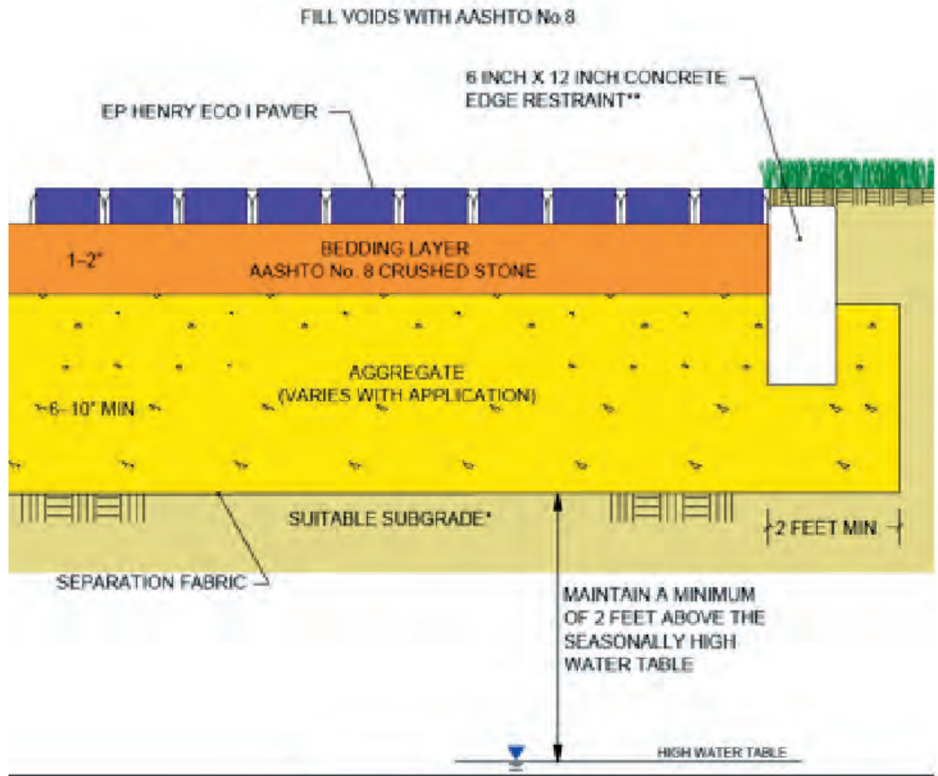
- Higher initial costs than conventional asphalt paving.
- Not as permeable as other alternatives.

Typical Design Section

Open jointed concrete pavers differ from common interlocking pavers in that they have either a spacer strip on each of the adjoining sides to prevent face to face contact between the surrounding pavers or they have indentations on the sides and corner that create void spaces even when the blocks are tightly jointed. The gap created by these techniques can create spaces that make up nearly 10% of the entire paved area. These voids allow for water and air to percolate into the base materials below the pavement. The joint is filled with sand during construction but remains permeable.

The general design and construction of open jointed concrete pavers remains very similar to that of standard interlocking pavers except that the base structure needs to be pervious as well. This can be accomplished through the use of washed large stone aggregate over a geo membrane to prevent the subgrade soil from rising up and filling the voids.

National Center of Excellence for Smart Innovations
Arizona State University



Residential Driveways with Stone Infill

Installation and Maintenance

- Preparation – Once the a suitable subgrade is established for the project (infiltration rate of 0.5inch/hour) a geo membrane fabric is laid down before the stone reservoir of 3⁄4" washed aggregate stone is added. This followed by a based layer, or bedding layer, consisting of 1-2" of AASHTO No. 8 (3.8") crushed stone.
- Placement – The units are placed manually or mechanically on the bedding layer and constrained by the edge restraints. The pavers are then vibrated using a high frequency plate vibrator which forces crushed aggregate into the bottom of the pavers and also begins compaction of the base layer. Sand is then spread into the joints until they are filled. Complete compaction turns the loose pavers into a tight, interlocking system that distributed vertical loads horizontally through shear force.
- Inspection – Determine if the open celled paver is free of sediment and debris such as mulch, leaves and other organic mater. Determine if standing water exists for long periods of time after a storm event. Make sure that the stormwater does not remain in the paver system for greater than 48 hours after an average storm. Check the paver system surface for structural deterioration, compaction or spalling once ever year.
- Maintenance and Repair – It is recommended that the paver joints be vacuumed as needed to remove organic debris that may cause reduced permeability. If undesired weeds or grasses begin to grow in joints it is recommended to you a nontoxic

vegetation killing agent. In areas of the pavement where the pavement has completely failed it is recommended that full depth removal reconstruction of that particular section be completed. This does not compromise the surrounding paver system.

LEED Credits

Pervious interlocking concrete pavers may contribute to LEED points in the following areas;

- SS Credit 4.4. Minimize Site Disturbance. By integrating paving and drainage, less site area may need to be used to manage stormwater, allowing a more compact site development footprint. May contribute to one point.
- SS Credit 7.1. Urban Heat Island Effect. By using pavers that have a resulting reflectance of 30% or greater for more than 30% of all paved surfaces the project can gain at least one point towards LEED® certification.
- SS Credit 6. Stormwater Management. By allowing water to soak through and infiltrate, pervious pavers reduces stormwater flow and pollutant loads. May contribute to two points.
- MR Credit 5. Regional Materials. Because both the aggregate and binders is extracted and distributed in Arizona this material could contribute to at least 2 points in this LEED® category.

CSI Number, City Codes and Specifications that Apply

CSI Code 02780 Unit Paver

Stabilized Aggregate, when used as part of a water management strategy may help to meet requirements for several City of Phoenix codes including;

- Chapter 32A GRADING AND DRAINAGE
- Chapter 32C STORMWATER QUALITY PROTECTION

Specifications – A wide array of specifications concerning interlocking pavers for all types of applications, soil conditions, and traffic loads is provided on the Interlocking Paver Institutes webpage, www.icpi.org.

Example Contractors

Advanced Pavement Technology (Illinois)
Website: www.advancedpavement.com
Phone: 877-551-4200

Air Void Block, Inc. (California)
Website: www.airvolblock.com
Phone: 805-543-1314

Capitol Ornamental Concrete Specialties, Inc. (New Jersey)

Website: www.capitolconcrete.com

Phone: 737-727-5460

EP Henry Corporation (New Jersey)

Website: www.ephernry.com

Phone: 800-444-3679

Pave Tech, Inc. (Minnesota)

Website: www.pavetech.com

Phone: 800-728-3832

SF Concrete Technology, Inc. (Ontario, Canada)

Website: www.sfconcrete.com

Phone: 905-828-2868

UNI-Group U.S.A. (Florida)

Website: www.uni-groupusa.com

Phone: 800-872-1864

Unilock, Ltd. (Illinois)

Website: www.unilock.com

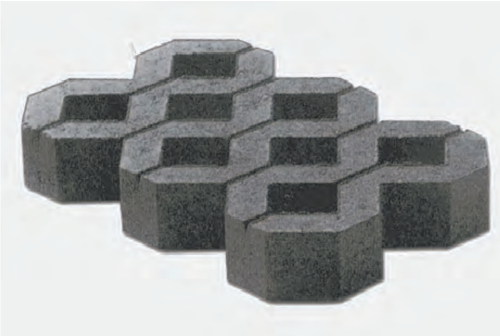
Phone: 800-864-5625

Additional Resources and Case Studies

Interlocking Concrete Paver Institute

Website: www.icpi.org

Phone: 202-712-936



Open-Celled Pavers

Definition

Concrete pavers that integral void for grass or drainage material.

Applications

Driveways, firelanes and parking lots.

Description

Open celled pavers come in a variety of designs centered on the common functionality of providing permeability and vegetation growth while maintaining a significant amount of load bearing capacity. The pavers can range from single blocks of less than a square foot to slabs reaching areas of a square yard. The large voids that form the permeable portion of the pavement system can result in a 39% permeable surface area when summed over the entire movement. The voids are back filled with a grass turf or with a permeable crushed stone aggregate. Open celled pavers are typically installed over a gravel base course that acts as storage for stormwater as it infiltrates through the porous paver system into underlying permeable soils.

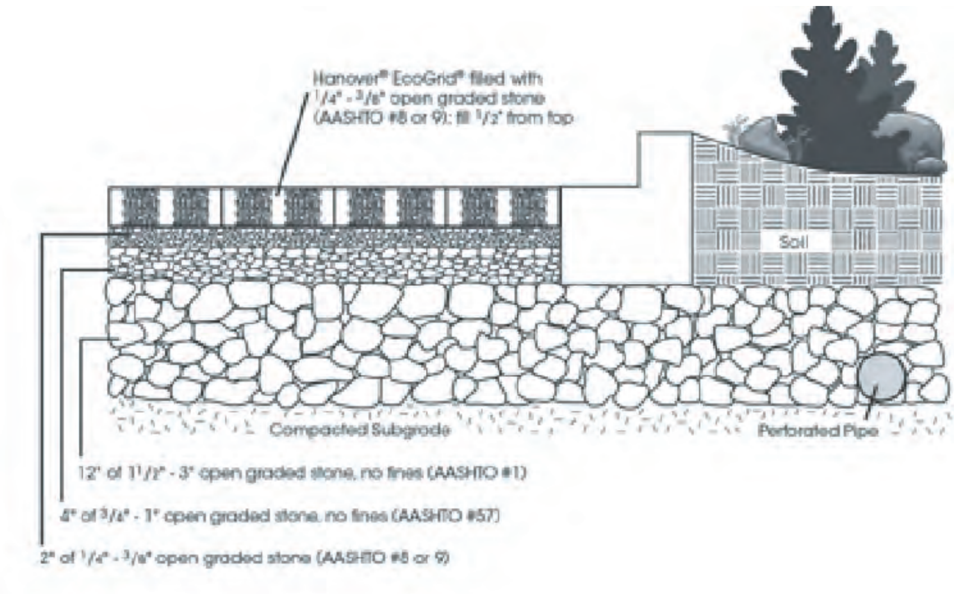
Benefits

- Vegetation, permeability and reflectivity can mitigate urban heat island effect.
- Allows water and air to transfer through surface for healthy tree growth.
- Applicable for heavy loads and high traffic volumes. .
- No cure time. Immediately drivable.
- Long operational lifespan.
- Reduced costs of utility cuts repair.
- Contributes to LEED® Certification.

Limitations

- Higher initial costs than conventional asphalt paving.
- Reflectance depends on the concrete mix and aggregate properties.
- Grass turf will require watering in dry climates in addition to regular mowing.

Typical Design Section



Installation and Maintenance

- Preparation – Once the a suitable subgrade is established for the project (infiltration rate of 0.5inch/hour) a geo membrane fabric is laid down before the stone reservoir of 3⁄4" washed aggregate stone is added. This followed by a based layer, or bedding layer, consisting of 1-2" of AASHTO No. 8 (3.8") crushed stone.
- Placement – The units are placed manually or mechanically on the bedding layer and constrained by the edge restraints. The pavers are then vibrated using a high frequency plate vibrator which forces crushed aggregate into the bottom of the pavers and also begins compaction of the base layer. Sand is then spread into the joints until they are filled. Complete compaction turns the loose pavers into a tight, interlocking system that distributed vertical loads horizontally through shear force.
- Inspection – Determine if the open celled paver is free of sediment and debris such as mulch, leaves and other organic mater. Determine if standing water exists for long periods of time after a storm event. Make sure that the stormwater does not remain in the paver system for greater than 48 hours after an average storm. Check the paver system surface for structural deterioration, compaction or spalling once ever year.
- Maintenance Activities – Inspect pavers surfaces for trash and organic matter such as mulch or leaves. Make sure all vegetated areas around the pavement system are stabilized and not draining into the pavement. Mow and remove clippings as required. Vacuum sweep paver system to keep free of sediment four times a year. Repair failed areas by replacing the top and base layers of the damaged area. In repairing a section, undamaged pavers on that section can be reinstalled after new base sections have been placed.

LEED Credits

Pervious open celled pavers may contribute to LEED points in the following areas;

- SS Credit 4.4. Minimize Site Disturbance. By integrating paving and drainage, less site area may need to be used to manage stormwater, allowing a more compact site development footprint. May contribute to one point.
- SS Credit 7.1. Urban Heat Island Effect. By using pavers that have a resulting reflectance of 30% or greater for more than 30% of all paved surfaces the project can gain at least one point towards LEED® certification.
- SS Credit 6. Stormwater Management. By allowing water to soak through and infiltrate, pervious pavers reduces stormwater flow and pollutant loads. May contribute to two points.

CSI Number, City Codes and Specifications that Apply

CSI Code 02780 Unit Paver

Stabilized Aggregate, when used as part of a water management strategy may help to meet requirements for several City of Phoenix codes including;

- Chapter 32A GRADING AND DRAINAGE
- Chapter 32C STORMWATER QUALITY PROTECTION

Example Regional Contractors

Bomanite (California)
Website: www.bomanite.com
Phone: 559-673-2411

D'Hanis (Texas)
Website: www.dhanisbricktile.com
Phone: 800-299-9399

EP Henry Corporation (New Jersey)
Website: www.ephenry.com
Phone: 800-444-3679

Hanover Architectural Products (Pennsylvania)
Website: www.hanoverpavers.com
Phone: 800-426-4242

Hastings Pavement Company, LLC (New York)
Website: www.hastingsarchitectural.com
Phone: 800-669-9294

Nicolock (New York)
Website: www.pavestone.com
800-580-7283

Additional Resources and Case Studies

It is best to contact the product supplier to learn more about specific techniques, design specifications and case studies concerning the different options among open celled block pavers.

Ground Cover Support Structures

Definition

A product used to increase the structural support of loose ground cover materials while maintaining their natural function and behavior.

Applications

Parking lots, fire lanes and erosion control.

Description

Interlocking open grid for stabilizing ground materials such as decomposed granite, soil, and vegetation. Usually made of a of recycled resins these support structures are laid down on top of a prepared subgrade and then filled in with natural materials. The open grid design supports heavy trucks and prevents the soils from shifting while still allowing full permeability.

Benefits

- Can support most all traffic volumes and loads.
- Can blend into the native landscape while controlling dust.
- Vegetation, high reflectivity and porosity help to mitigate urban heat island effect.
- Permeability prevents puddling and helps recharge groundwater.
- Very low embedded energy as compared to asphalt and Portland cement concrete.
- Very long lifespan.
- Simple installation and maintenance requirements.
- Made of recycled resins.
- Contributes to several LEEDTM point categories.

Limitations

- Not recommended for fast traffic areas.
- Grass field applications require watering, fertilizing and mowing and are not meant for areas with high traffic volumes.

Installation and Maintenance

The generalized construction process of a ground support structure is provided below;

- Preparation – Prepare sandy gravel base course to a depth determined by a soils engineer. Check drainage rate of existing base course before add mat.
- Placement of Filter Fabric and Mats – Cover entire area with filter fabric making sure to overlap at the joints between sections. Roll our open grid mats so that the sheets so that they will lock together. Trim section around curbs using scissors or saw. Hammer anchors at designated intervals to hold the mats in place.
- Filling in With Soil or Gravel– Fill the open grid structures with gravel using front-end

loader for large jobs and wheel barrow and shovel for smaller jobs. Use rakes and broom to evenly distribute the gravel to level slightly about the support structure.

- Compaction – Use a large driving roller or vibrating plate compactor to compact the gravel into the grid. Wetting the material may help the gravel interlocking.
- Inspection - Immediate drive over the surface to trouble shoot for any areas where gravel may in excess or additional compaction is required.
- Maintenance - When gravel is used, regular maintenance my include refilling in areas where gravel layer has been thinned out. Gravel section will also require raking and vacuuming of leaves to prevent excess organic build up. This can be accomplished as part of regular landscape maintenance. Grass covered support structures require watering in dry climates and will need regular trimming using standard mowing procedures. Do not aerate as this will damage the support structure.

Additional Considerations

- Slope should be considered as these structures perform better when the slope is less than eight percent.
- Underlying soils should have a percolation rate of 0.64cm to 1.3cm of water per hour.
- Bedrock should not be closer than two feet (0.6m) below the base course.
- Gravel and grass structures are not meant for areas where high speed acceleration or braking and turning occur. Examples of these areas include parking lot entrances and exits that connect to higher speed roads.

LEED® Credits

Ground cover support structures may contribute to LEED points in the following areas;

- SS Credit 4.4. Minimize Site Disturbance. By integrating paving and drainage, less site area may need to be used to manage stormwater, allowing a more compact site development footprint. May contribute to one point.
- SS Credit 7.1. Urban Heat Island Effect. The increase in surface permeability and potential to use highly reflective granite both contribute to at least one point for this credit.
- SS Credit 6. Stormwater Management. By allowing water to soak through and infiltrate, pervious paving reduces stormwater flow and pollutant loads. May contribute to two points.
- MR Credit 4. Recycled Content. Most products in this category are made of post industrial or post consumer recycled resins they can contribute to as much as 2 points towards certification.
- MR Credit 5. Regional Materials. Because the aggregate and soil can be extracted in Arizona this material could contribute to at least 1 point in this LEED® category.

Life-Cycle Cost Considerations

Most ground support products will have a useful life of 25 years in most climates when properly designed and maintained.

CSI Number, City Codes and Specifications that Apply

CSI 32 12 43 Flexible Porous Pavers

Stabilized Aggregate, when used as part of a water management strategy may help to meet requirements for several City of Phoenix codes including;

- Chapter 32A GRADING AND DRAINAGE (refer to attached documents)
- Chapter 32C STORMWATER QUALITY PROTECTION

Specifications – The specification developed by Invisible Structure, Inc. for their ground support structure, GravelPave® can found in Appendix X.

Example Regional Contractors

Invisible Structure, Inc. (Golden, Colorado)
Website: www.invisiblestructures.com
Phone: 800-233-1510

GeoSupply (Arizona)
Website: www.geosupply.com
Phone: 602-305-8094

NDS, Inc. (California)
Website: www.ndspro.com
Phone: 800-726-1994

PermaTurf Co., Inc. (New Hampshire)
Website: www.permaturf.com
800-498-4116

Presto Products Company (Wisconsin)
www.prestogeo.com
Phone: 800-548-3424

RK Manufacturing, Inc. (Massachusetts)
Website: www.rkmfg.com
Phone: 800-957-5575

Grid Technologies, Inc. (Rhode Island)
Website: www.gridtech.com
Phone: 800-959-7920

Additional Resources and Case Studies

www.epa.gov

Stabilized Graded Aggregate

Definition

Compacted crushed stone and sand held together by a bonding agent.

Applications

Walking paths, bike paths, driveways, fire lanes and parking lots.

Description

Crushed aggregate and sand that has been adequately mixed with a bonding agent is laid over a prepared subgrade. The water is added to activate the boding compound and the surface is compacted using multiple paths from a multi-ton roller with no vibration. The resulting surface is semi-permeable. Rate of infiltration can vary with the aggregate gradation. The surfaces look natural as whey will take on the same color of the stone aggregate. Chemical stains can added to the mix if additional colors are desired.

Benefits

- Appears natural and blends in with desert landscape.
- High reflectivity and porosity help to mitigate urban heat island effect.
- Permeability prevents puddling and helps recharge groundwater.
- Lower embedded energy than asphalt and Portland cement concrete.
- Produced locally in Phoenix using regional materials.
- May help a project obtain several LEEDTM points.

Limitations

- Not meant for roads and heavy trucks.
- May experience some loose rocks in the first year of operation.
- Maintenance requirements.

Installation and Maintenance

The construction process of a stabilized aggregate pavement generally consists of the following steps;

- Preparation – Make sure base course is adequately prepared and pre-soaked.
- Blending – Thoroughly mix stabilizer with crush stone/sand mix per specifications.
- Placement/Compaction – Place the aggregate on top of the base and smooth out to desired grade. Add required amount of water and wait a designated amount of time (6-48 hours) before compacting. Compact the surface using a 1 to 5 ton roller making sure that separation and/or plowing does not occur. The roller should make 4 to 8 paths in total for adequate compaction.
- Watering – A light spray of water is applied to the surface after compaction.
- Inspection – A completed surface should be checked for the uniform and solid

throughout, no evidence of chipping or cracking and no loose material should be present on the surface.

- Maintenance – Use a mechanical blower or hand rack as needed to remove, debris such as paper, grass clippings, leaves or other organic material. When snow plowing is necessary a rubber baffle or wheels should be attached to the plow blade to prevent damage to the surface.
- Repairs – If cracking occurs sweep fines into voids apply water and compact using an 8" to 10" hand tamp plate. For major damage, excavate area to full depth and replace with new aggregate and binder and compact using hand tamp or larger 1000lb roller. Traffic must remain off of repaired section for 12 to 48 hours.

LEED® Credits

Pervious stabilized aggregate surfaces may contribute to LEED points in the following areas;

- SS Credit 4.4. Minimize Site Disturbance. By integrating paving and drainage, less site area may need to be used to manage stormwater, allowing a more compact site development footprint. May contribute to one point.
- SS Credit 7.1. Urban Heat Island Effect. By using aggregate that have a resulting reflectance of 30% or greater for more than 30% of all paved surfaces the project can gain at least one point towards LEED® certification.
- SS Credit 6. Stormwater Management. By allowing water to soak through and infiltrate, pervious paving reduces stormwater flow and pollutant loads. May contribute to two points.
- MR Credit 5. Regional Materials. Because both the aggregate and binders is extracted and manufactured in Arizona this material could contribute to at least 2 points in this LEED® category.

Life-Cycle Cost Considerations

Stabilized aggregate surfaces will need to be inspected for damage at least every two years. If surface permeability is important to the project additional maintenance and cleaning requirements may be required. The life of the pavement greatly depends on the quality of its initial construction as well as regular maintenance procedures.

CSI Number, City Codes and Specifications that Apply

CSI 02795 Porous Paving

Stabilized Aggregate, when used as part of a water management strategy may help to meet requirements for several City of Phoenix codes including;

- Chapter 32A GRADING AND DRAINAGE (refer to attached documents)
- Chapter 32C STORMWATER QUALITY PROTECTION

Example Regional Contractors

Soil-Loc, Inc. (Scottsdale, Arizona)
Website: www.soilloc.com
Phone: 480- 948-8144

Matrix Industries (Phoenix, Arizona)
602-758-2815

Soilworks, LLC (Gilbert, Arizona)
Website: www.soilworks.com
Phone: 480-545-5454

Stabilizer Solutions, Inc. (Phoenix, Arizona)
Website: www.stabilizersolutions.com
Phone: 602-225-5900

EarthCare Consultants, LLC (Phoenix, Arizona)
Website: www.earthcareconsultants.com
Phone: 888-792-4001

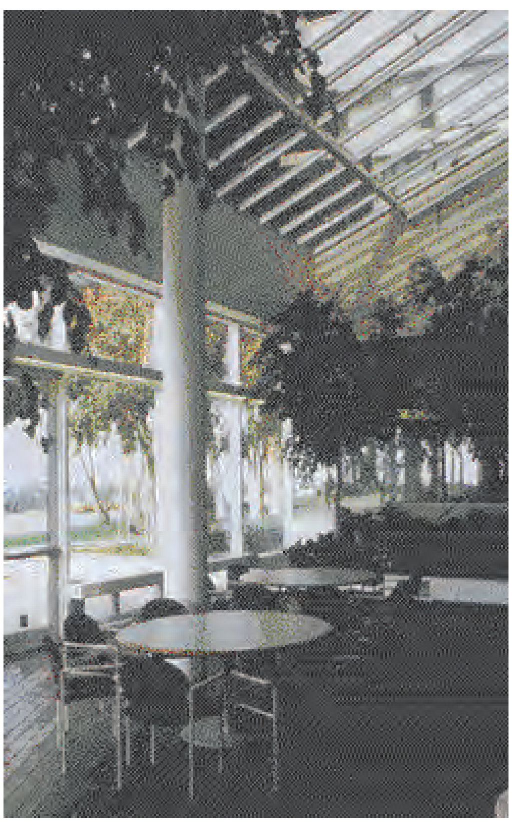
Reclamare Company (Washington)
Website: www.reclamare.com
Phone: 206-824-2385

Additional Resources

National Stone, Sand & Gravel Association
Website: www.nssga.org
Phone: 703-525-8788

Passive Solar Design

- PASSIVE SOLAR ENERGY
- EXTERIOR SHADING DEVICES
- EXTERIOR SHADING WITH VEGETATION



Passive Solar Energy

Applications

Passive solar energy design principles can be applied to any type of buildings. In hot climates, the design mitigates the sun's heat; in cold climates the design takes advantage of it.

Definition

Passive solar energy is a technology which makes use of the building's windows and materials to collect, store, and distribute the sun's heat in the winter and reject solar heat in the summer without the use of mechanical or electrical devices.

Description

Buildings designed for passive solar energy incorporate large south-facing windows and materials that absorb the sun's heat. The longest walls run from east to west. In most climates, passive solar designs also must block intense summer solar heat. They typically incorporate natural ventilation and roof overhangs to block the sun's strongest rays during that season.
Window design and glazing choices in particular, are critical factors for determining the effectiveness of passive solar heating system. In heating climates, large south-facing windows are used, as these have the most exposure to the sun in all seasons. In cold climates, large south-facing windows allow significant solar energy and also provide day lighting; properly sized overhangs can prevent overheating in the summer. In hot climates, north-facing windows can provide day lighting without heating the house.
In the other hand, east- and west-facing windows generally cause excessive heat gains in the summer and heat losses in the winter, and are usually sized small.

Benefits

- Passive solar design is highly energy efficient. Can reduce heating bills by as much as 50%.
- Energy from the sun is free.
- No investments in mechanical and electrical devices such as pumps, fans and electrical controls.
- Helps conserve valuable fossil fuel resources.
- A well-designed and built passive solar building does not have to sacrifice aesthetics either.
- Passive solar design also reduces greenhouse gases that contribute to global warming because it relies on solar energy, a renewable, nonpolluting resource.

Limitations

- In areas where experienced solar architects and builders are not available, construction costs can run higher than for conventional homes, and mistakes can be made in the choice of building materials, especially window glass. Passive solar homes are often built using glass that, unfortunately, rejects solar energy. Such a mistake can be costly.

- On the other hand, passive solar heating tends to work best and be most economical in climates with clear skies during the winter heating season and where conventional heating sources are relatively expensive.

Maintenance

Minimal cleaning maintenance.

Additional Considerations

Room and furniture layouts need to be planned carefully to avoid glare on equipment such as computers and televisions.

LEED Credits

May apply to the Energy and Atmosphere section.

First Costs

Passive solar design can be used in most parts of the world. If designed by an experienced passive solar architect, buildings using passive solar design principles don't have to cost more up front than conventionally designed buildings. And when they do, the savings in energy bills quickly pay for themselves.

Life Cycle Cost Considerations

Whenever integrating a passive solar energy design, it is important to think in terms of life-cycle costs rather than first costs. Life-cycle cost analysis takes into account factors such as durability, energy cost savings over a building's anticipated life, and the component's impacts on maintenance, replacement, and disposal costs, among other considerations. An increase in design cost of 2% to 4% over that of conventional buildings is considered acceptable for most sustainable, low-energy building designs. These increases, and those associated with materials and system enhancements, are often recouped in the first few years of operation through energy savings alone.

Codes and Specifications that Apply

Arizona's Solar Energy Credit provides an individual taxpayer with a credit for installing a solar or wind energy device at the taxpayer's Arizona residence. Qualifying technologies include solar domestic water heating systems, solar swimming pool and spa heating systems, solar photovoltaic systems, solar photovoltaic phones and street lights, passive solar building systems (trombe walls, thermal mass, etc), solar day lighting systems (excluding conventional skylights), wind generators, and wind powered pumps.

Source: http://www.ncsl.org/programs/energy/ArizonaFS.htm

Example Regional Contractors

Arizona Solar Center
c/o Janus II - Environmental Architects
4309 E. Marion Way
Phoenix, AZ 85018
http://www.azsolarcenter.com

Pictures

Source: http://www.engext.ksu.edu/ees/renewables/solar.html
Source: http://www.daviddarling.info/encyclopedia/P/AE_passive_solar_heating.html
Source: http://www.ivydene1.co.uk/vamp/stnicks/centre.html

Exterior Shading Devices

Applications

Multi-family housing projects, offices, administration buildings and other structures employing day lighting.

Definition

External shading devices incorporated in the building facade to limit the internal heat gain resulting from solar radiation.

Description

The use of sun control and shading devices is an important aspect of many energy-efficient building design strategies. In particular, buildings that employ passive solar heating or day lighting often depend on well-designed sun control and shading devices.

During cooling seasons, external window shading is an excellent way to prevent unwanted solar heat gain from entering a conditioned space.

The design of effective shading devices will depend on the solar orientation of a particular building facade. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer.

Benefits

- Reduces glare
- Reduces cooling loads
- Improves design aesthetics

Limitations

- Cleaning is a maintenance concern
- Increases capital cost

Maintenance

Need to be cleaned which turns out to be a maintenance concern.

Consideration should also be given to ensure that the window washing process is not adversely affected by the sunshades.

Additional Considerations

Care should be taken to integrate the design with the glazing and/or curtain wall design. Other design considerations should include seismic and snow loading.

When designing shading devices, carefully evaluate all operations and maintenance (O&M) and safety implications. In some locations, hazards such as nesting birds or earthquakes may reduce the viability of incorporating exterior shading devices in the design.

LEED Credits

May apply to Energy and Atmosphere section.

First Costs

It depends on the design. Nevertheless, the architectural value and occupant comfort are central issues but are difficult to quantify.

Life Cycle Cost Considerations

The need to maintain and clean shading devices, particularly operable ones, must be factored into any life-cycle cost analysis of their use.

Example Contractors

Industrial Louvers, Inc.
511 S. 7th Street
Delano, MN 55328
Tel 1-800-328-3421
(local) 763-972-2981
(fax) 763-972-2911
e-mail: ilinfo@industriallouvers.com

Ametco Manufacturing Corporation
4326 Hamann Parkway, P.O. Box 1210
Willoughby, OH 44096
Tel 1-800-321-7042
Fax 440-951-2542
e-mail: ametco@ametco.com

Pictures

Source: www.industriallouvers.com
Source: www.industriallouvers.com
Source: www.industriallouvers.com
Source: www.industriallouvers.com
Source: www.ametco.com

Exterior Shading with Vegetation

Applications

Any kind of building

Definition

Deciduous vegetation planted around buildings to block summer sun and to reduce cooling energy demand.

Description

Deciduous vegetation is often an attractive and inexpensive form of shading, because it follows the local seasons, not the solar calendar.

The effectiveness with which trees provide shade and save energy depends on their tree density, shape, and placement. The dimensions of the shaded building, the position of the sun in the sky, and whether a tree keeps its leaves year-round also determine overall energy savings.

Benefits

- Researchers in a joint study by the Department of Energy's Lawrence Berkeley National Laboratory (LBNL) and the Sacramento Municipal Utility District (SMUD) placed varying numbers of trees in containers around homes to shade windows and walls. Cooling energy savings ranged between 7% and 40% and was greatest when trees were placed to the west and southwest of buildings.
- Another LBNL study modeled the effects of shading homes with vegetation in seven U.S. cities. By providing 20% tree canopy – the equivalent of planting one tree to the west and another to the south of a home – buildings could achieve annual cooling savings of 8% to 18% and annual heating savings of 2% to 8%.

Limitations

- Need maintenance
- Needs space for planting

Maintenance

Watering and occasional pruning, fertilizing and mulching.

Additional Considerations

Vegetation used for shading should be properly located so as not to interfere with solar gain to buildings in winter. Also note that trees require maintenance, pruning, watering and feeding. As they grow they change their shading pattern, and they can be damaged or killed, leaving the building exposed.

Deciduous trees should be planted on the east, southeast, southwest and west sides of buildings. Highest priority should be given to planting shade trees due west of west-facing windows. Select trees that can be planted within 6 m of windows and grow to be at least 3 m taller than the window.

On the south side of a building, it is best to plant deciduous trees with high, spreading crowns that are near the building to maximize shading in the summer when the sun angle is high.

<u>LEED Credits</u>

May apply for Energy and Atmosphere section.

<u>First Costs</u>

It varies depending on the type of tree.

<u>Life Cycle Cost Considerations</u>

There would be some annual maintenance costs and time for watering and occasional pruning, fertilizing and mulching.

<u>Example Regional Contractors</u>

Arid Zone Trees
9750 East Germann Road
Mesa, Arizona
480-987-9094
Fax: 480-987-9092
www.aridzonetrees.com

Klean-Rite Landscaping
2121 S Mill Ave
Tempe, AZ
(480) 517-1949

Pdi Landscape Development
2020 S Mcclintock Dr
Tempe, AZ
(480) 985-7777

Dicks Landscaping
915 N Mary St
Tempe, AZ
(480) 429-8808

Pictures

Source: www.aridzonetrees.com

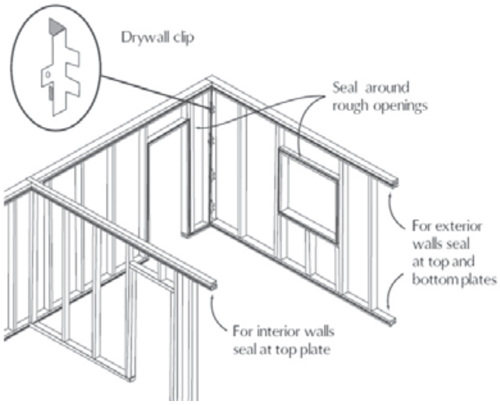
Source: www.aridzonetrees.com

Source: www.aridzonetrees.com

Source: www.aridzonetrees.com

Building Envelope: Thermal and Moisture Protection

- AIRTIGHT DRYWALL APPROACH
- DYNAMIC BUFFER ZONES
- RAISED ACCESS FLOORING
- PERLITE INSULATION
- CELLULOSE INSULATION
- CEMENTITOUS FOAM INSULATION
- CERAMIC COATINGS
- MINERAL WOOL EXTERIOR



Airtight Drywall Approach (ADA)

Applications

It may be applied to new construction or retrofit. All types of buildings could make use of this technology: residential, industrial or commercial.

Definition

A building construction technique used to create a continuous air retarder that uses the drywall, gaskets, and caulking. Gaskets are used rather than caulking to seal the drywall at the top and bottom. Although it is an effective energy-saving technique, ADA was designed to keep airborne moisture from damaging insulation and building materials within the wall cavity.

Description

Infiltration and exfiltration of air in buildings have serious consequences, because they are uncontrolled; the infiltrating air is untreated and can therefore entrain pollutants, allergens, and bacteria into buildings. Air infiltration and exfiltration are the cause of unnecessary energy consumption in buildings due to the added heating and cooling loads and the additional humidification or dehumidification needed.

The U.S. Department of Energy reports that up to 40% of the energy used by buildings for heating and cooling is lost due to infiltration. Using CONTAMW/TRNSYS modeling shows that in newer buildings infiltration is responsible for about 25% of the heating load and 4% of the cooling load (Emmerich, and Persily, 1998). To control air infiltration and exfiltration in buildings, a conceptual approach to air tightening is needed; an alternative is the airtight drywall approach (ADA).

The typical procedure for ADA is to seal any seams and joints where the foundation, sill plate, floor joist header, and sub-floor meet. The spaces between floors, the sub-floor, rim joist, and plates are also sealed. The wall-framing plates are sealed to the lower sub-floor and the upper rim joist. Gaskets are often used at the top and bottom wall plates (between the drywall and framing) and between ceiling drywall and attic joists.

Airtight electrical boxes (or standard electrical boxes sealed with caulk) complete the air barrier. Holes where pipes and cables pass through also need to be sealed before the wall and ceiling finishes are applied. After all this has been done and the perimeter drywall seams have been finished, the room is effectively sealed from expensive and uncomfortable drafts.

Such airtight buildings often consume one-third less energy when compared to similar unsealed buildings. Also, test measurements of airborne contaminants in an ADA-detailed building (including those with mechanical ventilation) found that the reduction of air infiltration did not diminish the indoor air quality significantly. However, for health and safety, it is strongly recommended that a heat recovery ventilator (HRV) or enthalpy recovery ventilators (ERV) be installed in an airtight home for proper ventilation.

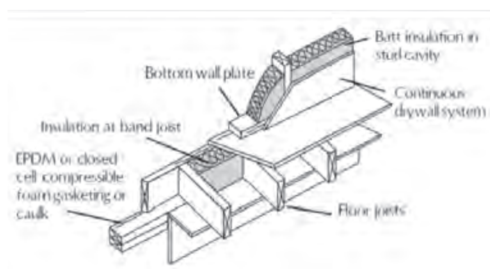
Benefits

- Builders can adapt ADA principles to suit any design and varying construction schedules.
- Airtight buildings often consume one-third less energy when compared to similar unsealed buildings
- Provides airtightening at the finishing stage of construction

Limitations

- Gaskets and caulking can be damaged by subcontractors when installing the drywall or utilities.
- It is not a vapor barrier. If required, a separate vapor barrier must be used with ADA. Faced insulation batts, polyethylene plastic or vapor barrier paint work well.
- Requires special electrical boxes for best results

Typical Design Section



Maintenance

The application can be expected to last the life of the building with adequate maintenance and when dismounted can be recycled into new material.

Additional Considerations

Little training is required to apply ADA successfully.

LEED Credits

It may be applicable to the energy and atmosphere section of LEED.

First Costs

Materials and labor for standard designs should only cost a few hundred dollars. Gasket cost is approximately 15-20¢/foot.

Life Cycle Cost Considerations

Sealing the home with an advanced sealing technique, such as ADA, can make a big difference in winter heating bills and overall comfort, as well as reduce the infiltration of dust and other outside pollutants, such as pollen.

Codes and Specifications that Apply

Check local codes and regulations, restrictions may apply in some states.

Example Regional Contractors

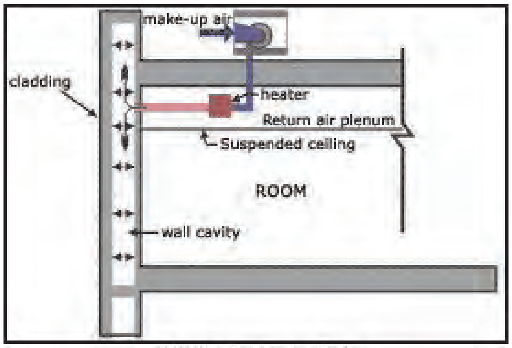
Atko Building Materials, Inc.
22255 N. Scottsdale Rd.
Scottsdale, AZ 85255
Phone: 480-585-7100
Fax: 602-254-9531

Henry Products, Inc.
1425 N. McQueen Rd.
Gilbert, AZ 85234
Phone: 480-926-1444
Fax: 480-497-8120

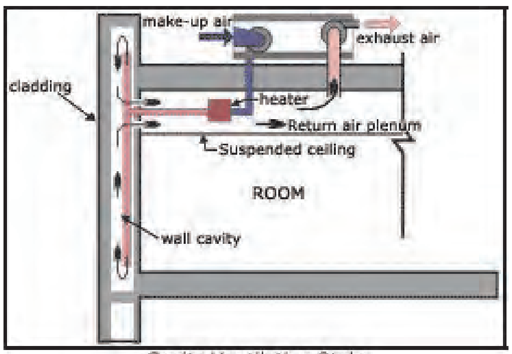
Thunderbird Building Materials
2808 N. 27th Ave.
Phoenix, AZ 85009-1707
Phone: 602-272-1394
Fax: 602-269-7930

Pictures

Source: www.southface.org
Source: www.southface.org



Cavity Pressure Style



Cavity Ventilation Style

Dynamic Buffer Zones

Applications

It could be applied to different building types: residential, commercial and industrial.

Definition

The DBZ is a technique to reduce moisture accumulation in external walls and halt their deterioration.

Description

New buildings and restored buildings are frequently upgraded to higher indoor humidity levels. Buildings that are humidified and pressurized often suffer from wall or roof cavity condensation due to imperfect air sealing, higher indoor humidity and an air pressure difference. Furthermore, condensation in exterior walls and roofs can lead to corrosion, wood rot, spalling of masonry and mortars, mold production.

The primary reason for implementation of this type of design solution (DBZ) is to ensure elimination of moisture accumulation from either interior or exterior sources within the enclosure assemblies. Generally, the DBZ works in the following manner: dry conditioned air is forced into and out of interstitial exterior wall cavities by means of dedicated mechanical systems in such a manner as to constantly ensure positive pressure within the cavities relative to interior environments.

Enclosure cavities are maintained at such low absolute humidity that the cavity air maintains a dew point temperature below the outdoor temperature for most of the time during winter. Since these types of building enclosures rely on mechanical systems, performance verification and commissioning are key components to the success of the assembly to achieve its objectives

A DBZ system, which can control construction cavity condensation effectively is gaining market acceptance for many types of buildings. There are two types of dynamic buffer zone (DBZ) systems, the ventilated cavity DBZ system and the pressure controlled cavity DBZ system.

In the ventilated cavity system, the construction cavities are ventilated with dry outdoor air and pressure relieved or controlled through a return and exhaust system. In some cases, the cavity air is recirculated if the dewpoint temperature of the air is low and the cavity air requires supplementary heat. Ventilated cavity systems have had limited application in buildings due to the complexity of the system, the required controls and poor performance in some applications.

In the pressurized cavity DBZ, the construction cavities are pressurized slightly above the indoor pressure of the building with preheated outdoor air but without a pressure relief or return air system. These systems are less expensive to design and build and more efficient at controlling construction cavity moisture conditions; however, pressurized cavity designs cannot provide perimeter heat.

Benefits

- Prevents condensation in exterior walls
- DBZ can make heritage buildings more comfortable places to work, eliminate the need for costly retrofit projects, and has the potential to reduce energy costs.

Limitations

- Indoor air quality problems if there are imperfect seals between the building and the wall cavity
- Ventilation design may result in decreased condensation control
  Preheating outdoor air may increase energy costs

Maintenance

A DBZ system may include supply and exhaust fans, temperature, RH and pressure sensors and controllers, sealed cladding components and a sealed interior plane of airtightness. These devices will need regular maintenance orders.

LEED Credits

May be applicable to the energy and atmosphere section.

First Costs

The cost of the application varies with the project building type and the area of application. However, from experience, the cost of modifying an exterior wall to perform as a DBZ system can vary between $220 and $350/m2.

Codes and Specifications that Apply

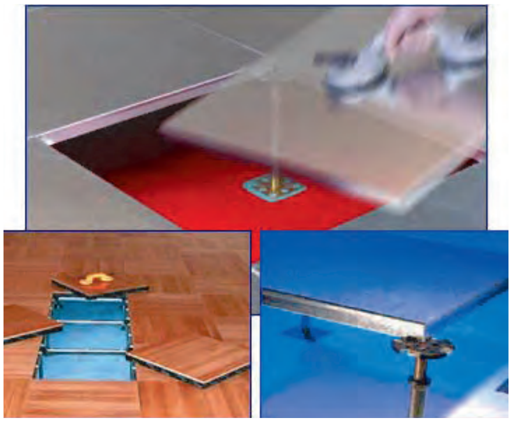
Building codes will vary, check local regulations.

Example Contractors

Rick Quirouette, B. Arch.
Quirouette Building Specialists Ltd.
532 Montreal Road, Suite 107
Ottawa ON
Canada K1K 4R4
tel 1 613 260 2224
fax 1 613 260 2228
rick.quirouette@sympatico.ca

Pictures

www.sustainablebuilding.com



Raised Access Flooring

Applications

The increasing demands for flexibility and information technology in the workplace have brought Access Flooring to be applied into offices, police stations, colleges, hospitals and many other environments. Access floors are designed into new buildings and can usually be accommodated into existing buildings, built before the demands of the modern workplace, as part of a refurbishment project.

Definition

Access floors are defined as a system of panels and supports that create a raised floor above the actual structural floor. By raising the floor up, a space is created in between the raised floor and the building structural floor where functional components like wiring for power, voice, and data can be routed and plumbing lines located. This space in between has also become increasingly valuable for heating, ventilation, and air conditioning (HVAC) distribution either as a plenum space or with defined ductwork.

Description

Access Flooring is used worldwide in offices, computer rooms, control rooms and now in some retail shops. It is sometimes referred to as , raised access flooring, safety flooring or industrial flooring. The raised floor provides numerous benefits in the provision of services during the building construction and its subsequent use as it is possible for the raised access floor panels to be lifted as required.

The cabling and cooling requirements of early mainframe computers led to the birth of Access Flooring - in simple terms panels (which are normally 600mm square) supported at the corners with pedestals down to the structural floor. This creates an accessible under floor void through which cables, ventilation and other services can be run.

Today's office worker typically requires access to data cables as well as telephone and power outlets. All of these requirements and changes need increased flexibility and a strategy to reduce the rate of churn and the cost of continually reconfiguring offices. Raised access flooring provides the answer by creating a fully accessible floor void in the room through which cables and/or ventilation can be run. Telephone, data, and power outlets can be mounted directly in floor panels, and these panels can be relocated quickly and easily for rapid reconfiguration.

The finishes available for raised access floors include:

- Vinyl, Linoleum, Caouchoc, Flex
- Velour, Needlefelt Carpets
- High Pressure Laminates, Wooden Parquet
- Loosely laid covering tiles

- Natural stone and ceramic

i.e. Wood core floor systems are ideal for projects where the architect / client do not have a specific requirement for sound insulation or fire protection. This type of raised access floor system is suitable for bonding anti-static vinyl, or for using loose laid carpet tile.

The system preferred over the traditional wood core panel is the Goldbach Norit Calcium Sulphate system. This raised floor system provides the client with a solid feel floor. This system has been manufactured from approximately 95 - 97% of recycled material.

Something important to know on access flooring is that holes are normally cut in panels for cable entry or ventilation. Cable entries are usually under machines and vents are more commonly in exposed positions. Panels with hole-cuts in them are inevitably of reduced strength. The amount by which the strength of a panel is reduced will depend on the shape and the position of the cut out and its dimensions.

Therefore, caution should be exercised in placing panels containing cut-outs in areas which are likely to be heavily trafficked by rolling loads. When equipment is being moved or maneuvered, spreader plates should be used.

Benefits

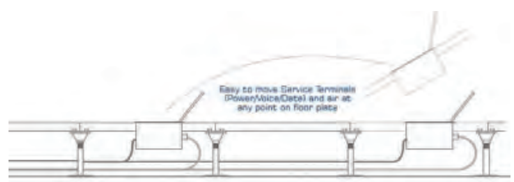
The savings, convenience, flexibility and more of access flooring systems makes having a raised floor a sustainable option, some of the benefits are as follows:

- Reduced wiring costs from traditional cable management practices, approximately 40% upon installation and reconfiguring costs can be eliminated up to 85%.
- It's easy to move HVAC air handlers and power, voice and data connections.
- No ladders required.
- Access flooring systems are noncombustible, solid, quiet, lightweight for handling ease, excellent grounding and electrical continuity, interchangeable with other panel strengths and have great rolling and ultimate load performances.

Limitations

- Higher initial costs
- Not recommended on exterior applications

Typical Design Section



Maintenance

The substructure should be checked whenever the opportunity presents itself. In order to prevent small problems becoming serious, adjustments and repairs should be made as quickly as possible. The remedy may be as fast and simple as changing standard panels in high traffic areas with others, which are in more remote positions.

LEED Credits

The United States Green Building Council (USGBC) has identified access flooring systems as a way to improve indoor air quality through their Leadership in Energy and Environmental Design (LEED) program.

First Costs

Typical raised access flooring systems can be installed for under $7 a square foot.

Life Cycle Cost Considerations

The life cycle costs will be derived from the amount of maintenance required. The repairs or services likely to be needed will depend upon function and the type and volume of traffic across the floor.

Codes and Specifications that Apply

International and National building codes may be applicable for electrical, seismic and other safety issues. i.e. International Building Code (IBC) and the BOCA National Building Code (BNBC).

Example Regional Contractors

ABTECH, Inc.
1567 E. Edinger Ave.
Anaheim, CA 92705
Phone: 714-550-9961, 800-394-7699 (toll free)
Fax: 714-550-9807
http://www.abtech.net

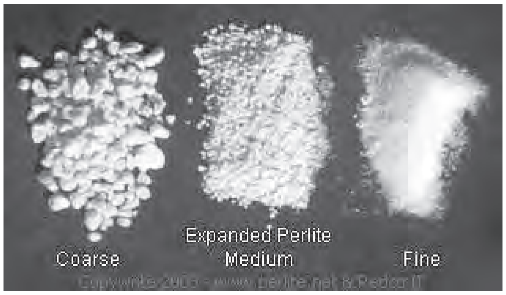
McNichols Co.
5525 W. Latham St., No. 7
Phoenix, AZ 85043-1601
Phone: 602-235-9733, 800-237-3820 (toll free)
Fax: 602-235-9734
http://www.mcnichols.com

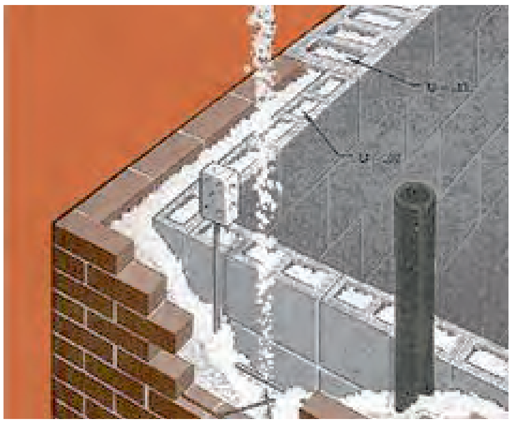
Pictures

Source: www.resourcefloors..com

Source: www.raisedfloor.co.uk

Source: www.ledportinteriors.com





Perlite Loose Fill Insulation

Applications

The physical properties of perlite include the product's lightweight feature, absorption ability and insulation values. These features make perlite applicable in many areas. These applications can be broken down into three general categories: construction applications, horticultural applications, and industrial applications. In this case, the focus will be perlite as insulation in construction and industrial area. More specifically, an example will be described of perlite loose fill insulation; this product is used in construction and could be applied to any type of new or retrofit building.

Definition

On the first hand, and as a background, it is relevant to mention that Perlite is not a trade name, is a naturally occurring siliceous rock that expands 4 to 20 times its original size when rapidly heated to approximately 3,000 °F. In reality, expanded Perlite is a "popped rock" that is inert, lightweight, sterile, permanent, incombustible, asbestos-free, non-toxic, rot and vermin proof and has a neutral pH. OSHA classifies it as a nuisance dust.

On the other hand, more specifically, Perlite loose fill insulation is an inert volcanic glass expanded by a special heat process that can be treated with water repellent material when necessary. The resultant lightweight product is a white granular material, which handles and pours easily. It provides a quick, inexpensive and permanent method for efficiently insulating masonry walls.

Description

Perlite is used in construction, it is substituted for sand or heavier aggregates in concrete and plaster mixes to reduce weights and achieve better insulation and fire protection. Perlite is naturally incombustible, resistant to thermal transmission and lightweight. Using lighter Perlite materials means that, in turn, structural building elements can be smaller, lighter and less expensive.

Perlite is also ideal for insulating low temperature and cryogenic vessels. When perlite is used as an aggregate in concrete, a lightweight, fire resistant, insulating concrete is produced that is ideal for roof decks and other applications. Perlite can also be used as an aggregate in Portland cement and gypsum plasters for exterior applications and for the fire protection of beams and columns. Other construction applications include under-floor insulation, chimney linings, paint texturing, gypsum boards, ceiling tiles, and roof insulation boards.

In regards to perlite loose fill insulation, this technology has several features. One of them is thermal insulation, the efficiency and economy of perlite loose fill insulation has been proven many years in the insulation of storage tanks for liquid gases at temperatures as low as -400 degrees F (-240 degrees C). This characteristic is also exhibited in construction, depending on design conditions, reductions in heat transmission of 50 percent or more may be obtained when perlite loose fill is used in the hollow cores of concrete block or cavity type masonry walls.

The next feature is permanency, Perlite is inorganic and therefore rot, vermin, and termite resistant and non-combustible with a fusion point of approximately 2300 degrees F (1260 degrees C). It is as permanent as the walls which contain it.

The next special characteristic is the fire rating, a UL design shows that a 2-hour rated 8, 10, or 12-inch concrete block wall is improved to 4 hours when cores are filled with perlite. One last feature is sound reduction; Perlite loose fill insulation has the ability to fill all voids, mortar lines, and ear holes thus enabling it to reduce airborne sound transmission through walls. Lightweight 8" masonry block filled with perlite achieves an STC of approximately 51 which exceeds HUD sound transmission standards.

Benefits

Perlite loose fill insulation functions as a permanent, non-toxic, non-combustible, rot-proof insulation which minimizes winter heat loss and summer heat gain. These properties allow for greater comfort at lower long-term cost.

Thermal performance tests using ASTM C-236 Guarded Hot Box Method have shown conclusively that perlite masonry loose fill insulation is the superior concrete block insulation when compared to expanded polystyrene (EPS) inserts, expanded polystyrene (EPS) beads, and vermiculite.

Limitations

Perlite loose fill insulation should be installed in well sealed cavities and masonry. All holes and openings in the wall through which insulation can escape must be permanently sealed or caulked prior to installation of the insulation. Copper, galvanized steel or fiberglass screening must be used in all weep holes.

LEED Credits

It may be applicable to the energy and atmosphere section of LEED.

First Costs

Insulation is essential in all construction for energy conservation. The original cost of installing perlite loose fill insulation can be recovered quickly due to substantial reductions in heating and air condition energy consumption. In addition, perlite loose fill insulation cuts installation costs since it is lightweight and pours easily and quickly in place without need for special installation equipment or skills.

Life Cycle Cost Considerations

A well insulated building should provide lower operational costs, greater conformity to environmental concerns, greater thermal comfort and often also greater soundproofing. Basically there are no operational costs due to maintenance, unless the insulation was applied without correctly sealing cavities before its application.

Codes and Specifications that Apply

- ASTM Specification C549 for Perlite Loose Fill Insulation
- ASTM Specification C520 Density of Granular Loose Fill Insulation
- ASTM Specification C236 Test Method for Steady-State Thermal
- Performance of Building Assemblies by Means of a Guarded Hot Box
- ASTM Specification E84 Test for Surface Burning Characteristics of Building Materials
- FHA Use of Materials Bulletin UM-37
- GSA Commercial Item Description A-A-903 Insulation, Thermal (Expanded Perlite)
- Brick Institute of America Technical Notes No 21A
- Federal Specification HH-I-515D

Example Regional Contractors

Harborlite Corp.
P.O. Box 960
Superior, AZ 85273-0960
Phone: 520-689-5723
Fax: 520-689-2362

Therm-O-Rock Inc.
6732 W. Willis Rd.
Chandler, AZ 85226
Phone: 520-796-1000
Fax: 520-796-0223

Horizon Energy Systems
610 E. Bell Rd., #350
Phoenix, AZ 85022-2393
Phone: 602-867-3176
Fax: 602-863-9915

Atlas Energy Products
222 S. Date
Mesa, AZ 85210
Phone: 480-969-5966
http://www.atlasroofing.com

Pictures

Source: www.perlite.net

Source: www.rolledalloys

Source: www.coldcrossing.com

CELLULOSE INSULATION

Applications

New constructions or retrofit buildings of any type: residential, industrial or commercial.

Definition

Cellulose building thermal insulation is a recycled material made from recovered newsprint and other paper (wood fiber) feedstock; it also has low embodied energy and typically delivers superior installed insulation performance.

Description

Cellulose insulation is made from recycled paper that is applied as either loose fill into attics and closed wall cavities or damp-sprayed into open wall cavities. Due to this recycled content and potentially higher energy and acoustic performance, cellulose is an environmentally-preferable product.

In the installation process, loose fibers are blown into building cavities or attics using pneumatic equipment. Some installers attach netting to the face of open wall and ceiling cavities and blow in loose cellulose. Cellulose can also be damp-sprayed into open wall cavities before the drywall is applied. In this case, the damp sprayed cellulose should have less than 25% water content before closing the cavities with drywall; if the moisture level is not tested it could lead to moisture and mold problems.

In both cases, and because loose-fill cellulose settles over time, it must be installed to its predicted settled density to achieve its R-value. R-Value is the standard for measuring insulation performance. At 3.6 to 3.8 per inch cellulose insulation is considerably better than most mineral fiber blowing wools. Nevertheless, r-value is only one factor to consider, energy savings, air infiltration and health considerations are a few more that must be taken into account.

On the first hand, actual buildings regularly show that cellulose-insulated buildings may use 20% to 40% less energy than buildings with fiber glass, even if the r-value of the insulation in the walls and ceilings is identical. On the other hand, when cellulose is pneumatically installed it takes on almost liquid-like properties that let it flow into cavities and around obstructions to completely fill walls and seal every crack and seam. No other fiber glass or rock wool material duplicates this action. Liquid-applied foam plastics do, but they cost much more than cellulose.

Lastly, a health consideration is another good characteristic of cellulose insulation. Unlike most fiberglass batts, cellulose insulation does not have formaldehyde-based binders that can be harmful to installers and offgas once installed. Fiberglass fibers are friable and can easily become airborne, particularly during installation. These fibers can be inhaled, and some health experts claim that this particulate matter is carcinogenic.

Benefits

- It offers more heat transfer resistance per inch than other fiber insulation materials.
- It seals the home against air infiltration better than other fiber insulations.
- Productively recycles a waste product that presents communities with a serious disposal problem.
- Saves more energy when the energy required making the material, "embodied energy", is figured into total energy savings.
- Makes homes safer by slowing the spread of fire.

Limitations

Cellulose insulation can hold moisture; repeated wetting and drying could cause the borate treatment to leach out and mold to grow.

Maintenance

Any insulation type will have problems if excessive moisture is allowed into the wall cavity. In this sense, the number one priority should be to eliminate moisture issues before considering the insulation. In other words, if wall cavities are kept dry, there should be no need for maintenance.

LEED Credits

Using this material potentially contributes to obtaining these credits in the US Green Building Council's LEED certification program:

Energy & Atmosphere

- EA Prerequisite 2 Minimum Energy Performance
- EA Credit 1 Optimize Energy Performance

Materials & Resources

- MR Credit 4.1 Recycled Content
- MR Credit 4.2 Recycled Content

First Costs

Cellulose insulation installed could cost anywhere from the same to twice that of fiberglass insulation, depending on the nature of the project. However, insulation costs are generally a small percentage of the total cost of construction. Furthermore, cellulose insulation sealing characteristics are superior and not comparable to those of fiberglass.

Life Cycle Cost Considerations

Designing a well-insulated envelope is relevant for attaining an environmentally sound building. If the heat transfer through the envelope is minimized, energy used to maintain the interior climate is similarly reduced. Therefore, both utility bills and the environmental costs of fossil fuel use are taking care of within the context of l life cycle cost considerations.

On the other hand, since insulation should be a one-time installation, ensuring quality workmanship and material is important as remedying substandard work later will be costly.

Codes and Specifications that Apply

Cellulose insulation is covered by American Society for Testing and Materials Standard Specifications C-739 for loose-fill insulation and C-1149 for spray-applied self supporting insulation.

Example Regional Contractors

Incide Technologies, Inc.
50 N. 41st. Ave., Suite A
Phoenix, AZ 85009-4618
Phone: 602-233-0756, 800-777-4569 (toll free)
Fax: 602-272-4864
http://www.incidetech.net

Pacific States Felt & Mfg. Co., Inc.
23850 Clawiter Rd., P.O. Drawer 5024
Hayward, CA 94545
Phone: 510-783-0277, 800-633-4470 (toll free)
Fax: 510-783-4725
http://www.pacificstatesfelt.net

Pictures

Source: www.cellulose.com
Source: www.phillipry e.com
Source: fransenergysavers.net

Cementitous Foam Insulation

Applications

Energy Conservation for Residential, Commercial, Industrial and Agricultural Uses on new or retrofit buildings.

Definition

Cementitious foam insulation material is a cement-based foam used as sprayed-foam or foamed-in-placed insulation.

Description

Cementitious foam it's a nontoxic and nonflammable material made from minerals (like magnesium oxide) extracted from seawater. One type of cementitious, spray-foam insulation is known as Air-KreteTM, it contains magnesium silicate and it has an initial consistency similar to shaving cream. After curing, it's similar to a thick pudding.

Air-KreteTM has an R-value of about 3.9 per inch. An insulation's resistance to heat flow is measured or rated in terms of its thermal resistance or R-value. The higher the R-value, the greater the insulating effectiveness. The R-value depends on the type of insulation and includes its material, thickness, and density. Installing more insulation in your home increases the R-value and the resistance to heat flow.

Cementitous foam can be used in new or retrofit buildings. To add insulation to existing homes, it is common practice to blow fibrous insulation material into enclosed wall, floor, and roof cavities. The same technique can be used in new construction by covering an open wall cavity tightly with a membrane fastened to the framing. A fabric similar to that used on the underside of furniture, nylon netting, or polyethylene is used as the membrane in various systems. Fiberglass, cellulose, and mineral blowing wool, can be used.

Cementitious foam is blown through a membrane with air, resulting in a continuous network of mineral surrounding bubbles of air. At its minimum density, it is rated at R-3.9 per inch, but it is fragile. To create a more durable product, the density can be doubled, reducing the insulating value to R-3.6 per inch.

Benefits

- Insulation improves the thermal resistance of exterior walls.
- It completely fills cavities with insulation.
- The process inhibits air circulation within the cavities, thereby eliminating an important cause of condensation and moisture problems.
- It can also help create a tighter house by inhibiting air movement through the envelope.

- Does not expand, shrink or settle and is 100% cavity filling. It fills around and behind any obstructions and crevices. (Dimensional stability- ASTM C 951: zero shrinkage).
- Does not inflict damage to environment or man. Material is non-toxic, does not create any ozone-depleting CFC's and does not contain any formaldehyde or carcinogenic fibers.

Limitations

- These systems are more costly than conventional fiberglass batts due to higher material costs.
- Spray insulations require special equipment and training; usually performed by specialized trade contractor.
- Insulation that entirely fills wall cavity makes snaking wires or pipes difficult after wall is complete; makes remodeling difficult.

LEED Credits

It may be applicable to two sections: Indoor environmental quality and energy and atmosphere section.

First Costs

Cementitious foam costs about $1.45 to $2.45 per s.f.

Life Cycle Cost Considerations

NA

Codes and Specifications that Apply

Insulation products must meet ASTM standards for fire and thermal resistance. Section R316 of the 2003 International Residential Code covers insulation products (other than foam plastic).

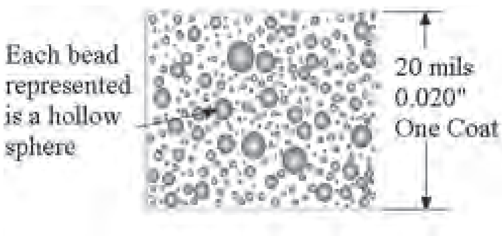
Example Regional Contractors

Arizona Foam & Spray
222 South Date Street
Mesa, AZ 85210
480 834-8176
www.arizonafoam.com

Pacific Stucco of Arizona
222 South 52nd Street Suite 2
Tempe, AZ 85281
phone: (480)968-4044

Pictures

Source: www.baurspecialty.com
Source: www.buildinggreen.com
Source: www.healthyhouseinstitute.com



Ceramic Coatings

Applications

All kinds of buildings: commercial, residential and commercial. It is also applicable to industrial equipment during operation.

Definition

A ceramic coating is a paint mixed with one or more ceramic compounds for application via spray or roller to exterior and interior surfaces. Depending on the ceramic compounds used (there are hundreds of varieties), this insulating product has the ability to prevent heat transfer and heat loading onto a structure. This means heat will not transfer into or out of a building.

Description

An insulation's resistance to heat flow is measured or rated in terms of its thermal resistance or R-value; the higher the R-value the greater the insulating effectiveness. The R-value depends on the type of insulation and includes its material, thickness, and density. Installing more insulation in your home increases the R-value and the resistance to heat flow. In the case of ceramic coatings, they are not given an R-value rating. Instead, they are measured by their emissivity. Emissivity measures both the ability to reflect heat and the amount of heat that is loaded onto a surface.

"The true key to insulation is preventing heat load," says J.E. Pritchett, founder and developer of SuperTherm, a ceramic coating product produced by Superior Products International. The concept is simple: Why use fiberglass insulation to slow the transfer of heat into a building when you can just prevent that heat from ever loading onto the building in the first place? If heat is kept off the structure to begin with, that fiberglass insulation becomes unnecessary. It's a change in the way we think about insulating our homes against energy lost. "R rating is for the 20th century," says Pritchett. "Emissivity is 21st century."

As an exterior surface coating, insulating ceramic paints or coatings can be applied to the roof and sides of a building. This includes roofing surfaces such as metal, felt, asphalt, aluminum, and sidings made of rubber, vinyl, and aluminum. Some ceramic coatings feature additional properties, like preventing moisture migration. Some structures see up to 25 percent of HVAC costs coming from dehumidification needs, but a ceramic coating can also bring savings through moisture management. Additional features can include mold and mildew control, sound attenuation properties, and fire resistance.

Benefits

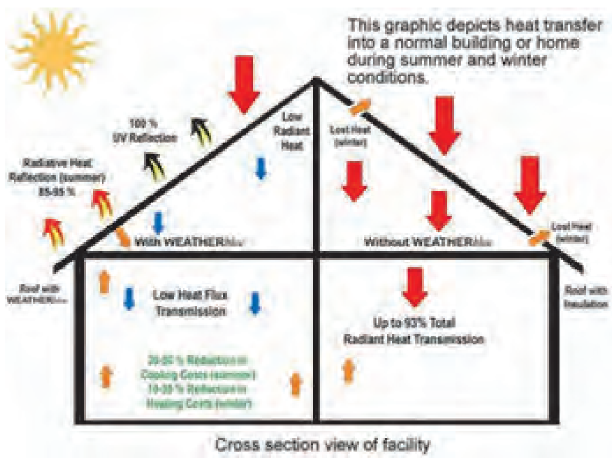
- Waterproofs, protects and prevents corrosion 100%
- Reduces thermal shock- contraction/expansion
- Reduces noise

- When applied to a thickness of 20 mils, Ceramic Insulation Coatings will reduce the surface temperature 60 to 80 degrees Fahrenheit. Additional coats can decrease the temperature 30 to 40 degrees Fahrenheit.
- Shutting down operations is not required because Ceramic Insulation Coatings can be applied up to 360 degrees Fahrenheit.
- Non-combustible and low flame spread, class 1.

Limitations

- Should not be applied to surfaces where the operating temperature exceeds 350oF
- Ceramic Cover should not be mixed with solvents or applied near where solvents may come in contact with the product prior to curing. Prior to application insure all substrates are free of rust, oil, grease, mil scale, moisture or any foreign substances which might effect adhesion.

Typical Design Section



Maintenance

Ceramic protection is impervious to moisture, provides corrosion protection and reduced maintenance for 3-4 times the normal surface life span. It is also an easy maintenance product, it is simple to wash with municipal water pressure and conventional techniques.

LEED Credits

May be applicable to the energy and atmosphere section.

First Costs

A home interior coated in ceramic paint can reduce energy costs due to heat loss in the colder months. "We estimate that a home can save up to 40 to 50 percent in energy costs using our product," Pritchett says. Payback on a product like SuperTherm, which retails for about $100 per gallon, can come in as little as two years.

Life Cycle Cost Considerations

Ceramic coating insulations could last from 20-25 years. Life cycle costs are substantial.

Codes and Specifications that Apply

There are many ceramic coating insulations and they use different ceramic compounds. Therefore, each product is certified under certain codes and has its own features.The following example details the features of Supertherm, a ceramic coating insulation:

VOC-Compliant: Only 67 grams/liter. Limit is 420 grams. Water-based

US Consumer Product Safety Commission approved

USDA \ CFIA approved for use around foods

Contains silver citrate to protect against mold, mildew and other pathogens

Flame Spread Class " A " Rating with " 0 " flame spread (NASA) (Omega Point Laboratories - ASTM E84 \ UL 723)

Smoke Developed Class " A " Rating with " 0 "smoke developed (Omega Point Laboratories - ASTM E84)

" K " Rating with No off gassing (NASA)

BOCA Evaluation Services Inc. Certified and listed as "Thermal Insulation Materials"

International Codes Council Approved

Energy Star approved partner

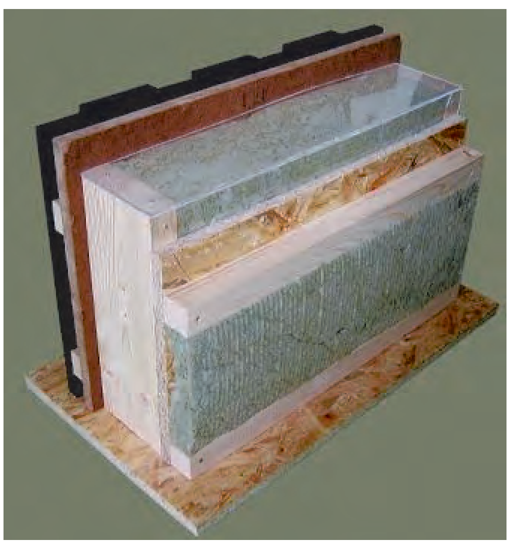
Example Regional Contractors

Ellsworth Adhesives
W129 N10825 Washington Dr., P.O. Drawer 1002
Germantown, WI 53022-1002
Phone: 262-253-8600, 800-888-0698 (toll free)
Fax: 262-253-8619
http://www.ellsworth.com

Advanced Insulation Systems
2419 North Black Canyon Highway Suite 22
Phoenix, Arizona USA 85009
Phone: 602 690 0320

Pictures

Source: www.mascoat.com
Source: www.deltacoat.com
Source: www.cosmodec.com
Source: img.alibaba.com



Mineral Wool Exterior

MINERAL WOOL – EXTERIOR AND INTERIOR INSULATION SYSTEMS

Applications

It could be used in new or retrofit buildings of any type: residential, commercial or industrial.

Definition

Mineral wool which is also known as rock wool and slag wool is a widely used material for insulation – not only is it used in insulating houses but also elsewhere – boats, caravans, various pipes, offices etc.

Description

Mineral wool is the most tested insulation material and the tests show that mineral wool is highly fire-resistant, with incredible insulation capabilities and provides great sound insulation as well. Mineral wool is not specially treated to acquire fire-resistant features. Various tests show that the material is not hazardous to health.

Mineral wool insulation helps reduce heating costs as it will keep the warm air in which would otherwise escape through the walls or gaps in walls, around the windows or doors. Most often it is used in insulating ceilings, roofs, internal and external walls.

An example of an internal use is the Acoustic Mineral Wool (AMW), this is used extensively in buildings and throughout industry to give acoustic, thermal and fire insulation. It is particularly useful as a sound absorbing infill for the reduction of airborne sound between flooring joists, suspended ceilings, stud partitioning and with our Resilient Bars.

In external uses is commonly referred as Exterior Insulation Finishing System (EIFS). It could be described as a building cladding that offers improved thermal and moisture performance over conventional cladding systems. EIFS basically consists of four layers. These are, from exterior to interior:

- A spray-applied acrylic and stone finish.
- A fiberglass reinforcing mesh.
- Insulation.
- An adhesive that attaches the cladding system to the building. Most EIFS systems use expanded polystyrene as the insulation.

Benefits

- Mineral wool is produced from natural products.
- Suits all building types.

- AMW: improves the sound insulation of separating floors and stud walls by up to 100%.
- EIFS: provides greater fire resistance and superior thermal performance which is not found in many other cladding systems.

Limitations

- EIFS: Improper installation could lead to moisture damage. Therefore, walls must be well sealed.

Maintenance

Mineral Wool insulation is maintenance free and the savings do not depend on equipment servicing or replacement.

Additional Considerations

Mineral wool consists of synthetic materials; fiberglass is one of them and is airborne, which is why a mask should be used when installing mineral wool insulation to avoid the dust to irritate your respiratory system.

LEED Credits

It may be applicable to the energy and atmosphere section of LEED.

First Costs

AMW: six 2''x4'x2'panels in a carton. $30 per carton *

(so $5.00 each panel or $10.00 per trap since each trap uses two 2'' panels)

* Approximate cost, it will vary.

Life Cycle Cost Considerations

As said before, improper installation could lead to moisture damage. Therefore, sealant on walls will be needed. Other than that, mineral wool insulation is operational costs free.

Codes and Specifications that Apply

In some situations, there is a requirement for party/compartment floors to achieve a one hour fire rating. If AMW100 is supported by 25mm chicken wire mesh stapled to joist sides, the insulation will provide a one hour fire rating.

Fire code regulations restrict the use of polystyrene insulation to low-rise buildings. One EIFS system utilizes mineral wool as the insulation layer to overcome this limitation; a mineral-wool based EIFS can be used for buildings of any height.

Example Regional Contractors

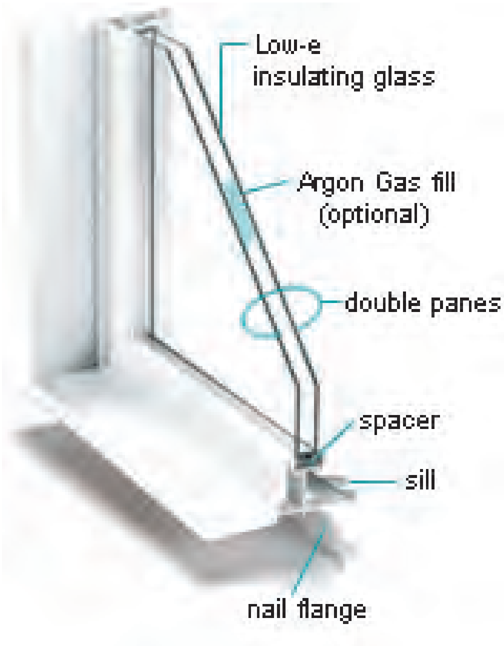
STO Corporation
3800 Camp Creek Parkway
Building 1400, Suite 120
Atlanta GA
USA 30331
tel 1 800 221 2397
www.stocorp.com

Pacific Insulation Company
Phoenix, AZ
215 South 14th St. 85034
(602) 276-1361
www.pacificinsulation.com

Pictures
Source: http://soundproof.mine.nu
Source: www.foam-tech.com
Source: www.peaktoprairie.com
Source: www.img2.timeinc.net

BUILDING ENVELOPE: OPENINGS

- ENERGY EFFICIENT WINDOWS
- INERT GAS WINDOW FILLS
- OPERABLE WINDOWS
- SPECTRALLY SELECTIVE GLAZING
- WARM EDGE WINDOWS



Energy-Efficient Windows

Applications

Can be applied to any type of building, new construction or retrofit project. Applicable to commercial, industrial and residential buildings.

Definition

An improved type of window that saves energy by incorporating different components such as high tech frames and glazing, as well as operational and installation strategies. An energy efficiency window can improve comfort by increasing surface temperatures and cutting drafts. They also reduce condensation, protecting building materials and reducing mold growth. Energy efficiency windows have the Energy Star label.

Description

A window's energy efficiency is dependent upon all of its components:

- Frames
- Glazing or glass
- Operation

FRAMES

Window frames are available in many styles, and are made of different materials. When purchasing energy-efficient windows, the thermal performance of the window frame has to be considered. Inefficient window frames should be avoided because they cause significant loss of heat and are a prime cause of condensation on the glazing. Although window frames comprise only 10% to 25% of the window area in commercial buildings, they can account for up to half of the window heat loss. The selected frame also bears on the final price of the window.

Framing materials used for windows include aluminum, wood, vinyl, fiberglass or a combination of different materials such as wood clad with vinyl or aluminum-clad wood or fiberglass filled with foam insulation. Good quality windows are available using any of these materials. Each material has advantages and disadvantages in terms of insulating value, strength, durability, cost, aesthetics and maintenance requirements. Low-conductivity materials include wood and vinyl. Wood and fiberglass are the most efficient, but they also require more maintenance and are more expensive. Aluminum conducts heat and loses heat faster than other options.

GLAZING OR GLASS

There are many types of glazing available for windows, especially since many glazing technologies can be combined. These window glazing technologies include the following:

- Gas fills: window manufacturers use inert gases—ones that do not react readily with other substances. Because these gases have a higher resistance to heat flow than air, they (rather than air) are sealed between the window panes to decrease a window's U-factor.

U-factor: The rate at which a window, door, or skylight conducts non- solar heat flow. It's usually expressed in units of Btu/hr-ft2-oF.

- Heat-absorbing tints: Tinted glass absorbs a large fraction of the incoming solar radiation through a window. This reduces the solar heat gain coefficient (SHGC) and glare.

Solar heat gain coefficient (SHGC): A fraction of solar radiation admitted through a window, door, or skylight—either transmitted directly and/or absorbed, and subsequently released as heat inside a home. The lower the SHGC, the less solar heat it transmits.

- Insulated (double-glazed, triple-glazed): Insulated window glazing refers to windows with two or more panes of glass. They are also called storm windows. The glass layers and the air spaces resist heat flow. As a result, insulated window glazing primarily lowers the U-factor, but it also lowers the solar heat gain coefficient.

- Low-emissivity (Low-E) coatings: Low-emissivity (Low-E) coatings on glazing or glass control heat transfer through windows with insulated glazing. Windows manufactured with Low-E coatings typically cost about 10%–15% more than regular windows, but they reduce energy loss by as much as 30%–50%.
- Reflective coatings: Reflective coatings on window glazing or glass reduce a window's visible transmittance (VT) and glare, but they also reduce a window's solar heat gain coefficient (SHGC). Reflective coatings usually consist of thin, metallic layers. They come in a variety of metallic colors, including silver, gold, and bronze.
- Spectrally selective coatings: Spectrally selective coatings are optically designed to reflect particular wavelengths but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting a higher portion of visible light. They help create a window with a low U-factor and solar heat gain coefficient but a high visible transmittance.

OPERATION

When selecting windows, it's also important to consider how they're operated. Some operating types have lower air leakage rates than others, which will improve the building's or home's energy efficiency.

There are numerous window operating types to consider. Traditional types include the following: awning, casement, fixed, hopper, single or double hung, and single or double sliding.

Source: www.eere.energy.gov

Benefits

- Energy and costs savings.
- Improved comfort.
- Less condensation.

- Increased light and view.
- Reduced fading.
- Lower HVAC costs.

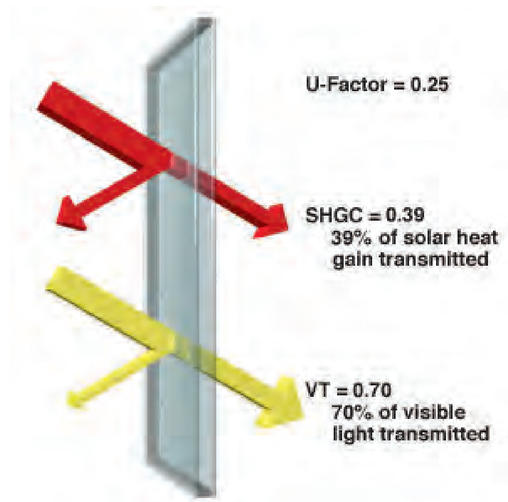
The graph below illustrates the significant savings in cooling season costs associated with improved windows for a house in a cooling-dominated climate. In warm regions, this means that high performance windows can face into the sun if desired without great energy penalties, although shading techniques remain important.

Source: http://www.efficientwindows.org

Limitations

- Higher initial costs.

Typical Design Section



Maintenance

Windows require periodic maintenance. They can be sources of large energy losses. They can make spaces within the building uncomfortable enough to drive away tenants. Most window designs are fairly efficient when new, but, as they age and deteriorate, their maintenance and energy costs increase. The problem is that the rate of deterioration for windows is usually so slow that it often goes unnoticed. The best defense against this slow deterioration is a program of regularly scheduled annual inspections.

Annual inspections should examine the physical condition of the windows. Are there any signs of rot or rust? Are all gaps between window frames and the walls properly sealed? Are sashes properly gasketed or weather stripped? Are operable windows easy to open and close? In this sense, inspections can identify small problems well before they develop into larger ones that will require significant repairs or total replacement.

LEED Credits

It may be applicable to two sections: 1) energy and atmosphere, and 2) indoor environmental quality.

First Costs

There are three major ways in which windows contribute to building energy costs: conduction losses and gains through the glazing and frames, solar heat gain through the glazing and air infiltration through gaps between window components.

All new windows offer a tight fit between components to limit the rate of infiltration. The other two types of heat loss or gain can be controlled by selecting specific features to be included in the replacement windows, including the number of glazings, the solar transmissivity of the glazings and the thermal characteristics of the window's frame.

While each of these features can reduce energy loss through windows, not all will be cost-effective in all applications. Factors such as climate, percentage of glass-to-wall area and building use will determine which features are most cost-effective. In general, the more energy efficient the window is, the higher its cost.

Life Cycle Cost Considerations

Window inspection programs will help to identify maintenance needs. These needs will determine the life cycle operational costs. Nevertheless, those needs will depend on the materials used in the construction of the window. For wooden windows, the single largest maintenance expense is painting. On the average, wooden windows must be repainted every four to five years. It is this expense that has led to the widespread use of aluminum- or vinyl-clad wood windows.

Painting is also a significant expense for steel windows. Depending on the environment, steel windows may require repainting every five to 10 years to avoid corrosion. Problems with corrosion have led to the replacement of steel windows with ones made from aluminum or vinyl.

Codes and Specifications that Apply

Whole window ratings, introduced in 1989 by the National Fenestration Ratings Council (NFRC), reflect the insulating value of the glass, the sash (where applicable), and the frame. The Energy Policy Act of 1992 (section 121) required that the NFRC develop, with industry cooperation, a national standard testing procedure, as well as labeling rules. The new labels use U-values (Btu/hr-ft2-oF) which are a measure of thermal conductivity. The U-value is the reciprocal of the R-value (R=1/U). For example: if R = 4, then U = 1/4 or 0.25. These performance ratings will probably become national standards in the near future.

Under the Energy Policy Act of 2005 you can get a tax credit if you installed energy efficient windows in the year 2006. Due to a new law created in 2006 the government is encouraging energy efficient homes. To qualify for energy efficient tax credits on your home it must be 1. Your primary home, and 2. Be located in the United States. The energy efficient items and procedures to your home can be used as a credit with limitations.

The new tax law provides for a tax credit to existing homes. You can get a 10 percent tax credit for buying qualified energy efficiency improvements. Read the 2000 International Energy Conservation Code to qualify.

Example Regional Contractors

Pacific Bulletproof Co.
4035 Leaverton Ct.
Anaheim, CA 92807
Phone: 714-630-5447, 888-358-2309 (toll free)
Fax: 714-630-5314
http://www.pacificbulletproof.com

Aegis Window & Door
5609 W. Latham St.
Phoenix, AZ 85043
Phone: 602-415-0414, 888-279-0316 (toll free)
Fax: 602-415-9880

Pictures

Source: http://www.efficientwindows.org/
Source: www.glassfacades.com
Source: www.precisionglassco.com
Source: www.milgard.com

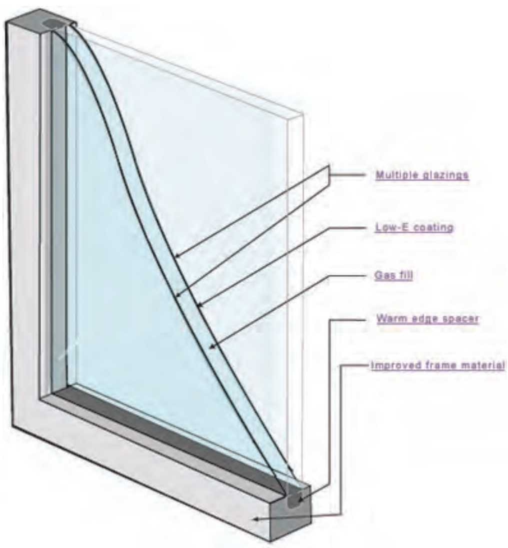
Inert Gas Window Fills

Applications

This technology could be applied to any type of building: residential, commercial or industrial. Retrofit or new construction.

Definition

The use of a low-conductivity inert gas instead of air in window glazing cavities in order to reduce heat transmission through the window.



Description

To improve the thermal performance of windows with insulated glazing, some manufacturers fill the space between the glass panes with gas. For these gas fills, window manufacturers use inert gases—ones that do not react readily with other substances. Because these gases have a higher resistance to heat flow than air, they (rather than air) are sealed between the window panes to decrease a window's U-factor.

U-factor

The rate at which a window, door, or skylight conducts non-solar heat flow. It's usually expressed in units of Btu/hr-ft2-oF. For windows, skylights, and glass doors, a U-factor may refer to just the glass or glazing alone. But National Fenestration Rating Council U-factor ratings represent the entire window performance, including frame and spacer material. The lower the U-factor, the more energy-efficient the window, door, or skylight.

Originally, this space was filled with air or flushed with dry nitrogen just prior to sealing. In a sealed glass insulating unit, air currents between the two panes of glazing carry heat to the top of the unit and settle into cold pools at the bottom. Filling the space with a less conductive, more viscous, or slow-moving gas minimizes the convection currents within the space, conduction through the gas is reduced, and the overall transfer of heat between the inside and outside is reduced.

The most common types of gas used by window manufacturers include argon and krypton. Argon is inexpensive, nontoxic, nonreactive, clear, and odorless. The optimal spacing for an argon-filled unit is the same as for air, about 1/2 inch (11-13 mm). Krypton has better thermal performance, but is more expensive to produce. Krypton is particularly useful when the space between glazings must be thinner than normally desired, for example, 1/4 inch (6 mm). The optimum gap width for krypton is 3/8" (9mm). A mixture of krypton and argon gases is also used as a compromise between thermal performance and cost.

Benefits

- These low-cost, gas fills reduce U-values without affecting shading coefficients or visible transmittance.

- Inert gas fills reduce conductive and convective heat transfer.
- Reduces summertime conduction heat gain.
- Reduces wintertime heat loss.

Limitations

- Can only be used in sealed glazing units

Maintenance

Refilling of inert gas is once every 20 years, approximately. Therefore, maintenance is un existent between those years.

Additional Considerations

Inert gas fills should make their use mandatory whenever a low-e coating is used in a glazing unit. The use of inert gas fills without a low-e coating is only marginally effective in reducing heat loss.

LEED Credits

It may be applicable to the following two sections:

- Energy and atmosphere
- Indoor environmental quality section

First Costs

The cost of this technology is about $2.53 to $4.22/m2 of window.

Life Cycle Cost Considerations

According to recent research, a window's gas fill can remain effective over its expected 20 year life. In this sense, operational costs are minimal.

Codes and Specifications that Apply

- Energy Policy Act of 2005
- Energy Star® Windows
- National Fenestration Rating Council (NFRC) Certified Products Directory: Contains performance characteristics for window assemblies from most manufacturers.

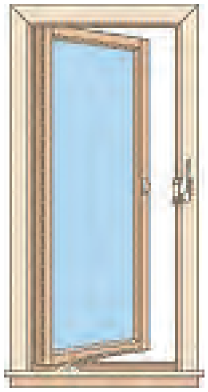
Example Regional Contractors

Republic West, Inc.
8101 E Mc Dowell Rd.
Scottsdale, AZ 85257
Phone: (480) 481-9595
Fax: (480) 481-0420

Pacific Bulletproof Co.
4035 Leaverton Ct.
Anaheim, CA 92807
Phone: 714-630-5447, 888-358-2309 (toll free)
Fax: 714-630-5314
http://www.pacificbulletproof.com

Pictures

Source: www.energystar.gov
Source: www.homedepot.com
Source: www.swscorp.net



Operable Windows

Applications

Hospitals, health institutions, testing laboratories, or any other building that requires really clean air are not good candidates for operable windows. Note that these are the exceptions; most commercial, industrial, or institutional buildings should consider the use of operable windows.

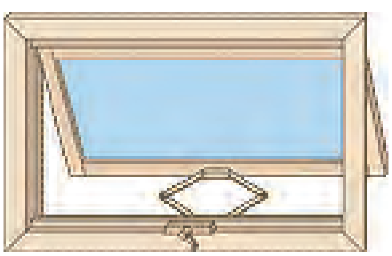
Definition

Windows that can be opened and closed as desired by the occupant to provide better control of space conditions.

Description

Many traditional office buildings seal all their windows and are constantly either heating or cooling the same air. For the contrary, in operable windows, in the warmer months they are open to let in fresh air and cooling breezes. In the winter, when they are closed, their energy efficiency insulates against extremes of temperature and reduces the need for heating with its attendant financial and environmental costs.

Windows have a tremendous environmental influence on a house, affecting the light, ventilation, temperature of the interior and furthermore, the comfort of the occupants. Windows are part of a home or a building's architectural identity. When you are choosing new windows, be sure the styles you select will suit your home both practically and aesthetically.



Operable window types include sliding, casement, awning, hopper, or tilt and turn. Each type of window has positive and negative aspects; evaluate which is most suitable for your particular application. Common operable window frame types include aluminum, wood, fiber glass, and PVC. Each of these window frame types has its own merits. Cost, thermal expansion, insulating properties, maintenance issues, fire resistance, and code compliance should be considered when choosing a frame type.

Benefits

There are two major benefits, and one is the concept of control - that an occupant has some control over his/her environment. The other benefit is the concept of natural ventilation. Air from open windows can effectively cool and ventilate (and can save on operating costs), rather than using fans that are driven by electricity.

Limitations

Threat of water and air leakage with operable windows: there could be a crack around the perimeter of a window that could be prone to leakage, or you may have people that inadvertently leave them open in inclement weather.

Operable windows could also bring with them noise, vibration and airborne pollutants, such as exhausts, pollen, and particulates.

Maintenance

Maintenance is minimal, normal cleaning tasks it is all it takes and change insulation whenever it gets damaged, insulation usually lasts a fair amount of years.

Additional Considerations

NA

LEED Credits

It may be applicable to the energy and atmosphere section.

First Costs

Operable windows are more expensive compared to fixed windows. Expect to pay approximately 20-percent more for fully operable windows vs. fixed windows. Price also changes by type of operable window - sliders are cheaper than casements, for example. There are a lot of differences in price.

Life Cycle Cost Considerations

Minimal, it is all based on the maintenance duties, see maintenance section.

Codes and Specifications that Apply

Accessible operable windows are required by all three national building codes: BOCA, SBCCI, and the UBC. Prior to 1998 included were those operable windows, within accessible spaces, required by Code for ventilation and also those required for emergency escape and rescue. All codes after 1998 additionally require that, if operable windows are provided in an accessible space, no less than one in each room shall be accessible. All Building Codes reference the ANSI A117.1 for technical accessibility technical requirements. Some states, such as California and Washington have created their own requirements for accessible operable windows.

Example Regional Contractors

Vortex Industries, Inc.
8270 S. Kyrene Dr., Suite 101
Tempe, AZ 85284
Phone: 480-598-1515, 800-698-6783 (toll free)
Fax: 480-598-1565
http://www.vortexind.com

State Seal Co.
4135 E. Wood St.

Phoenix, AZ 85040

Phone: 602-437-1532

Fax: 602-437-4332

http://www.stateseal.com

Pictures

Awning

Source: www.lowes.com

Double-Hung

Source: www.lowes.com

Casement

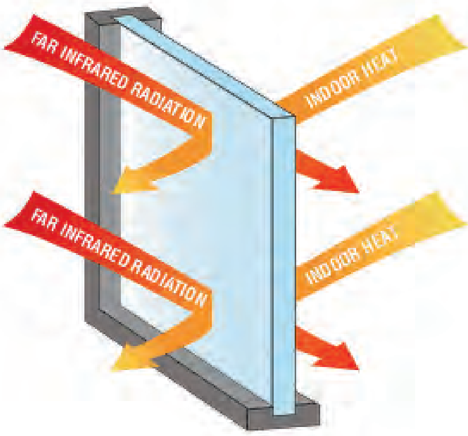
Source: www.lowes.com

Bay window

Source: www.lowes.com

Bow window

Source: www.lowes.com



Spectrally Selective Glazing

Applications

Spectrally selective coatings can be applied on various types of tinted glass to produce "customized" glazing systems capable of either increasing or decreasing solar gains according to the aesthetic and climatic effects desired. They can be used in windows, skylights, glass doors, and atria in all types of commercial and residential buildings.

Definition

Low-E and solar control low-E (also called spectrally selective) coatings can be used to boost the energy efficiency of windows. Low-E double pane windows, most common in cold and moderate climates, are more energy efficient than clear windows because the low-E coating reduces heat loss through the window.

Description

Spectrally selective glazings are designed specifically to admit a higher level of visible light while still controlling solar heat. They do so by responding differently to different wavelengths of solar energy allowing for much clearer glass with good solar control. Spectrally selective glazings are available with a range of performance characteristics. This provides a high level of design flexibility as different coatings and performance characteristics can be selected for each orientation providing optimal solar control while maintaining a uniform appearance.

Spectrally selective coatings filter out 40%–70% of the heat normally transmitted through insulated window glass or glazing, while allowing the full amount of light to be transmitted. Popular "low-emissivity" or "low-e" glazings are a type of spectrally selective glazing that is typically selected to provide enhanced insulation value, good visible transmittance and good solar control. Some low-e windows, however, can allow more solar heat to penetrate than others so it is important to evaluate glazing options against all of a project's design criteria.
By controlling solar heat gains in summer, preventing loss of interior heat in winter, and allowing occupants to reduce electric lighting use by making maximum use of daylight, spectrally selective glazing significantly reduces building energy consumption and peak demand. Computer simulations have shown that advanced window glazing with spectrally selective coatings can reduce the electric space cooling requirements of new homes in hot climates by more than 40%.

Spectrally selectivity is most effectively achieved by using microscopically thin, silver-based, multilayer, low-E coatings on glass or film. These coatings reflect rather than absorb incident solar radiation; less absorbed energy means less heat is transferred into the building.

Benefits

- In most U.S. climates, low-E coatings reduce heating costs associated with energy loss through windows by lowering the window's U-value.
- Cooling energy from solar gains will decrease because of spectrally selective glazing's lower solar heat gain coefficient.
- Lighting energy will decrease (if manual or automatic lighting controls are available) because of spectrally selective glazing's higher visible transmittance.
- Required heating energy may decrease if spectrally selective glazings with lower thermal conductance and emissivity are used.
- Summer peak demand from cooling and lighting will decrease because spectrally selective glazings will produce a reduction in solar heat gains, electric lighting requirements, and electric lighting heat gains.

Limitations

Spectrally selective products may not be applicable in the following situations:

- Heating load dominated buildings with small or no cooling requirements.
- Unoccupied buildings that are not air conditioned, such as warehouses and storage facilities, or naturally ventilated buildings, such as workshops with open doors or windows.
- Buildings with exterior shading devices, such as blinds, overhangs, and shade trees.

Maintenance

Maintenance requirements for spectrally selective windows are essentially the same as for conventional windows. Installations using sealed units require no extra care because the spectrally selective coating is inside the unit and not exposed to abrasion from cleaning or weather.

Additional Considerations

A selective glazing can also mean only a subtle tint to windows when a highly reflective glass would otherwise be necessary to achieve the same performance or clear glazing when a tint would otherwise be necessary.

LEED Credits

May be applicable to the indoor environmental quality section

First Costs

For new commercial construction, the incremental materials cost for use of a selective coating versus a standard low-E coating is $0.25 to $0.50/ft2), which includes an average 30% markup added by local distributors.

The incremental costs for selective products rather than nonselective products in new construction is zero. For retrofit situations, the incremental cost is zero if window replacement or improvements were already planned.

Life Cycle Cost Considerations

Low-E coatings save energy in most U.S. climates. In a simulation of a home located in Boston, low-E coating saved $103 per year.

Simulations from the Efficient Window Collaborative for a home with vinyl windows in Tucson, AZ, indicated that solar control glass reduces heating and cooling costs by $65 per year over double-pane clear glass.

For Low-E films attached to the glass, expect to pay $1.50 to $3.00/ft2-glass) for removal of the film after 10 to 15 years.

Codes and Specifications that Apply

The International Energy Conservation Code (IECC) includes state-by-state provisions for the energy efficiency of windows. Requirements are outlined on the Efficient Windows Collaborative Website at http://www.efficientwindows.org/code.cfm. Nevertheless, many states have adopted the American Society of Heating, and Air Conditioning Engineers (ASHRAE) 90.1 energy code standard, which acts as a guideline for commercial energy code legislation.

Example Regional Contractors

The following organizations and publications provide more information on advances in glazing technology.

Efficient Windows Collaborative
Alliance to Save Energy
1200 18th Street N.W., Suite 900
Washington, D.C. 20036
(202) 530-2245
Fax: 202-331-9588
Email: ewc@ase.org

Provides unbiased information on the benefits of energy-efficient windows, descriptions of how they work, and recommendations for their selection and use.

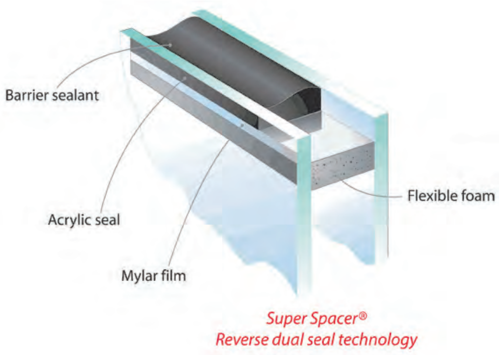
Windows & Daylighting Group
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-3111
Berkeley, California 94720

Provides technical support to government and industry efforts to help architects, engineers, and other commercial building specifiers choose energy-efficient and cost-effective residential windows.

Window & Door Manufacturers Association
1400 East Touhy Avenue, Suite 470
Des Plaines, IL 60018
Phone (800) 223-2301
Fax: (847) 299-1286
Email: admin@wdma.com

Pictures

Source: www.apexfilms.com
Source: www.tsec.ucf.edu



Warm Edge Windows

Applications

Warm-edge spacers for windows are suitable for all window systems and should be considered mandatory whenever low-e coatings and inert gas fills are used.

Definition

Warm Edge refers to the type of spacer material used to separate the panes of glass (or glazing) in an insulated window unit. If the material conducts less heat or cold than a conventional aluminum spacer at the edge of the glass, it is said to be 'warm-edge.' Most of these newer window spacers are less conductive and outperform pure aluminum.

Description

Warm edge refers to the type of spacer material used to separate the panes of glass in an insulated window unit. If the material conducts less heat or cold than a conventional aluminum spacer at the edge of the glass, it is said to be 'warm edge.' The warm edge spacer affects heat retention and loss, condensation on the windows, and the amount of noise that is transmitted. Best of all, the warm edge spacer reduces your energy costs.

Poorly insulated windows can attribute to 25 percent of a building's heating and cooling loads. As a homeowner, it is just as important to know what type of window spacer material is being used on the insulating glass unit as it is to know what type of glass package (or glazing) is going into the window. These characteristics, if well selected, the durability of the windows will remain thermally-efficient and condensation-free for many years.

Condensation occurs first around the window's edge - where the glass insulates least effectively and where surface temperatures are the coldest. If a standard "cold edge" spacer exists and outside temperatures fall to 0°F/-17.78°C, condensation will form on the glass edge even in homes with as little as 15% relative humidity. Therefore, the solution to condensation formation on glass is to increase the thermal efficiency of the edge of the glass: the window's weak link.

One of the benefits of using the warm edge insulation technology directly reflects on reduced heat loss. Pacific Coast Windows is a company that has a product called Intercept® spacers, this product is an example of the warm edge technology and the following is a brief description of its advantages and actual results in regards to heat loss: As you can see below, the temperature difference between the edge of an insulating glass unit with an ordinary spacer, and one with an Intercept® spacer system can be dramatic.

This thermograph or "heat picture' compares room side glass temperature for an Intercept® insulated glass (I.G.) unit (left, yellow is warmer, blue is cooler), and a conventional insulated glass unit (right). Since the Intercept® I.G. allows for significantly warmer glass temperature, especially at the edges, your home or the building will feel more comfortable.

Benefits

- "Warm-Edge" technology that reduces condensation problems around the window perimeter.
- Reduces heat loss.
- Improves insulation glass unit life.
- Warmer glass temperature which means better insulating value (89% higher R-value), lower energy bills and less drafts (improved comfort).

Limitations

Higher initial costs.

Typical Design Section

Warm Edge Technology Aluminum Spacer

Source: http://www.pacificcoastwindows.com

Maintenance

The durability of these warm edge-seals has been proven over the last few years and in fact some manufacturers note reduced seal failures because of the reduced thermal stress on the glazing. Therefore, this translates into less maintenance.

LEED Credits

May be applicable to the following sections:

- Energy and atmosphere.
- Indoor environmental quality.

First Costs

The cost of this technology is about $2.50 to $4.50/m2 of window.

Life Cycle Cost Considerations

Warm edge technology for windows can improve insulation glass unit life. This translates into less condensation which means less stains or damage to windows or walls, higher allowable relative humidity indoors/less annoying static electricity and better clarity of view.

Codes and Specifications that Apply

International Energy Conservation Code, International Building Code, International Residential Code, and American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.2-1993.

Example Contractors

Pacific Coast Windows
13120 Sherman Way
North Hollywood. CA 91605
Toll Free: 1-800-324-3030
Phone: 1-818-503-8000
Fax: 1-818-503-8005

TruSeal Technologies Inc.
23150 Commerce Park
Beachwood, OH, USA
Phone: 216-910-1500
FAX: 216-910-1505
http://www.swiggle.com

Pictures

Source: www.designerwindowsandsideing.com
Source: www.superspacer.co.uk
Source: www.theglazine.com

Electric and Natural Lighting

- T5 FLUORESCENT LAMPS
- LIGHT EMITTING DIODES (LED)
- HIGH EFFICIENT FLOURESCENT FIXTURES
- HIGH INTENSITY DISCHARGE (HID) LAMPS
- ELECTRONIC BALLASTS
- FIBER OPTIC LIGHTING
- SOLAR TUBES
- SWITCHABLE GLAZING

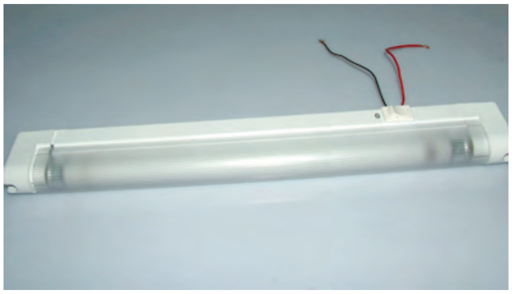
T5 Fluorescent Lamps

<ins>Applications</ins>

Industrial, commercial and residential buildings.

<ins>Definition</ins>

T5 lamps are fluorescent lamps that are 5/8" of an inch in diameter. Known to be the successors of T8 lamps.



<ins>Description</ins>

The T5 lamp operates only with electronic ballasts. The T5 has an efficiency of about 87 lm/W, compared to the ~77 lm/W achievable with T8 lamps. This technology has also made it possible to reduce the mercury content of lamps to about 3 mg, compared to the previous 15 mg.

T5 lamps are available for standard output and high output. The wattages for standard T5 lamps are 14, 21, 28, and 35 watts. The high-output T5 (T5 HO) lamps are available in 24, 39, 54, and 80 watts.

<ins>Benefits</ins>

- Increases energy efficiency.
- Decreases operating costs.

<ins>Limitations</ins>

- Higher cost compared to T8's.
- Another factor is that the warm-up time of T5 lamps may be longer than T8 lamps. This difference results from the optimal temperature of T5 lamps being 10°C (50°F) higher than that of T8 lamps.
- Potential glare problems.

<ins>Additional Considerations</ins>

T5 lamps differ from T8 and T12 lamps in length and socket size. T5 lamps also require different ballasts than T8 or T12 lamps do. These differences between T5 and T8 lamps make it inappropriate to replace T8 or T12 lamps with T5 lamps. For retrofit applications, the entire luminaire should be replaced with a T5 system.

<ins>LEED Credits</ins>

May be applicable to LEEDS' Energy and Atmosphere section.

<ins>First Costs</ins>

With respect to initial costs, T5 luminaires may have significant benefits if the higher output of T5 lamps leads to a large reduction in the number of lamps and luminaires per project, especially for large commercial projects.

Life Cycle Cost Considerations

Both T5 and T5HO lamps offer better lumen-maintenance performance than T8 lamps. The T5 lamps retain about 95 percent of their output after 40 percent of their rated life, compared with less than 90 percent for T8 lamps.

Codes and Specifications that Apply

ASHRAE/IESNA standard 90.1

Example Regional Contractors

Peerless Lighting
2246 Fifth Street
Berkeley CA
USA 94710
tel 1 510 845 2760
fax 1 510 845 2776
www.peerless-lighting.com

Hart Lighting & Supply
5017 S. 36th Street
Phoenix, AZ. 85040
Tel (602) 437-0375
Fax (602) 437-1264
www.hartlighting.com

City Lights Inc.
3911 West Van Buren #3
Phoenix, Arizona 85009
Tel (602) 233-2552
Fax (602)233-1102
www.citylightsphx.com

Pictures

Source: www.deslamps.co.uk
Source: www.germes-online.com
Source: www.osram.com
Source: www.zdsicc.com

LIGHT EMITTING DIODES (LEDS)

Applications

Light Emitting Diodes (LEDs) have great potential energy-efficient lighting for residential and even commercial building use. Some applications include: under-shelf fixtures, decorative lighting, pathway, step marking, walls, ceilings, traffic signals, exit signs, among others.

Definition

Solid-state lighting includes a variety of light producing semiconductor devices including light-emitting diodes (LEDs). It could be defined as a semi-conducting material which converts electricity directly into light, which makes the light very energy efficient.

Description

Designed for commercial, industrial, and institutional facilities where low maintenance and ease of installation are important. LEDs used as a replacement for incandescent light bulbs and fluorescent lamps are known as solid-state lighting (SSL) - packaged as a cluster of white LEDs grouped together to form a light source. LEDs are moderately efficient: the average commercial SSL currently outputs 32 lumens per watt (lm/W), and new technologies promise to deliver up to 80 lm/W. The long lifetime of LEDs make SSL very attractive. They are also more mechanically robust than incandescent light bulbs and fluorescent tubes. Currently, solid state lighting is becoming more available for household use, but is relatively expensive, although costs are decreasing.

In a more technical way, a LED could be described as a unique type of semiconductor diode. Like a normal diode, it consists of a chip of semi conducting material impregnated, or doped, with impurities to create a structure called a p-n junction. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers - electrons and electron holes - flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon.

Benefits

- Low energy consumption
- Low wattage
- Extremely long life
- Smallest dimensions (design flexibility)
- Very low early failure rate (highest reliability, lowest maintenance)
- No ultra-violet or infrared radiation
- Almost no heat generation
- High shock resistance

- Directional light

Limitations

- LEDs are currently more expensive, in lumens per dollar, than more conventional lighting technologies. The additional expense partially stems from the relatively low lumen output and the drive circuitry and power supplies needed.
- Potential failure if used in high temperatures without a cooling system.

Typical Design Section

Source: http://www.nrel.gov/buildings/highperformance/ttf_gallery.html

Maintenance

LEDs can eliminate the maintenance headaches associated with the old fluorescent and incandescent type lamps. This versatile LED bulb provides years of maintenance-free illumination at a minimal cost.

Additional Considerations

LED performance largely depends on the ambient temperature of the operating environment. Using it in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure. It will probably need a heat sink to cool down (i.e. a fan similar to the ones used in computer's CPUs).

LEED Credits

May be applicable to Energy and Atmosphere section.

First Costs

Prices vary depending on size and watts.

Life Cycle Cost Considerations

The following table shows an annual cost comparison between incandescent, fluorescent and LEDs:

COST COMPARISON CHART
(BASED ON 100 FIXTURES)

	Incandescent	**Fluorescent**	**LED**
Existing Watts	40	17	2.4
Hours per day	24	24	24
Cost per KWH	$0.10	$0.10	$0.10
ANNUAL ENERGY COST:	**$3,504.00**	**$1,489.00**	**$210.00**
Hourly Rate	$25.00	$25.00	$25.00
Replacement Time	30min.	30min.	30min.
Yearly Replacements	2.9	0.9	0
ANNUAL LABOR COST:	**$3,625.00**	**$1,125.00**	**$0.00**
# of Lamps	2@$3.25 ea	2@$4.86 ea	0
# Times Replaced	2.9	0.9	0
ANNUAL LAMP COST:	**$1,885.00**	**$875.00**	**$0.00**
TOTAL ANNUAL COST:	**$9,014.00**	**$3,488.00**	**$210.00**
SAVINGS:	**$8,804.00**	**$3,278.00**	

Codes and Specifications that Apply

National Lighting Energy Code: ASHRAE/IESNA 90.1

Example Regional Contractors

Hart Lighting & Supply
5017 S. 36th Street
Phoenix, AZ. 85040
Tel (602) 437-0375
Fax (602) 437-1264
www.hartlighting.com

City Lights Inc.
3911 West Van Buren #3
Phoenix, Arizona 85009
Tel (602) 233-2552
Fax (602)233-1102
www.citylightsphx.com

Pictures

Source: www.gx100.com

Source: www.lamps-manufacturer.com

Source: www.ledlite-power.co.uk

HIGH EFFICIENT FLOURESCENT FIXTURES

Applications

Used with any type of lamp for industrial, commercial and residential buildings.

Definition

A Lighting fixture (luminaire) is any device used to produce and project light. Its efficiency it's a very important factor. According to The Illuminating Engineering Society, defines luminaire efficiency as "the ratio of lumens emitted by a luminary to that emitted by the lamps therein."

Description

A lamp or lamp-ballast combination may produce light very efficiently, but if it's installed in an inefficient luminaire, the overall system efficiency may still be poor. The best luminaire manufacturers will design their fixtures around specific lamps to optimize the amount of light delivered to the work area. For example, a luminaire designed specifically for a compact fluorescent lamp can deliver almost 10 times as much illumination as an incandescent fixture fitted with the same compact fluorescent lamp.

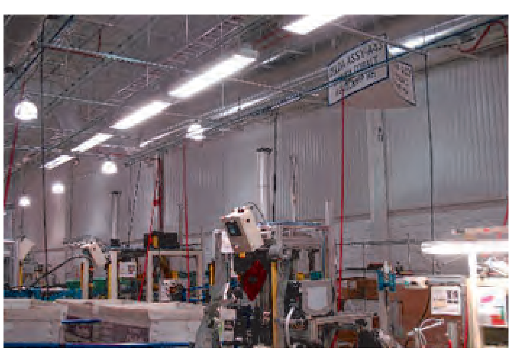
Luminaire components include reflectors, diffusers—which absorb some of the light from a lamp—and polarizing panels. Reflectors can be used to direct more of the light produced by the lamp out of the luminaire onto the work area. Polarizing panels can sometimes increase the contrast of a visual task.

When comparing luminaires, it's important to understand the following performance characteristics:

- Illuminance — the amount of light that reaches a surface. It's measured in footcandles (lumens/square foot) or lux (lumens/square meter).
- Luminaire Efficacy/Efficiency Rating (LER) — the light output (lumens) per watt of electricity use. The LER is part of a voluntary efficiency program for manufacturers under the National Lighting Collaborative, which was facilitated by the Energy Policy Act of 1992.

Benefits

- Selecting the adequate liminaires (fixtures) will not only help selecting the right number of fixtures or the most energy-efficient ones, but it will also provide a comfortable and more productive work environment



Additional Considerations

Before selecting luminaires or lighting fixtures for an office building, factory, warehouse, and even parking lots, it's a good idea to consult a certified lighting designer. A lighting designer will not only help you find the most energy-efficient luminaires, but also provide lighting that makes for a comfortable and more productive work environment.

Today, energy-efficient commercial lighting design includes more than just the ambient or general lighting of a workspace, such as the use of ceiling luminaires. When designing or retrofitting the lighting, the general luminance can be reduced if task lighting is implemented properly into the overall design. Task lighting can result in significant energy savings and improved visibility for workers.

The Illuminating Engineering Society of North America (IESNA) has established a procedure for determining how much luminance is needed for a given task. The procedure takes into account several factors, including type of activity, characteristic of visual task, task's required speed and accuracy, and reflectance of the task's background. In turn, this procedure will help determine what type of luminaire(s) would be appropriate.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

Prices vary depending on brands and characteristics. Nevertheless, having a lighting designer will not only help you find the most energy-efficient luminaires, but also provide lighting that make for a comfortable and more productive work environment. These last factors are usually not quantifiable, but do matter.

Life Cycle Cost Considerations

Cost-Effectiveness Example

Performance	Base Model	Recommended Level	Best Available
Luminaire Efficacy Rating (LER)	32	62	77
Luminaire Light Output	3600 lumens	3700 lumens	4400 lumens
Power Input	113 watts	60 watts	57 watts
Annual Energy Use	407 kWh	216 kWh	205 kWh
Annual Energy Cost	$24	$13	$12
Lifetime Energy Costa	$260	$140	$130
Lifetime Energy Cost Savings	---	**$120**	**$130**

a Lifetime energy cost is the sum of the discounted value of annual energy costs based on average usage and an assumed luminaire life of 15 years. Future electricity price trends and a discount rate of 3.4% are based on federal guidelines (effective from April 2000 to March 2001).

Cost-Effectiveness Assumptions: This example shows the cost effectiveness of energy-efficient 2' x 4' recessed, lensed luminaires. The base model uses three 34-watt T-12 lamps, while the recommended and best available models, despite providing equivalent or greater light output

(lumens), use only two 32-watt T8s. Usage assumption: 3,600 operating hours per year. Three sets of lamps would be used over the assumed luminaire lifespan of 15 years. Assumed electricity price: $0.06/kWh, the federal average electricity price in the U.S.
Source: http://www.eere.energy.gov/femp/procurement/eep_fluor_lum.cfm

Codes and Specifications that Apply

National Lighting Energy Code: ASHRAE/IESNA 90.1

Example Regional Contractors

Peerless Lighting
2246 Fifth Street
Berkeley CA
USA 94710
tel 1 510 845 2760
fax 1 510 845 2776
www.peerless-lighting.com

Hart Lighting & Supply
5017 S. 36th Street
Phoenix, AZ. 85040
Tel (602) 437-0375
Fax (602) 437-1264
www.hartlighting.com

City Lights Inc.
3911 West Van Buren #3
Phoenix, Arizona 85009
Tel (602) 233-2552
Fax (602)233-1102
www.citylightsphx.com

Pictures

Source: www.buyfixtures.com
Source: www.imgs.ebuild.com
Source: www.dek.cn
Source: www.global-sri.com

HIGH INTENSITY DISCHARGE (HID) LAMPS

Applications

Industrial, commercial and residential buildings. Some examples include: gymnasiums, large public areas, warehouses, outdoor activity areas, roadways, parking lots, and pathways.

Definition

HID lamps produce light by striking an electrical arc across tungsten electrodes housed inside a specially designed inner fused quartz or fused alumina tube.

Description

This tube used in HID lamps is filled with both gas and metals. The gas aids in the starting of the lamps. Then, the metals produce the light once they are heated to a point of evaporation, forming a plasma. Compared to fluorescent and incandescent lamps, high-intensity discharge (HID) lamps produce a large quantity of light in a small package.

Types of HID lamps include mercury vapor (CRI range 15-55), metal halide (CRI range 65-80), and high-pressure sodium (CRI range 22-75) (about CRI*).

* Color Rendering Index (CRI) — a measurement of a light source's accuracy in rendering different colors when compared to a reference light source with the same correlated color temperature. The highest attainable CRI is 100. Lamps with CRIs above 70 are typically used in office and living environments.

+ HID light sources, ranging from 20W to 2000W in size, can be found in numerous applications, from retail to industrial to public spaces. It is estimated that there are more than 105 million HID lamps in operation in the United States. HID lighting systems consume 12% of all lighting electricity consumed by the commercial sector, 31% in the industrial sector, and 87% in all outdoor stationary applications—an average of 17% of all electricity consumed by all lighting systems in the United States.

+ Facts and estimates concerning HID usage in the U.S. Source: U.S. Lighting Market Characterization: National Lighting Inventory and Energy Consumption Estimate, Navigant Consulting, Inc./U.S. Department of Energy, September 2002.

Benefits

- More light per watt
- Longer life. (i.e. Metal halide lamps have an average life of 15,000-20,000+ hours, more than ten times that of incandescent).
- Feature a compact point source similar to incandescent, allowing good optical control.
- Increased energy efficiency

- Wide range of operating devices to control them
- The output of metal halide lamps is closer to natural sunlight than most other light sources. People prefer white light because of better visual acuity, even at lower light levels.

Limitations

Are more expensive, but last longer.

Typical Design Section

Source: http://www.aboutlightingcontrols.org/education/papers/hiddimming.shtml

Maintenance

Once installed, maintenance is minimal.

Additional Considerations

HID's light is normally used when greater amounts of light are required and when energy efficiency and/or long life are desired. More recently, however, HID sources, especially metal halide (MH), have been used in small retail and residential environments.

LEED Credits

May be applicable in the Energy and Atmosphere section.

First Costs

There is a wide variety and prices change depending on the watts. (i.e. Oct-2006: 11 to 39 USD, Source: www.usalight.com,).

Life Cycle Cost Considerations

A 100 watt metal halide lamp provides five times the lumen output of a 100 watt incandescent lamp, and will last 20 times longer. Although incandescent has a low initial lamp cost, metal halide (HID lamp) has lower total operating cost over life.

Codes and Specifications that Apply

- ANSI C82.5-1990 (R1995)
  REFERENCE BALLASTS - HIGH-INTENSITY DISCHARGE AND LOW-PRESSURE SODIUM LAMPS
- National Lighting Energy Code: ASHRAE/IESNA 90.1

Example Regional Contractors

Hart Lighting & Supply
5017 S. 36th Street
Phoenix, AZ. 85040
Tel (602) 437-0375
Fax (602) 437-1264
www.hartlighting.com

City Lights Inc.
3911 West Van Buren #3
Phoenix, Arizona 85009
Tel (602) 233-2552
Fax (602)233-1102
www.citylightsphx.com

Pictures

Source: www.ragingspeed.co.uk
Source: www.me-dtc.com
Source: www.gelighting.com
Source: www.storesonlinepro.com

Electronic Ballasts

Applications

Fluorescent lamps and High Intensity Discharge (HID) lamps for use in industrial, commercial and residential buildings.

Definition

An electronic lamp ballast uses solid state electronic circuitry to provide the proper starting and operating electrical condition to power one or more fluorescent lamps or HID lamps.

Description

Electronic ballasts usually change the frequency of the power from the standard mains frequency to 20,000 Hz or higher, substantially eliminating the stroboscopic effect of flicker (100 or 120 Hz, twice the line frequency) associated with fluorescent lighting.

There are a variety of electronic ballasts available for use with fluorescent lamps. Electronic ballasts have been successfully used with lower watt high-intensity discharge (HID) lamps (primarily 35-100W MH). These ballasts provide an energy savings over magnetic ballasts of 8% to 20%. Their lighter weight also helps in some HID applications, such as track lighting. Electronic ballasts are also available as dimming ballasts. These ballasts allow the light level to be controlled between 1% and 100%.

Benefits

- Because more gas remains ionized in the arc stream, the lamps actually operate at about 9% higher efficiency above approximately 10 kHz. Lamp efficacy increases sharply to about 10 kHz and continues to improve until approximately 20 kHz (IES Lighting Handbook 1984).
- Because of the high frequency of operation, electronic ballasts are generally smaller, lighter, and more efficient (and thus run cooler) than line frequency magnetic ballasts.
- Generates less heat compared to magnetic ballasts.

Limitations

- Higher cost.
- See additional considerations section for use limitations.

Maintenance

50% less maintenance compared to magnetic ballasts. These last ones can only support two lamps and electronic ballasts up to four. Therefore, having fewer ballasts can result in lower maintenance of the system, since there are fewer components to go bad.

Additional Considerations

There are three starting methods available for electronic ballasts:

Instant Start

Start lamps without heating the cathodes at all by using a high voltage (around 600V). It is the most energy efficient type, but gives the least number of starts from a lamp as emissive oxides are blasted from the cold cathode surfaces each time the lamp is started. This is the best type for installations where lamps are not turned on and off very often.

Rapid Start

Applies voltage and heats the cathodes simultaneously. Provides superior lamp life and more cycle life, but uses slightly more energy as the cathodes in each end of the lamp continue to consume heating power as the lamp operates.

Programmed Start

More advanced version of rapid start. Applies cathode power first, then after a short delay to allow the cathodes to preheat, applies voltage to the lamps to strike an arc. Gives the best life and most starts from lamps. This is the preferred type of ballast for applications with very frequent power cycling such as vision examination rooms and restrooms with a motion detector switch.

LEED Credits

May be applicable for Energy and Atmosphere section.

First Costs

Electronic ballasts are the most expensive, but they're also the most efficient.

Life Cycle Cost Considerations

High-efficiency, high frequency electronic ballasts offer superior lighting performance and energy savings making their use cost-effective. Besides, electronic ballasts can control up to four lamps per ballast. Magnetic ballasts can only support up to two lamps. This feature allows for fewer ballasts in a lighting system thus less heat and higher energy savings. Furthermore, fewer ballasts can result in lower maintenance of the system, since there are fewer components to go bad.

Codes and Specifications that Apply

National Lighting Energy Code: ASHRAE/IESNA 90.1

Example Regional Contractors

Peerless Lighting
2246 Fifth Street
Berkeley CA
USA 94710
tel 1 510 845 2760
fax 1 510 845 2776
www.peerless-lighting.com

Advance Transformer Co.
O'Hare International Centre
10275 West Higgins Rd.
Rosemont IL
USA 60018
tel 1 800 332 2086
fax 1 847 390 5388
www.advancetransformer.com

Hart Lighting & Supply
5017 S. 36th Street
Phoenix, AZ. 85040
Tel (602) 437-0375
Fax (602) 437-1264
www.hartlighting.com

City Lights Inc.
3911 West Van Buren #3
Phoenix, Arizona 85009
Tel (602) 233-2552
Fax (602)233-1102
www.citylightsphx.com

Pictures

Source: www.solded.com
Source: www.aquatechtrade.com
Source: www.etlin.com

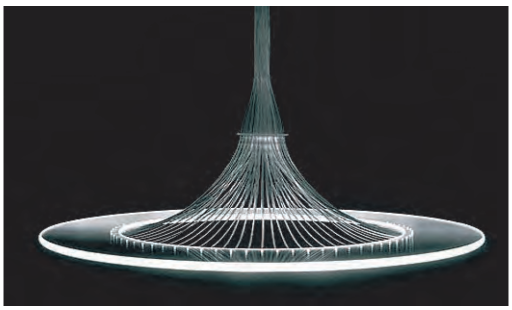
FIBER OPTIC LIGHTNING

Applications

It can be used for signs, building outlines, cove lighting, illuminate architectural fixtures, swimming pool perimeters, underwater lighting, landscape lighting and much more.

Definition

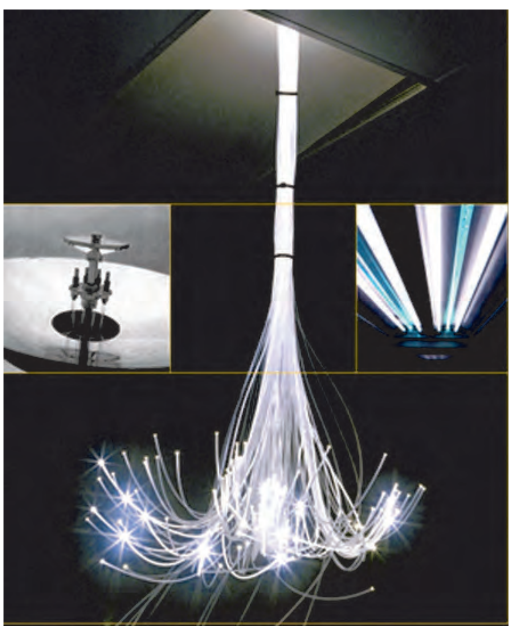
Fiber Optic Lighting is the technology of transmitting light from a centralized light source (illuminator) through an acrylic fiber cable (stranded or solid core) to a feature or fixture.



Description

Fiber optic lighting is generally energy- efficient and provides illumination over a given area. The only electrical connection needed for the system is at the illuminator (light source). No wiring or electrical connection is required along any part neither of the fiber optic cable nor at the actual point source fixture.

Flexible cabling allows for unique building signage and dynamic architectural accentuation. Easy system installation provides the opportunity to create visual interest at any surface, from floor to ceiling, within the space.



Fiber optic cable can be used above or below ground and is an excellent choice for use in or around water or anywhere heat or electricity is a concern. There is no safety concern because there is no electricity in the cable. Various size cables are available for different applications.

Benefits

- eliminates electricity in the line of light and at the point-source of light
- permits flexible designs because of durable, flexible fiber tubing allows for water illumination without electricity
- emits no heat
- virtually maintenance free
- reduces air conditioning needs

Limitations

Early illuminators had lower lumen output when compared to traditional light sources and fixtures

Typical Design Section

NA

Maintenance

Maintenance free

LEED Credits

May be applicable in Energy and Atmosphere section.

First Costs

The cost of a fiber optic lighting system is dependent upon many factors such as size, application, and use. Therefore an accurate average cost is unavailable.

Example Regional Contractors

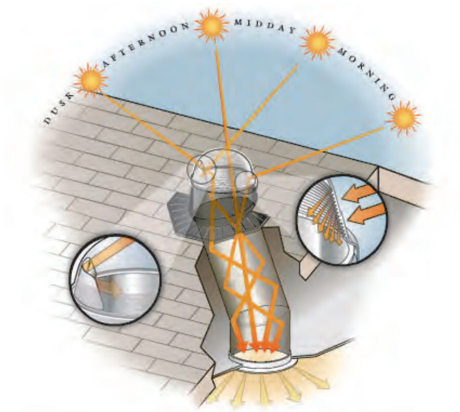
SUPER VISION INTERNATIONAL
8210 PRESIDENTS DRIVE
ORLANDO, FLORIDA 32809
UNITED STATES
TEL 407.857.9900
FAX 407.857.0050
www.svision.com

FIBERSTARS
44259 Nobel Drive
Fremont CA
USA 94538
tel 1 800 327 7877
fax 1 510 490 3247
www.fiberstars.com

Pictures

Source: www.ornl.gov
Source: www.inhabitat.com
Source: www.ecotality.com

SOLAR TUBES



Applications

Education facilities, retail environments, warehouses, industrial facilities, office buildings, healthcare facilities.

Definition

A solar tube captures light through a dome on the roof and channels it down to the building's interior through an internal reflective system.

Description

Solar tubes can be equipped with options like an integrated electric light (for night-time lighting), A Daylight Dimmer to turn the natural light off, as well as a ventilation fan, providing a two-or three-in-one unit from a single ceiling fixture.

The tubing is far more efficient than a traditional drywall skylight shaft, which can lose over half of the potential light. The tubing will fit between rafters and will install easily with no structural modification. At the ceiling level, a diffuser that resembles a recessed light fixture spreads the light evenly throughout the room.

A 10" (250mm) solar tube will provide light for up to a 150 square foot (14 sq meters) residential area. A 14" (350mm) Solatube lights up to a 250 square foot (23 sq meters) residential area. A 21" (530mm) Solatube lights up to a 400 square foot (37 sq meters) residential area.

Benefits

- Easy installation – new-build or retrofit
- Developed to provide unsurpassed performance, quality and durability
- Weatherproof, sealed system locks out dust, moisture and insects, and ensures minimum heat loss or gain
- Energy Star Efficiency product

Limitations

Light output will very depending on the intensity of the sun. For example, there will be more light at mid-day than in the morning or evening. Light output may also decrease as the length of tube increases.

Maintenance

Maintenance-free

Additional Considerations

For Commercial Building applications, please consult a solar tube design professional, since acceptable illuminated areas will greatly vary due to ceiling heights and space uses.

LEED Credits

Solatube has been used in several LEED projects and is specified in dozens of other projects that are still in design or currently under construction. Basically, under LEED Solatube can earn or contribute to the following credits:

- Credit for Daylight. (One point)
- There is also an Energy Optimization Performance Credit that Solatube can play a large part in. (One to Ten points available depending on the results of the energy simulation)
- There is a credit that relates to Recycled Content of the entire building. Solatube can play a part in this because recycled content is used in the lenses, fasteners, and trim pieces. (One point for 5%, an additional point is available if the recycled materials constitute 10% of the total value of the materials in the project)
- There is a credit available if the project uses a minimum of 20% of the building materials and products that are manufactured regionally within a radius of 500 miles. This is especially important for projects in Southern California and Arizona. (One point)
- There is a credit available for Controllability of Systems. (One to Two points)
- There is a credit for Innovation in Design where points are awarded for exceptional performance above the requirements set by the LEED Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System. (One to Four points)

First Costs

250 and 350 diameter Solatube® systems - September 2006

30° adjustable angle adaptors per kit	Straight 610mm extension sections	Installed distance*	250mm Solatube® into ceiling	350mm Solatube® into ceiling
(Qty)	(Qty)	(mm)	USD	USD
2	0	Up to 400	366.6	460.6
2	1	Up to 960	438.04	545.2
2	2	Up to 1520	509.48	629.8
2	3	Up to 2080	580.92	714.4
2	4	Up to 2640	652.36	799
2	5	Up to 3200	723.8	883.6
2	6	Up to 3760	795.24	968.2
2	7	Up to 4320	866.68	1052.8
2	8	Up to 4880	938.12	1137.4
2	9	Up to 5440	1009.56	1222

Codes and Specifications that Apply

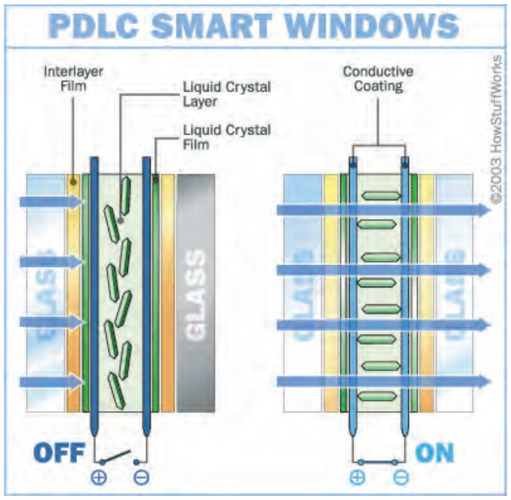
ASHRAE/IESNA Standard 90.1

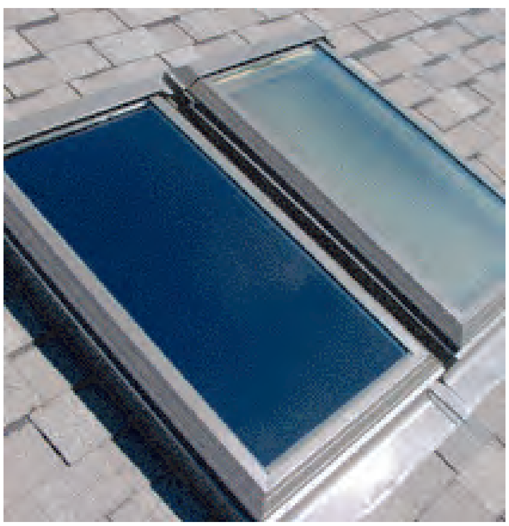
Example Regional Contractors

Solatube International, Inc
2210 Oak Ridge Way
Vista, CA 92081
Ph: 760-477-1120
Ph: 888-SOLATUBE
888-765-2882
Fax: 760-599-5181
www.solatube.com

Pictures

Source: www.inhabitat.com
Source: sunstor.net





SWITCHABLE GLAZING

Applications

This technology could be used in any type of building. Its potential uses for electrochromic technology include daylighting control, glare control, solar heat control, and fading protection in windows and skylights.

Definition

Switchable glazing are also called "smart windows". Switchable glazing can change the light transmittance, transparency, or shading of windows in response to an environmental signal such as sunlight, temperature or an electrical control.

Description

Windows are one of the most complex energy-using technologies in buildings. They play a role in lighting, heating, cooling, and ventilation. Aesthetics--appearance, view, and optical performance--are usually quite important to the occupant. Indeed, the serious lighting designer cannot ignore the energy implications of window choices.

New technologies help to resolve the historic problem of the trade-off between windows that reflect unwanted solar gains in the summer and those that admit a maximum amount of useful light. Todays window technologies can replace more primitive strategies for shielding a room from unwanted sunlight, such as tinted windows and curtains. One alternative are "smart" windows.

Switchable optical materials are of several types, each characterized by the means with which to control its properties, as summarized below.

- Photochromic materials change their properties as a function of light intensity. Sunglasses have used this technology for some time. The primary benefit is for visual comfort and glare control. Several skylight manufacturers now offer this option. Optical properties are changed as the metal halides in the glass are exposed to light. This creates a clouded appearance. As the absorptance increases, transmissivity decreases. The material reverts back to its original transparent state in the dark.
- Thermochromic materials change properties as a function of temperature. Optical properties are changed as liquid- and gel-based materials or thin-film solid-state devices are exposed to heat. The material reverts to its original state when cooled. In its exposed state, the material has a clouded appearance. As with photochromics, a disadvantage with thermochromics is that the threshold for change is fixed.
- Electrochromic materials change properties as a function of applied voltage. Properties range from colored, to intermediate, to bleached. These systems are more complex than thermo- and photochromic systems. The threshold for change can be altered in an existing unit, allowing for occupant, daily, and seasonal

adjustment. Controls can be operated manually or linked directly to building operating systems. Electrochromic coatings can be put on various layers of single- or double-pane units, or combined with other glazings (with or without other coatings).

- Another switchable technology, the liquid crystal suspended particle device (SPD), contains molecular particles suspended in a solution between plates of glass. In their natural state, the particles move randomly and collide, blocking the direct passage of light. When energized, the particles align rapidly and the glazing becomes transparent. This type of switchable glazing can block up to about 90 percent of light.

Benefits

- If used in conjunction with electronic dimmable ballasts, electrochromic windows can help attain considerable lighting energy savings relative to static window shading systems.
- The National Institute of Standards and Technology believe that "smart" windows can reduce a commercial building's energy use by 30 to 40 percent.
- In the summer months, electrochromic windows can block ultraviolet rays and radiant heat from direct sunlight from passing through windows and skylights to help lower cooling loads.
- They can also help slow the fading of interior furnishings by blocking out the sun's ultraviolet rays.
- Electrochromic windows offer the flexibility of control not available in photochromic or thermochromic windows (windows that turn opaque when exposed to light or warm temperatures).

Limitations

- There are no switchable glazings for residential purposes.
- Higer initial costs.
- Disadvantages with photochromics are that the threshold for change is fixed.

Therefore, there is no seasonal selectivity to allow more solar gain in winter and less in summer. When activated, photochromics reduce only the visual transmittance, not the infrared, so much of the solar heat gain is unaffected.

Maintenance

Many people feel that electrochromic materials are the most active and the most versatile, and in fact, most researchers are concentrating on this area. However, they also entail more complex maintenance and do require power in the form of electricity (although computers could be used to control them).

Additional Considerations

Electrochromic films require an electrical hookup that is not required for other types of solar-control window films and therefore requires unconventional wiring at windows and may require coordination of electrical and carpentry trades.

LEED Credits

May be applicable to the following sections:

- Energy and atmosphere.
- Indoor environmental quality.

First Costs

The cost of electrochromic windows can be from 2 to 3 times that of a standard window. Nevertheless, the market price of advanced window technologies vary widely. In markets where the technologies aren't well-known, prices can be extremely high (if the product is available at all). By contrast, in markets with considerable production and demand or where utility rebates or building codes call for such windows, prices can be quite reasonable.

System cost-effectiveness is determined by a combination of many factors. For new construction, the higher costs can often be partially--or even completely--offset by cost savings made possible by HVAC downsizing. In this case, the payback time is instantaneous, and any extra savings are pure profit.

Life Cycle Cost Considerations

The electricity used for switchable glazing is minimal compared with other energy savings. Low voltage products typically use less power than line voltage products and use virtually no power to maintain the glass in the clear state.

Codes and Specifications that Apply

Part 8 of the International Residential Code and the National Electric Code (NFPA 70) cover electrical requirements in residences. Electrical devices operating on line voltage in residences must be listed with an approved testing agency such as UL. Manufacturers may outline other requirements for installation such as the use of power conditioners, GFCI circuits, or others.

Example Regional Contractors

Pacific Bulletproof Co.
4035 Leaverton Ct.
Anaheim, CA 92807
Phone: 714-630-5447, 888-358-2309 (toll free)
Fax: 714-630-5314
http://www.pacificbulletproof.com

Republic West, Inc.
8101 E Mc Dowell Rd.
Scottsdale, AZ 85257
Phone: (480) 481-9595
Fax: (480) 481-0420

Pictures

Source: www.consumerenergycenter.org
Source: offbe.at

Heating and Cooling Systems

- ABSORPTION HEATERS AND CHILLERS
- ALTERNATIVE REFRIGERANTS
- WATER SOURCE HEAT PUMPS
- COMBO SPACE WATER HEATERS
- DESICCANT COOLING DEHUMIDIFICATION
- GAS FIRED HEATERS AND CHILLERS
- HIGH EFFICIENCY ROOFTOP UNITS
- LOW NO_x BURNERS
- RADIANT HEATING AND COOLING

ABSORPTION HEATERS & CHILLERS

Applications

Designed for applications requiring chilled water for space cooling during the summer and hot water for space heating during the winter. This includes commercial and residential buildings.

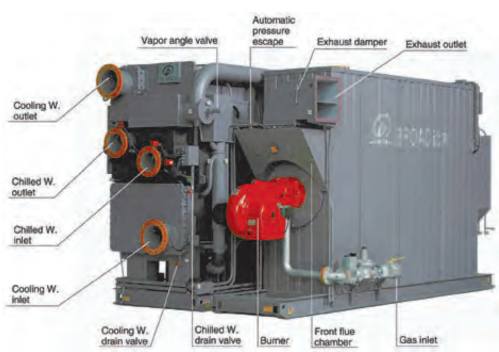
Definition

A device used to supply chilled water for cooling processes or air conditioning purposes and it could also be used for hot water supply. Recommended where electrical demand and consumption are expensive or in short supply.

Description

Gas fired chillers and heaters are also called absorption chillers or heaters. Direct-fired absorption chillers are competitive with electric centrifugal chillers in many parts of the country where electricity prices have risen dramatically over the last decade. They offer customers a choice in how they consume energy to produce chilled or hot water.

The absorption chiller uses natural gas or other fuels which do not use ozone depleting chemicals. As opposed to conventional chillers which work with refrigerants that contain CFCs or HCFCs that do have an impact on the ozone layer. The most common working fluids used in absorption chillers are water (the refrigerant) and lithium bromide (the absorbent); both are environmentally-benign substances that can be disposed of easily.



Benefits

- Lower operating costs
- Eliminate CFCs or HCFCs
- Reduce noise and vibration levels for quite operation
- Avoid peak electric demand charges
- Integrate microprocessor controls with automated building systems

Limitations

- Higher initial costs.
- Physical constraints in retrofit situations.

Maintenance

Gas-fired absorption chiller-heaters units are credited with a median service life of 23 years by ASHRAE.

Additional Considerations

- Standard and high-efficiency models ranging from 100 to 1100 tons are available.
- All sizes are also available with an auxiliary heat exchanger which provides simultaneous cooling and heating of water.

LEED Credits

May be applicable to Energy and Atmosphere section.

First Costs

Absorption chiller-heaters in the 500-ton capacity range are approximately USD 435/ton. Prices may vary in every state and among suppliers.

Life Cycle Cost Considerations

As an example of its implementation and the corresponding life cycle costs savings the following case study is explained: an old HCFC cooling system in Andover Elementary School was replaced with 260 tons of cooling from a direct fired absorption chiller, which handles both the older and the addition. Reduced operating costs with the natural gas system mean estimated savings over $5,800 per year.

Source: http://www.gasairconditioning.org/pdfs/case_studies

Codes and Specifications that Apply

Local regulations may require additional or modified air quality permits for gas-fired chillers. Absorption chillers can be installed in any location in the U.S. without additional costs for emissions control. Source: www.reliant.com

Example Regional Contractors

Innovative Technologies, Inc. – Scottsdale, AZ.
6522 E. Voltaire Ave.
Scottsdale, AZ 85254
Phone: 480-951-3104
Fax: 480-991-2484
Distributor, Manufacturer
Company Profile: Manufacturer & distributor of electric heaters, controls, sensors & accessories.

American Cooling Tower, Inc. - Tempe, AZ
1115 W. Ranch Rd.
Tempe, AZ 85284
Phone: 800-371-5959 (toll free)
Fax: 714-897-6689

Distributor, Service Company
Company Profile: Cooling towers, chillers, evaporative condensers; Distributor; rebuild, repair, component upgrade, inspection, rental

Heat Technology Products - Costa Mesa, CA (Serving Arizona)
2950 Airway Ave., Suite C3
Costa Mesa, CA 92626-6030
Phone: 714-549-0555
Fax: 714-549-0556
http://www.heattech.com
Distributor, Manufacturers' Rep, Service Company
Company Profile: Distributor, rep. & service of condensers, evaporators, brazed plate, embossed plates, heat exchangers, chillers, pre-insulated underground pipe, cooling towers & process analyzers.

Pictures

Source: www.broad.com
Source: www.dbdmart.com
Source: www.ubergizmo.com

Alternative Refrigerants

Applications

Commercial building's and car's refrigeration systems.

Definition

Refrigerants that do not destroy the earth's ozone layer.

Description

Refrigerants are chemical compounds consisting of basic elements from the table of elements. In fact not every basic element can be used to form a compound of refrigerants. Some basic elements are toxic, some are radio-active and others have a wrong boiling point for cooling-technical use. Consequently there remain 8 basic elements (carbon, azote, brimstone, hydrogen, fluorine, chlorine, bromine). Moreover chlorine and bromine drop out, because they damage the ozone layer.

To understand the complete context within alternative refrigerants it is relevant to get acquainted with the following three definitions and EPA's SNAP program:

- Chlorofluorocarbon (CFC): a compound consisting of chlorine, fluorine, and carbon. CFCs are very stable in the troposphere. They move to the Stratosphere and are broken down by strong ultraviolet light, where they release chlorine atoms that then deplete the ozone layer. CFCs are commonly used as refrigerants, solvents, and foam blowing agents. The most common CFCs are CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115.

- Hydrochlorofluorocarbon (HCFC): a compound consisting of hydrogen, chlorine, fluorine, and carbon. The HCFCs are one class of chemicals being used to replace the CFCs. They contain chlorine and thus deplete stratospheric ozone, but to a much lesser extent than CFCs. HCFCs have ozone depletion potentials (ODPs) ranging from 0.01 to 0.1. Production of HCFCs with the highest ODPs will be phased out first, followed by other HCFCs.

- Hydrofluorocarbon (HFC): a compound consisting of hydrogen, fluorine, and carbon, commonly (R134a). The HFCs are a class of replacements for CFCs. Because they do not contain chlorine or bromine, they do not deplete the ozone layer. All HFCs have an ozone depletion potential of 0.

On the other hand, The Significant New Alternatives Policy (SNAP) Program is EPA's program to evaluate and regulate substitutes for ozone-depleting chemicals being phased out under the stratospheric ozone protection provisions of the Clean Air Act (CAA). The purpose of the program is to allow a safe, smooth transition away from ozone-depleting compounds by identifying substitutes that offer lower overall risks to human health and the environment.

The SNAP program has reviewed substitutes for the following industrial sectors:

- Refrigeration & Air Conditioning
- Foam Blowing Agents
- Cleaning Solvents
- Fire Suppression and Explosion Protection
- Aerosols
- Sterilants
- Tobacco Expansion
- Adhesives, Coatings & Inks

A list of accepted alternative refrigerants is updated every year by EPA in the Federal Register. One example is # 71FR15589 which was issued on March 29th, 2006. In this case, the following alternative refrigerants were added:

- ICOR AT-22 is acceptable for use in new and retrofit equipment as a substitute for HCFC-22;
- ICOR XLT1 (R-422C) is an acceptable substitute for HCFC-22, R-502, R-402AR-402B, and R-408A;
- ICOR XAC1 (R-422B) is an acceptable substitute for HCFC-22;
- R-417A is an acceptable substitute for HCF-22;
- Hydrofluorocarbon (HFC)-245fa is an acceptable substitute for CFC-11, CFC-113, CFC-114, HCFC-21, HCFC-123, and HCFC-141b;
- R-420A is an acceptable substitute for CFC-12.

<u>Benefits</u>

- Do not deplete the earth's ozone layer.
- Decreases green house emissions.

<u>Limitations</u>

- Some alternative refrigerants are ozone depletion zero. But have a global warming potential (GWP) impact.
- May be more toxic than conventional refrigerants.

<u>Maintenance</u>

Equipment that uses CFCs as a refrigerant and that need maintenance represent an environmental impact to the ozone layer. Usually these equipments have to have the refrigerant released, then get fixed, and finally refill again. On the other hand, releasing accepted alternative refrigerants will not do any harm to the environment during its maintenance.

<u>Additional Considerations</u>

HFCs such as R134a have high global warming potential (GWP). There are alternates to R134a. Lithium bromide, a salt solution, is often used in absorption chillers. It is non-toxic, non-flammable and does not contribute to global warming. Ammonia is often used in low-temperature refrigeration applications such as ice-rinks; however, ammonia is very toxic. Research continues into other non-ozone depleting refrigerants.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

Changing from ozone-depleting chemicals to non-ozone depleting chemicals has had little effect on the price of equipment that uses them.

Life Cycle Cost Considerations

In the car industry, air conditioners using carbon dioxide (CFC) as a refrigerant are less energy efficient than HFC systems, according to evaluations conducted by the technical consulting firm Arthur D. Little. It was found that they require more energy for compression and bulkier hardware for increased heat transfer area. Carbon dioxide system costs are estimated at least 20% more than HFC systems and need further materials compatibility, durability, reliability and safety development. A.D. Little has estimated that annual additional consumer energy costs could be almost $7 billion in the U.S. and another $9 billion worldwide. Additionally, higher manufacturing costs could be $100 per air-conditioned vehicle. On the other hand, HFC-134a currently provides the best overall environmental, safety and comfort performance balance. Commercially available throughout the world, HFCs are energy efficient, low in toxicity, cost-effective, can be used safely and are reusable.

Codes and Specifications that Apply

Substitutes are reviewed on the basis of ozone depletion potential, global warming potential, toxicity, flammability, and exposure potential as described in the final SNAP rule (59 FR 13044).

The SNAP program makes decisions on a particular substitute in a particular end-use within a larger sector. For example, within the refrigeration and air conditioning sector, HFC-134a is acceptable as a substitute for CFC-12 in new and retrofitted household refrigerators. Acceptable substitutes are listed by end-use. These lists include substitutes that are either acceptable, acceptable subject to narrowed use limits, or acceptable subject to use conditions.

See The Federal Register for acceptable alternative refrigerants.

http://www.thefederalregister.com

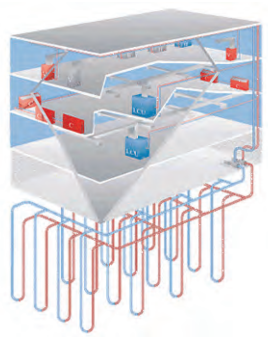
Example Regional Contractors

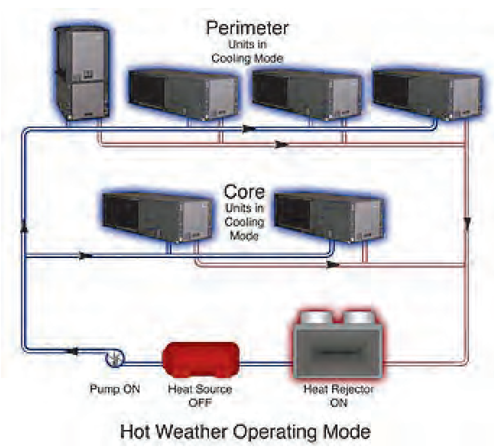
American Society of Heating, Refrigeration and Air Conditioning Engineers
1791 Tullie Circle NE
Atlanta GA
USA 30329-2305
tel 1 800 527 4723
fax 1 404 321 5478
www.ashrae.org

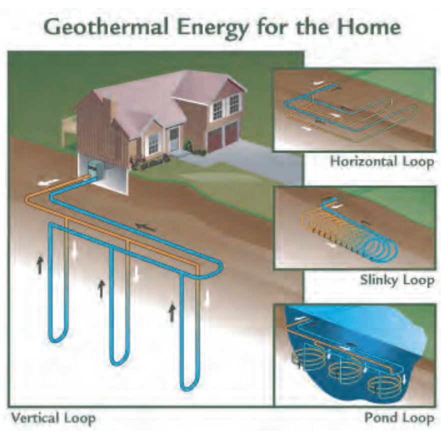
Pictures

Source: www.diytrade.com

Water Source Heat Pumps







<u>Applications</u>

Ideal for a wide range of building types including Office Buildings, Apartment Buildings, Assisted Living Facilities, Condominiums, Schools and much more.

<u>Definition</u>

Water Source Heat Pump (WSHP) systems are one of the most efficient, environmentally friendly ways to heat and cool buildings because of their ability to move energy from where it is not needed to where it is needed.

<u>Description</u>

In water source heat pumps heat is moved through an interconnected water loop and either rejected through a cooling tower, or put to work in other areas. Each unit is an independent, packaged system, eliminating the chance of a total system failure. If one unit goes down, the other units are not affected. These systems could work in three scenarios: Cold weather, hot weather and balanced mode.

In cold weather, the heat pump removes heat from the water loop via the unit's specially designed refrigerant-to-water coaxial heat exchanger and transfers it to the air.

In hot weather, when most or all of the units are operating in the cooling mode, heat is being taken from the zones in the building and rejected into the water loop. If not required somewhere else in the building, the heat is rejected from the building through an external fluid cooler attached to the loop.

In balanced mode, during certain times of the year, units in different zones may be operating in different modes, heating and cooling different spaces at the same time. When this occurs, heat is moved from one area to another via the water loop. During this time, the loop may not require either heat rejection or supply. This is when the system is most efficient. This is in contrast to fan coil systems which may require both a boiler and chiller to be operating simultaneously (4-pipe) or utilize inefficient electric heat.

<u>Benefits</u>

- Does not produce noise while in operation.
- Maintenance costs are reduced.
- No room space is needed inside the building.
- No equipment is needed in top of roof..

Limitations

- Higher initial investment.
- An outdoor space area is needed for the heat exchanger.
- The heat pumps use HFC and HCFC's as a refrigerant, they are knwn to affect the ozone layer.

Maintenance

When the system receives maintenance and/or is disassembled, it is important to put special attention to the removal or recycling of the HFC or HCFC's used as refrigerants in the heat pumps.

LEED Credits

May be applicable to the energy and atmosphere sections.

First Costs

While the initial purchase price of a residential WSHP system is often higher than that of a comparable gas-fired furnace and central air-conditioning system, it is more efficient, thereby saving money every month. In the winter, water heating costs are reduced by about half. On average, a WSHP system costs about $2,500 per ton of capacity, or roughly $7,500 for a 3-ton unit (a typical residential size).

Life Cycle Cost Considerations

Water source heat pump systems offer the high efficiency necessary to keep operating costs down. In fact, they offer a lower operating cost than most compatibly zoned systems. The difference lies in the system's ability to recover otherwise wasted energy and use it elsewhere in the facility. This dynamic, intelligent use of energy balances the needs of the entire facility while reducing operating costs. Approximately 20% of the total energy costs of a building can be saved with the introduction of a water source heat pump system. The following table shows a comparison of water base heat pumps against a traditional system:

traditional system comparisons	Annual Maintenance Expense	Annual Operating Expense	Total Annual Cost	Installation Cost
fan coil, chiller/boiler 4-pipe	.14	1.40	1.54	$12.00
Water loop heat pump	.10	.94	1.04	$8.00

Codes and Specifications that Apply

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 90.1 specifies minimum efficiency standards for water source heat pumps.

Example Regional Contractors

Water Furnace International
9000 Conservation Way
Fort Wayne IN
USA 46809
tel 1 800 222 5667
fax 1 219 479 3272
www.waterfurnace.com

Climate Master Inc.
7300 Southwest 44th Street
Oklahoma City OK
USA 73179
tel 1 405 745 6000
fax 1 450 745 6058
info@climatemaster.com
www.climatemaster.com

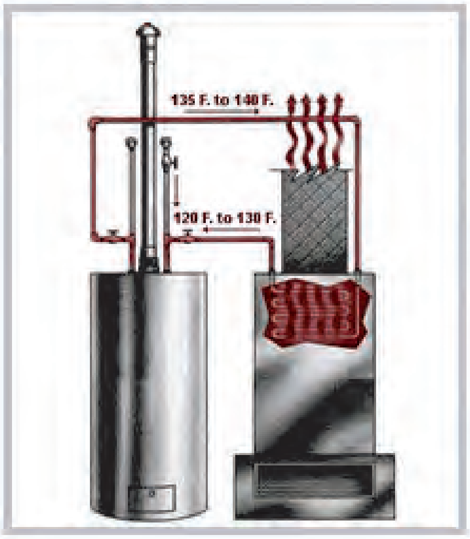
McQuay - Americas Headquarters
13600 Industrial Park Blvd.
Minneapolis, Minnesota 55441
800-432-1342 (Toll Free)
763-553-5330 (Direct)
763-553-5177 (Fax)

Pictures

Source: www.climatemaster.com

Source: www.climatemaster.com

Source: www.climatemaster.com



Combo Space Water Heaters

Applications

Commercial buildings, hotels, multifamily home buildings, and also for residential homes.

Definition

Combo space water systems use a gas water heater to provide domestic water and heating.

Description

Combination water and space heating systems use a high efficiency water heater or central boiler to supply heating energy to the space heating system while still meeting the needs for domestic hot water.

Combination systems perform most efficiently when used with a high efficiency gas water heater. Gas furnaces, water heaters and ranges are more efficient than similar electric appliances. Because gas is piped directly to the appliance and consumed on site there are no transmission and distribution losses which can be as 15-18 percent in moving electricity from power plants and end users.

Combination systems are very effective for use in hotels, apartment complexes and small homes but can also be effective in large homes using multiple or zoned water heating systems.

Benefits

- Last longer than conventional storage water heaters because of increased circulation of water and reduced sedimentation on the tank bottom.
- More energy efficient and the resulting reduction in air pollution compared to a conventional water heater and space heating installation.
- The reduction in energy use and operating costs leads to higher profits or lower rents on multi-family projects.
- When using a combo system, it reduces the need to install a separate furnace.

Limitations

- Only available in small sizes.

Maintenance

The operation and maintenance of a combination space and water system will be the same as for standard water heaters and space heating systems. Maintenance will include regular replacement of filters for forced air systems, annual draining of the water heater to reduce buildup of mineral deposits and annual servicing of the HVAC.

Additional Considerations

Water heaters selected for combination applications must be sized to meet the space heating demand of the dwelling in which they will be used. Water heaters sized to meet the heating demand will also meet the domestic hot water needs except when a hot tub or jacuzzi must be served by the water heater.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

For small loads, the cost of a combination system can be less than separate systems for space and water heating. On the other hand, for large loads, first costs will favor separate systems.

Life Cycle Cost Considerations

- Over the long term, combo systems reduce replacement costs by eliminating the need to replace the furnace, since none exists.
- In combo systems hot water is circulated more often through the water heater. This results in less build up of calcium deposits in the water heater leading to a longer usable life for the water heater.

Codes and Specifications that Apply

- Must meet applicable codes.
- CSI Numbers: 15424 Domestic Water Heaters, 15700 Liquid Heat Transfer

Example Regional Contractors

First Co.
8273 Moberly Lane
Dallas TX
USA 75227
tel 1 214 388 5751
fax 1 214 388 2255
www.firstco.com

Takagi Industrial Co. USA, Inc.
6 Goddard
Irvine, CA 92618
(888) 882-5244
www.takagi-usa.com

WGLHoldings, Inc.
101 Constitution Avenue, NW
Washington, DC 20080
(703) 750-2000
info@wglholdings.com

Pictures

Source: www.firstco.com

Two-Wheel Desiccant System

DESICCANT COOLING DEHUMIDIFICATION

Applications

Desiccant systems can be used to create very low humidity environments (5-10% relative humidity) which would otherwise be difficult and expensive to maintain using compression-refrigeration equipment. Therefore, desiccant cooling systems are best suited to health-care buildings where healthy indoor air is critical, and to buildings housing humidity-sensitive processes, for example, microelectronics, photography, printing and archiving.

Definition

Desiccants are materials that attract moisture and can be dried, or regenerated, by adding heat supplied by natural gas, waste heat, or the sun. Desiccant Cooling is an energy efficient, cost effective and environmentally safe way of improving the indoor air quality of a building, by reducing both temperature and humidity and thus increasing comfort.

Description

In most systems, a wheel that contains a desiccant turns slowly to pick up humidity from incoming air and discharge that humidity to the outdoors. Dehumidified air is usually directed to the supply of an air conditioning system. A desiccant system can be combined with a conventional air conditioning system in which the desiccant removes humidity and the air conditioner lowers air temperature.

The use of desiccant cooling for residential use is being explored in conjunction with energy recovery ventilators (ERV). An energy recovery ventilator is designed to provide energy recovery in a mechanical ventilation system during the heating season. ERVs recover heat and humidity from indoor air to preheat and humidify incoming fresh air. Desiccant cooling is designed to dehumidify incoming fresh air in the summer. Combined, they make a year-round energy recovery device for homes with mechanical ventilation.

Benefits

- According to the National Renewable Energy Laboratory, desiccant dehumidification could reduce total residential electricity demand by as much as 25 percent in humid regions.
- Smaller footprints - takes up less space than conventional mechanical systems.
- Reduces the growth of moulds, fungi, bacteria and virus's - making the best choice for buildings where good indoor air quality is critical such as hospitals.
- Desiccant systems can efficiently handle the large volumes of fresh air required to conform to the new standards set out by ASHRAE.
- Very environmentally friendly with no ozone depleting gases.

Limitations

- Desiccant cooling systems are not commercially available for residential applications. However, a combined Energy Recovery Ventilator (ERV) and desiccant cooling system is in the development stage.
- Increased first cost
- Increased maintenance of the added desiccant equipment
- Cost of energy (usually natural gas) to regenerate the desiccant at a high temperature to drive off the entrained moisture
- In some cases, the need for piping of cooling (typically tower) water to remove the heat of adsorption and pre-cool the heated air off the desiccant units

Maintenance

Like any other mechanical equipment, desiccant components must be maintained according to a recommended schedule. The following web page offers a maintenance tutorial for this type of technology www.gri.org

Additional Considerations

Desiccant cooling is not suitable for small unitary systems, except where heat recovery is already going to be provided and the upgrade cost to a desiccant-coated heat wheel is small.

LEED Credits

May be applicable to the Energy and Atmosphere sections.

First Costs

Higher initial costs are present when using desiccant cooling systems.

Life Cycle Cost Considerations

- Very cost effective - massive energy savings compared to conventional refrigeration systems.

- Improves the efficiency of refrigeration equipment by operating at higher evaporator temperatures and higher COP (Co-efficient of Performance).

Codes and Specifications that Apply

The Air-Conditioning and Refrigeration Institute (ARI) has published a new standard, ARI Standard 940-98 "Desiccant Dehumidification Components," that applies to thermally regenerated desiccant components.

If gas is used for desiccant regeneration, proper venting will be required to eliminate air quality concerns.

Example Regional Contractors

Brenner-Fiedler & Associates, Inc.
2117 S. 48th, Suite 102
Tempe, AZ 85282
Phone: 602-438-2710, 800-280-1629 (toll free)
Fax: 602-438-2763

AGM Container Controls, Inc.
P.O. Box 40020
Tucson, AZ 85717-0020
Phone: 520-881-2130, 800-995-5590 (toll free)
Fax: 520-881-4983
http://www.agmcontainer.com

Pictures

Source: www.solarmirror.com
Source: http://desiccantdryair.com

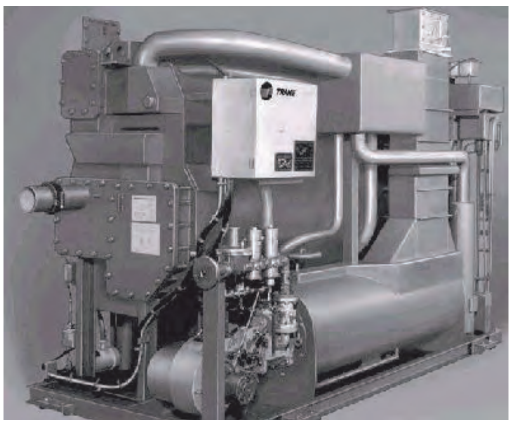
Gas Fired Heaters & Chillers

Applications

Designed for applications requiring chilled water for space cooling during the summer and hot water for space heating during the winter. This includes commercial and residential buildings.

Definition

A device used to supply chilled water for cooling processes or air conditioning purposes and it could also be used for hot water supply. Recommended where electrical demand and consumption are expensive or in short supply.



Description

Gas fired chillers and heaters are also called absorption chillers or heaters. Direct-fired absorption chillers are competitive with electric centrifugal chillers in many parts of the country where electricity prices have risen dramatically over the last decade. They offer customers a choice in how they consume energy to produce chilled or hot water.

The absorption chiller uses natural gas or other fuels which do not use ozone depleting chemicals. As opposed to conventional chillers which work with refrigerants that contain CFCs or HCFCs that do have an impact on the ozone layer. The most common working fluids used in absorption chillers are water (the refrigerant) and lithium bromide (the absorbent); both are environmentally-benign substances that can be disposed of easily.

Benefits

- Energy costs reduction.
- Decreasing environmental impacts by avoiding the use of refrigerants that affect the ozone layer.

Limitations

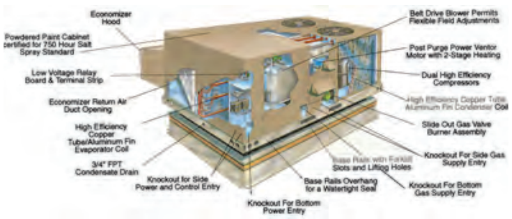
- Higher initial costs.
- Physical constraints in retrofit situations.

Additional Considerations

- Standard and high-efficiency models ranging from 100 to 1100 tons are available.
- All sizes are also available with an auxiliary heat exchanger which provides simultaneous cooling and heating of water.

Pictures

Source: www.pedco2000.com
Source: www.energysolutions.org
Source: www.energytechpro.com
Source: www.hitachi-ap.com



HIGH EFFICIENCY ROOFTOP UNITS

Applications

The majority of high efficiency rooftop installations are in schools and office buildings. Higher efficiency rooftop heaters are best suited for colder climates where a large heating demand exists.

Definition

Gas fired rooftop units are commonly used to provide space heating and cooling, they are relatively inexpensive, can be integrated into a standard forced air duct system and can be placed easily on the exterior of a building so they don't take up valuable internal space. They also offer higher energy savings as opposed to regular rooftop units.

Description

The majority of current commercial gas-fired rooftop air conditioning units are single-speed non condensing units with combustion efficiencies in the range of 78-82%. Newer high units using condensing heat exchangers or pulse combustion can boost this efficiency to 89-97%. They include a secondary heat exchanger to extract most of the heat remaining in the combustion by-products.

Another method of increasing energy efficiency is modulating the burner and combustion air flows. Modulating units regulate combustion air and natural gas flows according to heating demand. By regulating the flow, the units may operate for longer periods, thus significantly reducing cycling losses and minimizing operating costs. These systems also provide better temperature control, and are capable of maintaining high comfort levels in multiple zones.

Benefits

- Lowers environmental impacts.
- Less space requirements for indoors.
- Better comfort.
- Increases energy savings.
- Less mechanical room space.
- Relatively easy to install.

Limitations

- Higher first costs.
- Condensation in low temperature weather conditions. Technically difficult to eliminate.

Maintenance

Besides the monthly filters change the required maintenance should be having it serviced at least once a year. This includes greasing the bearings, checking pulleys, refrigerant charge, etc.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

A typical 20-ton Trane GasPak unit typically costs about $12,000, while a 30-ton Trane Intellipak unit with the modulating gas burner would cost $35,000, resulting in a cost premium of about $500/ton.

Source: Emerging Technologies & Practices: 2004, ACEEE

Life Cycle Cost Considerations

According to Pacific Northwest National Laboratories when using the UAC Cost Estimator it shows life cycle cost savings of $1700 for a simple payback of 3.6 years when replacing one rooftop air conditioner with an energy-efficient unit.

Source: www.pnl.gov , High Efficiency Rooftop Air Conditioners.

Codes and Specifications that Apply

The National Energy Policy Act of 1992 mandates that all states adopt energy codes at least as stringent as ASHRAE Standard 90. 1-1989.

Example Regional Contractors

Custom Mechanical Equipment LLC
2080 Energy Drive
East Troy WI
USA 53120
www.cmemultizone.com

Phoenix, AZ
850 West Southern Ave
Tempe, AZ USA 85282
602.258.9600
602.253.3801
www.trane.com/Phoenix

Tucson, AZ
4520 S. Coach Drive
Tucson, AZ USA 85714
520.748.1234
520.748.1492
www.trane.com/Tucson

Pictures

Source: www.docs.hvacpartneres.com
Source: www.jnaonline.com
Source: www.commercial carrier.com

Low NOx Retrofits

LOW NOx BURNERS

Applications

Industrial, commercial and residential buildings where the following is needed:

- Where low NOx emissions are required
- Where uniform heat flux distribution is important
- Heater retrofits for the purpose of NOx reduction

Definition

Natural gas burners with improved energy efficiency and lower emissions of nitrous oxides.

Description

In Low NOx burners (LNBs), a fuel-rich combustion stage or zone is created by forcing additional air to the outside of the firing zone (auxiliary air) and by delaying the combustion of coal, this makes the flame to look blue. By doing this procedure, a reduction in the range of 30 to 55 percent of NOx can be achieved. There are also advanced stage combustion technologies which use over fire air (OFA) and gas or coal reburning to achieve even greater reductions of NOx.

The reason for the development of this technology has its roots in the following facts: NOx emissions have been linked to acid rain, photochemical smog, and troposphere ozone destruction. This has led to establishment of regulatory measures and to development of technologies to reduce NOx emissions. NOx increases with flame temperature, the most important of several variables affecting NOx generation. Therefore, low NOx burners incorporate a mechanism for reducing the peak flame temperature relative to conventional burners.

LNBs and LNBs plus OFA are being used commercially in Europe, Japan, and the United States. New boilers in industrialized countries all use low-NOx burners, and retrofits of old boilers are being legislated in many cases.

Benefits

- Lowers NOx emissions.
- Are more efficient than conventional burners.

Limitations

- Need more space compared to conventional burners
- Lack of environmental regulations requiring NOx emission control is the main reason for the limited use of these technologies in developing countries.

Typical Design Section

Source: http://www.maxoncorp.com/products/lownox-sls.html

Maintenance

Periodic maintenance is required and the cost depends on the type of staging combustion system (LNB, LNB + OFA, reburning).

Additional Considerations

The low-NOx burner used for commercial and residential space heating is larger in size than conventional burners, although it is designed for ease of installation. On the other hand, lack of environmental regulations requiring NOx emission control is the main reason for the limited use of these technologies in developing countries.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

Retrofitting existing boilers with LNBs range from US$5/kW for LNB to US$50/kW for reburning. The initial investment for introducing such systems into new boilers is a fraction of the costs for retrofitting existing boilers. For example, incorporating a LNB + OFA into a new boiler adds only US$3 to 10/kW, whereas retrofitting an existing boiler may cost up to US$25/kW.

Source: www.worlsbank.org

Life Cycle Cost Considerations

Retrofitting an existing boiler with LNBs technologies takes 3 to 10 weeks approximately. The use of low-NOx burners is not expected to affect the design, manufacture, and construction of new boilers.

The cost-effectiveness (in terms of US$/ton of NOx removed) depends on the capital costs, and required NOx reduction. Typical ranges of cost-effectiveness are as follows:

- LNB: 100 to 400 US$/ton NOx removed
- LNB + OFA: 200 to 400 US$/ton NOx removed
- Reburning: 500 to 1,200 US$/ton NOx removed.

  Source: www.worlsbank.org

Codes and Specifications that Apply

The burner should meet the requirements of I.R.I, NFPA-85, FM, and CSD-1. Nevertheless, regulations may change from state to state.

Example Regional Contractors

Aqua-Man Aquatic Service, Inc.
6890 N. Camino Martin, Suite 110
Tucson, AZ 85741-2273
Toll Free: (866) 400-AQUA (2782) M-F 7am-5pm MST
Office: (520) 572-9840
Fax: (520) 572-8479
Email: sales@aqua-man.com

Heat Technology Products - Costa Mesa, CA (Serving Arizona)
Southern California Office
2950 Airway Avenue, Suite C3
Costa Mesa, CA 92626-6030
Tel 714-549-0555
Fax 714-549-0556
Sales@heattech.com

Pictures

Source: http://www.maxoncorp.com/products/lownox-mpakt.html
Source: http://www.zeeco.com/burners/burners.html#5
Source: http://www.zeeco.com/burners.html

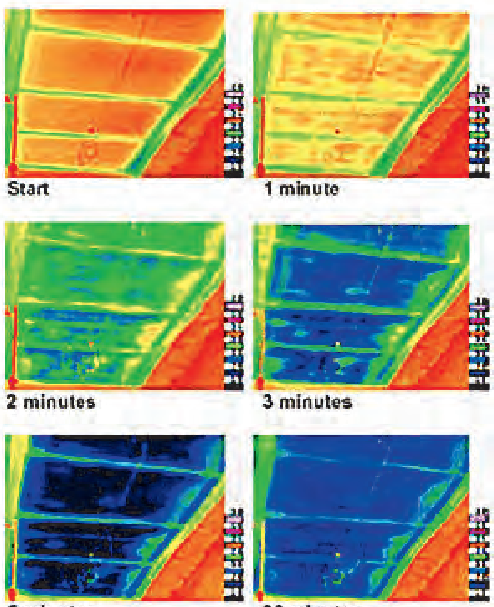
Radiant Heating & Cooling

Applications

Commercial and residential buildings.

Definition

A technology used to heat and cool buildings. It basically works through radiation heat transfer. Typically, heated or chilled water is circulated though floor or ceiling panels to condition the space.



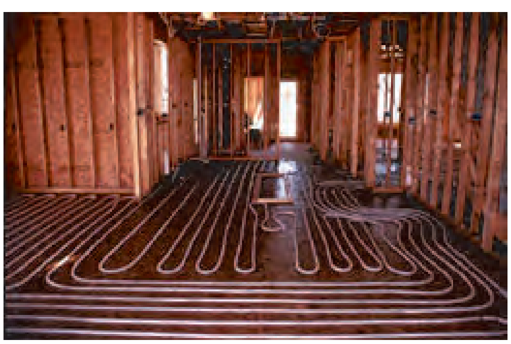
Description

With Radiant Floor Heating water is used to carry heat. Water is one of the best conductors of heat; it can be circulated positively and its temperatures can be accurately controlled so you get a more even heat with less temperature fluctuations. Radiant floor heating has been used to resolve difficult heating challenges such as high ceilings, weather-exposed floors, floors with high back losses and large amount of infiltration.

Radiant floor is a good option for buildings because it does not dry out the air; it doesn't create burnt dust on heating elements, use less energy because it warms building occupants instead of the building air. It sues the principle of "Hydronic," which means using water to transport heat. In addition, hot water can be run by solar panels.

Cooling can be also done through radiant floor. However, there are some limitations such as limited load, condensation, and cooling location. Additional radiant cooling can be done on walls, ceiling, and concrete core. A standard solution for larger buildings is a compression-cycle chiller, but the alternative systems include evaporative cooler, or geo-exchange system.

This technology uses metal radiant panels that can be ceiling mounted, either attached directly to the ceiling or as part of a T-bar suspended ceiling. For floor systems, flexible plastic piping is embedded in the concrete floor or in gypsum topping on a wooden sub-floor. Ceiling mounted systems are usually best for combined heating and cooling systems. Floor systems are best for heating-only systems (provided the floor isn't covered with heavy carpets).



Benefits

- Radiant heating and cooling is more energy efficient
- Uses less mechanical energy to deliver
- Uses a lower temperature to heat and cool than air delivery systems
- Provides more uniform heating - more uniform heating of room
- Avoids noise and drafts of air-based HVAC system.

Limitations

The system cannot be operated at lower temperatures in cooling mode without the risk of condensation. To prevent condensation on cooling panels, an auxiliary air-conditioning system may be needed to dry the air and meet latent cooling load.

Typical Design Section

Source: http://www.allamericanheatingcooling.com/p8.html

Maintenance

Low maintenance as there is few electrical devices compared to a forced air system.

Additional Considerations

Radiant heating and cooling systems can be used in most commercial buildings provided there are not excessive internal heat gains. Because of the limited cooling output of the radiant panels, a radiant cooling system would not be able to maintain comfort conditions in buildings with high lighting loads (jewelry stores) or process loads (industrial facilities).

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

* An approximate cost of an installed hydronic radiant floor heating system by a licensed mechanical contractor can range from $6 to $12 per square foot. This cost can be more or less depending on specific heating requirements and energy efficiency results. In addition to the heating system, a mechanical ventilation system is required in the house.

Source: www.descoenergy.com

* Panel's examples: Ceiling-mounted radiant panels approximately cost about $88/m2 of panel, installation extra. Radiant floor systems cost about $57/m2 installed. However, part of this cost is offset by savings in ducting costs.

Source: www.advacedbuildings.org

* Complete system example: 20,000 square foot industrial building with boiler and 10 heating zones:

20,000 square ft industrial slab floor area $10,000.00

Ten heating zones $ 7,000.00

Boiler allowance $ 8,000.00

TOTAL $25,000.00

Source: www.radiantec.com

* For other prices examples please see: http://www.radiantmadesimple.com/productsandpricing.html

Life Cycle Cost Considerations

A properly maintained system can last for as long as 30 to 40 years. Manufacturers claim radiant floor heating saves 20 to 40 percent on monthly heating bills. It is recommended that annual maintenance be done on mechanical equipment such as the pumps, hot water heater, controls etc. If there was a problem or failure, it is commonly found in these mechanical parts.

Codes and Specifications that Apply

A new and seldom-used technology, radiant cooling is not regulated in the codes like radiant heating. The regulations change from state to state.

Example Regional Contractors

WOLFF MECHANICAL, INC.
1701 S. INDIAN BEND
SUITE 101
TEMPE, AZ 85281 TEL: 480-968-8208
FAX: 480-968-8229
http://www.wolffmechanical.com

Pictures

Source: http://www.sterlingheat.com/html/radiant_heating.htm
Source: www.radiantcooling.org
Source: http://www.jonasoil.com/index.htm?radiantheat.htm~mainFrame
Source: http://www.radiantmadesimple.com/?gclid=CNy-4YC4k4gCFRL1Ygod4DvJMg

Onsite Energy Generation

- PHOTOVOLTAIC
- BUILDING INTEGRATED PHOTOVOLTAIC (BIPV)
- COGENERATION
- WIND ENERGY
- FUEL CELLS

Photovoltaic Panels

Applications

Photovoltaics can be used in a wide range of products, from small consumer items to large commercial solar electric systems. Some examples include: prime buildings, outbuildings, emergency telephones, irrigation pumps, fountains, lighting for parking lots, pathways, security, clearance, billboards, bus shelters or signs, and remote operation of gates, irrigation valves, traffic signals, radios, telemetry, or instrumentation.

Definition

Photovoltaic (PV) technology is the direct conversion of sunlight to electricity using semiconductor devices called solar cells.

Description

Photovoltaics or PV for short is a solar power technology that uses solar photovoltaic arrays or solar cells to provide electricity for human activities. A PV cell (or solar cell) is a small crystal wafer with a permanent internal electric field. When sunlight hits the cell, electrons are released, generating an electric current. Solar cells produce direct current electricity from the sun's rays, which can be used to power equipment or to recharge a battery.

When more power is required than a single cell can deliver, cells are generally grouped together to form "PV modules" that may in turn be arranged in "solar arrays" which are sometimes ambiguously referred to as solar panels.

Benefits

- Most states receive tax incentives for incorporating this type of technology. See Database of State Incentives for Renewables and Efficiency (DSIRE). http://www.dsireusa.org/
- Reduces green house emissions.
- Reduces non-renewable energy demand.

Limitations

- Requires energy storage in batteries or a connection to electrical utility grid.
- Increases capital costs.
- High-capacity systems will require large areas to place the solar panels.
- Must have uninterrupted access to sunshine or won't work.

Maintenance

Any energy system requires maintenance, but experience shows that PV systems require less maintenance than other alternatives. A well-designed PV system will operate unattended and requires minimum periodic maintenance. The savings in labor costs and travel expenses can be significant.

Additional Considerations

PV panels produce direct current, not the alternating current used to power most building equipment. Direct current is easily stored in batteries; a device called an inverter is required to transform the direct current to alternating current. The cost of reliable batteries to store electricity, and the cost of an inverter, increase the overall cost of a system.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

The cost of energy produced by PV systems continues to drop. However, kilowatt-hour for kilowatt-hour, and depending on where you live, PV energy still usually costs more than energy from your local utility.

Solar energy technologies often have a higher "first cost." This means that a person is likely to pay more money up front to purchase and install a solar system. Still, in nearly all cases, the high initial cost is recovered through substantial fuel savings over the life of the product (15-30 years).

Life Cycle Cost Considerations

Photovoltaics are almost maintenance-free and seem to have a long life span. The photoelectric conversion process produces no pollution and can make use of free solar energy. Overall, the longevity, simplicity, and minimal resources used to produce electricity via PV systems make this a highly sustainable technology.

Most of today's PV modules are based on a proven technology that has experienced little degradation in more than 15 years of operation.

Codes and Specifications that Apply

Article 60 of the National Electric Code

Example Regional Contractors

Arizona Pacific Services (APS)
Postal address:
P.O. Box 53999
Phoenix AZ 85072-3999

Physical address:
400 N 5th St
Phoenix, AZ 85021
Tel (602) 371-7171
www.aps.com

Kyocera Solar, Inc.
7812 East Acoma Drive
Scottsdale AZ
USA 85260
tel 1 800 223 9580
fax 1 480 483 2986
www.kyocerasolar.com

Pictures

Source: www.aps.com

BUILDING INTEGRATED PHOTOVOLTAIC (BIPV)

Applications

BIPV systems can be used for homes, offices, public buildings or remote sites where grid connection is either unavailable or too expensive. PV systems can be mounted on roofs into all types of buildings, from domestic homes and offices through to public buildings and factories. It can be mounted on buildings either fully integrated with the building envelope or as a separate element.

Definition

A Building Integrated Photovoltaics (BIPV) system consists of integrating photovoltaics modules into the building envelope, such as the roof or the facade. By simultaneously serving as building envelope material and power generator.

Description

Building Integrated Photovoltaics (BIPV) is the integration of photovoltaics (PV) into the building envelope. The PV modules serve the dual function of building skin—replacing conventional building envelope materials—and power generator. Different types of photovoltaic roofing products compliment many different types of roofing materials including asphalt shingles, standing seam metal roofing, and slate or concrete tiles. The PV roofing products are produced separately from the standard roofing products by PV manufacturers whose products are designed to serve both functions -- as a roofing material to protect the home and as an electrical device to produce electricity.

Electricity can be produced from daylight through a process called photovoltaics (PV). "Photo" refers to light and "voltaic" to electricity. The term describes a solid-state electronic cell that produces direct current electrical energy from the radiant energy of the sun. When sunlight strikes a photovoltaic cell, direct current (D.C.) is generated. By putting an electric load across the cell, this current can be utilized. The amount of useful electricity generated by a PV module is proportional to the intensity of light energy, which falls onto the conversion area. So, the greater the available solar resource, the greater the electricity generation potential. A PV system will not generate electricity at night but a system is able to store collected energy in a battery for use during non-daylight hours.

Benefits

- The generating component produces electricity silently.
- Does not emit any harmful gases during operation.
- The PV modules are made out of silicon which is entirely benign, and is available in abundance.
- For homes not in proximity of electric power lines, PV systems may be less costly than

extending power lines to the home. Unlike generators, they operate silently and require little maintenance.

- PV roofing not only protects the home from storms and rainy weather but on sunny days produces free electricity for use in the home.
- BIPV systems can provide savings in materials and electricity costs, reduce use of fossil fuels and emission of ozone depleting gases, and add architectural interest to the building.
- BIPV systems often have lower overall costs than PV systems requiring separate, dedicated, mounting systems.

Limitations

- One of the greatest barriers to the widespread adoption of PV roofing systems is their high initial cost.
- They also require an unobstructed exposure to sunlight to obtain their maximum efficiency.

Typical Design Section

A complete BIPV system includes:

a. the PV modules (which might be thin-film or crystalline, transparent, semi-transparent, or opaque);
b. a charge controller, to regulate the power into and out of the battery storage bank (in stand-alone systems);
c. a power storage system, generally comprised of the utility grid in utility-interactive systems or, a number of batteries in stand-alone systems;
d. power conversion equipment including an inverter to convert the PV modules' DC output to AC compatible with the utility grid;
e. backup power supplies such as diesel generators (optional-typically employed in stand-alone systems); and
f. appropriate support and mounting hardware, wiring, and safety disconnects.

Maintenance

PV panel's performance is highly dependent upon its ability to remain clean. Accessibility for frequent maintenance and cleaning of the panels from the exterior of the building must be considered as part of the PV building design. Other components such as inverters and batteries will also require maintenance.

Additional Considerations

The light of the sun consists both of direct light and indirect or diffuse light, (which is the light that has been scattered by dust and water particles in the atmosphere). Photovoltaic cells not only use the direct component of the light, but also produce electricity when the sky is overcast. It is a common misconception that PV only operates in direct sunshine and is therefore not suitable for use in temperate climates. This is not correct: photovoltaics make use of diffuse solar radiation as well as direct sunlight. To determine the PV electricity generation potential for a particular site, it is important to assess the average total solar energy received over the year.

LEED Credits

May be applicable to the energy and atmosphere section of LEED.

First Costs

Expected cost of electricity produced from a PV system is equal to about 25 to 50 cents per kilowatt-hour (kWh) when considering initial cost spread over the lifetime of the system, plus maintenance costs. This compares with an average rate of about 8 cents per kWh for utility supplied power (utility rates can range from anywhere between 6-17 cents and peak rates can be over 20 cents per kWh in the United States).

Life Cycle Cost Considerations

Because reliability has proven good thus far, PV cells actually reduce the cost of powering homes and other buildings. The amount varies depending on the size of the system, the building's location, and the building's energy needs.

The exact energy payback for PV systems is obviously dependent on the available solar resource and on the degree to which the system is operational. High levels of solar irradiation and a high utilization factor will offer more rapid energy paybacks than if there is less sun and less usage, but typically energy payback will be realized within three to four years.

Codes and Specifications that Apply

As a new variation on a laminated glass panel, PVs as a building material must adhere to specific code requirements. These vary from state to state.

Example Regional Contractors

ETA Engineering, Inc.
2010 E. University Dr., Ste #20
Tempe, AZ 85281
Phone: 480-966-1380
Toll Free: 1-877-964-4188
Fax: 1-480-966-1516
energy@etaengineering.com
www.etaengineering.com

Renewable Energy of Illinois
Contact: Scott Majer- President

Phone: (630) 620-1021 or (630)-988-4043
Fax: (630) 620-9079
E-mail: reoiinc@aol.com
Address:9 N. Main
Lombard, IL 60148

Clean Energy Design Inc.
Phone: 508-428-5616
Contact: Tom Wineman & Nancy Reynolds
Email: info@cleanenergydesign.com
URL: http://www.cleanenergydesign.com/
Address: 11 Oak Lane
Osterville, MA 02655

Pictures

Source: www.daviddarling.info
Source: www.inhabitat.com
Source: www.kyocerasolar.com
Source: www.z2building.com

Cogeneration

Applications

Market segments to consider include:

1. Utility use of cogeneration heat
   a. Industrial buildings
   b. Commercial buildings
   c. Institutional Buildings
   d. Offline engine block heating
   e. Power plant, power plant shop, power plant office space heating.
2. Utility sale of cogeneration heat to end-use heat consumers
   a. Community water loop temperature maintenance
   b. Public facility space heating
   c. District heat system
3. End-use heating customers' sale of electricity to utility
   a. Micro-cogeneration units to heat households, sell excess electricity back to utility

Definition

A process in which an industrial facility uses its waste energy to produce heat or electricity.

Description

Cogeneration is an excellent technology for generating heat and electric power. Traditional coal, oil or natural-gas fired thermal generating stations convert only about one-third of the initial energy contained within the fuel into useful electricity. However, with a cogeneration system, it is possible to harness the heat generated and use it for process heat (steam) in many industries or as lower temperature heat suitable for space heating in buildings.

Benefits

- Flexibility: can be fired by fuels other than natural gas (wood, agricultural waste, peat moss, etc).
- Increase energy efficiency.
- Reduces energy costs.
- Reduces green house emissions.

Limitations

- Substantial initial investment.
- Financial returns vary according to price of electricity and fuels.

Maintenance

The most important factor of success for a cogeneration project is the electricity price. Maintenance costs, as well as fuel, operating and capital costs are secondary considerations for developing a cogeneration system. Cogeneration has been used for nearly a century, but it was in the 1980's that relatively low costs of natural gas made it an attractive alternative for new power generation.

Additional Considerations

Source: www.aidea.org

LEED Credits

It may be useful for the Energy and Atmosphere section.

First Costs

There are two cost factors for cogeneration systems. The first concerns the cost of the cogeneration unit itself in $/kW of output rating as it might be purchased from a supplier. The second cost factor is the total installed cost, which includes such items as:

- building and associated soundproofing
- electrical interconnection
- heating system interconnection
- engineering
- soft cost including project development, environmental, legal and permitting costs.

Both factors are affected by economies of scale. This means that large installations cost less on a $/kW basis than smaller projects. An example is given for a 5MW plant.

- building and Civil Costs: $1.5 million USD
- cogeneration Plant: $5.2 million USD ($1004/kW)
- engineering: $0.8 million USD
- soft costs: $0.14 million USD
- as built costs: $1600/kW

Life Cycle Cost Considerations

The engineering economic potential is represented on figure A by the total life cycle comparison between separate production of electricity and heat and cogeneration production of electricity and heat as described in the next figure:

Figure A. Simplified Engineering Economic Comparison between Separate Production and Cogeneration. Source: www.aidea.org

Codes and Specifications that Apply

None

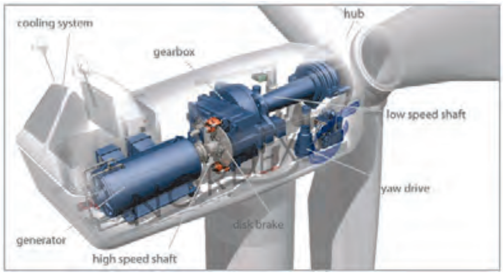
Example Regional Contractors

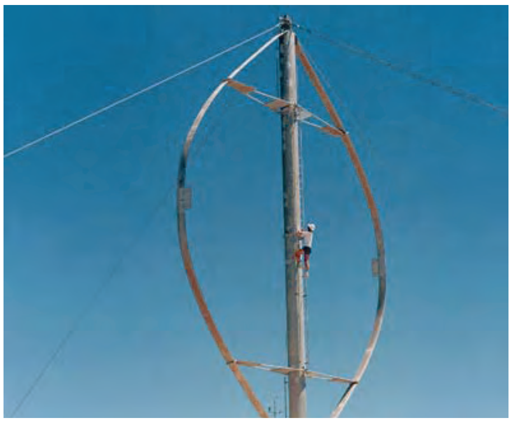
Honeywell Power

16404 N Black Canyon Highway AZ15/HN6
Phoenix AZ
USA 85023
tel 1 602 313 5000
fax 1 602 313 3299
www.honeywell.com

Pictures

Source: www.sustainabledesignupdate.com
Source: www.graph.exportpages.com
Source: www.ok4me2.net





Wind Energy

Applications

Homes, farms, communities, remote communities, process industries, national and provincial networks.

Definition

The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity.

Description

Energy from the wind has been used for a long time to pump water and grind grain. But today it is also being used to help generate electricity to power homes, businesses, schools, and the like.

Wind can be used to turn a turbine in much the same way as steam and water are used. The wind hits the blades of the wind turbine and turns the turbine. The turbine then turns a shaft which is connected to a generator. As the shaft in the generator turns it produces electricity. To produce enough electricity a number of wind turbines are built at the same place. This is called a wind farm.

Modern wind technology takes advantage of advances in materials, engineering, electronics, and aerodynamics. A single turbine may provide enough power for a home, school, or business.

Benefits

- Wind energy is abundant, renewable, widely distributed, clean, and mitigates the greenhouse effect if it is used to replace fossil-fuel-derived electricity.

Limitations

- Wind turbines need to be built where there is a reliable source of wind. The wind needs to be strong enough and regular.
- Wind farms can be visually unattractive. They can also be noisy.
- Wind turbines can be expensive to maintain.
- The electricity generated by the wind needs to be stored.

Maintenance

According to research done on 5000 Danish wind turbines installed since 1975, it demonstrated that newer generations of turbines have relatively lower repair and maintenance costs that the older generations. Older Danish wind turbines (25-150 kW) have annual maintenance costs with an average of around 3 per cent of the original turbine investment. For newer machines the estimates range around 1.5 to 2 per cent per year of the original turbine investment.

Source: http://www.windpower.org/en/tour/econ/oandm.htm

Additional Considerations

Regulatory barriers to use in certain jurisdictions.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

The cost of wind energy is determined by:

- the initial cost of the wind turbine installation
- the interest rate on the money invested
- the amount of energy produced

Any wind turbine that is installed in a very windy area generates less expensive electricity than the same unit installed in a less windy area. So it's important to assess the wind at the potential site.

Modern wind turbine generators cost between $1500 and $2000 per kilowatt for wind farms that use multiple-unit arrays of large machines. Smaller individual units cost up to $3000 per kilowatt. In good wind areas, the costs of generating electricity range between five and ten cents per kilowatt hour. That cost is somewhat higher than the costs associated with an electrical facility, but wind energy costs are decreasing every year, whereas most conventional generation costs continue to increase.

Life Cycle Cost Considerations

The actual lifetime of a wind turbine depends both on the quality of the turbine and the local climatic conditions, e.g. the amount of turbulence at the site. An example are the Danish wind turbines, they are designed to last 20 years. Extending the span life will involve replacing some parts. For example, the price of a new set of rotor blades, a gearbox, or a generator is usually in the order of magnitude of 15-20 per cent of the price of the turbine.

Codes and Specifications that Apply

Wind systems requirements must meet IEEE 929-2000 and UL 1741 standards.

Example Regional Contractors

Aeromax Energy

- Business type: retail sales, wholesale supplier
- Product types: wind turbines (small), wind energy towers and structures (small), wind energy systems (small), DC to AC power inverters, hybrid power systems.
- Service types: Engineering, Aeromag aerospace technology products
- Address: 1157 North Highway 89, Chino Valley, Arizona USA 86314
- Telephone: 928-775-0085 or 888-407-WIND

- FAX: 928-775-0803

ETA Engineering, Inc.

- Business type: retail sales, wholesale supplier, component manufacturer, engineering services, inverter repair
- Product types: renewable energy systems, photovoltaics, solar battery charge controllers, meters, and load regulators, solar roofing systems, solar water pumping, solar energy kits, solar trackers, power inverters, inverter repair, rv and marine power-up kits, cathodic protection controls, evaporative coolers, batteries, interconnects, efficient appliances, composting toilets.
- Service types: consulting, repair, sales, design,manufacturing, engineering, project development services, education and training services, research services, site survey and assessment services
- Address: 2010 E. University Drive - Suite 20, Tempe, Arizona USA 85281
- Telephone: 480-966-1380 or toll free 1-877-964-4188
- FAX: 480-966-1516

EV Solar Products, Inc.

- Business type: service, retail sales, mail order
- Product types: solar electric systems, photovoltaics, solar panels, inverters, deep cycle batteries, packaged systems, back-up power, solar water pumping, solar water heating, wind power, solar thermal, green building products, energy efficient appliances, energy efficient lighting.
- Service types: system installation, system design, site evaluation
- Address: 2655 N. Hwy 89, Chino Valley, Arizona USA 86323
- Telephone: 928-636-2201
- FAX: 928-636-1664

Mike's Windmill Shop

- Business type: manufacturer, retail sales, wholesale supplier, exporter
- Product types: wind turbines (small), wind energy systems (small), wind energy system components (small).
- Address: 1391 Branch Lane, Show Low, Arizona USA 85901
- Telephone: 928-532-1607

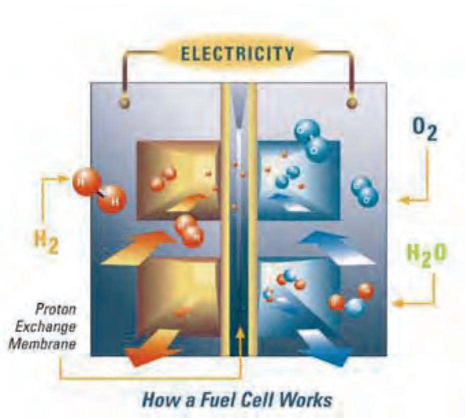
Pictures

Source: www.highfieldwindenergy.co.uk

Source: www.worldofenergy.com

Source: oregonstate.edu

Source: www.trentmesa.com



Fuel Cells

Applications

Industrial plants, recreation complexes and mixed-use buildings (for example, buildings with apartments, retail and laundry facilities).

Definition

A fuel cell is a device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electrochemical process. A single fuel cell consists of an electrolyte sandwiched between two thin electrodes (a porous anode and cathode).

Description

A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water and heat as its by-product. As long as fuel is supplied, the fuel cell will continue to generate power. Since the conversion of the fuel to energy takes place via an electrochemical process, not combustion, the process is clean, quiet and highly efficient – two to three times more efficient than fuel burning.

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. A few of the most promising types include:

- Polymer Electrolyte Membrane (PEM)
- Phosphoric Acid
- Direct Methanol
- Alkaline
- Molten Carbonate
- Solid Oxide
- Regenerative (Reversible)
- Fuel Cell Comparisons
- Electrochemical reactions of the Fuel Cell types

Benefits

No other energy generation technology offers the combination of benefits that fuel cells do. In addition to low or zero emissions, benefits include high efficiency and reliability, multi-fuel capability, sitting flexibility, durability, sand ease of maintenance. Fuel cells are also scalable and can be stacked until the desired power output is reached. Since fuel cells operate silently, they reduce noise pollution as well as air pollution and the waste heat from a fuel cell can be used to provide hot water or space heating for a home or office.

Limitations

- Fuel cells are more expensive than cogeneration systems.

Maintenance

Stationary fuel cells systems have been installed in North America, primarily in large commercial or industrial buildings. Maintenance costs are approximately $0.017 USD/kWh generated. The fuel cell has a rated life of 40,000 hours (or 5 years of continuous operation).

LEED Credits

Impact on Energy and Atmosphere section.

First Costs

The installed price for a 200 kW fuel cell systems is approximately C$4,500/kW; this is approximately three times that of reciprocating cogeneration systems.

Life Cycle Cost Considerations

The payback for investing in such a system is approximately 15 years.

PEM Fuel Cells for Commercial Buildings - report prepared by Pacific Northwest National Laboratory for the U.S. Department of Energy's Office of Building Technology, State and Community Programs. Document Number PNNL - 12051. Primary author, D.R. Brown. November 1998.

Example Regional Contractors

Materials and Electrochemical Research
MER Corporation
7960 South Kolb Road
Tucson, Arizona 85706
Phone: (520) 574-1980
Fax: (520) 574-1983
www.mercorp.com
mercorp@mercorp.com

<u>Case Studies</u>

http://www.dodfuelcell.com/pafc/davis.php4

http://www.dodfuelcell.com/pafc/huachuca.php4

<u>Pictures</u>

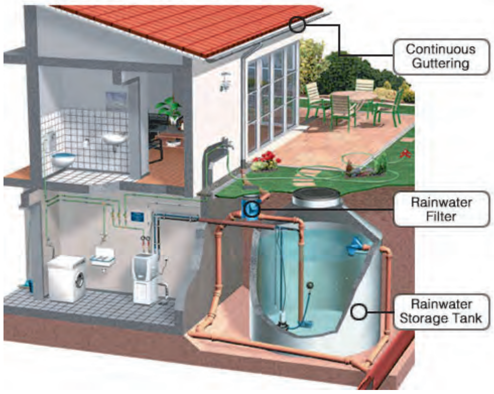
Source: www.consumerenergycenter.org

Source: www.fuelcells.org

Source: www.ornl.gov

Water Use and Conservation

- RAINWATER HARVESTING SYSTEMS
- GREY WATER RECYCLING
- ULTRA LOW FLUSH TOILETS
- WATER EFFICIENT LANDSCAPES



Rainwater Harvesting Systems

Applications

It could be used in all type of buildings: commercial, industrial and residential. New construction or retrofit building.

Definition

A rainwater harvesting system consists of the supply (rainfall), the demand (water needed), and a system for collecting water and moving it to the plants. Simple systems distribute rainwater immediately. Complex systems store some or all of the rainwater for later use.

Description

There are four basic components to a well designed rainwater harvesting system and the quality of water collected and stored depends on these components more than any other:

(1) Collection area: this could be the roof.

(2) Conveyance group: it consists of the gutters, downspouts, first flush diverter and piping to the tank or tanks. The "roof washer" or "first flush" device should be as simple as possible so that little or no maintenance is required. The purpose is to divert the first few gallons of water off the roof to a drain (or other catchments) so that the water in the cistern stays as clean as possible.

(3) Storage facility: a cistern is normally used and represents the most expensive component of the system. Therefore, it should be carefully selected to the intended use of the water. There are two types of cisterns, above-ground and in-ground. Most applications will benefit from an above-ground tank so that the water will flow out of the cistern by gravity. In-ground tanks are more costly to install and require a pump to recover the water, but they are out of sight and the water stays cooler.

The most economical and easiest to install above-ground tanks are vertical polyethylene, flat-bottom tanks with an 18" man way on the top for maintenance. These should be black to eliminate algae growth inside the tank, but can be painted white for cooler storage.

(4) Distribution group: this consists of the piping and filtration, if used. If the water is going to be used for domestic potable consumption, it is recommended that some form of filtration be installed. This can be as basic as a sand filter or as sophisticated as a reverse osmosis system depending on local conditions and personal preference.

Benefits

- Saves you money by reducing your water bills.
- Reduces demand on the municipal water supply.
- Makes efficient use of a valuable resource.
- Reduces flooding, erosion and the contamination of surface water with sediments.
- Fertilizers and pesticides in rainfall run-off.

Limitations

- It can be installed in existing buildings, but will cost more, because of the extra plumbing required.
- It is not only for houses, bungalows and commercial premises are also very suitable, the only limitation is the area of the roof to capture rain, compared to the number of users; this puts a limitation on flats and apartments.
- Water supply depends on rainfall (uncertainty of rainfall is another limitation)

Maintenance

The following maintenance checklist could be useful to keep in good conditions the rainwater harvesting system:

- Keep debris out of holding areas.
- Clean and repair channels.
- Clean and repair dikes, and moats.
- Keep debris out of gutters and downspouts.
- Flush debris from storage container bottoms.
- Clean and maintain filters, especially those on drip irrigation systems.

The internal filter should be washed about once a quarter, otherwise maintenance is not needed. The only moving components - pump and float switch have an extremely long life. The system should be designed to overflow a few times a year, to remove and floating matter.
If the rainwater is to be used for drinking water, the inside of the finished cistern should be scrubbed down with a 10 percent bleach solution and rinsed thoroughly before the system is put in use. The cistern will need to be drained and emptied of accumulated sediment every few years. At that time, cracks should be patched with a non-toxic sealant. Be sure to employ vigorous, positive ventilation when working inside the tank.

LEED Credits

May be applicable to the water efficiency section.

First Costs

The capital cost of rainwater harvesting systems is highly dependent on the type of catchments, conveyance and storage tank materials used. The most expensive part of a rainwater system is usually the cistern itself. Water tanks with a capacity of 2000 gallons or less cost between

$0.45 and $1.00 per gallon of storage; concrete tanks are more expensive than equivalent synthetic tanks. Larger-volume concrete tanks cost roughly $1.25 per gallon of storage. Hiring a contractor to install a large, heavy tank on a remote farmstead is also expensive. This cost is very specific to the site; call local contractors for estimates. The other major expense that may be incurred for some systems is concrete work, for a cast-in-place cistern. For large cisterns, this approach may be cheaper than bringing a precast tank onto the site.

Life Cycle Cost Considerations

Directly dependent on maintenance.

Codes and Specifications that Apply

Regulations vary greatly from city-to-city, county-to-county, and state-to-state. Arizona is very progressive in gray water re-use, having published 13 best practices that simplify the permit process. So far, no other state has published a similar guide for rainwater harvesting. Hopefully states will become more proactive in saving water and eventually push for a national standard in this area.

Example Regional Contractors

Zonagardens
Tucson, AZ
Phone 520-867-8038
Fax 520-867-8039

The Rain Well
Contact - Greg Whitfield
201 Bayonne Dr
Mansfield, TX 76063
United States
817-676-4440
http://www.therainwell.com

Pictures

Source: www.rainwater-solutions.com
Source: www.spec-net.com
Source: www.zonagardens.com

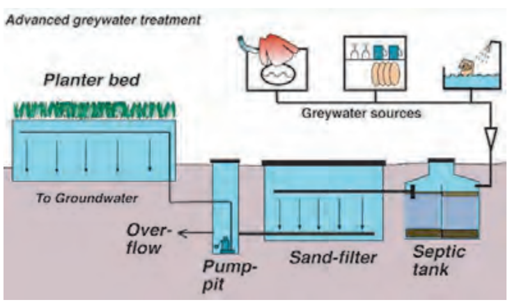
Grey Water Recycling

Applications

Untreated grey water can be used for several water consuming activities, most notably outdoor washing and irrigation.

Definition

Any water that has been used in the home, except water from toilets, is called grey water. Dish, shower, sink, and laundry water comprise 50-80% of residential "waste" water. This may be reused for other purposes, especially landscape irrigation.



Description

The domestic wastewater that comes from the laundry and bathroom is called "grey water". On the other hand, just to make the differentiation, toilet water is termed "black water". Black water should never be reused in the home because of possible contamination by bacteria, viruses, and other pathogens. Definitions of grey water may vary from state to state, for the purpose of regulation in Arizona; water from kitchen sinks and dishwashers is not considered grey water. The reason for this is the potential for increased health risks associated with the organic matter commonly associated with food preparation and cooking.

Gray water may contain food particles, detergent or soap residue, and possibly some human pathogens. But as a general rule, gray water does not require extensive chemical or biological treatment before being used for landscape irrigation. Gray water can be put to other uses. It is best to use gray water on ornamental plants and lawns, or to irrigate trees, rather than on food plants, especially those that are often eaten raw; such as carrots or lettuce or herbs.

Considering the above mentioned limitations, recycling household grey water for use on garden beds is still an excellent way of saving water and saving money. It's a waste to irrigate with great quantities of drinking water when plants thrive on used water containing small bits of compost. A grey water system can be so simple and also so complex, depending on your interest. The goal is to find the level of system that makes maximum use of the grey water while minimizing the purchasing, installation and maintenance costs.

Benefits

- Unlike rainwater harvesting, which is seasonally available, grey water is available every time you shower or wash.
- Lower fresh water use
- Less strain on failing septic tank or treatment plant
- Grey water treatment in topsoil is highly effective
- Ability to build in areas unsuitable for conventional treatment
- Less energy and chemical use

- Groundwater recharge
- Plant growth
- Reclamation of otherwise wasted nutrients

Limitations

- The major concern with grey water reuse is the quality of the water. It is imperative for grey water to be separated from black water; even then, pathogenic microorganisms can still be found in grey water.
- Contact with humans is not recommended due to public health concerns.
- It is also not recommended for grey water to be stored for long periods of time because it can create breeding grounds for bacteria and pathogens, as well as foul odors.
- If water from kitchen sinks is used, it may be necessary to include grease traps in the recycling system, and the filter selected must be able to separate out food particles.
- To install a grey water system on an existing home is more costly and complicated than to develop a system for a new home

Maintenance

Treated grey water requires filters; the type of filters required depends largely upon the amount of grey water to be filtered and the type of contaminants present. Many types of commercial filters are available. A gravity filter is used for low volumes and a pressure filter for flows greater than 20 gallons per minute. Most filters use cellulose, or a ceramic cartridge that must be cleaned or replaced regularly.

Another type of filter are the sand filters, these are shallow layers of stone, medium gravel, and pea gravel beneath a deep layer of sand, these require cleaning and replacement of the top layer of media when maintenance is required.

Additional Considerations

Grey water use should be avoided on irrigation of acid-loving plants, as most grey water is slightly alkaline due to soaps and detergents present. It is also possible that extended grey water use may elevate sodium levels in soils, causing drainage problems and potential damage to plants. Therefore, it is recommended that the use of harsh detergents or cleansers, such as boron or bleaches, be discontinued if grey water is to be used for irrigation.

LEED Credits

It may be applicable to the water efficiency section.

First Costs

Costs to assemble and install a grey water system will vary greatly depending upon whether you do your own work or have it done professionally. For a retrofit system the cost could range from $135 - $1250, plus the needed irrigation system. In the case of a grey water system cost in new construction the range will be from $65 to $650, plus the desire irrigation system.

Life Cycle Cost Considerations

Re-using grey water reduces the amount of fresh water that is needed to operate a building and its site, and as water becomes a less available resource, this is a crucial improvement that we need to make in our construction and inhabitation practices. Water is also not free, and reducing the amount of fresh water that you use reduces your monthly operating costs.

Codes and Specifications that Apply

In some areas, reuse of water is either prohibited by health officers and/or plumbing inspectors, or requires an inspection and permit. Make sure that it is legal in your area before setting up a gray water collection site in your home.

In the case of Arizona, re-use of gray water used to require a permit, which could be granted only after the homeowner submitted specific design plans for review. As a result, the State of Arizona's Department of Environmental Quality (ADEQ) in January 2001 instituted a general permit for homeowners whose gray water systems meet the certain Best Management Practices.

Those regulations include new guidelines for the use of residential gray water. If you would like a copy of the new regulations, you can contact ADEQ at www.adeq.state.az.us or 1-800-234-5677.

Example Regional Contractors

SpectraPure®, Inc.
215 S. Industrial Dr., Suite 2A
Tempe, AZ 85281-2941
Phone: 480-894-5437, 800-685-2783 (toll free)
Fax: 877-527-7873 (toll free)
http://www.spectrapure.com/

Douglas Tanks
23341 Wagon Trail Rd.
Diamond Bar, CA 91765
Phone: 909-861-3640
Fax: 909-861-0185
http://www.douglastank.com

Pictures

Source: www.greywater.com
Source: www.mjunitug.org.au
Source: www.spec-net.com.au

Ultra Low Flush Toilets

Applications

All kinds of buildings, new construction or retrofit: commercial, industrial and residential.

Definition

A typical toilet will use 5 to 8 gallons per flush (gpf), whereas ultra-low-flush toilets use only about 1.5 gpf (a 70 to 80 percent savings). Ultra-low-flush toilets work as well or even better than low-flush models (which use 1.6 to 3.5 gpf). Green Seal has a standard for certification of a 1.6 gallon maximum flush volume.

Description

Water conservation technologies and strategies are often the most overlooked aspects of a whole-building design strategy. However, the planning for various water uses within a building is increasingly becoming a high priority. This is due to a number of reasons, namely that new and existing water resources are becoming increasingly scarce in a number of regions throughout the country; per capita water consumption is increasing annually; water and sewer rates have increased dramatically over the last decade (100-400%); etc.

Because of the above mentioned reasons, there is the increasing recognition of the water, energy, and O&M savings that can be realized through the implementation of water saving initiatives. One example is water savings through improvements on toilet's technology. In this section three toilet models will be described: two-button flush toilets, vacuum-assisted toilets and pressurized tank toilets. All the leading toilet manufacturers have this technology, and low-flush toilets are now sold in most hardware and home building stores.

Two-button Flush Toilets:

These types of toilets have two flushing modes, a half flush (0.8gpf) for liquid and a full flush (1.6gpf) for solids. A study conducted in Seattle measured water use in single-family homes before and after installation of high efficiency toilets (Mayer, et. al., 2000). About half of the toilets installed were standard 1.6 gallon per flush (gpf) models. The other half were dual flush toilets that offer a 0.8 gallon flush for liquid and a 1.6 gallon flush for solids. The results are shown below in Table 1.

Table 1: Water use in homes with standard, 1.6 gallon, and dual flush toilets

Avg. Gallons per Flush	Avg. Gallons per Person Per Day
Non-conserving Home	3.61 18.8
Conserving home (1.6 gpf toilet)	1.549.1
Conserving home (dual flush toilet)	1.25 6.9

Source: www.dpw.co.santa-cruz.ca.us

Vacuum-assisted Toilets:

These are gravity-flush toilets which use vacuum-assisted technology. In this case, a pressurized tank placed inside the porcelain tank compresses a pocket of air and releases pressurized water into the bowl and out the trap way at high velocity. The system allows the toilet to give a complete, clean flush using only the rim holes inside the upper toilet bowl. The flushing action of these toilets is noisy and they require a minimum water pressure of 25 psi to operate properly. They can use as little as 1 pint (about half a liter) of water.

Pressurized Toilets:

These are found in most commercial buildings. They have no tank but rely instead on a pressure-operated valve directly connected to the building's water supply. Releasing the valve forces pressurized water into the bowl 500 times greater than that of a conventional gravity-flush toilet. These toilets require a minimum water pressure of 25 psi to operate well. Generally, they remove wastes more effectively than other type, but are also noisier and more expensive.

Benefits

- Water savings (as natural capital & economical point of view)

Limitations

- ULF toilets models are more expensive than traditional gravity-flush toilets.
- Maintenance spare parts are more expensive.

Maintenance

Gravity toilets in buildings with cast-iron waste lines may clog more readily, because of the roughness of the interior of the pipe. New buildings use PVC pipe, through which waste flows more easily. Choosing pressurized toilets for buildings served by cast-iron pipe may reduce maintenance needs.

Additional Considerations

Two things that should be considered when purchasing a toilet are glazed trap ways and noise levels. On the first hand, glazed trap ways is a feature that improves waste removal and reduces staining. On the other hand, pressure-assisted toilets tend to be louder than gravity models. Noisy toilets could be a distracter in office environment.

LEED Credits

May be applicable to the water efficiency section.

First Costs

The range is from $125 to $800. Some factors that affect the price are:

Color: none white color may cost more.

Bowl shape: elongated bowls are normally more expensive.

Design: One-piece or two-piece models are available. One-piece models are usually more expensive.

Codes and Specifications that Apply

Toilets and urinals should be installed in compliance with all applicable regional plumbing and building codes.

Example Regional Contractors

www.homedepot.com

Able Distributing Co., Inc.
2727 W. Grovers Ave.
Phoenix, AZ 85053
Phone: 602-993-1140
Fax: 602-942-3491
http://www.abledistributing.com

Pictures

Source: www.niagaraconservation.com
Source: www.img2.timeinc.net
Source: www.foxnews.com

Water Efficient Landscapes

Applications

Water efficient landscapes can be used anywhere - from small residential yards to large commercial sites.

Definition

Water efficient landscaping is also known as water-wise, water-smart, low-water and natural landscaping. While these terms vary in philosophy and approach, they are all based on the same principles. One of the first conceptual approaches developed to formalize these principles is known as "xeriscape landscaping".

The word "xeriscape" is derived from the Greek "xeros," meaning dry, and "scape," a kind of view or scene. Together, xeriscaping is landscaping with slow-growing, drought-tolerant plants to conserve water and establish a waste-efficient landscape.

Xeriscaping focuses on the implementation of the following principles: (1) planning and design, (2) use turf appropriately, (3) efficient irrigation, (4) conditioning soil, (5) mulching, (6) plant selection and (7) appropriate maintenance.

Description

The goal of a xeriscape is to create a visually attractive landscape that uses plants selected for their water efficiency. Properly maintained, a xeriscape can easily use less than one-half the water of a traditional landscape. Once established, a xeriscape should require less maintenance than turf landscape. The following is a brief description of the seven principles.

1. Planning and Design
   How do you use your yard? For recreation? For looks? What kind of look are you going for?
2. Use Turf Appropriately
   Choose low water requirement turf. Long, narrow strips of turf should be eliminated.
3. Irrigate Efficiently
   Hand watering is preferable. Group plants according to water usage.
4. Conditioning Soil
   Soil should be generally crumbly to the touch. Well conditioned soil promotes water conservation by absorbing water more efficiently. Bare soil should be covered with mulch.
5. Mulching
   Apply 2-4 inches deep. This minimizes evaporation, reduces weed growth, and slows erosion.
6. Plant Selection
   Choose plants suitable to the local climate.

7. Maintaining Landscapes

   Proper planning and design reduces maintenance time. Using native plants reduces the need for fertilizers and pesticides.

Benefits

- Lower water bills from reduced water use.
- Conservation of natural resources and preservation of habitat for plants and wildlife such as fish.
- Decreased energy use (and air pollution associated with its generation) because less pumping and treatment of water is required.
- Reduced home or office heating and cooling through the careful placement of trees and plants.
- Reduced landscaping labor and maintenance costs.

Limitations

- The initial costs of xeriscaping can be higher than other landscaping due to its comprehensive nature.
- There could be site limitations that will affect the planning and design principle.

Maintenance

Maintenance time for a new garden is similar to a traditional landscape, but it decreases over time. In addition to weeding, proper irrigation, pruning, fertilizing and pest control will keep your landscape beautiful and water thrifty. When your garden is well taken care of, you can sit back and enjoy it.

Additional Considerations

Xeriscaping cannot completely alleviate the need for landscaping maintenance and watering. Some plants may need more watering during the period that they are becoming established in the environment. Gardeners and landscape architects must plan and specify layouts more carefully to place appropriate vegetation in appropriate locations.

LEED Credits

It may be applicable to the water efficiency section.

First Costs

The initial costs of xeriscaping can be higher than other landscaping due to its comprehensive nature. Planners must study the area and find suitable vegetation, and the costs to install the vegetation may be higher as well.

Life Cycle Cost Considerations

Xeriscaping allows the creation of aesthetically pleasing landscapes with minimal consumption of dwindling water resources. Replacing expansive lawns with indigenous ground covers or unmown native grasses can reduce clipping disposal problems and irrigation costs. Using drought-tolerant plants can significantly reduce water bills, and avoid the cost of expensive engineered irrigation systems.

Codes and Specifications that Apply

Xeriscaping requires a common-sense approach. While local code authorities may need to approve some site plans, xeriscaping techniques do not usually involve code or regulatory issues.

Example Regional Contractors

Nature's Image, Inc.
Glendale, Az. 85312
Phone 623-412-2611
1-888-412-2611
Fax 623-412-7779
Info@NaturesImage.com

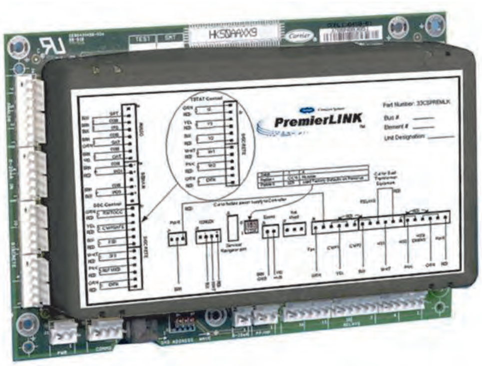
Zonagardens
Tucson, AZ.
Phone 520-867-8038
Fax 520-867-8039
info@zonagardens.com

Pictures

Source: www.phoenix.gov
Source: www.aridscape.com
Source: www.flagstaff.az.gov

Ventilation and Indoor Environmental Quality

- CO_2 CONTROLLED VENTILATION
- DISPLACEMENT VENTILATION
- ENTHALPY HEAT EXCHANGERS
- HEAT & RECOVERY VENTILATORS



CO_2 Controlled Ventilation

Applications

Applications of CO_2-based DCV has the most energy savings potential in buildings where occupancy fluctuates during a 24-hour period, is unpredictable, and peaks at a high level. For example, office buildings, government facilities, retail stores and shopping malls, movie theaters, auditoriums, schools, entertainment clubs and night clubs.

Definition

Demand-controlled ventilation (DCV) using carbon dioxide (CO_2) sensing is a combination of two technologies: CO_2 sensors that monitor CO_2 levels in the air inside a building, and an air-handling system that uses data from the sensors to regulate the amount of ventilation admitted.

Description

Indoor air pollution is primarily due to the presence of humans, and includes water vapor, CO_2 and other gases due to respiration and bodily odors, as well as dust brought in by clothing and footwear or becomes whirled up from floors, carpets etc. In addition, large amounts of vapors and particles from materials may be released - particularly in so-called modern buildings. Work-related processes in industry and various other activity may contribute less common pollutants. However, such non-human contributions to indoor climate may to a large extent be reduced by applying existing knowledge and protective measures

Years of research and experience have sufficed to show that the concentration of CO_2 is a useful and relevant indicator of total indoor air quality, being directly indicative of people's presence through CO_2 from respiration. Fresh air contains 370 - 400 ppm (part-per-million) of CO_2, while each exhalation of air from humans carries 3 % of CO_2. In several countries, health authorities have set standards for indoor air of 800 - 1,000 ppm of CO_2, as upper limits that should not be exceeded.

In demand controlled ventilation (DCV) each room is served by a CO_2 gas sensor, which allows ventilation to be activated before air quality in any room is reduced beyond administratively set limits. Ventilation may then be reduced or turned off wherever air quality standards are satisfied. In this manner, the capacity of the ventilation system essentially becomes moved around the building on local demands, depending on which rooms are occupied at any time. Such functions may easily be automated by communicating sensor signals to a central command unit with computer-based decision routines.

CO_2 is comparatively easy to measure with various methods, chiefly chemical, electrochemical and infrared. The limiting problem has been to do it reliably, reproducibly and cost-effectively, so that CO_2 sensor calibrations are not lost after a few months' time. That problem has now been solved by recent developments in infrared CO_2 gas sampling. Those new, digital IR CO2 gas sensors remove any existing obstacles for the introduction of DCV on a large scale, in old and new buildings alike.

There are multiple sources indicating that the return on investment for DCV systems using CO_2 Sensors can be as short as 2-3 years. A report by Lawrence Berkley National Laboratory cited five case studies in large office buildings with CO_2 based DCV, all of which reported energy savings that resulted in payback times of from 0.4 to 2.2 years. (FEMP, "Demand-Controlled Ventilation using CO_2 Sensors" pg8. 03/04).
It can be costly to install a CO_2 sensor in each space of a multiple-space system, however, especially for spaces that will always be overventilated regardless of operating conditions. For these applications, consider installing CO_2 sensors only in those spaces, such as conference rooms and reception areas, that experience widely varying patterns of occupancy and are likely to become critically underventilated. Use the sensor in each "critical" space to reset the system-level ventilation airflow based on local need.

Benefits

- The potential of CO_2-based DCV for energy savings is estimated at from $0.05 to more than $1 per square foot. The highest payback can be expected in high-density spaces in which occupancy is variable and unpredictable.
- A carefully designed CO_2 control strategy can maintain ASHRAE established, cfm-per-person ventilation rates at all times. Even if a space is not intermittently occupied, CO_2 control can ensure that a space is not over or under-ventilated for current occupancy levels. It is the only simple method of ensuring that fresh air is actually distributed to spaces in proportion to their occupancy.
- CO_2 control does not make a distinction between fresh air resulting from infiltration or mechanical ventilation. If an open window or leaky construction is providing plenty of fresh air, CO_2 control will reduce mechanical ventilation proportionally, again providing opportunity for energy savings.
- Improved humidity control: In humid climates, DCV can prevent unnecessary influxes of humid outdoor air that makes occupants uncomfortable and encourages mold and mildew growth.

Limitations

- Perhaps the most significant limitation of controlled ventilation (CV) is that using CO_2 sensors to indicate or control ventilation rate (the most common approach) does not alone guarantee good indoor air quality (IAQ). Ventilation control based on CO_2 levels is an important tool that can help control occupant-related pollutants and satisfy occupant-based ventilation standards. However, a thorough IAQ strategy also should involve a complete audit of potential pollutant sources in the building, such as vapors from copiers and cleaning solutions. Ventilation control based on CO_2 levels may do nothing to control these pollution sources. Measurement of volatile organic compounds (VOCs) with a VOC sensor can help complete the IAQ picture.

- Does not control the concentration of other indoor pollutants.

Maintenance

Maintenance of sensors themselves is not generally reported to be a problem. Manufacturers offer sensors that recalibrate themselves automatically and are guaranteed not to need calibration for up to 5 years.

Additional Considerations

In addition to the installation of sensors, other components such as variable frequency drives and control input and output hardware often are needed to control the whole building.

LEED Credits

May be applicable to the indoor environmentally quality section

First Costs

Costs for sensors have dropped by 50% over the last several years. Sensors typically cost about $250 to $260 each, uninstalled. For a new system, the installed cost will generally be about $600 to $700 per zone.

Life Cycle Cost Considerations

Life cycle costs considerations will be affected mainly by two reasons: On the first hand, if the CO_2 sensors used need to be calibrated manually (do not calibrate themselves). On the other hand, battery replacements for sensors. In this case, given the advances in battery technology and microprocessor controlled power management, sensors can be expected to operate for 2-3 years before they require a battery change.

Codes and Specifications that Apply

ASHRAE Standard 62.

Example Regional Contractors

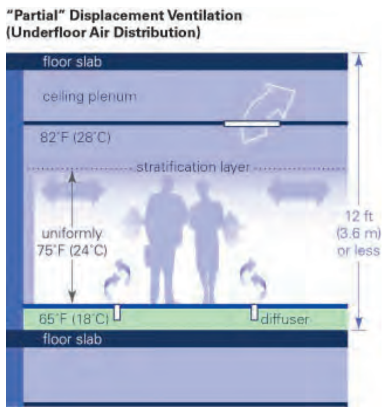
Englehard Sensor Technologies
6489 Calle Real
Goleta CA
USA 93117
tel 1 805 964 1699
fax 1 805 964 2129
www.engelhard.com

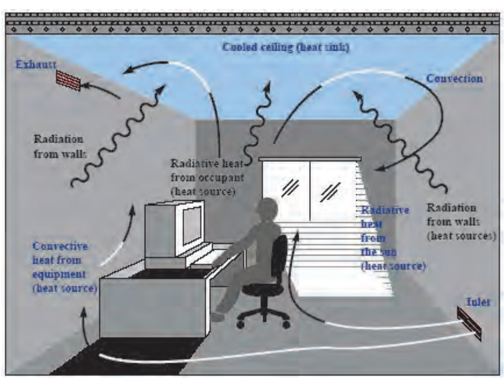
La Brea Heating & Air Conditioning Co., Inc.
5601 W. Slauson Ave., Suite 262
Culver City, CA 90230-6598
Phone: 310-258-9100, 800-452-2732 (toll free)
Fax: 310-258-9110
http://www.labrearentals.com

American Cooling Tower, Inc.
1115 W. Ranch Rd.
Tempe, AZ 85284
Phone: 800-371-5959 (toll free)
Fax: 714-897-6689

Pictures

Source: www.siglercontrols.com
Source: www.ferret.com.au
Source: fsec.ucf.edu





Displacement Ventilation

Applications

First developed for industrial buildings, displacement ventilation now enjoys an increasing percentage of market shares for many applications throughout the world. Displacement systems are appropriate in spaces such as classrooms and conference rooms with high ventilation requirements. They have also been used with great success in office space. Although relatively new to the United States, displacement ventilation has been in use in the Scandinavian countries since the 1970s, where it is now seen as a proven technology.

Definition

Displacement ventilation or low ventilation displacement ventilation (LVDV) is an innovative concept for the supply of conditioned air and ventilation of buildings. It uses the natural buoyancy of warm air to provide improved ventilation and comfort.

Description

Displacement ventilation systems differ from conventional HVAC systems in several important ways. In a conventional HVAC system, air is supplied at the ceiling, at a relatively high velocity, at a temperature about 20&degF below the desired room temperature. The supply air mixes with the room air to provide a nearly uniform temperature throughout the space. Because of the mixing effect, "used" room air recirculates, resulting in relatively low ventilation efficiency.

On the other hand, in a displacement ventilation system, supply air is introduced to the space at very low velocity of, say, 0.2 m/s and at a small temperature difference of 2-3°C (greater for industrial applications) below that of setpoint. Because the entering supply air is less buoyant than the warmer air in the space, the incoming air will fall to the lowest level, displacing the warmer air in the room. The incoming air will then spread, and as it finds a heat source will become warm, more buoyant and begin to rise.

As it rises, it lifts any airborne contaminants to exhaust at a higher level. By treating the air in this manner, only the occupied zone is conditioned (and not the area above), thus much reducing plant size and energy requirements. The occupants of the space are always in clean fresh air without the drafts, cross contamination or higher noise levels present in the customary mixing systems. LVDV Systems are suitable for open spaces of 2.8 meters or higher.

In a study by (Cullen, et., al.)* comparing displacement ventilation and conventional mixing ventilation, displacement ventilation consumed 57% less energy. Indoor environmental quality (IEQ) was also improved as measured by a 57% reduction in carbon monoxide emissions. The Local Mean Age of Air was 7-9 minutes in the occupied zone for the mixing system and 2-8 minutes for the displacement system. The plume around the occupants provided air to the occupant breathing zone with an age of 2.5-3 minutes. The less time the air is in the room

(before breathing), the less pollutants are absorbed into the air and the higher the IEQ.
* Cullen, N., Lea, H. High Performance Displacement Ventilation Using Fabric Diffusers - A Case Study, London: CIBSE.

Benefits

- Much cleaner air for occupants (IEQ)
- Reduced cross contamination between occupants
- Greater ventilation effectiveness
- Reduced power consumption
- Better acoustics (less air noise)
- Lower equipment cost

Limitations

- In some cases, larger quantities of supply air may be required.
- Because of the high supply air temperature, indoor humidity must be carefully controlled.
- Displacement ventilation systems may not be appropriate when contaminants are heavier than air, or not associated with heat sources.
- When very high loads exist, a displacement system will require uncomfortably cold supply air. Therefore, displacement ventilation may not be appropriate in extremely warm climates.
- Performance of the displacement system is dependent upon ceiling height. Displacement ventilation may not be appropriate in spaces with low ceilings.
- May add complexity to supply air ducting

Because of these advantages and limitations, displacement ventilation is typically seen as appropriate for schools, classrooms, lecture halls and theaters with high ceilings, and large ventilation loads relative to the sensible cooling load in the space. However, it may, in theory, also be used to great advantage in office spaces in temperate climates.

Maintenance

Displacement ventilation systems use remote central or semi-central cooling systems reducing the number of fans and compressors compared to decentralized systems that may use wall mounted units or unit ventilators or dedicated packaged rooftop units Therefore reducing the potential frequency of service calls.

Additional Considerations

The primary requirement for displacement systems is a high ceiling. This allows heat and contaminants to be carried away effectively to the ceiling exhaust. A nine-foot ceiling is adequate, but a high ceiling (12 ft) will enhance the benefits.

LEED Credits

May be applicable to the energy and atmosphere section of LEED.

First Costs

The additional costs of the displacement ventilation systems are for the low-velocity displacement diffusers and for the enhanced compressor capacity control needed to maintain the flow rate and temperature. The displacement diffusers carry a slight cost premium of about $1 to $2/ft2 over a conventional set of four ceiling diffusers. Some of this is offset by the simplification of ductwork. In some cases, using displacement ventilation provides an opportunity to downsize cooling equipment, which will offset some of the added diffuser and capacity control cost.

Life Cycle Cost Considerations

As explained on the maintenance section, Displacement ventilation systems provide servicing benefits compared to systems using mixed ventilation and should result in reduced down-time and service calls.

Codes and Specifications that Apply

Codes and regulations may vary from state to state. i.e. In the state of California the regulations are principally the Energy Code provisions (Part 6) of the State of California Building Code (Title 24) and ASHRAE Standard 90.1 dealing with non-residential building energy use. Other corollary programs, that rely in part on provisions of the California Energy Code (Title 24, Part 6) and ASHRAE 90.1 Standard are the Collaborative for High Performance Schools (CHPS), Leadership in Energy and Environmental Design (LEED®) and Savings By Design.

Example Regional Contractors

Parker Hannifin Corp., Partek Operation
7075 E. South point Rd.
Tucson, AZ 85706-9407
Phone: 520-574-2600
Fax: 520-574-2700
http://www.parker.com/partek

Pictures

Source: www.trane.com
Source: www.hanscare.com
Source: www.cabe.org.uk

Enthalpy Heat Exchangers

Applications

- The main use of enthalpy heat wheels is for preconditioning the minimum ventilation air stream in commercial buildings.
- Projects that require a large percentage of outdoor and have the exhaust air duct in close proximity to the intake.
- Existing buildings where codes require it or they have "sick building" syndrome and the amount of outdoor air intake must be increased, Sick building: when building occupants complain of symptoms such as: headache, eye, nose, throat irritation, cough, dry or itchy skin, dizziness and nausea, difficulty in concentrating, fatigue, sensitivity to odors.
- New buildings where the required amount of ventilation air causes excess loads or where the desired equipment does not have sufficient latent energy capacity.

Definition

Enthalpy heat exchangers transfer heat and moisture between exhaust air and incoming air. Unlike conventional heat exchangers, which only transfer heat, the ability of an enthalpy exchanger to transfer moisture means that both sensible and latent heat is transferred.

Description

An enthalpy heat wheel is made of honeycomb, and the honeycomb is coated with desiccant. It looks very much like a desiccant wheel, but in contrast to desiccant wheels, an enthalpy wheel contains very little desiccant, it turns 60 times faster than the desiccant wheel and there is no heat added to reactivate its desiccant.

Instead of heat, an enthalpy wheel depends on dry air for reactivation. That dry air is drawn from the building's exhaust system. So, any time the buildings' exhaust air is drier than the outside air, an enthalpy heat wheel can take moisture from incoming outside air, transferring that water vapor to the exhaust air. In an enthalpy wheel Cool, dry, exhaust air enters one side of the rotating Heat Wheel, chilling the wheel and drying the desiccant coating.

This cool and dry part of the wheel then rotates into the supply air where it absorbs heat and humidity from the incoming fresh air before the air is mechanically cooled to room temperature. The Heat Wheel can reduce the ventilation air-conditioning load by up to 90%, which saves energy and reduces the size of required air-conditioning equipment.

Depending on its size relative to the air flows and its rotation speed, an enthalpy wheel moves 70 to 90% of the moisture difference from the incoming air to the exhaust. For example, if the exhaust contains 75 gr/lb and the outside air contains 125 gr/lb, there is a moisture difference of 50 gr/lb. The wheel can move between 35 and 45 gr/lb of that moisture from the incoming air to the exhaust.

Benefits

- Passive dehumidification, no extra heat required
- Winter heat recovery by the same device
- Summer cooling recovery in addition to dehumidification

Limitations

- Exhaust air must be oil and grease-free, and brought to the same location as incoming fresh air
- No dehumidification unless exhaust air is drier than outside air
- When the wheel rotates at minimum speed to avoid overheating the building, dehumidification ceases. This may cause problems during the hundreds of hours per year when outside air is between 60 and 75 deg. and humid.

Typical Design Section

Source: http://cipco.apogee.net

Maintenance

- Requires that the air streams must be relatively clean and may require filtration,
- Requires a rotating mechanism that requires it be periodically inspected and maintained, as does the cleaning of the fill medium and any filtering of air streams,
- In cold climates, there may be an increase in service needs.

Additional Considerations

Applications to avoid:

- Where the intake or exhaust air ducts must be rerouted extensively, the benefits are likely not to offset the higher fan energy and first cost.
- Use of an enthalpy wheel where there are contaminants in one of the air streams. Corrosion, scale, and fouling of the wheel and its fill where a wetted condition can occur are all needs to be addressed carefully.

LEED Credits

It may be applicable to the indoor environmental quality section.

First Costs

The cost averages $1.50/L/S for the unit itself; smaller units have a higher cost per unit flow.

Life Cycle Cost Considerations

Enthalpy air to air exchangers are capable of recovering the sensible and the latent energy normally exhausted, providing HVAC systems with higher energy efficiency and lower operational costs.

Codes and Specifications that Apply

In some states building codes require enthalpy heat exchange systems.

Example Regional Contractors

Engineered Energy, Inc.
2111 S. Industrial Pk.
Tempe, AZ 85282
Phone: 480-966-4866, 800-561-9900 (toll free)
Fax: 480-966-8843

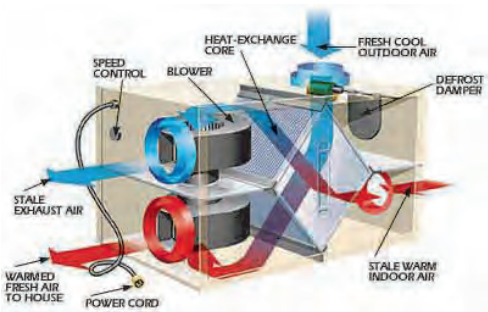
Guardian Energy Systems, Inc.
906 S. Priest Dr., Suite 104
Tempe, AZ 85281
Phone: 480-966-2545
Fax: 480-966-5415

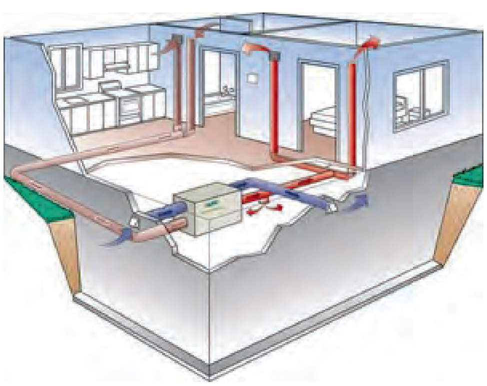
Brenner-Fiedler & Associates, Inc.
2117 S. 48th, Suite 102
Tempe, AZ 85282
Phone: 602-438-2710, 800-280-1629 (toll free)
Fax: 602-438-2763

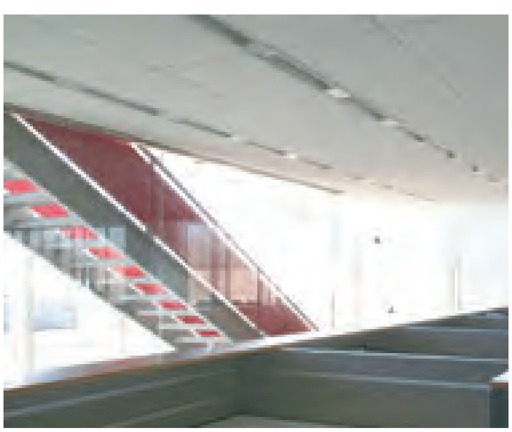
Pictures

Source: www.yorkupg.com
Source: www.ohlone.edu

Heat Recovery Ventilators







Applications

Heat recovery ventilation systems save heating and cooling energy in applications where mechanical ventilation is needed. In the case of energy recovery ventilation, this one is quickly justified in buildings with high, continuous occupancy or activity rates. Examples would be schools, institutions and applications with more than an eight-hour work day. Applications with specific air quality pollutants (such as cigarette smoke in restaurants or moisture in swimming pools) and where high ventilation rates can be a primary solution are also good applications for energy recovery ventilation.

Definitions

A heat recovery ventilator (HRV) brings in fresh air from the outside, preheats the incoming air during the winter and precools the incoming air during the summer. It can provide clean fresh air every day while helping to keep energy costs low.
An energy recovery ventilator (ERV) saves energy and helps to keep indoor humidity within a healthy range. It transfers heat and moisture between the incoming and outgoing air.

Description

A heat recovery ventilator (HRV) can help make mechanical ventilation more cost effective by reclaiming energy from exhaust airflows. HRVs use heat exchangers to heat or cool incoming fresh air, recapturing 60 to 80 percent of the conditioned temperatures that would otherwise be lost.

HRVs work in the following manner: One set of ducts collects stale moist air from the kitchen, laundry and bathrooms. This stale contaminated air passes through the HRV unit and is exhausted to the outside. The other ducting system draws in fresh clean air from outdoors through the HRV unit. As the two air streams pass each other within the heat exchanger core, heat is transferred from the outgoing stale air to the fresh incoming air. There is no mixing of air streams. The HRV unit is able to capture up to 85% of the energy from the outgoing stale air. Filtered, preconditioned fresh air is delivered where you need it - in the living areas of your home.

Models that exchange moisture between the two air streams are referred to as Energy Recovery Ventilators (ERVs). ERVs are especially recommended in climates where cooling loads place strong demands on HVAC systems. By applying ERVs into HVAC systems, air conditioning and heating loads can be reduced therby downsizing the necessary equipment considerably. The use of ERVs to reduce cooling loads in hot and humid climates is significant. However, it is important to keep in mind that ERVs are not dehumidifiers. They transfer moisture from the humid air stream (incoming outdoor air in the summer) to the exhaust air stream.

Although some window or wall mounted units are available, HRVs and ERVs are most often designed as ducted whole-house systems. The heat exchanger is the heart of an HRV, usually consisting of a cube-shaped transfer unit made from special conductive materials. Incoming and outgoing airflows pass through different sides of the cube (but are not mixed), allowing conditioned exhaust air to raise or lower the temperature of incoming fresh air.

ERVs also allow the exchange of moisture to control humidity. This can be especially valuable in situations where problems may be created by extreme differences in interior and exterior moisture levels. For instance in cold, heating-dominated climates, better air flow and the introduction of humidity to the indoor environment can help control wintertime window condensation. In humid summer climates which are cooling dominated, it can be critical to dry out incoming air so that mildew or mold do not develop in ductwork.

After passing through the heat exchanger, the warmed or cooled fresh air goes through the HVAC air handler, or may be sent directly to various rooms. Stale air from return ducts pre-conditions the incoming flow before exiting. Systems in various sizes and configurations are available to automatically maintain 0.35 air changes per hour, the rate usually recommended to maintain good air quality. Many systems include filters to further control contaminants that would otherwise re-circulate through the home.

Conventional fan and vent assemblies for bathrooms and kitchens, often required by code, may allow significant energy losses. An HRV system can incorporate small, separately switched booster fans in these rooms to control moisture or heat generated by activities like showering or cooking. Odors and pollutants can quickly removed, but energy used to condition the air is recycled in the heat exchanger. Some codes or applications may still require stoves to be separately vented for removal of grease or gas fumes.

Benefits

- HRVs: fresh air is provided to every room in the house – even when the windows are closed! This allows you to close windows to keep out exterior noise and still have fresh air moving into every room.
- An HRV controls humidity levels. Low humidity causes throat irritation. High humidity encourages the growth of mould and house mites, which can cause health problems.
- Air filters can be added to the HRV to ensure incoming air is clean, healthy and fresh.
- ERVs: improves indoor air quality
- Improves energy efficiency
- Lowers peak energy demand

Limitations

- The dessicant wheels used in many ERVs become saturated fairly quickly and the moisture transfer mechanism becomes less effective with successive hot, humid periods.
- May not be compatible with existing mechanical systems.

Maintenance

Maintenance of proper humidity and air exchange levels can be important to controlling problems like window condensation in hot humid climate conditions.

LEED Credits

May be applicable to the energy and atmosphere section.

First Costs

HRV systems generally cost between $700 and $2,000 installed, with variables like home size and the design of existing or planned HVAC systems being major factors. ERVs will cost more. In the case of ERVs, the prices will range from $500 to $1,700 for these units.

Life Cycle Cost Considerations

Costs of running the ventilation fans can be offset by savings on heating and cooling in areas where ventilation is needed. Periodic replacement of filters may also be necessary.

Codes and Specifications that Apply

HRV and ERV systems should be covered by the HVAC sections in applicable local building codes. Many jurisdictions require conformance to model energy codes requiring higher insulation standards, increasing the likelihood that mechanical ventilation will be needed. Some codes also have minimum ventilation or air exchange requirements.

Example Regional Contractors

Building Performance Equipment, Inc.TM
Contact - Klas C. Haglid, P.E.
80 Broadway Avenue
Hillsdale, NJ, USA 07642-2740
Phone: 201-722-1414
http://www.lowkwh.com

United Metal Products
1920 E. Encanto Dr.
Tempe, AZ 85281
Phone: 480-968-9550
Fax: 480-968-9555
http://www.unitedmetal.com

Heat Technology Products
2950 Airway Ave., Suite C3
Costa Mesa, CA 92626-6030
Phone: 714-549-0555
Fax: 714-549-0556
http://www.heattech.com

Pictures

Source: www.daviddarling.info
Source: windows.lbl.gov
Source: img.alibaba.com
Source: www.solaceenergy.com

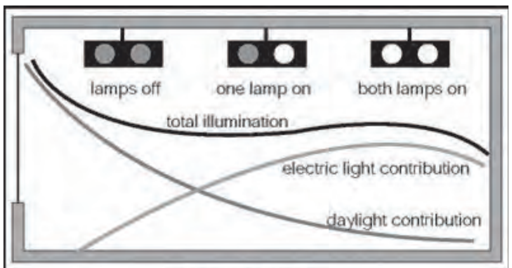
BUILDING AUTOMATION

- DAY-LIGHTING CONTROLS
- OCCUPANCY DETECTION SENSORS
- BUILDING AUTOMATION SYSTEMS

Daylighting Controls

Applications

Daylighting controls have been used in office workstations, private offices, conference rooms, classrooms, and hospitals. But in this spec sheet two types of daylighting control systems will be described: dimming and switching. Dimming systems are best suited to offices, schools and any areas where desk work is being performed. Switching systems can be used in areas with high natural light levels (e.g., atria, entranceways) and where non-critical visual tasks are being performed (e.g., cafeterias, hallways).



Daylighting controls

Definition

A system of sensors that assesses the amount of natural daylight and controls lighting or shading devices to maintain a specified lighting level.

Description

In most office spaces, lighting has traditionally been designed to provide equal amount of light for all occupant spaces. However, lighting may not be needed in all spaces; part-time occupancy and daylight may eliminate lighting needs. Individual workers needs and expectations also vary, for this issue, new lighting control products now allow individuals more flexibility in setting light levels for their spaces, most allow workers to change lighting levels using their computers or remote control devices.

There are basically four options available for integrating daylight and control systems:

- Manual dimming. Occupants can be given the capability of dimming the lights in an area. However, this will probably not result in maximum energy savings.
- Automatic shutoff. This can be accomplished using one of two methods. The simplest method is to use a time clock. On a regular schedule, the entire fixture can be shut off or individual lamps can be shut off to achieve dual light levels, typically 100% and 50%. The other method is use a light sensor combined with a relay and switch. The light sensor measures ambient daylight and if enough light is measured, the fixture or individual lamps within the fixture are switched off. Staging the switching in a fixture by enabling shutoff of, say, two lamps, then the other two lamps, is often called stepped switching.
- Automatic stepped dimming. Similar to automatic shutoff, stepped dimming can be based on a time-of-day schedule or on sensed quantity of daylight. However, with dimming, light output is gradually reduced, which is less jarring than lights switching on and off. Stepped dimming is often called bi-level dimming because the strategy often involves two levels of light output, usually 100% and 50%. However, if more flexibility is required, stepped dimming can involve three levels of light output.
- Automatic continuous dimming. Based on a schedule or sensed quantity of daylight, fixture light output can be gradually dimmed over the full range, from 100% to

1/5/10% (fluorescent) or 100% to 50% (HID).

The main components of a daylighting control system are:

- The photosensor which determines when daylight illumination levels are adequate for the task.
- Matching the control algorithm (open vs. closed loop) and corresponding photosensor placement and photosensor range are crucial for proper system operation.
- A controller which interprets the signal from the photosensor and translates the signal to a switching or dimming device.
- The switching device (i.e. relay) or dimming device (i.e. dimming ballast).

Benefits

- Increases energy savings: 20% - 50% electrical energy savings are typical, along with peak load reductions.
- Automatic and manually adjustable lighting control system.

Limitations

- Initial higher investment costs.
- Changes in light intensity can disturb some occupants.

Maintenance

Sensors must be periodically calibrated and tested to ensure long-term energy savings.

LEED Credits

May be applicable to the energy and atmosphere section.

First Costs

Dimming lighting controls are approximately twice the price of switching controls and require electronic dimmable ballasts. Nevertheless, the overall cost of the daylighting control system will depend on the size of the daylighting zones, whether the system provides for switching or dimming of the electric lights and whether or not the daylighting controls are integrated with other control systems such as occupancy sensing or a building energy management system.

Life Cycle Cost Considerations

In any case, a cost-effective daylighting control system, whether for new construction or retrofit situation, depends on careful design, implementation, and a strong commitment to commissioning and maintenance.

Codes and Specifications that Apply

Regulations vary from state to state. California has what many consider the strictest energy code in the country—The Energy Efficiency Standards for Residential and Nonresidential Buildings, Title 24, Part 6, of the California Code of Regulations. The state recently updated Title 24 with a new 2005 version designed to respond to legislation and the recent energy crunch. The 2005 code changes will take effect October 1, 2005 and supersede the 2001 standards.

Example Regional Contractors

Daylight Controls
5325 N. Commerce Avenue
Moorpark CA
USA 93021
tel 1 805 529 0119
fax 1 805 529 9466
www.daylightcontrols.com

The Watt Stopper
Corporate Office:
2800 De La Cruz Blvd.
Santa Clara, CA 95050
Phone: 408/988-5331
Fax: 408/988-5373
www.thewattstopper.com

Pictures

Source: www.wattstopper.com
Source: www.pages.drexel.edu

Occupancy Detection Sensors

Applications

Occupancy sensors could be used in all kinds of buildings: residential, commercial and industrial buildings.

Definition

Occupancy Sensors provide automatic ON/OFF switching of lighting loads for long-term energy savings, security, and convenience. More specifically, occupancy sensors are used in place of establishing the occupant's behavior to shut off lights upon exiting the room.

Description

Occupancy sensors automatically turn off lighting in unoccupied spaces such as classrooms, conference rooms, public spaces, dormitories, and large offices. According to the Federal Energy Management Program from the DOE, the typical office spends 29 % of its electrical energy costs for lighting. Furthermore, The Florida Power Lighting Company in its energy advisor section mentions that occupancy sensors can reduce these charges by 50% or more, at an energy savings of 5¢ - 20¢ per square foot.

Two technologies dominate the occupancy sensor market: infrared and ultrasonic. Passive infrared sensors detect temperature changes in a room, and work where the entire room is within the sensor's field of view. Ultrasonic sensors use high frequency sound, much like bats do, to detect motion (even around corners). Dual technology sensors use both methods, increasing accuracy and flexibility, but at a higher price.

Benefits

Energy savings, security, and convenience.

Limitations

Not suitable for areas where the occupancy sensor cannot see occupants.

Maintenance

Maintenance tasks such as ballasts change is reduced when occupancy sensors are implemented.

Additional Considerations

Occupancy sensors have a limited sensing range. Sensors can detect slight hand motion up to 3 m and full body motion up to 10 m.

LEED Credits

May be applicable to the Energy and Atmosphere section.

First Costs

Occupancy sensors costs range from approximately $30 to $130, depending on the type. Payback period of occupancy sensors retrofits range from 0.5 to 5 years, depending upon the level of occupancy and energy savings potential of the area controlled.

Life Cycle Cost Considerations

Other savings can be generated in addition to lighting energy cost reduction: Reduced lamp and ballast maintenance, and investment tax credit which is often available for new installations. In addition, air-conditioning costs could be reduced, since less heat is generated from operating lamps and ballasts which are turned off by occupancy sensors.

Codes and Specifications that Apply

ASHRAE Standard 90.2 is the energy Code for low-rise occupancy sensors.

Example Regional Contractors

Steven Engineering
230 Ryan Way
South San Francisco, CA 94080
Phone: 888-790-0022 (toll free)
Fax: 800-314-0716 (toll free)
http://www.stevenengineering.com

Matheson Group, The
P.O. Box 43427
Phoenix, AZ 85080-3421
Phone: 623-434-9541
Fax: 623-780-4967

Pictures

Source: www.lutron.com
Source: www.ramelectricalcorp.com
Source: www.ledalite.com

BUILDING AUTOMATION SYSTEMS

Applications

This technology could be applied to any type of building: residential, commercial and industrial (new or retrofit).

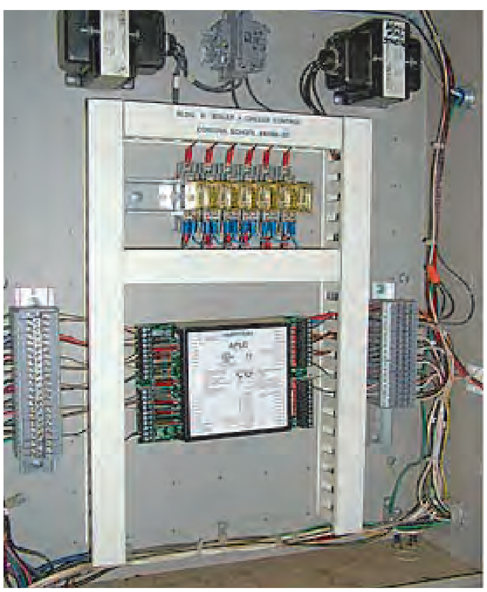
Definition

The objective of a BAS is to monitor, control and optimize the building's environmental variables (temperature and lights, for instance) and achieve an optimal level of control of occupant comfort while minimizing energy use.

Description

Some of the key functions of modern BAS are controlling, monitoring and optimizing variables such as pressure, humidity, and temperatures. The earliest forms of BAS involved a simple time clock and a thermostat. Indeed, many of these systems are still being used. Typically, these systems are wired directly to the end-use equipment and mostly function autonomously from other system components.

Progressing with technology microprocessor-based systems have emerged, as a consequence, BASs has quickly moved to its current state of computer based, digitally controlled systems (DDC). They function by measuring particular system variables (temperature, for instance), processing those variables (comparing a measured temperature to a desired set point), and then signaling a terminal device (air damper/mixing box) to respond.



Modern BASs have three necessary elements: sensors, controllers, and the controlled devices. Some of the more common sensors include: temperature, humidity, pressure, flow rate, and power. In regards to controllers, their function is to compare a signal received from the sensor to a desired set point, and then send out a corresponding signal to the controlled device for action. Finally, the controlled device is the terminal device receiving the signal from the controller. Amongst others, typical controlled devices include: air dampers, mixing boxes, control valves, and in some cases, fans, pumps, and motors.

Benefits

- Reduces energy costs derived from the automated management (monitoring, controlling and optimizing) of the building's environmental variables.
- Reduces time assigned to monitor the building's operation.
- Provides computerized information of the system's performance from a remote location. BAS software has the ability to keep records of the environmental comfort variables.

Limitations

- The system must be manually operated to change the desired values in the variables. This involves knowing how to manipulate the software. Thus, training of maintenance personnel is required.

Maintenance

The required maintenance for sensors (calibration process) could be one of the overlooked activities in BAS. Sensors out of calibration can lead to enormous energy penalties. Furthermore, as with steam traps, these penalties can go undetected for years without a proactive maintenance program.

Additional Considerations

The ability of a BAS to efficiently control energy use in a building is a direct function of the data provided to the BAS. The value of a BAS in making decisions is dependent upon the accuracy of the information in the system. Therefore, careful input of accurate, up-to-date data is essential.

LEED Credits

It may be applied to the Energy and Atmosphere section.

First Costs

Building automation system (BAS) controls are expensive and require high initial investments, making the task of convincing the retail facility manager or owner to invest a challenging one.

Life Cycle Cost Considerations

This section is directly related to the maintenance section. Calibration of sensors can be made by internal technicians that are properly trained. Otherwise, there will be a need for technical support. These costs are variable.

Codes and Specifications that Apply

The U.S. Food and Drug Administration (FDA) on Title 21, CFR Part 11, requires clear, documented assessments of all systems serving the pharmaceutical, bio-tech and medical device facility spaces. BAS software has the ability to keep records of the environmental comfort variables.

Example Regional Contractors

Pro Services
Phoenix
4818 South 40th Street
Phoenix, AZ 85040
(602) 437-8110
Fax: (602) 437-3894
Email: info@pro-services-az.com

Pro Services
Tucson
3855 South Evans Blvd. #404
Tucson, AZ 85714
Phone: (520) 622-2202
Fax: (520) 624-4993
Email: info@pro-services-az.com

Pictures

Source: www.usinenouvelle.com
Source: www.w1.siemens.com
Source: www.enovity.com

services

- ENERGY PERFORMANCE CONTRACTS

Energy Performance Contracts

Applications

Performance based contracting (PBC) is a technique that has been mainly used in the energy industry, but has great potential for being applied to many parts of business activity.

Definition

Under PBC, a third party contractor, an Energy Saving Company (ESCo) takes responsibility for the management of a specific part of the business. The contractor adopts the risk for managing that part of the business but also gains financial rewards for making it more efficient. The efficiency gains are shared between the contractor and the owner of the business.

Description

In the energy industry one way that PBC can work is that Performance Based Contractors approach firms with proposals to improve their energy efficiency over a period of time, normally from 5 to 10 years, at no cost to the firms. The savings made by the energy efficiency improvements are used to pay the contractor and also are returned to the firm. It is clear that such an approach can be used for many aspects of a firm's inputs and outputs - water, transport, waste, chemicals etc.

Under an energy performance contract, the ESCo provides a service package that typically includes the design and engineering, financing, installation, and maintenance of retrofit measures to improve energy efficiency. The scope of the improvements can range from work that affects a single part of a building's energy-using infrastructure (such as lighting) to a complete package of improvements for multiple buildings and facilities. Generally, the service provider will guarantee savings as a result of improvements in both energy and maintenance efficiencies. Flat-fee payments tend to be structured to maintain a positive cash flow to the customer with whom the agreement is made. With the increasing deregulation of conventional energy utilities, several larger utilities have formed unregulated subsidiaries that offer a full range of energy efficiency services under performance agreements.

Benefits

PBC is a particularly useful tool for firms that do not have ready access to capital, or the necessary expertise to implement cleaner production. In such cases, the contractor will organize the capital required for the changes to be made, with the cost of the capital being paid for by the efficiency improvements achieved by the firm.

Limitations

With some ESCos, the customer is required to have a certain minimum level of capital investment (generally $200,000 or more) before a contract will be considered.

Additional Considerations

While several excellent guides exist for selecting and negotiating energy performance contracts, large or complicated contracts should be negotiated with the assistance of experienced legal counsel.

First Costs

An energy performance contract must define the methodology for establishing the baseline costs and cost savings and for the distribution of the savings to the parties.

With some ESCos, the customer is required to have a certain minimum level of capital investment (generally $200,000 or more) before a contract will be considered.

Life Cycle Cost Considerations

The contract must also specify how the savings will be determined and address contingencies that could lead to a contract's maintenance. An example could be any utility rate changes and variations in the use and occupancy of a building.

Codes and Specifications that Apply

It varies from state to state. In the case of Arizona, there is the Municipal Energy Management Program (ARS 34-455, ARS 34-456) applicable to all public agencies, school districts, municipalities, state colleges and universities, counties and state.

Example Regional Contractors

National Association of Energy Service Companies
1615 M Street, NW, Suite 800, Washington, DC 20036
202/822-0950 FAX: 202/822-0955
info@naesco.org
www.naesco.org

ABOUT THE AUTHORS

The National Center of Excellence (NCE) on SMART Innovations is a research cluster at Arizona State University administered by the Global Institute of Sustainability and comprised of researchers from the School Iof Sustainability, Ira A. Fulton School of Engineering, College of Design, the W. P. Carey School of Business, and the College of Liberal Arts and Sciences. It is funded in part by the US EPA and industry sponsors. NCE researchers are developing the next generation of Sustainable Materials and Renewable Technologies (SMART) for urban energy and climate needs. This includes development and application of materials for renewable energy products, innovative building and pavements that reduce energy demand, as well as materials which can improve regional impacts from Urban Heat Islands. In addition to SMART research, the NCE provides customized management strategies and technical advice to local and regional governments, industry and NGOs seeking to incorporate sustainable technologies and organizational strategies for economic, social and environmental benefits.

Contact: info@asusmart.com | www.asusmart.com

Joby D. Carlson

Joby Carlson is the lead researcher, photographer and author for Climate, Energy and Urbanization. Carlson serves as a research engineer and laboratory manager for the National Center of Excellence on SMART Innovations. He holds degrees in Mechanical and Civil/Environmental Engineering and is a LEEDTM Accredited Professional. Born and raised in the Valley of the Sun, Carlson has experienced the rapid growth of the region firsthand. As a youth camping in the Southwest, he realized early that thoughtful planning, a respect for nature, awareness of your surroundings, and adaptability is essential to survival in the desert. He admires the way nature has, with years of practice, figured out how not only to survive, but flourish in this hot dry climate – often wondering if humans can do the same. Carlson is glad to have been part of this project and sincerely hopes the information contained within Climate, Energy and Urbanization is a valuable resource for those who strive towards more sustainable and livable cities.

Jay S. Golden, Ph.D.

Jay Golden is an Assistant Professor in the School of Sustainability and Affiliate of the Civil and Environmental Engineering Department at Arizona State University. He is also the Director of the National Center of Excellence on SMART Innovations. In 2004, he was appointed to a US EPA workgroup for sustainable materials in urban regions and was named an AT&T Ecology Fellow. In 2006 he was voted onto the American Council on Renewable Energy (ACORE) Higher Education Committee and in 2008 he as appointed to the Board on Urban Environments for the American Meteorological Society. Dr. Golden focuses his research on organizational strategies, policies and engineering designs to both adapt and mitigate impacts from climate change and energy.

Acknowledgements

Climate, Energy, and Urbanization: A Guide to Strategies, Materials and Technologies for Sustainable Development in the Desert was developed for the City of Phoenix as part of a two year agreement with the National Center of Excellence on SMART Innovations at ASU. The authors would like to recognize the contribution of many people and organizations without whose support this guidebook would have not been possible. Most notably, we would like to thank Cynthia Parker, Aviation Environmental Coordinator and lead contact between ASU and the City of Phoenix during the course of this project. Parker guided the project between ASU and the City of Phoenix and her time, edits, and suggestions were extremely valued and have been extensively incorporated throughout the document. The look and feel of Climate, Energy, and Urbanization was meticulously designed by Michelle Boady of the City of Phoenix's Print Shop. Her patience and diligence transformed an unwieldy conglomeration of text and figures into a beautiful work of art.

We would also like to thank Sergio Blanco who, during his doctoral program in Environmental Planning at ASU, collected much of the information for the product summaries included in Chapter 4: Systems, Materials and Technologies. We would also like to thank the assistance provided by the University of Buffalo's Energy Management team whose High Performance Building Design Guide served as a valuable resource and model for Chapter 3: Design for Climate and Energy. There were also many reviewers that contributed their comments and suggestions including Dean Brennan, City of Phoenix Planning Department; Dr. Harvey Bryan, Professor of Architecture at ASU; Dr. Patrick Phelan, Professor of Mechanical Engineering at ASU; Dr. Kamil Kaloush, Associate Professor of Civil Engineering at ASU; Lincoln Pratson, Professor of Geological Sciences at Duke University; and last but not least, the many graduate students involved in the project: Jin Ho Jo, Shruti Kasarekar, Vairavan 'Vee' Subramanian, Todd Otanicar, Rahul Bhardwaj, Humberto Silva, Rob Taylor, Sarah Roberts and Jooseng 'Gavin' Gui. We are also grateful for the time and efforts of our editors Lauren Kuby and Katherine Kyle of the Global Institute of Sustainability.