Sustainable Design & its Applications

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Introduction

Sustainable design (also called environmental design, environmentally sustainable design, environmentally conscious design, etc.) is the philosophy of designing physical objects, the built environment, and services to comply with the principles of economic, social, and ecological sustainability.

Intentions

The intention of sustainable design is to "eliminate negative environmental impact completely through skillful, sensitive design". Manifestations of sustainable design require no non-renewable resources, impact the environment minimally, and relate people with the natural environment.

Applications

Applications of this philosophy range from the microcosm — small objects for everyday use, through to the macrocosm — buildings, cities, and the Earth's physical surface. It is a philosophy that can be applied in the fields of architecture, landscape architecture, urban design, urban planning, engineering, graphic design, industrial design, interior design, and fashion design.

Sustainable design is mostly a general reaction to global environmental crises, the rapid growth of economic activity and human population, depletion of natural resources, damage to ecosystems, and loss of biodiversity.

The limits of sustainable design are reducing. Whole earth impacts are beginning to be considered because growth in goods and services is consistently outpacing gains in efficiency. As a result, the net effect of sustainable design to date has been to simply improve the efficiency of rapidly increasing impacts. The present approach, which focuses on the efficiency of delivering individual goods and services, does not solve this problem. The basic dilemmas include: the increasing complexity of efficiency improvements; the difficulty of implementing new technologies in societies built around old ones; that physical impacts of delivering goods and services are not localized, but are distributed throughout the economies; and that the scale of resource use is growing and not stabilizing.

Sustainable Design Principles

While the practical application varies among disciplines, some common principles are as follows:

- Low-impact materials: choose non-toxic, sustainably produced or recycled materials which require little energy to process
- Energy efficiency: use manufacturing processes and produce products which require less energy
- Quality and durability: longer-lasting and better-functioning products will have to be replaced less frequently, reducing the impacts of producing replacements
- Design for reuse and recycling: "Products, processes, and systems should be designed for performance in a commercial 'afterlife'."
- Design Impact Measures for total carbon footprint and life-cycle assessment for any resource used are increasingly required and available. Many are complex, but some give quick and accurate whole-earth estimates of impacts. One measure estimates any spending as consuming an average economic share of global energy use of 8,000btu per dollar and producing CO_2 at the average rate of 0.57 kg of CO_2 per dollar (1995 dollars US) from DOE figures.
- Sustainable Design Standards and project design guides are also increasingly available and are vigorously being developed by a wide array of private organizations and individuals. There is also a large body of new methods emerging from the rapid development of what has become known as 'sustainability science' promoted by a wide variety of educational and governmental institutions.
- Biomimicry: "redesigning industrial systems on biological lines ... enabling the constant reuse of materials in continuous closed cycles..."
- Service substitution: shifting the mode of consumption from personal ownership of products to provision of services which provide similar functions, e.g., from a private automobile to a carsharing service. Such a system promotes minimal resource use per unit of consumption (e.g., per trip driven).
- Renewability: materials should come from nearby (local or bioregional), sustainably managed renewable sources that can be composted when their usefulness has been exhausted.
- Robust eco-design: robust design principles are applied to the design of a pollution sources).

Bill of Rights for the Planet

A model of the new design principles necessary for sustainability is exemplified by the "Bill of Rights for the Planet" or "Hannover Principles" - developed by William McDonough Architects for EXPO 2000 that was held in Hannover, Germany.

The Bill of Rights:

1. Insist on the right of humanity and nature to co-exist in a healthy, supportive, diverse, and sustainable condition.
2. Recognize Interdependence. The elements of human design interact with and depend on the natural world, with broad and diverse implications at every scale. Expand design considerations to recognizing even distant effects.

3. Respect relationships between spirit and matter. Consider all aspects of human settlement including community, dwelling, industry, and trade in terms of existing and evolving connections between spiritual and material consciousness.
4. Accept responsibility for the consequences of design decisions upon human well-being, the viability of natural systems, and their right to co-exist.
5. Create safe objects of long-term value. Do not burden future generations with requirements for maintenance or vigilant administration of potential danger due to the careless creations of products, processes, or standards.
6. Eliminate the concept of waste. Evaluate and optimize the full life-cycle of products and processes, to approach the state of natural systems in which there is no waste.
7. Rely on natural energy flows. Human designs should, like the living world, derive their creative forces from perpetual solar income. Incorporate this energy efficiently and safely for responsible use.
8. Understand the limitations of design. No human creation lasts forever and design does not solve all problems. Those who create and plan should practice humility in the face of nature. Treat nature as a model and mentor, not an inconvenience to be evaded or controlled.
9. Seek constant improvement by the sharing of knowledge. Encourage direct and open communication between colleagues, patrons, manufacturers and users to link long term sustainable considerations with ethical responsibility, and re-establish the integral relationship between natural processes and human activity.

These principles were adopted by the World Congress of the International Union of Architects (UIA) in June 1993 at the American Institute of Architect's (AIA) Expo 93 in Chicago. Further, the AIA and UIA signed a "Declaration of Interdependence for a Sustainable Future." In summary, the declaration states that today's society is degrading its environment and that the AIA, UIA, and their members are committed to:

- Placing environmental and social sustainability at the core of practices and professional responsibilities
- Developing and continually improving practices, procedures, products, services, and standards for sustainable design
- Educating the building industry, clients, and the general public about the importance of sustainable design
- Working to change policies, regulations, and standards in government and business so that sustainable design will become the fully supported standard practice
- Bringing the existing built environment up to sustainable design standards

In addition, the Interprofessional Council on Environmental Design (ICED), a coalition of architectural, landscape architectural, and engineering organizations, developed a vision statement in an attempt to foster a team approach to sustainable design. ICED states: The ethics, education and practices of our professions will be directed to shape a sustainable future. . . . To achieve this vision we will join . . . as a multidisciplinary partnership."

These activities are an indication that the concept of sustainable design is being supported on a global and interprofessional scale and that the ultimate goal is to become more environmentally responsive. The world needs facilities that are more energy efficient and that promote conservation and recycling of natural and economic resources.

Conceptual Problems to Solve

- Diminishing Returns: The principle that all directions of progress run out, ending with diminishing returns, is evident in the typical 'S' curve of The Technology Life Cycle and in the useful life of any system as discussed in Industrial Ecology and Life Cycle Assessment. It's as reliable an expectation as any principle of science that diminishing returns signal natural limits. Common office and business management practice is to read diminishing returns in any direction of effort as an indication of diminishing opportunity, a potential for accelerating their decline and signal to turn elsewhere.

- Unsustainable Investment: A problem arises when the limits of a resource are hard to see, so increasing investment in response to diminishing returns may seem profitable as in the Tragedy of the Commons, but may lead to a collapse. This problem of increasing investment in diminishing resources has also been studied in relation to the causes of civilization collapse by Joseph Tainter among others. This natural error in investment policy contributed to the collapse of both the Roman and Mayan, among others. Relieving over-stressed resources requires reducing pressure on them, not continually increasing it whether more efficiently or not

Waste Prevention

Negative Effects of Waste About 80 million tonnes of waste in total are generated in the U.K. alone, for example, each year. And with reference to only household waste, between 1991/92 and 2007/08, each person in England generated an average of 1.35 pounds of waste per day.

Experience has now shown that there is no completely safe method of waste disposal. All forms of disposal have negative impacts on the environment, public health, and local economies. Landfills have contaminated drinking water. Garbage burned in incinerators has poisoned air, soil, and water. The majority of water treatment systems change the local ecology. Attempts to control or manage wastes after they are produced fail to eliminate environmental impacts.

The toxic components of household products pose serious health risks and aggravate the trash problem. In the U.S., about eight pounds in every ton of household garbage contains toxic materials, such as lead, cadmium, and mercury from batteries, insect sprays, nail polish, cleaners, and other products. When burned or buried, toxic materials also pose a serious threat to public health and the environment.

The only way to avoid environmental harm from waste is to prevent its generation. Pollution prevention means changing the way activities are conducted and eliminating the source of the problem. It does not mean doing without, but doing differently. For example, preventing waste pollution from litter caused by disposable beverage containers does not mean doing without beverages; it just means using refillable bottles.

Waste Prevention Strategies In planning for facilities, a comprehensive design strategy is needed for preventing generation of solid waste. A good garbage prevention strategy would require that everything brought into a facility be recycled for reuse or recycled back into the environment through biodegradation. This would mean a greater reliance on natural materials or products that are compatible with the environment.

Any resource-related development is going to have two basic sources of solid waste — materials purchased and used by the facility and those brought into the facility by visitors. The following waste prevention strategies apply to both, although different approaches will be needed for implementation:

- use products that minimize waste and are nontoxic
- compost or anaerobically digest biodegradable wastes
- reuse materials onsite or collect suitable materials for offsite recycling

Energy Sector

Sustainable technology in the energy sector is based on utilizing renewable sources of energy such as solar, wind, hydro, bioenergy, geothermal, and hydrogen. Wind energy is the world's fastest growing energy source; it has been in use for centuries in Europe and more recently in the United States and other nations. Wind energy is captured through the use of wind turbines that generate and transfer electricity for utilities, homeowners and remote villages. Solar power can be harnessed through photovoltaics, concentrating solar, or solar hot water and is also a rapidly growing energy source.

The availability, potential, and feasibility of primary renewable energy resources must be analyzed early in the planning process as part of a comprehensive energy plan. The plan must justify energy demand and supply and assess the actual costs and benefits to the local, regional, and global environments. Responsible energy use is fundamental to sustainable development and a sustainable future. Energy management must balance justifiable energy demand with appropriate energy supply. The process couples energy awareness, energy conservation, and energy efficiency with the use of primary renewable energy resources.

Water Sector

Sustainable water technologies have become an important industry segment with several companies now providing important and scalable solutions to supply water in a sustainable manner.

Beyond the use of certain technologies, Sustainable Design in Water Management also consists very importantly in correct implementation of concepts. Among one of these principal concepts is the fact normally in developed countries 100% of water destined for consumption, that is not necessarily for drinking purposes, is of potable water quality. This concept of differentiating qualities of water for different purposes has been called "fit-for-purpose". This more rational use of water achieves several economies, that are not only related to water itself, but also the consumption of energy, as to achieve water of drinking quality can be extremely energy intensive for several reasons.

Sustainable technologies

Sustainable technologies use less energy, fewer limited resources, do not deplete natural resources, do not directly or indirectly pollute the environment, and can be reused or recycled at the end of their useful life. There is a significant overlap with appropriate technology, which emphasizes the suitability of technology to the context, in particular considering the needs of people in developing countries. However, the most appropriate technology may not be the most sustainable one; and a sustainable technology may have high cost or maintenance requirements that make it unsuitable as an "appropriate technology," as that term is commonly used.

Encouraging sustainability

Training meeting with factory workers in a stainless steel ecodesign company from Rio de Janeiro - Brazil

The Passivhaus-Institut promotes and establishes standards for the Passive House - Passivhaus international program for Low-energy houses and other low-energy building techniques and structures.

The use of sustainable technologies may be encouraged through means such as reducing the capacity of the electrical cable supplying a home, such as Australia's Crystal Waters Village. In some cases the electricity supplier charges a higher rate for the energy used when the capacity of the supply is increased.

Chapter- 1

Examples of Sustainable Design

Sustainable Planning

Urban planners that are interested in achieving sustainable development or sustainable cities use various design principles and techniques when designing cities and their infrastructure. These include Smart Growth theory, Transit-oriented development, sustainable urban infrastructure and New Urbanism. Smart Growth is an urban planning and transportation theory that concentrates growth in infill sites within the existing infrastructure of a city or town to avoid urban sprawl; and advocates compact, transit-oriented development, walkable, bicycle-friendly land use, including mixed-use development with a range of housing choices. Transit-oriented development attempts to maximise access to public transport and thereby reduce the need for private vehicles. Public transport is considered a form of Sustainable urban infrastructure, which is a design approach which promotes protected areas, energy-efficient buildings, wildlife corridors and distributed, rather than centralised, power generation and wastewater treatment. New Urbanism is more of a social and aesthetic urban design movement than a green one, but it does emphasize diversity of land use and population, as well as walkable communities which inherently reduce the need for automotive travel.

Both urban and rural planning can benefit from including sustainability as a central criterion when laying out roads, streets, buildings and other components of the built environment. Conventional planning practice often ignores or discounts the natural configuration of the land during the planning stages, potentially causing ecological damage such as the stagnation of streams, mudslides, soil erosion, flooding and pollution. Applying methods such as scientific modelling to planned building projects can draw attention to problems before construction begins, helping to minimise damage to the natural environment.

Cohousing is an approach to planning based on the idea of intentional communities. Such projects often prioritize common space over private space resulting in grouped structures that preserve more of the surrounding environment.

Watershed assessment of carrying capacity; estuary, riparian zone restoration and groundwater recharge for hydrologic cycle viability; and other opportunities and issues about Water and the environment show that the foundation of smart growth lies in the protection and preservation of water resources. The total amount of precipitation landing on the surface of a community becomes the supply for the inhabitants. This supply amount then dictates the carrying capacity - the potential population - as supported by the "water crop."

Sustainable architecture

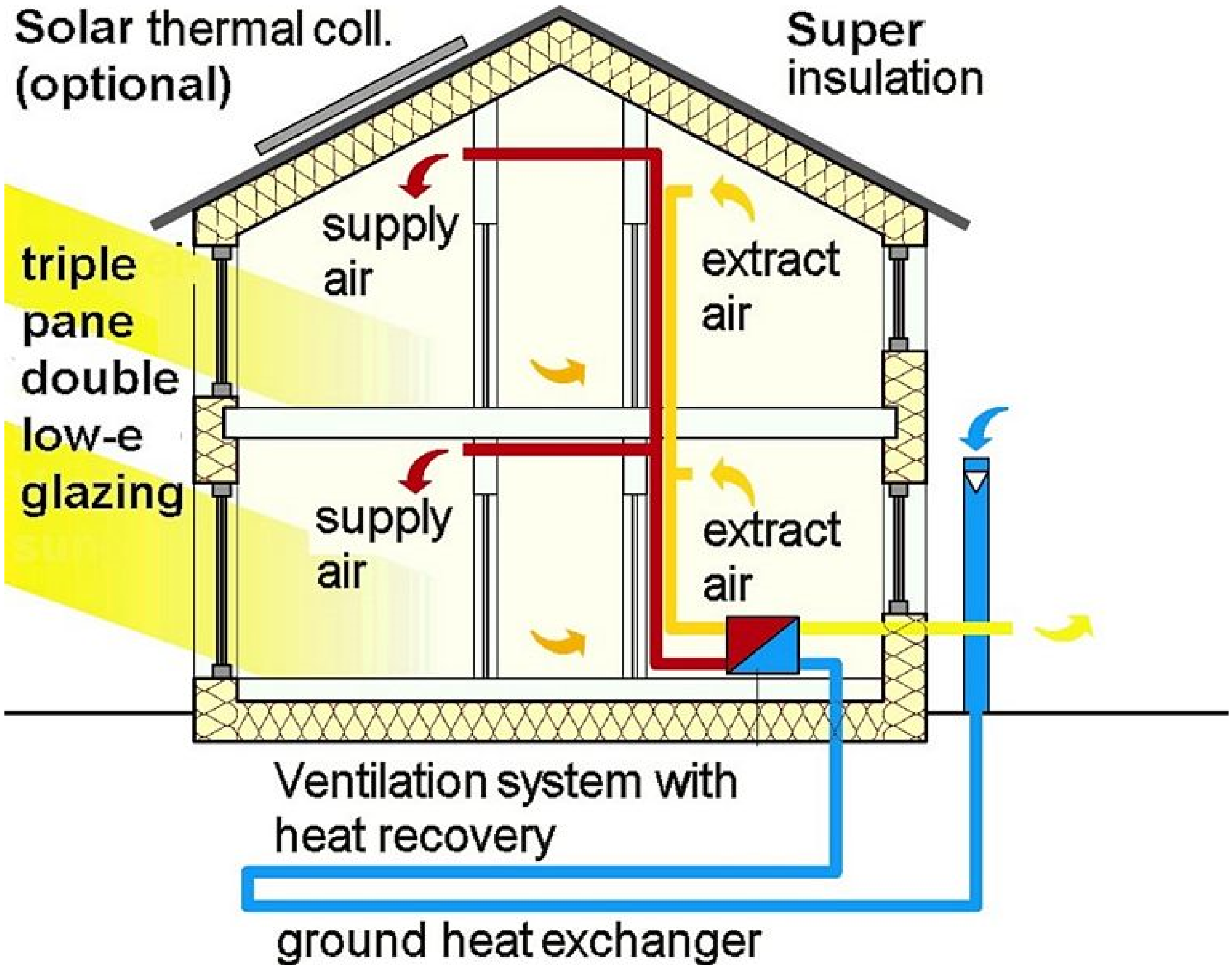
Sustainable portable classroom design proposal

Sustainable architecture is a general term that describes environmentally conscious design techniques in the field of architecture. Sustainable architecture is framed by the larger discussion of sustainability and the pressing economic and political issues of our world. In the broad context, sustainable architecture seeks to minimize the negative environmental impact of buildings by enhancing efficiency and moderation in the use of materials, energy, and development space. Most simply, the idea of sustainability, or ecological design, is to ensure that our actions and decisions today do not inhibit the opportunities of future generations. This term can be used to describe an energy and ecologically conscious approach to the design of the built environment.

Sustainable energy

K2 sustainable apartments in Windsor, Victoria, Australia by Hansen Yuncken (2006) features passive solar design, recycled and sustainable materials, photovoltaic cells, wastewater treatment, rainwater collection and solar hot water.

Following its destruction by a tornado in 2007, the town of Greensburg, Kansas (USA) elected to rebuild to highly stringent LEED Platinum environmental standards. Shown is the town's new art center, which integrates its own solar panels and wind generators for energy self-sufficiency.



The passivhaus standard combines a variety of techniques and technologies to achieve ultra-low energy use.

Energy efficiency over the entire life cycle of a building is the single most important goal of sustainable architecture. Architects use many different techniques to reduce the energy needs of buildings and increase their ability to capture or generate their own energy.

Heating, Ventilation and Cooling System Efficiency

The most important and cost effective element of an efficient heating, ventilating, and air conditioning (HVAC) system is a well insulated building. A more efficient building requires less heat generating or dissipating power, but may require more ventilation capacity to expel polluted indoor air.

Significant amounts of energy are flushed out of buildings in the water, air and compost streams. Off the shelf, on-site energy recycling technologies can effectively recapture energy from waste hot water and stale air and transfer that energy into incoming fresh cold water or fresh air. Recapture of energy for uses other than gardening from compost leaving buildings requires centralized anaerobic digesters.

Site and building orientation have some major effects on a building's HVAC efficiency.

Passive solar building design allows buildings to harness the energy of the sun efficiently without the use of any active solar mechanisms such as photovoltaic cells or solar hot water panels. Typically passive solar building designs incorporate materials with high thermal mass that retain heat effectively and strong insulation that works to prevent heat escape. Low energy designs also requires the use of solar shading, by means of awnings, blinds or shutters, to relieve the solar heat gain in summer and to reduce the need for artificial cooling. In addition, low energy buildings typically have a very low surface area to volume ratio to minimize heat loss. This means that sprawling multi-winged building designs (often thought to look more "organic") are often avoided in favor of more centralized structures. Traditional cold climate buildings such as American colonial saltbox designs provide a good historical model for centralized heat efficiency in a small scale building.

Windows are placed to maximize the input of heat-creating light while minimizing the loss of heat through glass, a poor insulator. In the northern hemisphere this usually involves installing a large number of south-facing windows to collect direct sun and severely restricting the number of north-facing windows. Certain window types, such as double or triple glazed insulated windows with gas filled spaces and low emissivity (low-E) coatings, provide much better insulation than single-pane glass windows. Preventing excess solar gain by means of solar shading devices in the summer months is important to reduce cooling needs. Deciduous trees are often planted in front of windows to block excessive sun in summer with their leaves but allow light through in winter when their leaves fall off. Louvers or light shelves are installed to allow the sunlight in during the winter (when the sun is lower in the sky) and keep it out in the summer (when the sun is high in the sky). Coniferous or evergreen plants are often planted to the north of buildings to shield against cold north winds.

In colder climates, heating systems are a primary focus for sustainable architecture because they are typically one of the largest single energy drains in buildings.

In warmer climates where cooling is a primary concern, passive solar designs can also be very effective. Masonry building materials with high thermal mass are very valuable for retaining the cool temperatures of night throughout the day. In addition builders often opt for sprawling single story structures in order to maximize surface area and heat loss. Buildings are often designed to capture and channel existing winds, particularly the especially cool winds coming from nearby bodies of water. Many of these valuable strategies are employed in some way by the traditional architecture of warm regions, such as south-western mission buildings.

In climates with four seasons, an integrated energy system will increase in efficiency: when the building is well insulated, when it is sited to work with the forces of nature, when heat is recaptured (to be used immediately or stored), when the heat plant relying on fossil fuels or electricity is greater than 100% efficient, and when renewable energy is utilized.

Renewable energy generation

Solar Panels

Active solar devices such as photovoltaic solar panels help to provide sustainable electricity for any use. Electrical output of a solar panel is dependent on orientation, efficiency, latitude, and climate--solar gain varies even at the same latitude. Typical efficiencies for commercially available PV panels range from 4% to 28%. The low efficiency of certain photovoltaic panels can significantly affect the payback period of their installation. A good rule of thumb for the cost of installing solar panels is roughly about $4.30/Watt.

Roofs are often angled toward the sun to allow photovoltaic panels to collect at maximum efficiency. For any solar panel, a true-south facing orientation maximizes yield. If true-south is not possible, solar panels can produce adequate energy if aligned within 30° of south. However, at higher latitudes, winter energy yield will be significantly reduced for non-south orientation.

To maximize efficiency in winter, the collector should be angled above horizontal Latitude + 15°. To maximize efficiency in summer, the angle should be Latitude - 15°. However, for an annual maximum production, the angle of the panel above horizontal should be equal to its latitude.

Wind Turbines

Undersized wind turbines (normal turbines are often over 250 feet) may have been oversold and do not always provide the returns promised, particularly for North American households. The use of undersized wind turbines in energy production in sustainable structures requires the consideration of many factors. In considering costs, small wind systems are generally more expensive than larger wind turbines relative to the amount of energy they produce. For small wind turbines, maintenance costs can be a deciding factor at sites with marginal wind-harnessing capabilities. At low-wind sites, maintenance can consume much of a small wind turbine’s revenue. Wind turbines begin operating when winds reach 8 mph, achieve energy production capacity at speeds of 32-37 mph, and shut off to avoid damage at speeds exceeding 55 mph. The energy potential of a wind turbine is proportional to the square of the length of its blades and to the cube of the speed at which its blades spin. Though wind turbines are available that can supplement power for a single building, because of these factors, the efficiency of the wind turbine depends much upon the wind conditions at the building site. For these reasons, for wind turbines to be at all efficient, they must be installed at locations that are known to receive a constant amount of wind (with average wind speeds of more than 15 mph), rather than locations that receive wind sporadically. A small wind turbine can be installed on a roof. Installation issues then include the strength of the roof, vibration, and the turbulence caused by the roof ledge. Small-scale rooftop wind turbines have been known to be able to generate power from 10% to up to 25% of the electricity required of a regular domestic household dwelling. Turbines for residential scale use are available. They are usually approximately 7 feet (2 m) to 25 feet (8 m) in diameter and produce electricity at a rate of 900 watts to 10,000 watts at their tested wind speed. In the United States, residential wind turbines with outputs of 2-10 kW, typically cost between $12,000 and $55,000 installed ($6 per watt), although there are incentives and rebates available in 19 states that can reduce the purchase price for homeowners by up to 50 percent, to ($3 per watt).

Solar Water Heating

Solar water heaters—also called solar domestic hot water systems—can be a cost-effective way to generate hot water for your home. They can be used in any climate, and the fuel they use—sunshine—is free.

There are two types of solar water systems- active and passive. An active solar collector system will cost approximately $2,500 to $3,500 installed and produce about 80 to 100 gallons of hot water per day. A passive system will cost about $1,000 to $2,000 installed but will have a lower capacity.

There are also two types of circulation, direct circulation systems and indirect circulation systems. Direct circulation systems loop the domestic water through the panels. They should not be used in climates with temperatures below freezing. Indirect circulation loops glycol or some other fluid through the solar panels and uses a heat exchanger to heat up the domestic water.

The two most common types of collector panels are Flat-Plate and Evacuated-tube. The two work similarly except that evacuated tubes do not convectively lose heat, which greatly improves their efficiency (5%-25% more efficient). With these higher efficiencies, Evacuated-tube solar collectors can also produce higher-temperature space heating, and even higher temperatures for absorption cooling systems.

Electric-resistance water heaters that are common in homes today have an electrical demand around 4500 KWh/year. With the use of solar collectors, the energy use is cut in half. The up-front cost of installing solar collectors is high, but with the annual energy savings, payback periods are relatively short.

Heat Pumps

Air-source heat pumps (ASHP) can be thought of as reversible air conditioners. Like an air conditioner, an ASHP can take heat from a relatively cool space (e.g. a house at 70°F) and dump it into a hot place (e.g. outside at 85°F). However, unlike an air conditioner, the condenser and evaporator of an ASHP can switch roles and absorb heat from the cool outside air and dump it into a warm house.

Air-source heat pumps are inexpensive relative to other heat pump systems. However, the efficiency of air-source heat pumps decline when the outdoor temperature is very cold or very hot; therefore, they are only really applicable in temperate climates.

For areas not located in temperate climates, ground-source (or geothermal) heat pumps provide an efficient alternative. The difference between the two heat pumps is that the ground-source has one of its heat exchangers placed underground—usually in a horizontal or vertical arrangement. Ground-source takes advantage of the relatively constant, mild temperatures underground, which means their efficiencies can be much greater than that of an air-source heat pump. The in-ground heat exchanger generally needs a considerable amount of area. Designers have placed them in an open area next to the building or underneath a parking lot.

Energy Star ground-source heat pumps can be 40% to 60% more efficient than their air-source counterparts. They are also quieter and can also be applied to other functions like domestic hot water heating.

In terms of initial cost, the ground-source heat pump system costs about twice as much as a standard air-source heat pump to be installed. However, the up-front costs can be more than offset by the decrease in energy costs. The reduction in energy costs is especially apparent in areas with typically hot summers and cold winters.

Other types of heat pumps are water-source and air-earth. If the building is located near a body of water, the pond or lake could be used as a heat source or sink. Air-earth heat pumps circulate the building's air through underground ducts. With higher fan power requirements and inefficient heat transfer, Air-earth heat pumps are generally not practical for major construction.

Sustainable building materials

Some examples of sustainable building materials include recycled denim or blown-in fiber glass insulation, sustainably harvested wood, Trass, Linoleum, sheep wool, concrete (high and ultra high performance, roman self-healing concrete), panels made from paper flakes, baked earth, rammed earth, clay, vermiculite, flax linnen, sisal, seegrass, cork, expanded clay grains, coconut, wood fibre plates, calcium sand stone, locally obtained stone and rock, and bamboo, which is one of the strongest and fastest growing woody plants, and non-toxic low-VOC glues and paints.

Recycled Materials

Recycling items for building

Some sustainable architecture incorporates the use of recycled or second hand materials, such as reclaimed lumber. The reduction in use of new materials creates a corresponding reduction in embodied energy (energy used in the production of materials). Often sustainable architects attempt to retro-fit old structures to serve new needs in order to avoid unnecessary development. Architectural salvage and reclaimed materials are used when appropriate. When older buildings are demolished, frequently any good wood is reclaimed, renewed, and sold as flooring. Any good dimension stone is similarly reclaimed. Many other parts are reused as well, such as doors, windows, mantels, and hardware, thus reducing the consumption of new goods. When new materials are employed, green designers look for materials that are rapidly replenished, such as bamboo, which can be harvested for commercial use after only 6 years of growth, sorghum or wheat straw, both of which are waste material that can be pressed into panels, or cork oak, in which only the outer bark is removed for use, thus preserving the tree. When possible, building materials may be gleaned from the site itself; for example, if a new structure is being constructed in a wooded area, wood from the trees which were cut to make room for the building would be re-used as part of the building itself.

Lower Volatile Organic Compounds

Low-impact building materials are used wherever feasible: for example, insulation may be made from low VOC (volatile organic compound)-emitting materials such as recycled denim or cellulose insulation, rather than the building insulation materials that may contain carcinogenic or toxic materials such as formaldehyde. To discourage insect damage, these alternate insulation materials may be treated with boric acid. Organic or milk-based paints may be used. However, a common fallacy is that "green" materials are always better for the health of occupants or the environment. Many harmful substances (including formaldehyde, arsenic, and asbestos) are naturally occurring and are not without their histories of use with the best of intentions. A study of emissions from materials by the State of California has shown that there are some green materials that have substantial emissions whereas some more "traditional" materials actually were lower emitters. Thus, the subject of emissions must be carefully investigated before concluding that natural materials are always the healthiest alternatives for occupants and for the Earth.

Volatile organic compounds (VOC) can be found in any indoor environment coming from a variety of different sources. VOCs have a high vapor pressure and low water solubility and are suspected of causing sick building syndrome type symptoms. This is because many VOCs have been known to cause sensory irritation and central nervous system symptoms characteristic to sick building syndrome, indoor concentrations of VOCs are higher than in the outdoor atmosphere, and when there are many VOCs present, they can cause additive and multiplicative effects.

Green products are usually considered to contain fewer VOCs and be better for human and environmental health. A case study conducted by the Department of Civil, Architectural, and Environmental Engineering at the University of Miami that compared three green products and their non-green counterparts found that even though both the green products and the non-green counterparts both emitted levels of VOCs, the amount and intensity of the VOCs emitted from the green products were much safer and comfortable for human exposure.

Waste management

Waste takes the form of spent or useless materials generated from households and businesses, construction and demolition processes, and manufacturing and agricultural industries. These materials are loosely categorized as municipal solid waste, construction and demolition (C&D) debris, and industrial or agricultural by-products. Sustainable architecture focuses on the on-site use of waste management, incorporating things such as grey water systems for use on garden beds, and composting toilets to reduce sewage. These methods, when combined with on-site food waste composting and off-site recycling, can reduce a house's waste to a small amount of packaging waste.

Water management

Rainwater harvesting and grey water reuse are some of the possibilities for reducing water demand.

Building placement

One central and often ignored aspect of sustainable architecture is building placement. Although many may envision the ideal environmental home or office structure as an isolated place in the middle of the woods, this kind of placement is often detrimental to the environment. First, such structures often serve as the unknowing frontlines of suburban sprawl. Second, they usually increase the energy consumption required for transportation and lead to unnecessary auto emissions. Ideally, most building should avoid suburban sprawl in favor of the kind of light urban development articulated by the New Urbanist movement. Careful mixed use zoning can make commercial, residential, and light industrial areas more accessible for those traveling by foot, bicycle, or public transit, as proposed in the Principles of Intelligent Urbanism.

Social sustainability in architecture

The building structure must also be considered. Cost/effectiveness is an important issue in sustainable architecture projects, and one of the most efficient designs herein is the Public housing approach. This approach lets everyone have their own sleeping/recreation space, yet incorporate communal spaces eg. mess halls, Latrines, public showers, ...

Architectural design can play a large part in influencing the ways that social groups interact. Communist Russia's Constructivist Social condensers are a good example of this, buildings which were designed with the specific intention of controlling or directing the flow of everyday life to "create socially equitable spaces".

Sustainable design can help to create a sustainable way of living within a community. While the existing social constructs can be seen to influence architecture, the opposite can also be true. An overtly socially sustainable building, if successful, can help people to see the benefit of living sustainably; this can be seen in many of Rural Studio's buildings in and around Hale County, Alabama, and in the design of ALA Himmelwright's "model fireproof farmhouse," located at Rock Lodge Club in Stockholm, New Jersey. The same can be said for environmentally sustainable design, in that architecture can lead the way for the greater community.

Art can be a powerfully positive social force. It can help to reduce stress in many situations, lowering the risk of stress-related health problems, both physical and mental. Art can also be a way of individual expression, which can add to the community as a whole. Hundertwasser's buildings in Austria are an inspiring example of art giving back to the community.

It is interesting to note that the cohousing movement with a high degree of social sustainability and participation where the majority of participants are non-architects invariably uses traditional architecture that resonates with the general public. Unfortuatley un-loved projects have a short lifespan and are a waste of resources.

In addition, to decrease costs of operation (heating, cooling, ...) techniques as Earth sheltering, Trombe walls, ... are often incorporated.

- Chris Bosse
- Bill Browning
- Finegold Alexander + Associates Inc
- Glenn Murcutt
- Hellmuth, Obata and Kassabaum
- James Wines
- Jose Picciotto
- Ken Yeang
- Laurie Baker
- Lawrence Scarpa
- Malcolm Wells
- Mitchell Joachim
- Mithun, Inc
- Norman Foster
- Paolo Soleri
- Reclaimed Space
- Renzo Piano
- Richard Rogers
- Sim Van der Ryn
- Tom Bender
- Walter Segal
- William McDonough

Criticism

Sustainable architecture, it can be argued, does not rigorously form a part of architecture as a discipline. Rather, it is a concern in the building construction industry as a whole, and given the dominance of construction techniques and building subsystems, it should be considered a part of civil engineering as a discipline. Numerous schools of architecture exclude sustainable architecture as a part of their curriculum, and it is considered to be a fashionable subject at the moment.

Sustainable buildings

- 30 St Mary Axe
- Tour Oxygène
- Tour Incity
- Bank of America Tower (New York City)

Sustainable landscape architecture

Sustainable landscape architecture is a category of sustainable design concerned with the planning and design of outdoor space.

This can include ecological, social and economic aspects of sustainability. For example, the design of a sustainable urban drainage system can: improve habitats for fauna and flora; improve recreational facilities, because people love to be beside water; save money, because building culverts is expensive and floods cause severe financial harm.

The design of a green roof or a roof garden can also contribute to the sustainability of a landscape architecture project. The roof will help manage surface water, provide for wildlife and provide for recreation.

Sustainability appears to be a new addition to the traditional Vitruvian objectives of the design process: commodity, firmness and delight. But it can be seen as an aspect of both firmness and commodity: an outdoor space is likely to last longer and give more commodity to its owners if it requires low inputs of energy, water, fertiliser etc, and if it produces fewer outputs of noise, pollution, surface water runoff etc.

Sustainable landscaping

Sustainable landscaping encompasses a variety of practices that have developed in response to environmental issues. These practices are used in every phase of landscaping, including design, construction, implementation and management of residential and commercial landscapes.

Sustainability issues for landscaping

Sustainability Issues for Landscaping include: Carbon Sequestration by Plants; Global Climate Change; Air Pollution; Water Pollution; Pesticide Toxicity; Non-Renewable Resources; Energy Usage. Non-sustainable practices encompass: Contamination of soil, air and water; persistence of toxic compounds in the environment; non-sustainable consumption of natural resources; Greenhouse gas emissions.

Effects of non-sustainable practices

Some of the effects of non-sustainable practices are: Threats to health, well-being and even survival of humans and other life forms and their habitats; sedimentation of surface waters caused by stormwater runoff; chemical pollutants in drinking water caused by pesticide runoff; health problems caused by toxic fertilizers, toxic pesticides, improper use, handling, storage and disposal of pesticides; air and noise pollution caused by landscape equipment; and over-use of limited natural resources.

Sustainable landscaping solutions

Some of the solutions being developed are:

- Reduction of stormwater run-off through the use of bio-swales, rain gardens and green roofs and walls.
- Reduction of water use in landscapes through design of water-wise garden techniques (sometimes known as xeriscaping™)
- Bio-filtering of wastes through constructed wetlands
- Landscape irrigation using water from showers and sinks, known as gray water
- Integrated Pest Management techniques for pest control
- Creating and enhancing wildlife habitat in urban environments
- Energy-efficient landscape design in the form of proper placement and selection of shade trees and creation of wind breaks
- Permeable paving materials to reduce stormwater run-off and allow rain water to infiltrate into the ground and replenish groundwater rather than run into surface water
- Use of sustainably harvested wood, composite wood products for decking and other landscape projects, as well as use of plastic lumber
- Recycling of products, such as glass, rubber from tires and other materials to create landscape products such as paving stones, mulch and other materials
- Soil management techniques, including composting kitchen and yard wastes, to maintain and enhance healthy soil that supports a diversity of soil life
- Integration and adoption of renewable energy, including solar-powered landscape lighting

Background

A sustainable landscape is designed to be both attractive and in balance with the local climate and environment and it should require minimal resource inputs. Thus, the design must be "functional, cost-efficient, visually pleasing, environmentally friendly and maintainable" As part of the concept called sustainable development it pays close attention to the preservation of limited and costly resources, reducing waste and preventing air, water and soil pollution. Also, compost, fertilization, grass cycling, pest control measures that avoid or minimize the use of chemicals, integrated pest management, using the right plant in the right place, appropriate use of turf, irrigation efficiency and xeriscaping or water-wise gardening are all components of sustainable landscaping.

Benefits

The geographic location can determine what is sustainable due to differences in precipitation and temperature. For example, the California Waste Management Board emphasizes the link between minimizing environmental damage and maximizing one's bottom line of urban commercial landscaping companies. In California, the benefits of landscapes often do not outweigh the cost of inputs like water and labor. However, using appropriately selected and properly sited plants may help to ensure that maintenance costs are lower than they otherwise would be due to reduced chemical and water inputs.

Programs

There are several programs in place that are open to participation by various groups. For example, the Audubon Cooperative Sanctuary Program for Golf Courses, the Audubon Green Neighborhoods™ Program and the National Wildlife Federation's Backyard Habitat™ Program, to name a few.

The Sustainable Sites Initiative, the cooperative effort between the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center and the United States Botanic Garden, began in 2005 and will provide a points-based certification for landscapes, similar to the LEED program for buildings operated by the Green Building Council. The Sustainable Sites Initiative now has a document titled Guidelines and Performance Benchmarks. The credit system is expected to be completed in 2011.

Proper design

The primary step to landscape design is to do a "sustainability audit". This is similar to a landscape site analysis that is typically performed by landscape designers at the beginning of the design process. Factors such as lot size, house size, local covenants and budgets should be considered. The steps to design include a base plan, site inventory and analysis, construction documents, implementation and maintenance. Other considerations include orientation to the sun, soil type, slopes, location of utility lines and planned usage.

Composting

Composting is a way to recycle kitchen and garden waste while creating inexpensive organic fertilizer for the garden and landscape. Earthworms, microbes and other soil flora and fauna feast on such organic matter when provided adequate nitrogen and proper temperatures and moisture. The ideal size for a compost pile or bin is one cubic yard (3' x 3' x 3'). It should be placed in a partly shady location to avoid intense sun and drying out, as this will delay the decomposition process. The pile heats up during the decomposition process, then cools as material is transformed, this is a good time to turn the pile, so that undecomposed materials on the periphery of the pile can be moved to the center to complete the process. With adequate moisture, nitrogen, proper temperature and correct timing of turning the pile, compost can be made in about a 30-day period. Left alone this pocess will still occur, but may take three to four months under less-than-ideal conditions.

Compost can be added as an amendment to poorly draining soil, as a fertilizer on flower and vegetable beds, to fruit trees or used as a potting soil for potted plants. Trimmings from lawns, trees and shrubs from a large landscape site can be used as feedstock for on-site composting. Reusing on-site organic materials will decrease the need for purchasing other soil additives.

Irrigation

Using mulch is a great way to reduce water loss due to evaporation, reduce weeds, minimize erosion, dust and mud problems. Mulch will also add nutrients to the soil when it decomposes.

Grass cycling turf areas (using mulching mowers that leave grass clippings on the lawn) will also decrease the amount of fertilizer needed, reduce landfill waste and reduce costs of disposal.

A common recommendation is to adding 2-4 inches of mulch in flower beds and under trees away from the trunk. Mulch should be applied under trees to the dripline (extension of the branches) in lieu of flowers, hostas, turf or other plants that are often planted there. This practice of planting under trees is detrimental to tree roots, especially when such plants are irrigated to an excessive level that harms the tree.

The practice of xeriscaping or water-wise gardening suggests that placing plants with similar water demands together will save time and low-water or drought tolerant plants would be a smart initial consideration.

A homeowner may consider consulting an accredited irrigation technician/auditor and obtain a water audit of current systems. In the event that the situation is difficult to manage, drip or sub-surface irrigation may be most effective. If the system has been in use for over five years, upgrading to evapotranspiration (ET) controllers, soil sensors and refined control panels will improve the system. Oftentimes irrigation heads are in need of readjustment to avoid sprinkling on sidewalks or streets. Business owners may consider developing watering schedules based on historical or actual weather data and soil probes to monitor soil moisture prior to watering.

Building materials

When deciding what kind of building materials to put on a site it is important to recycle as often as possible. Reusing old bricks from sidewalks as patio pavers is one way to provide an aesthetic appeal to an area while reducing what goes to the landfill.

But it is also important to be careful about what materials you use, especially if you plan to grow food crops of any kind. Old telephone poles and railroad ties have usually been treated with a substance called creosote that can leach into the soils and make any food grown there toxic enough to cause harm to anyone that eats it. In general, you should avoid any kind of treated material, especially wood, that could leach into the soil with rain.

The Forest Stewardship Council was formed in 1993 "to change the dialogue about and the practice of sustainable forestry worldwide." Sustainably harvested lumber - also called certified wood is now available, in which ecological, economic and social factors are integrated into the managament of trees used for lumber. A chain of custody document is used in the certification process.

Planting selection

One important part of sustainable landscaping is plant selection. Most of what makes a landscape unsustainable is the amount of inputs required to grow a non-native plant on it. What this means is that a local plant, which has adapted to local climate conditions will require less work on the part of some other agent to flourish. For example, it does not make sense to grow tomatoes in Arizona because there is not enough natural rainfall for them to survive without constant watering. Instead, drought tolerant plants like succulents and cacti are better suited to survive. Also, by choosing native plants, one can avoid certain problems with insects and pests because these plants will also be adapted to deal with any local invader. The bottom line is that by choosing the right kind of local plants, a great deal of money can be saved on amendment costs, pest control and watering.

Plants used as windbreaks can save up to 30% on heating costs in winter. They also help with shading a residence or commercial building in summer, create cool air through evapo-transpiration and can cool hardscaped areas such as driveways and sidewalks.

While xeriscaping is an intelligent option, in many temperate and subtropical areas flora selection can be optimized.

For example, a house surrounded by local broadleaf deciduous trees enjoys multiple benefits. First of all, plants release water vapor in the air through transpiration and water has the ability to reduce temperature extremes in the areas near it (water boasts very high heat capacity). The larger the plant, the most water vapor it produces. Also, broadleaf decidous trees provide shading in the summer while permitting large amounts of heat-carrying solar radiation to strike the house in the winter.

Additionally, trees arranged in a close matrix are fundamental in the creation of stable, healthy and productive ecosystems (such as forests) - in fact this is an important principle of permaculture.

However, a sustainable house can not be entirely encircled by trees, as it will most likely have south-facing (north-facing in the S. hemisphere) photovoltaic panels installed, and a large, south-facing glazing as a result of passive solar heating design. The efficiency of both systems is very sensitive to shading; the tree selection described above is valid if applied only on east, west and north-facing walls.

If the surrounding trees are further chosen to produce edible fruit they can provide a sustainable food source for the occupants of the house. Even if some are fairly demanding (especially in the summer), irrigation is an excellent end-use option in greywater recycling and rainwater harvesting systems, and a composting toilet can cover (at least) some of the nutrient requirements. Research suggests that diluted human urine might be as effective as chemical fertilizers. It must be noted that not all fruit trees are suitable for greywater irrigation, as reclaimed greywater is typically of high pH and acidophile plants don't do well in alkaline environments.

Maintenance

Pest Problems Maintaining plant health will eliminate most pest problems. It is best to start with pest-free plant materials and supplies and close inspection of the plant upon purchase is also recommended. Establishing diversity within the area of plant species will encourage beneficial organism populations (e.g. birds, insects), which feed on potential plant pests. Because plant pests vary from plant to plant, assessing the problem correctly is half the battle. The owner must consider whether the plant can tolerate the damage caused by the plant. If not, then does the plant value justify some sort of treatment? While pesticide is often chosen to solve the problem, physical barriers and repellents may help. If pesticides are the chosen method, selective organic or natural pesticide is often better because it has less impact on non-target species.

Pruning Proper pruning will increase air circulation and decrease the likelihood of plant diseases. However, improper pruning is detrimental to shrubs and trees. Hedging, topping and shearing of landscape plants causes excessive plant growth. In addition, topping is a hazardous practice which creates a hazardous tree which is highly susceptible to wind damage. Natural pruning techniques during the proper season, on the other hand, promotes healthier, more stable plants. In temperate areas, deciduous plants should be pruned during dormancy. Plants should never be pruned at the end of a growing season because growth is stimulated and such new growth will be too tender to survive winter freezing temperatures.

Pollution Prevention Landscape managers should make use of the Integrated Pest Management (IPM) to reduce use of pesticides and herbicides and reduce non-point source solution.

Sustainable gardening

Sustainable gardening (which is taken here to include sustainable landscapes, sustainable landscape design, sustainable landscape architecture and sustainable sites) comprises a disparate group of horticultural interests that share, to a greater or lesser extent, the aims and objectives associated with the international post-1980s sustainable development and sustainability programs developed to address the fact that humans are now using natural biophysical resources faster than they can be replenished by nature. Included within this compass are those home gardeners, and members of the landscape and nursery industries and municipal authorities, that integrate environmental, social and economic factors in an attempt to create a more sustainable future.

Organic gardening and the use of native plants are integral to sustainable gardening.

Historical development

After the establishment of sustainable agriculture in the early 1980s it was some time before the emergence of Sustainable Horticulture (as sustainable *production* horticulture) at the International Society of Horticultural Science's First International Symposium on Sustainability in Horticulture held at the International Horticultural Congress in Toronto in 2002. This symposium produced "conclusions ... on Sustainability in Horticulture and a Declaration for the 21st Century". The principles and objectives outlined at this conference were discussed in more practical terms at the following conference at Seoul in 2006.

Many of the eco-friendly principles and ideas espoused by sustainable gardens, landscapes and sites perpetuate sustainable practices established as a reaction to resource-intensive industrial agriculture. These practices were established as movements for self-sufficiency and small-scale farming based on a holistic systems approach and ecological principles. Included here would be: biodynamic agriculture, no-till farming, agroecology, Fukuoka farming, forest gardening, organic gardening and others. On a larger scale there is the more recent "whole farm planning" which was established in 1995, and ecoagriculture established in 2000, and other variants of sustainable agricultural systems. Perhaps the most influential of these approaches is permaculture, established by Australians Bill Mollison and David Holmgren as both a design system and a loosely defined philosophy or lifestyle ethic. Permaculture shares many principles and practices of the above but not the broad philosophical base as indicated by the title of the 2002 publication *Permaculture, principles and pathways beyond sustainability*. The application of sustainability principles to the horticultural sphere has now becoming broadly accepted in commerce and academia.

Definition

The American Sustainable Sites Initiative is an interdisciplinary approach used by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center and the United States Botanic Garden to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices: it was founded in 2005. Using the United Nations Brundtland Report's definition of sustainable development as a model, it defines sustainability within its own sphere of reference as:

… *design, construction, operations and maintenance practices that meet the needs of the present without compromising the ability of future generations to meet their own needs*

by attempting to:

...protect, restore and enhance the ability of landscapes to provide ecosystem services that benefit humans and other organisms.

Principles & concepts

Managing global biophysical cycles and ecosystem services for the benefit of humans, other organisms and future generations has now become a global human responsibility. The method of applying sustainability to gardens, landscapes and sites is still under development and varies somewhat according to the context under consideration. However, there are a number of basic and common underlying biological and operational principles and practices in the sustainable sites literature.

Biological principles

Sustainable management of man-made landscapes emulates the natural processes that sustain the biosphere and its ecosystems. First and foremost is the harnessing the energy of the Sun and the cycling of materials thereby minimising waste and energy use.

Running within, and dependent on, the natural economy there is the production and consumption of goods and services in the "human economy" which has now significantly altered, in a detrimental way, natural biogeochemical cycles (notable here are the water cycle, carbon cycle and nitrogen cycle so sustainable practices maximise support for ecosystem services.

Native plants

The use of native plants in a garden or landscape can both preserve and protect natural ecosystems, and reduce the amount of care and energy required to maintain a healthy garden or landscape. Native plants are adapted to the local climate and geology, and often require less maintenance than exotic species. Native plants also support populations of native birds, insects, and other animals that they coevolved with, thus promoting a healthy community of organisms.

Plants in a garden or maintained landscape often form a source population from which plants can colonize new areas. Avoiding the use of invasive species helps to prevent such plants from establishing new populations. Similarly, the use of native species can provide a valuable source to help these plants colonise new areas.

Some non-native species can form an ecological trap in which native species are lured into an environment that appears attractive but is poorly suited to them.

Operational principles

Enhancement of ecosystem services is encouraged throughout the lifecycle of any site by providing clear design, construction, (operations), and management criteria. To be sustainable over the long term requires environmental, social and economic demands are integrated to provide intergenerational equity by providing regenerative sustainable systems. Operational guidelines will link to and supplement existing guidelines for the built environment (supplementing existing green building and landscape guidelines), the wider environment, and they will include metrics (benchmarks, audits, criteria, indexes etc.) that give some measure of sustainability (a rating system) by clarifying what is sustainable or not sustainable or, more likely, what is more or less sustainable.

Scale

Impacts of a site can be assessed and measured over any spatio-temporal scale or context.

Direct and indirect environmental impact

Impacts of a site may be *direct* by having direct measurable impacts on biodiversity and ecology at the site itself or *indirect* when impacts occur away from the site.

Site principles

- Do no harm
- Use the Precautionary principle

- Design with nature and culture
- Use a decision-making hierarchy of preservation, conservation, and regeneration
- Provide regenerative systems as intergenerational equity
- Support a living process
- Use a system thinking approach
- Use a collaborative and ethical approach
- Maintain integrity in leadership and research
- Foster environmental stewardship

Measuring site sustainability

One major feature distinguishing the approach of sustainable gardens, landscapes and sites from other similar enterprises is the quantification of site sustainability by establishing performance benchmarks. Because sustainability is such a broad and inclusive concept the environmental impacts of sites can be categorised in numerous ways depending on the purpose for which the figures are required. The process can include minimising negative environmental impacts and maximising positive impacts. As currently applied the environment is usually given priority over social and economic factors which may be added in or regarderd as an inevitable and integral part part of the management process. A home gardener is likely to use simpler metrics than a professional landscaper or ecologist. Factors that are considered include:

1. Sustainable Sites Initiative is producing recommendations for the American Landscape Industry. The standards and guidelines finally adopted will lead to a uniform national standard, which does not currently exist; Sustainable Sites will produce a rating system by 2011. The U.S. Green Building Council supports the project and plans to adopt the Sustainable Sites metrics into future versions of its Leadership in Energy and Environmental Design Green Building Rating System. Sites are rated according to their impact on ecosystem services: The following ecosystem services have been identified by the study group:

- Local climate regulation
- Air and water cleansing
- Water supply and regulation
- Erosion and sediment control
- Hazard mitigation
- Pollination
- Habitat functions
- Waste decomposition and treatment
- Global climate regulation
- Human health and well-being benefits
- Food and renewable non-food products
- Cultural benefits

INPUTS	OUTPUTS	PROCESSES

- Fossil fuels
- Embodied energy and water
- Compost
- Mulch
- Ecology & biodiversity
- Fertilizer
- Hard landscape materials
- Equipment
- Products

- Energy & water
- Food
- Green waste
- Ecology & biodiversity
- Chemicals
- Old hard landscape materials
- Old equipment
- Old products

Constraints

Any kind of auditing or benchmarking will depend on the selection and weighting of the metrics chosen; the depth and detail of analysis required; the purpose for which the figures are required; and the environmental circumstances of the particular site.

Sustainable graphic design

Sustainable graphic design is the application of sustainability principles to graphic design. It considers the environmental impacts of graphic design products (such as packaging, printed materials, publications, etc.) throughout a life cycle that includes: raw material; transformation; manufacturing; transportation; use; and disposal.

Graphic designers engaged in sustainable practice use techniques, processes, and materials that will help reduce the detrimental environmental, social, and economic impact of their designs, also known as the Triple Bottom Line.

When subjecting a design to a sustainability audit, a designer might consider:

- reducing the amount of materials required for production
- using paper and materials made with recycled, post-consumer waste
- printing with low-VOC inks
- what production methods require the least amount of transport
- which vendors use renewable energy
- if the product can fulfill more than one purpose
- if the end-product is biodegradable or recyclable

- if the end-product can be replaced by a digital, rather than printed, format
- just-in-time production to reduce number of units produced and warehoused
- which vendors sell products certified by third party NGOs

Chapter- 2

Sustainable Agriculture

Sustainable agriculture is the practice of farming using principles of ecology, the study of relationships between organisms and their environment. It has been defined as "an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- Satisfy human food and fiber needs
- Make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls
- Sustain the economic viability of farm operations
- Enhance the quality of life for farmers and society as a whole."

Sustainable Agriculture in the United States was addressed by the 1990 farm bill. More recently, as consumer and retail demand for sustainable products has risen, organizations such as Food Alliance and Protected Harvest have started to provide measurement standards and certification programs for what constitutes a sustainably grown crop.

Farming and Natural Resources

The physical aspects of sustainability are partly understood. Practices that can cause long-term damage to soil include excessive tillage (leading to erosion) and irrigation without adequate drainage (leading to salinization). Long-term experiments have provided some of the best data on how various practices affect soil properties essential to sustainability.

The most important factors for an individual site are sun, air, soil and water. Of the four, water and soil quality and quantity are most amenable to human intervention through time and labour.

Although air and sunlight are available everywhere on Earth, crops also depend on soil nutrients and the availability of water. When farmers grow and harvest crops, they remove some of these nutrients from the soil. Without replenishment, land suffers from nutrient depletion and becomes either unusable or suffers from reduced yields. Sustainable agriculture depends on replenishing the soil while minimizing the use of non-renewable resources, such as natural gas (used in converting atmospheric nitrogen into synthetic fertilizer), or mineral ores (e.g., phosphate). Possible sources of nitrogen that would, in principle, be available indefinitely, include:

1. recycling crop waste and livestock or treated human manure
2. growing legume crops and forages such as peanuts or alfalfa that form symbioses with nitrogen-fixing bacteria called rhizobia
3. industrial production of nitrogen by the Haber Process uses hydrogen, which is currently derived from natural gas, (but this hydrogen could instead be made by electrolysis of water using electricity (perhaps from solar cells or windmills)) or
4. genetically engineering (non-legume) crops to form nitrogen-fixing symbioses or fix nitrogen without microbial symbionts.

The last option was proposed in the 1970s, but is only recently becoming feasible. Sustainable options for replacing other nutrient inputs (phosphorus, potassium, etc.) are more limited.

More realistic, and often overlooked, options include long-term crop rotations, returning to natural cycles that annually flood cultivated lands (returning lost nutrients indefinitely) such as the Flooding of the Nile, the long-term use of biochar, and use of crop and livestock landraces that are adapted to less than ideal conditions such as pests, drought, or lack of nutrients.

Water

In some areas, sufficient rainfall is available for crop growth, but many other areas require irrigation. For irrigation systems to be sustainable they require proper management (to avoid salinization) and must not use more water from their source than is naturally replenished, otherwise the water source becomes, in effect, a non-renewable resource. Improvements in water well drilling technology and submersible pumps combined with the development of drip irrigation and low pressure pivots have made it possible to regularly achieve high crop yields where reliance on rainfall alone previously made this level of success unpredictable. However, this progress has come at a price, in that in many areas where this has occurred, such as the Ogallala Aquifer, the water is being used at a greater rate than its rate of recharge.

Several steps should be taken to develop drought-resistant farming systems even in "normal" years, including both policy and management actions: 1) improving water conservation and storage measures, 2) providing incentives for selection of drought-tolerant crop species, 3) using reduced-volume irrigation systems, 4) managing crops to reduce water loss, or 5) not planting at all.

Soil

Soil erosion is fast becoming the one of the worlds greatest problems. It is estimated that "more than a thousand million tonnes of southern Africa's soil are eroded every year. Experts predict that crop yields will be halved within thirty to fifty years if erosion continues at present rates." Soil erosion is not unique to Africa but is occurring worldwide. The phenomenon is being called *Peak Soil* as present large scale factory farming techniques are jeopardizing humanities ability to grow food in the present and in the future. Without efforts to improve soil management practices, the availability of arable soil will become increasingly problematic.

Some Soil Management techniques

1. Growing wind breaks to hold the soil
2. Incorporating organic matter back into fields
3. Stop using chemical fertilizers (which contain salt)

Economics

Socioeconomic aspects of sustainability are also partly understood. Regarding less concentrated farming, the best known analysis is Netting's study on smallholder systems through history. The Oxford Sustainable Group defines sustainability in this context in a much broader form, considering effect on all stakeholders in a 360 degree approach

Given the finite supply of natural resources at any specific cost and location, agriculture that is inefficient or damaging to needed resources may eventually exhaust the available resources or the ability to afford and acquire them. It may also generate negative externality, such as pollution as well as financial and production costs.

The way that crops are sold must be accounted for in the sustainability equation. Food sold locally does not require additional energy for transportation (including consumers). Food sold at a remote location, whether at a farmers' market or the supermarket, incurs a different set of energy cost for materials, labour, and transport.

Methods

What grows where and how it is grown are a matter of choice. Two of the many possible practices of sustainable agriculture are crop rotation and soil amendment, both designed to ensure that crops being cultivated can obtain the necessary nutrients for healthy growth. Soil amendments would include using localy available compost from community recycling centers. These community recyclying centers help produce the compost needed by the local organic farms.

Many scientists, farmers, and businesses have debated how to make agriculture sustainable. Using community recycling from yard and kitchen waste utilizes a local area's commonly available resources. These resources in past were thrown away into large waste desposal sites, are now used to produce low cost organic compost for organic farming. Other practices includes growing a diverse number of perennial crops in a single field, each of which would grow in separate season so as not to compete with each other for natural resources. This system would result in increased resistance to diseases and decreased effects of erosion and loss of nutrients in soil. Nitrogen fixation from legumes, for example, used in conjunction with plants that rely on nitrate from soil for growth, helps to allow the land to be reused annually. Legumes will grow for a season and replenish the soil with ammonium and nitrate, and the next season other plants can be seeded and grown in the field in preparation for harvest.

Monoculture, a method of growing only one crop at a time in a given field, is a very widespread practice, but there are questions about its sustainability, especially if the same crop is grown every year. Today it is realized to get around this problem local cities and farms can work together to produce the needed compost for the farmers around them. This combined with growing a mixture of crops (polyculture) sometimes reduces disease or pest problems but polyculture has rarely, if ever, been compared to the more widespread practice of growing different crops in successive years (crop rotation) with the same overall crop diversity. Cropping systems that include a variety of crops (polyculture and/or rotation) may also replenish nitrogen (if legumes are included) and may also use resources such as sunlight, water, or nutrients more efficiently (Field Crops Res. 34:239).

Replacing a natural ecosystem with a few specifically chosen plant varieties reduces the genetic diversity found in wildlife and makes the organisms susceptible to widespread disease. The Great Irish Famine (1845-1849) is a well-known example of the dangers of monoculture. In practice, there is no single approach to sustainable agriculture, as the precise goals and methods must be adapted to each individual case. There may be some techniques of farming that are inherently in conflict with the concept of sustainability, but there is widespread misunderstanding on impacts of some practices. Today the growth of local farmers markets offer small farms the ability to sell the products that they have grown back to the cities that they got the recycled compost from. By using local recycling this will help move us away from, the slash-and-burn techniques that are the characteristic feature of shifting cultivators are often cited as inherently destructive, yet slash-and-burn cultivation has been practiced in the Amazon for at least 6000 years; serious deforestation did not begin until the 1970s, largely as the result of Brazilian government programs and policies. To note that it may not have been slash-and-burn so much as slash-and-char, which with the addition of organic matter produces terra preta, one of the richest soils on Earth and the only one that regenerates itself.

There are also many ways to practice sustainable animal husbandry. Some of the key tools to grazing management include fencing off the grazing area into smaller areas called paddocks, lowering stock density, and moving the stock between paddocks frequently.

Several attempts have been made to produce an artificial meat, using isolated tissues to produce it in vitro; Jason Matheny's work on this topic, whichin the New Harvest project, is one of the most commented.

Soil treatment

Soil steaming can be used as an ecological alternative to chemicals for soil sterilization. Different methods are available to induce steam into the soil in order to kill pests and increase soil health. Community and farm composting of kitchen, yard, and farm organic waste can provide most if not all the required needs of local farms.

Off-farm impacts

A farm that is able to "produce perpetually", yet has negative effects on environmental quality elsewhere is not sustainable agriculture. An example of a case in which a global view may be warranted is over-application of synthetic fertilizer or animal manures, which can improve productivity of a farm but can pollute nearby rivers and coastal waters (eutrophication). The other extreme can also be undesirable, as the problem of low crop yields due to exhaustion of nutrients in the soil has been related to rainforest destruction, as in the case of slash and burn farming for livestock feed.

Sustainability affects overall production, which must increase to meet the increasing food and fiber requirements as the world's human population expands to a projected 9.3 billion people by 2050. Increased production may come from creating new farmland, which may ameliorate carbon dioxide emissions if done through reclamation of desert as in Palestine, or may worsen emissions if done through slash and burn farming, as in Brazil. Additionally, Genetically modified organism crops show promise for radically increasing crop yields, although many people and governments are apprehensive of this new farming method.

Some advocates of sustainable agriculture favour as the only system which can be sustained over the long-term. However, organic production methods, especially in transition, yield less than their conventional counterparts and raise the same problems of sustaining populations globally While evidence suggests that organic farms handle periods of drought better

Urban planning

There has been considerable debate about which form of human residential habitat may be a better social form for sustainable agriculture.

Many environmentalists advocate urban developments with high population density as a way of preserving agricultural land and maximizing energy efficiency. However, others have theorized that sustainable ecocities, or ecovillages which combine habitation and farming with close proximity between producers and consumers, may provide greater sustainability.

The use of available city space (e.g., rooftop gardens, community gardens, garden sharing, and other forms of urban agriculture) for cooperative food production is another way to achieve greater sustainability.

One of the latest ideas in achieving sustainable agricultural involves shifting the production of food plants from major factory farming operations to large, urban, technical facilities called vertical farms. The advantages of vertical farming include year-round production, isolation from pests and diseases, controllable resource recycling, and on-site production that reduces transportation costs. While a vertical farm has yet to become a reality, the idea is gaining momentum among those who believe that current sustainable farming methods will be insufficient to provide for a growing global population. For vertical farming to become a reality, billions of dollars in tax credits and subsidies will need to be made available to the operation.

Chapter- 3

Sustainability in Energy Sector

Solar energy

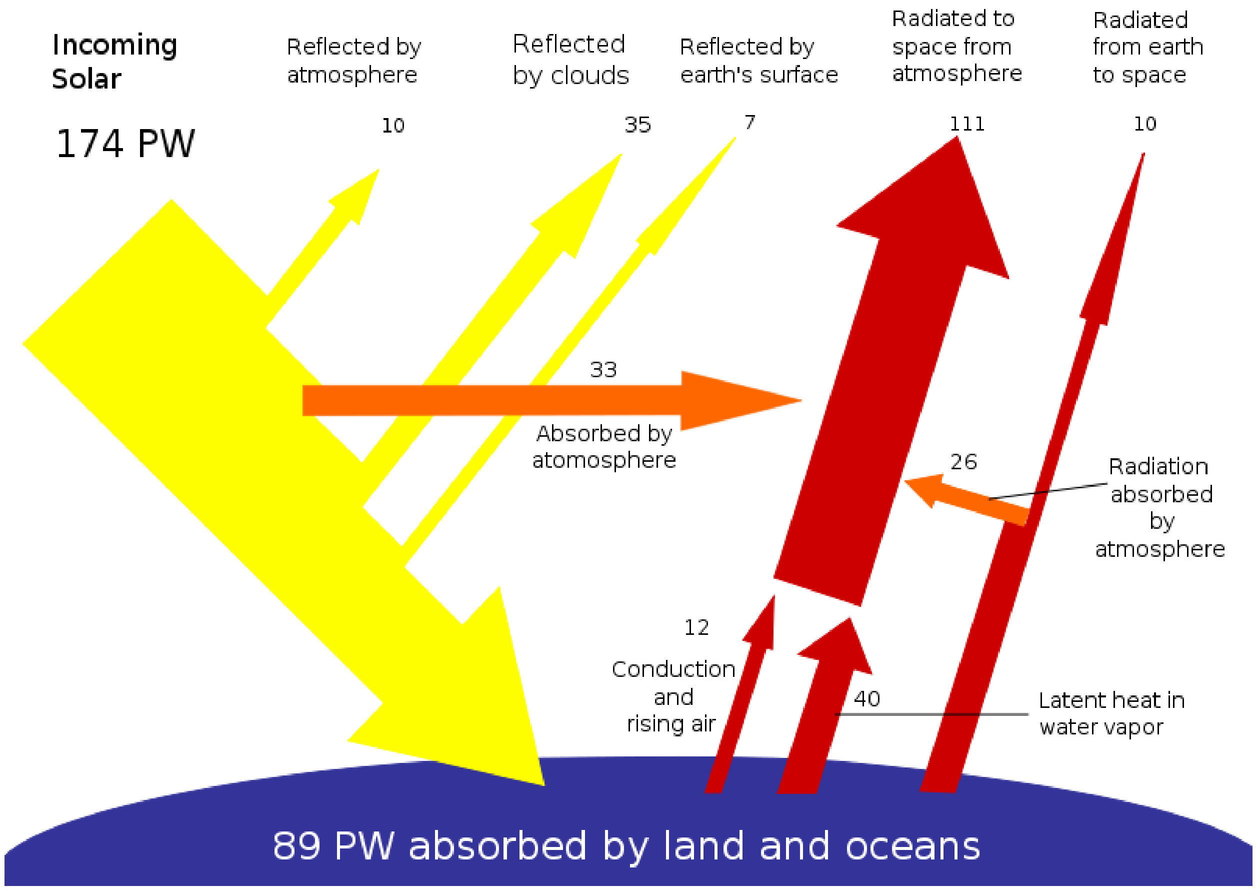
A parabolic dish and stirling engine system, which concentrates sunlight to produce useful solar power.

Solar energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, account for most of the available renewable energy on earth. Only a minuscule fraction of the available solar energy is used.

Solar powered electrical generation relies on heat engines and photovoltaics. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, daylighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes.To harvest the solar energy, the most common way is to use solar panels.

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Energy from the Sun



About half the incoming solar energy reaches the Earth's surface

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.

Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.

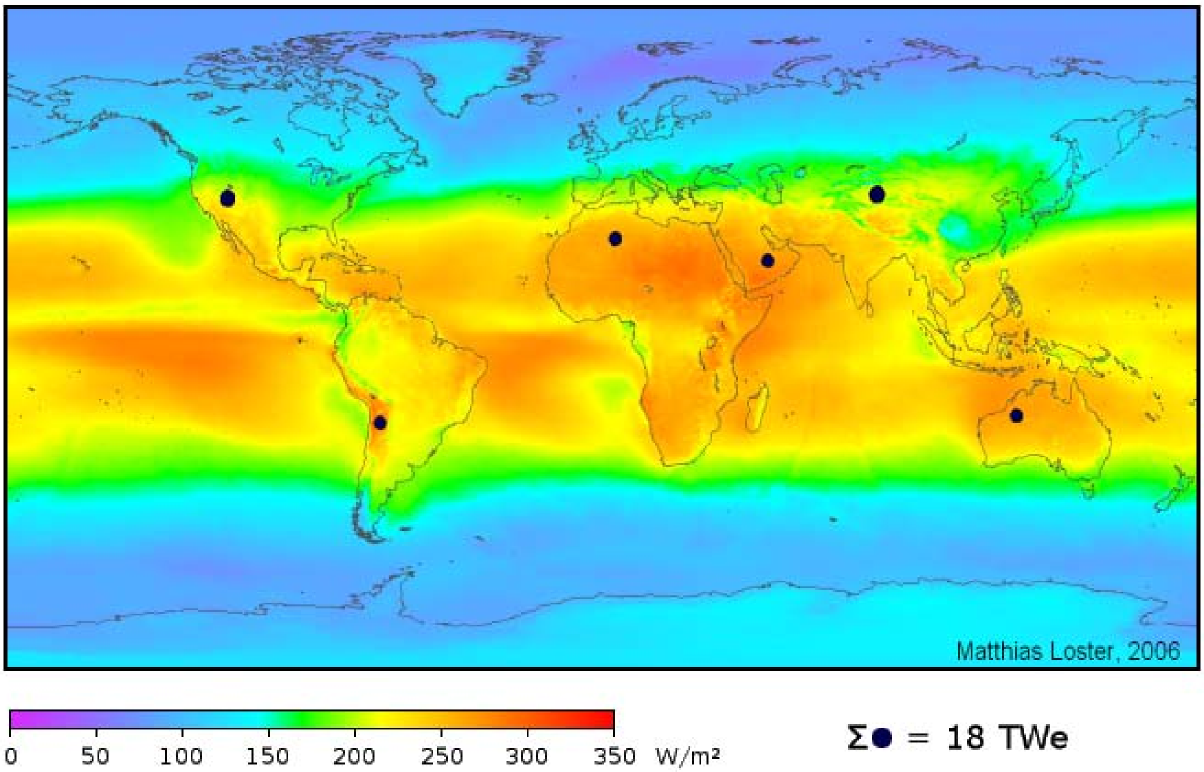
Yearly Solar fluxes & Human Energy Consumption	
Solar	3,850,000 EJ
Wind	2,250 EJ
Biomass	3,000 EJ
Primary energy use (2005)	487 EJ
Electricity (2005)	56.7 EJ

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined.

From the table of resources it would appear that solar, wind or biomass would be sufficient to supply all of our energy needs, however, the increased use of biomass has had a negative effect on global warming and dramatically increased food prices by diverting forests and crops into biofuel production. As intermittent resources, solar and wind raise other issues.

Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available.

Applications of solar technology



Average insolation showing land area (small black dots) required to replace the world primary energy supply with solar electricity. 18 TW is 568 Exajoule (EJ) per year. Insolation for most people is from 150 to 300 W/m² or 3.5 to 7.0 kWh/m²/day.

Solar energy refers primarily to the use of solar radiation for practical ends. However, all renewable energies, other than geothermal and tidal, derive their energy from the sun.

Solar technologies are broadly characterized as either passive or active depending on the way they capture, convert and distribute sunlight. Active solar techniques use photovoltaic panels, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

Architecture and urban planning

Darmstadt University of Technology in Germany won the 2007 Solar Decathlon in Washington, D.C. with this passive house designed specifically for the humid and hot subtropical climate.

Sunlight has influenced building design since the beginning of architectural history. Advanced solar architecture and urban planning methods were first employed by the Greeks and Chinese, who oriented their buildings toward the south to provide light and warmth.

The common features of passive solar architecture are orientation relative to the Sun, compact proportion (a low surface area to volume ratio), selective shading (overhangs) and thermal mass. When these features are tailored to the local climate and environment they can produce well-lit spaces that stay in a comfortable temperature range. Socrates' Megaron House is a classic example of passive solar design. The most recent approaches to solar design use computer modeling tying together solar lighting, heating and ventilation systems in an integrated solar design package. Active solar equipment such as pumps, fans and switchable windows can complement passive design and improve system performance.

Urban heat islands (UHI) are metropolitan areas with higher temperatures than that of the surrounding environment. The higher temperatures are a result of increased absorption of the Solar light by urban materials such as asphalt and concrete, which have lower albedos and higher heat capacities than those in the natural environment. A straightforward method of counteracting the UHI effect is to paint buildings and roads white and plant trees. Using these methods, a hypothetical "cool communities" program in Los Angeles has projected that urban temperatures could be reduced by approximately 3 °C at an estimated cost of US$1 billion, giving estimated total annual benefits of US$530 million from reduced air-conditioning costs and healthcare savings.

Agriculture and horticulture

Greenhouses like these in the Westland municipality of the Netherlands grow vegetables, fruits and flowers.

Agriculture and horticulture seek to optimize the capture of solar energy in order to optimize the productivity of plants. Techniques such as timed planting cycles, tailored row orientation, staggered heights between rows and the mixing of plant varieties can improve crop yields. While sunlight is generally considered a plentiful resource, the exceptions highlight the importance of solar energy to agriculture. During the short growing seasons of the Little Ice Age, French and English farmers employed fruit walls to maximize the collection of solar energy. These walls acted as thermal masses and accelerated ripening by keeping plants warm. Early fruit walls were built perpendicular to the ground and facing south, but over time, sloping walls were developed to make better use of sunlight. In 1699, Nicolas Fatio de Duillier even suggested using a tracking mechanism which could pivot to follow the Sun. Applications of solar energy in agriculture aside from growing crops include pumping water, drying crops, brooding chicks and drying chicken manure. More recently the technology has been embraced by vinters, who use the energy generated by solar panels to power grape presses.

Greenhouses convert solar light to heat, enabling year-round production and the growth (in enclosed environments) of specialty crops and other plants not naturally suited to the local climate. Primitive greenhouses were first used during Roman times to produce cucumbers year-round for the Roman emperor Tiberius. The first modern greenhouses were built in Europe in the 16th century to keep exotic plants brought back from explorations abroad. Greenhouses remain an important part of horticulture today, and plastic transparent materials have also been used to similar effect in polytunnels and row covers.

Solar lighting

Daylighting features such as this oculus at the top of the Pantheon, in Rome, Italy have been in use since antiquity.

The history of lighting is dominated by the use of natural light. The Romans recognized a right to light as early as the 6th century and English law echoed these judgments with the Prescription Act of 1832. In the 20th century artificial lighting became the main source of interior illumination but daylighting techniques and hybrid solar lighting solutions are ways to reduce energy consumption.

Daylighting systems collect and distribute sunlight to provide interior illumination. This passive technology directly offsets energy use by replacing artificial lighting, and indirectly offsets non-solar energy use by reducing the need for air-conditioning. Although difficult to quantify, the use of natural lighting also offers physiological and psychological benefits compared to artificial lighting. Daylighting design implies careful selection of window types, sizes and orientation; exterior shading devices may be considered as well. Individual features include sawtooth roofs, clerestory windows, light shelves, skylights and light tubes. They may be incorporated into existing structures, but are most effective when integrated into a solar design package that accounts for factors such as glare, heat flux and time-of-use. When daylighting features are properly implemented they can reduce lighting-related energy requirements by 25%.

Hybrid solar lighting is an active solar method of providing interior illumination. HSL systems collect sunlight using focusing mirrors that track the Sun and use optical fibers to transmit it inside the building to supplement conventional lighting. In single-story applications these systems are able to transmit 50% of the direct sunlight received.

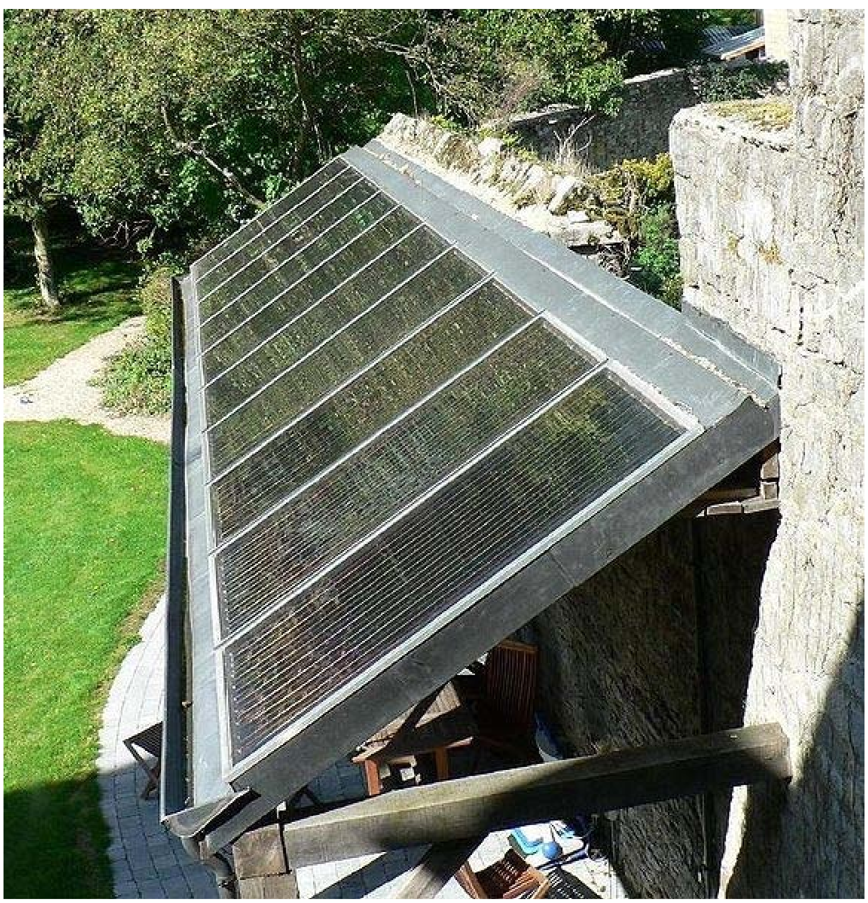
Solar lights that charge during the day and light up at dusk are a common sight along walkways.

Although daylight saving time is promoted as a way to use sunlight to save energy, recent research has been limited and reports contradictory results: several studies report savings, but just as many suggest no effect or even a net loss, particularly when gasoline consumption is taken into account. Electricity use is greatly affected by geography, climate and economics, making it hard to generalize from single studies.

Solar thermal

Solar thermal technologies can be used for water heating, space heating, space cooling and process heat generation.

Water heating



Solar water heaters facing the Sun to maximize gain

Solar hot water systems use sunlight to heat water. In low geographical latitudes (below 40 degrees) from 60 to 70% of the domestic hot water use with temperatures up to 60 °C can be provided by solar heating systems. The most common types of solar water heaters are evacuated tube collectors (44%) and glazed flat plate collectors (34%) generally used for domestic hot water; and unglazed plastic collectors (21%) used mainly to heat swimming pools.

As of 2007, the total installed capacity of solar hot water systems is approximately 154 GW. China is the world leader in their deployment with 70 GW installed as of 2006 and a long term goal of 210 GW by 2020. Israel and Cyprus are the per capita leaders in the use of solar hot water systems with over 90% of homes using them. In the United States, Canada and Australia heating swimming pools is the dominant application of solar hot water with an installed capacity of 18 GW as of 2005.

Heating, cooling and ventilation

Solar House #1 of Massachusetts Institute of Technology in the United States, built in 1939, used seasonal thermal storage for year-round heating.

In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ) of the energy used in commercial buildings and nearly 50% (10.1 EJ) of the energy used in residential buildings. Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

Thermal mass is any material that can be used to store heat—heat from the Sun in the case of solar energy. Common thermal mass materials include stone, cement and water. Historically they have been used in arid climates or warm temperate regions to keep buildings cool by absorbing solar energy during the day and radiating stored heat to the cooler atmosphere at night. However they can be used in cold temperate areas to maintain warmth as well. The size and placement of thermal mass depend on several factors such as climate, daylighting and shading conditions. When properly incorporated, thermal mass maintains space temperatures in a comfortable range and reduces the need for auxiliary heating and cooling equipment.

A solar chimney (or thermal chimney, in this context) is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. Performance can be improved by using glazing and thermal mass materials in a way that mimics greenhouses.

Deciduous trees and plants have been promoted as a means of controlling solar heating and cooling. When planted on the southern side of a building, their leaves provide shade during the summer, while the bare limbs allow light to pass during the winter. Since bare, leafless trees shade 1/3 to 1/2 of incident solar radiation, there is a balance between the benefits of summer shading and the corresponding loss of winter heating. In climates with significant heating loads, deciduous trees should not be planted on the southern side of a building because they will interfere with winter solar availability. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain.

Water treatment

Solar water disinfection in Indonesia

Small scale solar powered sewerage treatment plant

Solar distillation can be used to make saline or brackish water potable. The first recorded instance of this was by 16th century Arab alchemists. A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas. The plant, which had solar collection area of 4,700 m², could produce up to 22,700 L per day and operated for 40 years. Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect. These stills can operate in passive, active, or hybrid modes. Double-slope stills are the most economical for decentralized domestic purposes, while active multiple effect units are more suitable for large-scale applications.

Solar water disinfection (SODIS) involves exposing water-filled plastic polyethylene terephthalate (PET) bottles to sunlight for several hours. Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions. It is recommended by the World Health Organization as a viable method for household water treatment and safe storage. Over two million people in developing countries use this method for their daily drinking water.

Solar energy may be used in a water stabilisation pond to treat waste water without chemicals or electricity. A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable.

Cooking

The Solar Bowl in Auroville, India, concentrates sunlight on a movable receiver to produce steam for cooking

Solar cookers use sunlight for cooking, drying and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers. The simplest solar cooker is the box cooker first built by Horace de Saussure in 1767. A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90–150 °C. Panel cookers use a reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers. Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container. These cookers reach temperatures of 315 °C and above but require direct light to function properly and must be repositioned to track the Sun.

The solar bowl is a concentrating technology employed by the Solar Kitchen in Auroville, Pondicherry, India, where a stationary spherical reflector focuses light along a line perpendicular to the sphere's interior surface, and a computer control system moves the receiver to intersect this line. Steam is produced in the receiver at temperatures reaching 150 °C and then used for process heat in the kitchen.

A reflector developed by Wolfgang Scheffler in 1986 is used in many solar kitchens. Scheffler reflectors are flexible parabolic dishes that combine aspects of trough and power tower concentrators. Polar tracking is used to follow the Sun's daily course and the curvature of the reflector is adjusted for seasonal variations in the incident angle of sunlight. These reflectors can reach temperatures of 450–650 °C and have a fixed focal point, which simplifies cooking. The world's largest Scheffler reflector system in Abu Road, Rajasthan, India is capable of cooking up to 35,000 meals a day. As of 2008, over 2,000 large Scheffler cookers had been built worldwide.

Process heat

STEP parabolic dishes used for steam production and electrical generation

Solar concentrating technologies such as parabolic dish, trough and Scheffler reflectors can provide process heat for commercial and industrial applications. The first commercial system was the Solar Total Energy Project (STEP) in Shenandoah, Georgia, USA where a field of 114 parabolic dishes provided 50% of the process heating, air conditioning and electrical requirements for a clothing factory. This grid-connected cogeneration system provided 400 kW of electricity plus thermal energy in the form of 401 kW steam and 468 kW chilled water, and had a one hour peak load thermal storage.

Evaporation ponds are shallow pools that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from sea water is one of the oldest applications of solar energy. Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams.

Clothes lines, clotheshorses, and clothes racks dry clothes through evaporation by wind and sunlight without consuming electricity or gas. In some states of the United States legislation protects the "right to dry" clothes.

Unglazed transpired collectors (UTC) are perforated sun-facing walls used for preheating ventilation air. UTCs can raise the incoming air temperature up to 22 °C and deliver outlet temperatures of 45–60 °C. The short payback period of transpired collectors (3 to 12 years) makes them a more cost-effective alternative than glazed collection systems. As of 2003, over 80 systems with a combined collector area of 35,000 m² had been installed worldwide, including an 860 m² collector in Costa Rica used for drying coffee beans and a 1,300 m² collector in Coimbatore, India used for drying marigolds.

Electrical generation

Sunlight can be converted into electricity using photovoltaics (PV), concentrating solar power (CSP), and various experimental technologies.

PV has mainly been used to power small and medium-sized applications, from the calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array.

For large-scale generation, CSP plants (also called solar thermoelectric plants) like SEGS, have been the norm but recently multi-megawatt PV plants are becoming common. Completed in 2007, the 14 MW power station in Clark County, Nevada, United States and the 20 MW site in Beneixama, Spain are characteristic of the trend toward larger photovoltaic power stations in the United States and Europe.

As sometime an intermittent power source, solar power can require a backup supply, which can partially be complemented with wind power. Local backup usually is done with batteries, while utilities normally use pumped-hydro storage. The Institute for Solar Energy Supply Technology of the University of Kassel in Germany pilot-tested a combined power plant linking solar, wind, biogas and hydrostorage to provide load-following power around the clock, entirely from renewable sources. CSP plants can also store energy in salt tanks.

Experimental solar power

Solar Evaporation Ponds in the Atacama Desert, South America

A solar pond is a pool of salt water (usually 1–2 m deep) that collects and stores solar energy. Solar ponds were first proposed by Dr. Rudolph Bloch in 1948 after he came across reports of a lake in Hungary in which the temperature increased with depth. This effect was due to salts in the lake's water, which created a "density gradient" that prevented convection currents. A prototype was constructed in 1958 on the shores of the Dead Sea near Jerusalem. The pond consisted of layers of water that successively increased from a weak salt solution at the top to a high salt solution at the bottom. This solar pond was capable of producing temperatures of 90 °C in its bottom layer and had an estimated solar-to-electric efficiency of two percent.

Thermoelectric, or "thermovoltaic" devices convert a temperature difference between dissimilar materials into an electric current. First proposed as a method to store solar energy by solar pioneer Mouchout in the 1800s, thermoelectrics reemerged in the Soviet Union during the 1930s. Under the direction of Soviet scientist Abram Ioffe a concentrating system was used to thermoelectrically generate power for a 1 hp engine. Thermogenerators were later used in the US space program as an energy conversion technology for powering deep space missions such as Cassini, Galileo and Viking. Research in this area is focused on raising the efficiency of these devices from 7–8% to 15–20%.

Solar chemical

Solar chemical processes use solar energy to drive chemical reactions. These processes offset energy that would otherwise come from an alternate source and can convert solar energy into storable and transportable fuels. Solar induced chemical reactions can be divided into thermochemical or photochemical.

Hydrogen production technologies been a significant area of solar chemical research since the 1970s. Aside from electrolysis driven by photovoltaic or photochemical cells, several thermochemical processes have also been explored. One such route uses concentrators to split water into oxygen and hydrogen at high temperatures (2300-2600 °C). Another approach uses the heat from solar concentrators to drive the steam reformation of natural gas thereby increasing the overall hydrogen yield compared to conventional reforming methods. Thermochemical cycles characterized by the decomposition and regeneration of reactants present another avenue for hydrogen production. The Solzinc process under development at the Weizmann Institute uses a 1 MW solar furnace to decompose zinc oxide (ZnO) at temperatures above 1200 °C. This initial reaction produces pure zinc, which can subsequently be reacted with water to produce hydrogen.

Sandia's Sunshine to Petrol (S2P) technology uses the high temperatures generated by concentrating sunlight along with a zirconia/ferrite catalyst to break down atmospheric carbon dioxide into oxygen and carbon monoxide (CO). The carbon monoxide can then be used to synthesize conventional fuels such as methanol, gasoline and jet fuel.

A photogalvanic device is a type of battery in which the cell solution (or equivalent) forms energy-rich chemical intermediates when illuminated. These energy-rich intermediates can potentially be stored and subsequently reacted at the electrodes to produce an electric potential. The ferric-thionine chemical cell is an example of this technology.

Photoelectrochemical cells or PECs consist of a semiconductor, typically titanium dioxide or related titanates, immersed in an electrolyte. When the semiconductor is illuminated an electrical potential develops. There are two types of photoelectrochemical cells: photoelectric cells that convert light into electricity and photochemical cells that use light to drive chemical reactions such as electrolysis.

A combination thermal/photochemical cell has also been proposed. The Stanford PETE process uses solar thermal energy to raise the temperature of a thermionic metal to about 800C to increase the rate of production of electricity to electrolyse atmospheric CO2 down to carbon or carbon monoxide which can then be used for fuel production, and the waste heat can be used as well.

Solar vehicles

Australia hosts the World Solar Challenge where solar cars like the Nuna3 race through a 3,021 km (1,877 mi) course from Darwin to Adelaide.

Development of a solar powered car has been an engineering goal since the 1980s. The World Solar Challenge is a biannual solar-powered car race, where teams from universities and enterprises compete over 3,021 kilometres (1,877 mi) across central Australia from Darwin to Adelaide. In 1987, when it was founded, the winner's average speed was 67 kilometres per hour (42 mph) and by 2007 the winner's average speed had improved to 90.87 kilometres per hour (56.46 mph). The North American Solar Challenge and the planned South African Solar Challenge are comparable competitions that reflect an international interest in the engineering and development of solar powered vehicles.

Some vehicles use solar panels for auxiliary power, such as for air conditioning, to keep the interior cool, thus reducing fuel consumption.

In 1975, the first practical solar boat was constructed in England. By 1995, passenger boats incorporating PV panels began appearing and are now used extensively. In 1996, Kenichi Horie made the first solar powered crossing of the Pacific Ocean, and the *sun21* catamaran made the first solar powered crossing of the Atlantic Ocean in the winter of 2006–2007. There are plans to circumnavigate the globe in 2010.

Helios UAV in solar powered flight

In 1974, the unmanned AstroFlight Sunrise plane made the first solar flight. On 29 April 1979, the *Solar Riser* made the first flight in a solar powered, fully controlled, man carrying flying machine, reaching an altitude of 40 feet (12 m). In 1980, the *Gossamer Penguin* made the first piloted flights powered solely by photovoltaics. This was quickly followed by the *Solar Challenger* which crossed the English Channel in July 1981. In 1990 Eric Raymond in 21 hops flew from California to North Carolina using solar power. Developments then turned back to unmanned aerial vehicles (UAV) with the *Pathfinder* (1997) and subsequent designs, culminating in the *Helios* which set the altitude record for a non-rocket-propelled aircraft at 29,524 metres (96,864 ft) in 2001. The *Zephyr*, developed by BAE Systems, is the latest in a line of record-breaking solar aircraft, making a 54-hour flight in 2007, and month-long flights are envisioned by 2010.

A solar balloon is a black balloon that is filled with ordinary air. As sunlight shines on the balloon, the air inside is heated and expands causing an upward buoyancy force, much like an artificially heated hot air balloon. Some solar balloons are large enough for human flight, but usage is generally limited to the toy market as the surface-area to payload-weight ratio is relatively high.

Solar sails are a proposed form of spacecraft propulsion using large membrane mirrors to exploit radiation pressure from the Sun. Unlike rockets, solar sails require no fuel. Although the thrust is small compared to rockets, it continues as long as the Sun shines onto the deployed sail and in the vacuum of space significant speeds can eventually be achieved.

The High-altitude airship (HAA) is an unmanned, long-duration, lighter-than-air vehicle using helium gas for lift, and thin-film solar cells for power. The United States Department of Defense Missile Defense Agency has contracted Lockheed Martin to construct it to enhance the Ballistic Missile Defense System (BMDS). Airships have some advantages for solar-powered flight: they do not require power to remain aloft, and an airship's envelope presents a large area to the Sun.

Energy storage methods

Solar Two's thermal storage system generated electricity during cloudy weather and at night

Solar energy is not available at night, and energy storage is an important issue because modern energy systems usually assume continuous availability of energy.

Thermal mass systems can store solar energy in the form of heat at domestically useful temperatures for daily or seasonal durations. Thermal storage systems generally use readily available materials with high specific heat capacities such as water, earth and stone. Well-designed systems can lower peak demand, shift time-of-use to off-peak hours and reduce overall heating and cooling requirements.

Phase change materials such as paraffin wax and Glauber's salt are another thermal storage media. These materials are inexpensive, readily available, and can deliver domestically useful temperatures (approximately 64 °C). The "Dover House" (in Dover, Massachusetts) was the first to use a Glauber's salt heating system, in 1948.

Solar energy can be stored at high temperatures using molten salts. Salts are an effective storage medium because they are low-cost, have a high specific heat capacity and can deliver heat at temperatures compatible with conventional power systems. The Solar Two used this method of energy storage, allowing it to store 1.44 TJ in its 68 m^3 storage tank with an annual storage efficiency of about 99%.

Off-grid PV systems have traditionally used rechargeable batteries to store excess electricity. With grid-tied systems, excess electricity can be sent to the transmission grid. Net metering programs give these systems a credit for the electricity they deliver to the grid. This credit offsets electricity provided from the grid when the system cannot meet demand, effectively using the grid as a storage mechanism.

Pumped-storage hydroelectricity stores energy in the form of water pumped when energy is available from a lower elevation reservoir to a higher elevation one. The energy is recovered when demand is high by releasing the water to run through a hydroelectric power generator.

Development, deployment and economics

Nellis Solar Power Plant in the United States, the largest photovoltaic power plant in North America.

Beginning with the surge in coal use which accompanied the Industrial Revolution, energy consumption has steadily transitioned from wood and biomass to fossil fuels. The early development of solar technologies starting in the 1860s was driven by an expectation that coal would soon become scarce. However development of solar technologies stagnated in the early 20th century in the face of the increasing availability, economy, and utility of coal and petroleum.

The 1973 oil embargo and 1979 energy crisis caused a reorganization of energy policies around the world and brought renewed attention to developing solar technologies. Deployment strategies focused on incentive programs such as the Federal Photovoltaic Utilization Program in the US and the Sunshine Program in Japan. Other efforts included the formation of research facilities in the US (SERI, now NREL), Japan (NEDO), and Germany (Fraunhofer Institute for Solar Energy Systems ISE).

Commercial solar water heaters began appearing in the United States in the 1890s. These systems saw increasing use until the 1920s but were gradually replaced by cheaper and more reliable heating fuels. As with photovoltaics, solar water heating attracted renewed attention as a result of the oil crises in the 1970s but interest subsided in the 1980s due to falling petroleum prices. Development in the solar water heating sector progressed steadily throughout the 1990s and growth rates have averaged 20% per year since 1999. Although generally underestimated, solar water heating and cooling is by far the most widely deployed solar technology with an estimated capacity of 154 GW as of 2007.

Solar thermoelectric plants orientatively uses an space of 110 Has (for plants without storage) and of 200 Has (with storage in salt tanks) to generate 50 MW. The inversion for this model 50 MW plant is 300 M euros. Companies with these plants are, between others, Acciona, ACS-Cobra, Abengoa, Elecnor, Iberdrola Renovables, Ibereolica and Renovables SAMCA.

ISO Standards

The International Organization for Standardization has established a number of standards relating to solar energy equipment. For example, ISO 9050 relates to glass in building while ISO 10217 relates to the materials used in solar water heaters.

Alternative energy

Offshore wind turbines near Copenhagen

Alternative energy is an umbrella term that refers to any source of usable energy intended to replace fuel sources without the undesired consequences of the replaced fuels.

The term "alternative" presupposes a set of undesirable energy technologies against which "alternative energies" are contrasted. As such, the list of energy technologies excluded is an indicator of what problems that the alternative technologies are intended to address. Controversies regarding dominant sources of energy and their alternatives have a long history. The nature of what was regarded alternative energy sources has changed considerably over time, and today, because of the variety of energy choices and differing goals of their advocates, defining some energy types as "alternative" is highly controversial.

In a general sense in contemporary society, alternative energy is that which is produced without the undesirable consequences of the burning of fossil fuels, such as high carbon dioxide emissions, which is considered to be the major contributing factor of global warming according to the Intergovernmental Panel on Climate Change. Sometimes, this less comprehensive meaning of "alternative energy" excludes nuclear energy (e.g. as defined in the Michigan Next Energy Authority Act of 2002).

Definitions

Source	Definition
Oxford Dictionary	energy fuelled in ways that do not use up natural resources or harm the environment.
Princeton WordNet	energy derived from sources that do not use up natural resources or harm the environment.
Responding to Climate Change 2007	energy derived from nontraditional sources (e.g., compressed natural gas, solar, hydroelectric, wind).

Natural Resources Defense Council	energy that is not popularly used and is usually environmentally sound, such as solar or wind energy (as opposed to fossil fuels).
Materials Management Services	Fuel sources that are other than those derived from fossil fuels. Typically used interchangeably for renewable energy. Examples A** include: wind, solar, biomass, wave and tidal energy.
Torridge District Council	Energy generated from alternatives to fossil fuel. Need not be renewable.

History

Historians of economies have studied the key transitions to alternative energies and regard the transitions as pivotal in bringing about significant economic change. Prior to shift to an alternative energy, supplies of the dominant energy type became erratic, accompanied by rapid increases in energy prices.

Coal as an alternative to wood

Historian Norman F. Cantor describes how in the late medieval period, coal was the new alternative fuel to save the society from overuse of the dominant fuel, wood:

"Europeans had lived in the midst of vast forests throughout the earlier medieval centuries. After 1250 they became so skilled at deforestation that by 1500 AD they were running short of wood for heating and cooking... By 1500 Europe was on the edge of a fuel and nutritional disaster, [from] which it was saved in the sixteenth century only by the burning of soft coal and the cultivation of potatoes and maize."

Petroleum as an alternative to whale oil

Whale oil was the dominant form of lubrication and fuel for lamps in the early 19th century, but the depletion of the whale stocks by mid century caused whale oil prices to skyrocket setting the stage for the adoption of petroleum which was first commercialized in Pennsylvania in 1859.

Alcohol as an alternative to fossil fuels

In 1917, Alexander Graham Bell advocated ethanol from corn and other foodstuffs as an alternative to coal and oil, stating that the world was in measurable distance of depleting these fuels. For Bell, the problem requiring an alternative was lack of renewability of orthodox energy sources. Since the 1970s, Brazil has had an ethanol fuel program which has allowed the country to become the world's second largest producer of ethanol (after the United States) and the world's largest exporter. Brazil’s ethanol fuel program uses modern equipment and cheap sugar cane as feedstock, and the residual cane-waste (bagasse) is used to process heat and power. There are no longer light vehicles in Brazil running on pure gasoline. By the end of 2008 there were 35,000 filling stations throughout Brazil with at least one ethanol pump.

Cellulosic ethanol can be produced from a diverse array of feedstocks, and involves the use of the whole crop. This new approach should increase yields and reduce the carbon footprint because the amount of energy-intensive fertilizers and fungicides will remain the same, for a higher output of usable material. As of 2008, there are nine commercial cellulosic ethanol plants which are either operating, or under construction, in the United States.

Coal gasification as an alternative to petroleum

In the 1970s, President Jimmy Carter's administration advocated coal gasification as an alternative to expensive imported oil. The program, including the Synthetic Fuels Corporation was scrapped when petroleum prices plummeted in the 1980s.

Renewable energy vs non-renewable energy

Renewable energy is generated from natural resources—such as sunlight, wind, rain, tides and geothermal heat—which are renewable (naturally replenished). When comparing the processes for producing energy, there remain several fundamental differences between renewable energy and fossil fuels. The process of producing oil, coal, or natural gas fuel is a difficult and demanding process that requires a great deal of complex equipment, physical and chemical processes. On the other hand, alternative energy can be widely produced with basic equipment and naturally basic processes. Wood, the most renewable and available alternative energy, burns the same amount of carbon it would emit if it degraded naturally.

Ecologically friendly alternatives

Renewable energy sources such as biomass are sometimes regarded as an alternative to ecologically harmful fossil fuels. Renewables are not inherently alternative energies for this purpose. For example, the Netherlands, once leader in use of palm oil as a biofuel, has suspended all subsidies for palm oil due to the scientific evidence that their use "may sometimes create more environmental harm than fossil fuels". The Netherlands government and environmental groups are trying to trace the origins of imported palm oil, to certify which operations produce the oil in a responsible manner. Regarding biofuels from foodstuffs, the realization that converting the entire grain harvest of the US would only produce 16% of its auto fuel needs, and the decimation of Brazil's CO_2 absorbing tropical rain forests to make way for biofuel production has made it clear that placing energy markets in competition with food markets results in higher food prices and insignificant or negative impact on energy issues such as global warming or dependence on foreign energy. Recently, alternatives to such undesirable sustainable fuels are being sought, such as commercially viable sources of cellulosic ethanol.

Relatively new concepts for alternative energy

Algae fuel

Algae fuel is a biofuel which is derived from algae. During photosynthesis, algae and other photosynthetic organisms capture carbon dioxide and sunlight and convert it into oxygen and biomass. The benefits of algal biofuel are that it can be produced industrially, thereby obviating the use of arable land and food crops (such as soy, palm, and canola), and that it has a very high oil yield as compared to all other sources of biofuel.

Biomass briquettes

Biomass briquettes are being developed in the developing world as an alternative to charcoal. The technique involves the conversion of almost any plant matter into compressed briquettes that typically have about 70% the calorific value of charcoal. There are relatively few examples of large scale briquette production. One exception is in North Kivu, in eastern Democratic Republic of Congo, where forest clearance for charcoal production is considered to be the biggest threat to Mountain Gorilla habitat. The staff of Virunga National Park have successfully trained and equipped over 3500 people to produce biomass briquettes, thereby replacing charcoal produced illegally inside the national park, and creating significant employment for people living in extreme poverty in conflict affected areas.

Biogas digestion

Biogas digestion deals with harnessing the methane gas that is released when waste breaks down. This gas can be retrieved from garbage or sewage systems. Biogas digesters are used to process methane gas by having bacteria break down biomass in an anaerobic environment. The methane gas that is collected and refined can be used as an energy source for various products.

Biological Hydrogen Production

Hydrogen gas is a completely clean burning fuel; its only by-product is water. It also contains relatively high amount of energy compared with other fuels due to its chemical structure.

$2H_2 + O_2 \longrightarrow 2H_2O + \text{High Energy}$

$\text{High Energy} + 2H_2O \longrightarrow 2H_2 + O_2$

This requires a high-energy input, making commercial hydrogen very inefficient. Use of a biological vector as a means to split water, and therefore produce hydrogen gas, would allow for the only energy input to be solar radiation. Biological vectors can include bacteria or more commonly algae. This process is known as biological hydrogen production. It requires the use of single celled organisms to create hydrogen gas through fermentation. Without the presence of oxygen, also known as an anaerobic environment, regular cellular respiration cannot take place and a process known as fermentation takes over. A major by-product of this process is hydrogen gas. If we could implement this on a large scale, then we could take sunlight, nutrients and water and create hydrogen gas to be used as a dense source of energy. Large-scale production has proven difficult. It was not until 1999 that we were able to even induce these anaerobic conditions by sulfur deprivation. Since the fermentation process is an evolutionary back up, turned on during stress, the cells would die after a few days. In 2000, a two-stage process was developed to take the cells in and out of anaerobic conditions and therefore keep them alive. For the last ten years, finding a way to do this on a large-scale has been the main goal of research. Careful work is being done to ensure an efficient process before large-scale production, however once a mechanism is developed, this type of production could solve our energy needs.

Floating wind farms

Floating wind farms are similar to a regular wind farm, but the difference is that they float in the middle of the ocean. Offshore wind farms can be placed in water up to 40 metres (130 ft) deep, whereas floating wind turbines can float in water up to 700 metres (2,300 ft) deep. The advantage of having a floating wind farm is to be able to harness the winds from the open ocean. Without any obstructions such as hills, trees and buildings, winds from the open ocean can reach up to speeds twice as fast as coastal areas. A Norwegian energy company, StatoilHydro, will launch the first test period for the floating wind farms in autumn 2009.

Investing in alternative energy

Over the last three years publicly traded alternative energy have been very volatile, with some 2007 returns in excess of 100%, some 2008 returns down 90% or more, and peak-to-trough returns in 2009 again over 100%. In general there are three subsegments of "alternative" energy investment: solar energy, wind energy and hybrid electric vehicles. Alternative energy sources which are renewable, free and have lower carbon emissions than what we have now are wind energy, solar energy, geothermal energy, and bio fuels. Each of these four segments involve very different technologies and investment concerns.

For example, photovoltaic solar energy is based on semiconductor processing and accordingly, benefits from steep cost reductions similar to those realized in the microprocessor industry (i.e., driven by larger scale, higher module efficiency, and improving processing technologies). PV solar energy is perhaps the only energy technology whose electricity generation cost could be reduced by half or more over the next 5 years. Better and more efficient manufacturing process and new technology such as advanced thin film solar cell is a good example of that helps to reduce industry cost.

The economics of solar PV electricity are highly dependent on silicon pricing and even companies whose technologies are based on other materials (e.g., First Solar) are impacted by the balance of supply and demand in the silicon market. In addition, because some companies sell completed solar cells on the open market (e.g., Q-Cells), this creates a low barrier to entry for companies that want to manufacture solar modules, which in turn can create an irrational pricing environment.

In contrast, because wind power has been harnessed for over 100 years, its underlying technology is relatively stable. Its economics are largely determined by siting (e.g., how hard the wind blows and the grid investment requirements) and the prices of steel (the largest component of a wind turbine) and select composites (used for the blades). Because current wind turbines are often in excess of 100 meters high, logistics and a global manufacturing platform are major sources of competitive advantage. These issues and others were explored in a research report by Sanford Bernstein. Some of its key conclusions are shown here.

Alternative energy in transportation

Due to steadily rising gas prices in 2008 with the US national average price per gallon of regular unleaded gas rising above $4.00 at one point, there has been a steady movement towards developing higher fuel efficiency and more alternative fuel vehicles for consumers. In response, many smaller companies have rapidly increased research and development into radically different ways of powering consumer vehicles. Hybrid and battery electric vehicles are commercially available and are gaining wider industry and consumer acceptance worldwide.

For example, Nissan USA introduced the world's first mass-production Electric Vehicle "Nissan Leaf".

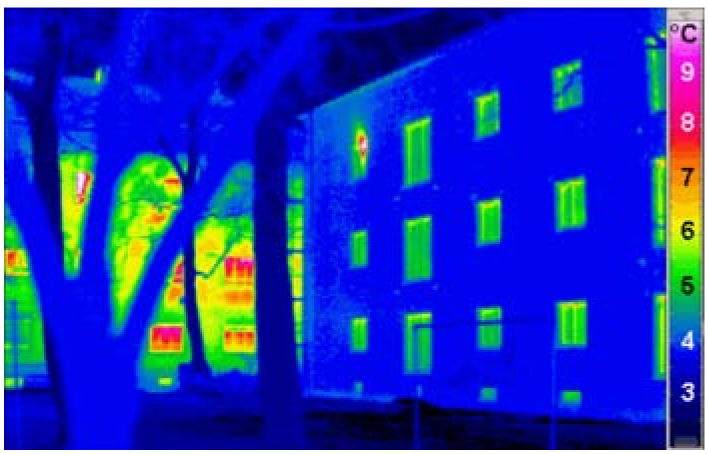
Making Alternative Energy Mainstream

Before alternative energy becomes main-stream there are a few crucial obstacles that it must overcome: First there must be increased understanding of how alternative energies work and why they are beneficial; secondly the availability components for these systems must increase and lastly the pay-off time must be decreased.

For example, electric vehicles (EV) and Plug-in Hybrid Electric Vehicles (PHEV) are on the raise. These vehicles depend heavily on an effective charging infrastructure such as a smart grid infrastructure to be able to implement electricity as mainstream alternative energy for future transportations.

Chapter- 4

Low-energy House



A thermogram compares the "heat radiation" of the windows and walls of two buildings: sustainable low-energy passive house (right) and conventional leaking house (left)

A **low-energy house** is any type of house that from design, technologies and building products uses less energy, from any source, than a traditional or average contemporary house. In the practice of sustainable design, sustainable architecture, low-energy building, energy-efficient landscaping low-energy houses often use active solar and passive solar building design techniques and components to reduce their energy expenditure.

General usage

The meaning of the term 'low-energy house' has changed over time, but in Europe it generally refers to a house that uses around half of the German or Swiss low-energy standards referred to below for space heating, typically in the range from 30 kWh/m²a to 20 kWh/m²a (9,500 Btu/ft²/yr to 6,300 Btu/ft²/yr). Below this the term 'Ultra-low-energy building' is often used.

The term can also refer to any dwelling whose energy use is below the standards demanded by current building codes. Because national standards vary considerably around the world, 'low-energy' developments in one country may not meet 'normal practice' in another.

National standards

In some countries the term relates to a specific building standard. In particular these seek to limit the energy used for space heating, since in many climate zones it represents the largest energy use. Other energy use may also be regulated. The history of passive solar building design gives an international look at one form of low-energy building development and standards.

Europe

In Germany a low-energy house *(Niedrigenergiehaus)* has a limit equivalent to 7 litres of heating oil for each square metre of room *for space heating* annually (50 kWh/m^2a or 15,850 $Btu/ft^2/yr$). In Switzerland the term is used in connection with the *MINERGIE* standard (42 kWh/m^2a or 13,300 $Btu/ft^2/yr$).

In comparison, the German *Passivhaus* ultra-low-energy standard, currently undergoing adoption in some other European countries, has a maximum space heating requirement of 15 kWh/m^2a or 4,755 $Btu/ft^2/yr$.

A "sub-10 passive house" is under construction in Ireland that has an independently evaluated PHPP (Passive House) rating of 9.5 $KW/m^2/yr$. It's form of construction also tackles the issue of embodied energy, which can significantly distort the lifecycle CO_2 emissions associated with even low energy use houses.

North America

In the United States, the ENERGY STAR program is the largest program defining low-energy homes, and consumer products. Homes earning ENERGY STAR certification use at least 15% less energy than standard new homes built to the International Residential Code, although homes typically achieve 20%-30% savings.

In addition, the US Department of Energy launched a program in 2008 with the goal of spreading zero-energy housing over the US. Currently, participating builders commit to constructing new homes that achieve 30% savings on a home energy rating scale.

Zero-energy and energy-plus buildings

Beyond ultra-low-energy buildings are those that use, on average over the course of a year, no imported energy - zero-energy buildings – or even those that generate a surplus - energy-plus houses – both of which have been and are being successfully built.

This can be achieved by a mixture of energy conservation technologies and the use of renewable energy sources. However, in the absence of recognized standards, the mix between these – and consequently the energy-use profile and environmental impact of the building – can vary significantly.

At one end of the spectrum are buildings with an ultra-low space heating requirement that therefore require low levels of imported energy, even in winter, approaching the concept of an autonomous building.

At the opposite end of the spectrum are buildings where few attempts are made to reduce the space heating requirement and which therefore use high levels of imported energy in winter. While this can be balanced by high levels of renewable energy generation throughout the year, it imposes greater demands on the traditional national energy infrastructure during the peak winter season.

- Superinsulation
- PlusEnergy

Low-energy technology

Introduction

Low-energy buildings typically use high levels of insulation, energy efficient windows, low levels of air infiltration and heat recovery ventilation to lower heating and cooling energy. They may also use passive solar building design techniques or active solar technologies. These homes may use hot water heat recycling technologies to recover heat from showers and dishwashers. Lighting and miscellaneous energy use is allieviated with fluorescent lighting and efficient appliances. Weatherization provides more information on increasing building energy efficiency.

Passive Houses are required to achieve a whole building air change rate of no more than 0.6 ac/hr under forced pressurisation and depressurisation testing at 50Pa minimum. On site blower door testing by certified testers is used to prove compliance.

A significant feature of ultra-low-energy buildings is the increasing importance of heat loss through linear thermal bridging within the construction. Failure to eliminate thermal pathways from warm to cold surfaces ("bridges") creates the conditions for interstitial condensation forming deep within the construction and lead to potentially serious issues of mould growth and rot. With near zero filtration losses through the fabric of the dwelling, air movement cannot be relied upon to dry out the construction and a comprehensive condensation risk analysis of every abutment detail is recommended.

Improvements to heating, cooling, ventilation and water heating

- Absorption refrigerator
- Annualized geothermal solar
- Earth cooling tubes
- Passive cooling
- Renewable heat
- Seasonal thermal storage

- Geothermal heat pump
- Heat recovery ventilation
- Hot water heat recycling
- Solar air conditioning
- Solar hot water
- Solar devices

Passive solar design and landscape

Passive solar building design and energy-efficient landscaping support the low-energy house in conservation and can integrate them into a neighborhood and environment. Following passive solar building techniques, where possible buildings are compact in shape to reduce their surface area, with principle windows oriented towards the equator - south in the northern hemisphere and north in the southern hemisphere - to maximize passive solar gain. However, the use of solar gain, especially in temperate climate regions, is secondary to minimizing the overall house energy requirements. In climates and regions needing to reduce excessive summer passive solar heat gain, whether from the direct or reflected sources, can be done with a Brise soleil, trees, attached pergolas with vines, vertical gardens, green roofs, and other techniques.

Low-energy houses can be constructed from dense or lightweight materials, but some internal thermal mass is normally incorporated to reduce summer peak temperatures, maintain stable winter temperatures, and prevent possible over-heating in spring or autumn before the higher sun angle "shades" mid-day wall exposure and window penetration. Exterior wall color, when the surface allows choice, for reflection or absorption insolation qualities depends on the predominant year-round ambient outdoor temperature. The use of deciduous trees and wall trellised or self attaching vines can assist in climates not at the temperature extremes.

- Sustainable landscaping
- Sustainable landscape architecture
- Sustainable gardening
- Rainwater harvesting
- Water conservation

Lighting and electrical appliances

To minimize the total primary energy consumption, the many passive and active daylighting techniques are the first daytime solution to employ. For low light level days, non-daylighted spaces, and nighttime; the use of creative-sustainable lighting design using low-energy sources such as 'standard voltage' compact fluorescent lamps and solid-state lighting with Light-emitting diode-LED lamps, organic light-emitting diodes, and PLED - polymer light-emitting diodes; and 'low voltage' electrical filament-Incandescent light bulbs, and compact Metal halide, Xenon and Halogen lamps, can be used.

Solar powered exterior circulation, security, and landscape lighting - with photovoltaic cells on each fixture or connecting to a central Solar panel system, are available for gardens and outdoor needs. Low voltage systems can be used for more controlled or independent illumination, while still using less electricity than conventional fixtures and lamps. Timers, motion detection and natural light operation sensors reduce energy consumption, and light pollution even further for a Low-energy house setting.

Appliance consumer products meeting independent energy efficiency testing and receiving Ecolabel certification marks for reduced electrical-'natural-gas' consumption and product manufacturing carbon emission labels are preferred for use in Low-energy houses. The ecolabel certification marks of Energy Star and EKOenergy are examples.

- Energy-saving lighting
- Lighting
- Windows
- Energy conservation
- Alternative energy

Chapter- 5

Improvements to Heating, Cooling, Ventilation and Water Heating

Renewable heat

Renewable heat is an application of renewable energy and it refers to the renewable generation of heat, rather than electrical power (e.g. replacing a fossil fuel boiler using concentrating solar thermal to feed radiators).

Many colder countries consume more energy for heating than electrical power. For example, in 2005 the United Kingdom consumed 354 TWh of electric power, but had a heat requirement of 907 TWh, the majority of which (81%) was met using gas. The residential sector alone consumed a massive 550 TWh of energy for heating, mainly in the form of gas. Almost half of the final energy consumed in the UK (49%) was in the form of heat, of which 70% was used by households and in commercial and public buildings. Households used heat for mainly for space heating (69%) and heating water.

Renewable electric power is becoming cheap and convenient enough to place it, in many cases, within reach of the average consumer. By contrast, the market for renewable heat is mostly inaccessible to domestic consumers due to inconvenience of supply, and high capital costs. Heating accounts for a large proportion of energy consumption, however a universally accessible market is still in its early stages.

Leading renewable heat technologies

Solar heating

Solar heating is a style of building construction which uses the energy of summer or winter sunshine to provide an economic supply of primary or supplementary heat to a structure. The heat can be used for both space heating and water heating. Solar heating design is divided into two groups:

- Passive solar heating relies on the design and structure of the house to collect heat. Passive solar building design must also consider the storage and distribution of heat, which may be accomplished passively, or use air ducting to draw heat actively to the foundation of the building for storage. One such design was measured lifting the temperature of a house to 24 °C (74 °F) on a partially sunny winter day (-7 °C or 19 °F), and it is claimed that the system provides passively for the bulk of the building's heating. The 4,000-square-foot (370 m^2) home cost $125 per square foot (or 370 m^2 at $1,351/$m^2$), similar to the cost of a traditional new home.

- Active solar heating uses pumps to move air or a liquid from the solar collector into the building or storage area. Applications such as solar air heating and solar water heating typically capture solar heat in panels which can then be used for applications such as space heating and supplementation of residential water heaters. In contrast to photovoltaic panels, which are used to generate electricity, solar heating panels are less expensive and capture a much higher proportion of the sun's energy.

Solar heating systems usually require a small supplementary backup heating system, either conventional or renewable.

Geothermal heating

Hot Springs located in Nevada

Heat from the Earth, or geothermal - Geo (Earth) + thermal (heat) - energy can be and already is accessed by drilling water or steam wells in a process similar to drilling for oil. Geothermal energy is an enormous, underused heat and power resource that is clean (emits little or no greenhouse gases), reliable (average system availability of 95%), and homegrown (making populations less dependent on oil).

The earth absorbs the sun's energy and stores it as heat underground. The temperature remains constant at a point of 42 °F to 100 °F all year round depending on where you live on earth. A geothermal heating system takes advantage of the consistent temperature found below the Earth's surface and uses it to heat and cool buildings. The system is made up of a series of pipes installed underground, connected to pipes in a building. A pump circulates liquid through the circuit. In the winter the fluid in the pipe absorbs the heat of the earth and uses it to heat the building. In the summer the fluid absorbs heat from the building and disposes of it in the earth.

Heat Pump

Heat pumps use work to move heat from one place to another, and can be used for both heating and air conditioning. Though capital intensive, heat pumps are economical to run and can be powered by renewable electricity. Two common types of heat pump are air-source heat pumps (ASHP) and ground-source heat pumps (GSHP), depending on whether heat is transferred from the air or from the ground. Air source heat pumps are not effective when the outside air temperature is lower than about -15 °C, while ground-source heat pumps are not affected. The efficiency of a heat pump is measured by the coefficient of performance (CoP): For every unit of electricity used to pump the heat, an air source heat pump generates 2.5 to 3 units of heat (i.e. it has a CoP of 2.5 to 3), whereas a GSHP generates 3 to 4 units of heat. Based on current fuel prices for the United Kingdom, assuming a CoP of 3-4, a GSHP is a cheaper form of space heating than gas, electric, oil, and solid fuel heating. Heat pumps can be linked to interseasonal thermal stores, doubling the CoP from 4 to 8 by extracting heat from warmer ground.

Interseasonal heat transfer

Interseasonal Heat Transfer combines active solar collection to store surplus summer heat in thermal banks with GSHPs to extract it for space heating in winter. This reduces the "Lift" needed and doubles the CoP of the heat pump because the pump starts with warmth from the thermal bank in place of cold from the ground.

CoP and lift

The CoP increases as the temperature difference, or "Lift", decreases between heat source and destination. The CoP can be maximized at design time by choosing a heating system requiring only a low final water temperature (e.g., underfloor heating), and by choosing a heat source with a high average temperature (e.g., the ground). Domestic hot water (DHW) and conventional radiators require high water temperatures, affecting the choice of heat pump technology. Low temperature radiators provide an alternative to conventional radiators.

CoP variation with Output Temperature

Pump type and source	Typical use case	35 °C (e.g. heated screed floor)	45 °C (e.g. low temp. radiator or heated screed floor)	55 °C (e.g. low temp. radiator or heated timber floor)	65 °C (e.g. std. radiator or DHW)	75 °C (e.g. std. radiator & DHW)	85 °C (e.g. std. radiator & DHW)
High Efficiency ASHP air at -20 °C		2.2	2.0	-	-	-	-
Two Stage ASHP air at -20 °C	Low source temp.	2.4	2.2	1.9	-	-	-

High Efficiency ASHP air at 0 °C	Low output temp.	3.8	2.8	2.2	2.0	-	-
Prototype Transcritical CO_2 (R744) Heat Pump with Tripartite Gas Cooler, source at 0 °C	High output temp.	3.3	-	-	4.2	-	3.0
GSHP water at 0 °C		5.0	3.7	2.9	2.4	-	-
GSHP ground at 10 °C	Low output temp.	7.2	5.0	3.7	2.9	2.4	-
Theoretical Carnot cycle limit, source -20 °C		5.6	4.9	4.4	4.0	3.7	3.4
Theoretical Carnot cycle limit, source 0 °C		8.8	7.1	6.0	5.2	4.6	4.2
Theoretical Lorentz Cycle limit (CO_2 pump), return fluid 25 °C, source 0 °C		10.1	8.8	7.9	7.1	6.5	6.1
Theoretical Carnot cycle limit, source 10 °C		12.3	9.1	7.3	6.1	5.4	4.8

Wood-pellet heating

Wood Stove

Wood Pellets

Wood-pellet heating and other types of wood heating systems have achieved their greatest success in heating premises that are off the gas grid, typically being previously heated using heating oil or coal. Solid wood fuel requires a large amount of dedicated storage space, and the specialized heating systems can be expensive (though grant schemes are available in many European countries to offset this capital cost.) Low fuel costs mean that wood fuelled heating in Europe is frequently able to achieve a payback period of less than 3 to 5 years. Because of the large fuel storage requirement wood fuel can be less attractive in urban residential scenarios, or for premises connected to the gas grid (though rising gas prices and uncertainty of supply mean that wood fuel is becoming more competitive.)

Wood-stove heating

Burning wood fuel in an open fire is both extremely inefficient (0-20%) and polluting due to low temperature partial combustion. In the same way that a drafty building loses heat through loss of warm air through poor sealing, an open fire is responsible for large heat losses by drawing very large volumes of warm air out of the building.

However modern wood stove designs allow for extremely efficient combustion and then heat extraction. In the United States, all new wood stoves are certified by the U.S. Environmental Protection Agency (EPA) and burn cleaner and more efficiently (the overall efficiency is 60-80%) and draw only small volumes of warm air from the building. High efficiency stoves meet the following design criteria:

- Well sealed and precisely calibrated to draw a low yet sufficient volume of air. Air-flow restriction is critical; a lower inflow of cold air cools the furnace less (a higher temperature is thus achieved). It also allows greater time for extraction of heat from the exhaust gas, and draws less heat from the building.
- The furnace must be well insulated to increase combustion temperature, and thus completeness.
- A well insulated furnace radiates little heat. Thus heat must be extracted instead from the exhaust gas duct. Heat absorption efficiencies are higher when the heat-exchange duct is longer, and when the flow of exhaust gas is slower.
- In many designs, the heat-exchange duct is built of a very large mass of heat-absorbing brick or stone. This design causes the absorbed heat to be emitted over a longer period - typically a day.

Renewable natural gas

Renewable natural gas is defined as gas obtained from biomass which is upgraded to a quality similar to natural gas. By upgrading the quality to that of natural gas, it becomes possible to distribute the gas to customers via the existing gas grid. According to the Energy research Centre of the Netherlands, renewable natural gas is 'cheaper than alternatives where biomass is used in a combined heat and power plant or local combustion plant'. Energy unit costs are lowered through 'favourable scale and operating hours', and end-user capital costs eliminated through distribution via the existing gas grid.

Energy efficiency

Renewable heat goes hand in hand with energy efficiency. Indeed renewable heating projects depend heavily for their success on energy efficiency; in the case of solar heating to cut reliance on the requirement supplementary heating, in the case of wood fuel heating to cut the cost of wood purchased and volume stored, and in the case of heat pumps to reduce the size and investment in heat pump, heat sink and electricity costs.

Two main types of improvement can be made to a building's energy efficiency:

Insulation

Improvements to insulation can cut energy consumption greatly, making a space cheaper to heat and to cool. However existing housing can often be difficult or expensive to improve. Newer buildings can benefit from many of the techniques of superinsulation. Older buildings can benefit from several kinds of improvement:

- **Solid wall insulation**: A building with solid walls can benefit from internal or external insulation. External wall insulation involves adding decorative weather-proof insulating panels or other treatment to the outside of the wall. Alternatively, internal wall insulation can be applied using ready-made insulation/plaster board laminates, or other methods. Thicknesses of internal or external insulation typically range between 50 and 100 mm.
- **Cavity wall insulation**: A building with cavity walls can benefit from insulation pumped into the cavity. This form of insulation is very cost effective.
- **Programmable thermostats** allow heating and cooling of a room to be switched off depending the time, day of the week, and temperature. A bedroom, for example, does not need to be heated during the day, but a living room does not need to be heated during the night.
- **Roof insulation**
- **Insulated windows and doors**
- **Draught proofing**

Underfloor heating

Underfloor heating is substantially more energy efficient than traditional methods of heating:

- Water circulates within the system at low temperatures (35 °C - 50 °C) making gas boilers, wood fired boilers, and heat pumps significantly more efficient.
- Rooms with underfloor heating are cooler near the ceiling, where heat is not required, but warmer underfoot, where comfort is most required.
- Traditional radiators are frequently positioned underneath poorly insulated windows, heating them unnecessarily.

Waste-water heat recovery

Recycling heat

It is possible to recover significant amounts of heat from waste hot water via hot water heat recycling. On average 90% of a property's domestic hot water is used for showering. Incoming fresh water is typically of a far lower temperature than the waste water from a shower. An inexpensive heat exchanger recovers up on average 40% of the heat that would normally be wasted, by warming incoming cold fresh water with heat from outgoing waste water.

Passive cooling

Passive cooling refers to technologies or design features used to cool buildings without power consumption, such as those technologies discussed in the Passive house project.

Passive cooling

The term "passive" implies that energy-consuming mechanical components like pumps and fans are not used.

Passive cooling building design attempts to integrate principles of physics into the building exterior envelope to:

1. **Slow heat transfer into a building.** This involves an understanding of the mechanisms of heat transfer: heat conduction, convective heat transfer, and thermal radiation (primarily from the sun).
2. **Remove unwanted heat from a building.** In mild climates with cool dry nights this can be done with ventilating. In hot humid climates with uncomfortable warm / humid nights, ventilation is counterproductive, and some type of solar air conditioning may be cost effective.

Shading

Shading a building from solar radiation can be achieved in many ways.

Buildings can be orientated to take advantage of winter sun (longer in the East / West dimension), while shading walls and windows from direct hot summer sun. This can be achieved by designing location-specific wide eaves or overhangs above the Equator-side vertical windows (South side in the Northern hemisphere, North side in the Southern hemisphere).

Passive solar buildings should not allow direct sunlight through, use large glass areas directly into the living space in the summer. A greenhouse / solarium is usually integrated into the equator side of the building. It captures low winter sun, and blocks direct sunlight in the summer, when the sun's altitude is 47 degrees higher. The outer glass of the solarium, plus interior glass between the solarium and the interior living quarters acts like a Thermal Buffer Zone - Two smaller temperature differentials produce much lower heat transfer than one large temperature differential.

The quality of window-and-door fenestration can have a significant impact on heat transfer rate (and therefore on heating and cooling requirement). A solid wood door with no windows conducts heat about twelve times faster than a foam-filled Energy Star door. Older fenestration, and lower-quality doors and windows can leak a lot of outside air infiltration, conduct and radiate a lot of undesirable heat transfer through the exterior envelope of a building, which can account for a major portion of heating and cooling energy bills.

For many good thermal reasons, roof-angled glass is not a great option in any building in any climate. In the summer, it creates a solar furnace, with the sun nearly perpendicular to it. On cold winter days, the low angle of the sun mostly reflects off of roof-angled glass. Warm air rises by natural convection, touches the roof angled glass, and then conducts and radiates heat outside. Vertical equator-facing glass is far superior for solar gain, blocking summer heat, and daylighting throughout a well-designed passive solar building.

Awnings, shade screen, trellises or climbing plants can be fitted to existing buildings for a similar effect. West-facing rooms are especially prone to overheating because the low afternoon sun penetrates deeper into rooms during the hottest part of the day. Methods of shading against low East and West sun are deciduous planting and vertical shutters or blinds. West-facing windows should be minimized or eliminated in passive solar design.

Solar heat also enters a building through its walls and roof. In temperate climates, a poorly insulated building can overheat in summer and will require more heating in winter.

One sign of poor thermal design is an attic that gets hotter than the peak outside summer air temperature. This can be significantly reduced or eliminated with a cool roof or a green roof, which can reduce the roof surface temperature by 70 degrees F (21 degrees C) in the summer. Below the roof there should be a radiant barrier and an air gap, which blocks 97% of downward radiation from the sun.

Of the three mechanisms of heat transfer (conduction, convection and radiation), radiation is one of the most significant in most climates, and is the least easy to model. There is a linear relationship between temperature differential and conductive / convective heat transfer rate. But, radiation is an exponential relationship, which is much more significant when the temperature differential is large (summer or winter).

The rate of heat transfer (which is related to heating-and-cooling requirement) is determined in part by the surface area of the building. Decorative corners can double or triple the exterior envelope surface area, and also create more opportunities for air infiltration leaks.

In mild arid climates with comfortable cool dry nights, two types of natural ventilation can be achieved through careful design: cross ventilation and passive-stack ventilation.

Cross ventilation requires openings on two sides of a room.

Passive-stack ventilation uses a vertical space, like a tower, that creates a vacuum as air rises by natural convection. An inlet for cool air at the bottom of this space creates an upward-moving air current.

Allergens such as pollen can be an issue when windows are used for fresh air ventilation. Anything that creates an air pressure difference (like an externally vented clothes dryer, fireplace, kitchen and bathroom vents) will draw unfiltered outside air in through every small air leak in a building. As an alternative, air can be filtered through a Minimum Efficiency Reporting Value MERV 8+ air filter to remove allergens.

An energy audit uses a calibrated exhaust fan to measure and locate poor-weatherization air-infiltration leaks cause by careless conventional construction.

In hot humid climates with uncomfortable nights, fresh air ventilation can be controlled, filtered, dehumidified, and cooled (possibly using an air exchanger). A solar air conditioner can be used to cool and dehumidify hot humid air. ASHRAE, an international society of HVAC engineers, recommends a minimum 0.35 air changes / hour AND 15 CFM of fresh air for each person in a room (year round regardless of outside conditions). Carbon dioxide monitors can be used to increase fresh air intake in high-occupancy rooms when the air becomes unhealthy.

In a climate that is cool at night and too warm in the day, thermal mass can be strategically placed and insulated to slow the heating of the building when the sun is hot. Phase change materials can be designed to extract unwanted heat during the day, and release it at night.

Geothermal heat pump

Ground source heating and cooling

Ground source heating and cooling

A **geothermal heat pump**, **ground source heat pump** (GSHP), or **ground heat pump** is a central heating and/or cooling system that pumps heat to or from the ground. It uses the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems, and may be combined with solar heating to form a geosolar system with even greater efficiency. Geothermal heat pumps are also known by a variety of other names, including **geoexchange, earth-coupled, earth energy** or **water-source heat pumps**. The engineering and scientific communities prefer the terms "geoexchange" or "ground source heat pumps" to avoid confusion with traditional geothermal power, which uses a high temperature heat source to generate electricity. Ground source heat pumps harvest a combination of geothermal energy (from the Earth's core) and solar energy (heat absorbed at the Earth's surface) when heating, but work against these heat sources when used for air conditioning.

Depending on latitude, the upper 3 metres (9.8 ft) of Earth's surface maintains a nearly constant temperature between 10 and 16 °C (50 and 60 °F). Like a refrigerator or air conditioner, these systems use a heat pump to force the transfer of heat from there. Heat pumps can transfer heat from a cool space to a warm space, against the natural direction of flow, or they can enhance the natural flow of heat from a warm area to a cool one. The core of the heat pump is a loop of refrigerant pumped through a vapor-compression refrigeration cycle that moves heat. Heat pumps are always more efficient at heating than pure electric heaters, even when extracting heat from cold winter air. But unlike an air-source heat pump, which transfers heat to or from the outside air, a ground source heat pump exchanges heat with the ground. This is much more energy-efficient because underground temperatures are more stable than air temperatures through the year. Seasonal variations drop off with depth and disappear below seven meters due to thermal inertia. Like a cave, the shallow ground temperature is warmer than the air above during the winter and cooler than the air in the summer. A ground source heat pump extracts ground heat in the winter (for heating) and transfers heat back into the ground in the summer (for cooling). Some systems are designed to operate in one mode only, heating or cooling, depending on climate.

The geothermal pump systems reach fairly high Coefficient of performance (CoP), 3-6, on the coldest of winter nights, compared to 1.75-2.5 for air-source heat pumps on cool days. Ground source heat pumps (GSHPs) are among the most energy efficient technologies for providing HVAC and water heating. Actual CoP of a geothermal system which includes the power required to circulate the fluid through the underground tubes can be lower than 2.5. The setup costs are higher than for conventional systems, but the difference is usually returned in energy savings in 3 to 10 years. System life is estimated at 25 years for inside components and 50+ years for the ground loop. As of 2004, there are over a million units installed worldwide providing 12 GW of thermal capacity, with an annual growth rate of 10%.

Differing terms and definitions

There is a great deal of controversy and confusion with regard to exactly what geothermal heat pumps do. There are several concepts commonly attached to the idea of geothermal:

- Using geologically hot rocks, which have little relationship to the surface climate and derive their heat from deep in the earth, to run a heat engine which produces electricity. Such a system can be operated only until the rock around the bore cools, then it gradually loses its generating ability. All of these systems are in tectonically or volcanically active areas. Most people are pretty clear that this should be called "geothermal power".

- Using geologically hot rocks to heat some type of liquid or gas which is pumped up to be used to heat a building is often called "geothermal heating".

- Using a heat exchanger with a finite amount of external material to incorporate additional thermal mass to a building. This makes the building change temperature slowly, and allows the inhabitants to go through a time period with less overall temperature variation. This is the main focus of this article, and many terms have been applied. The most common ones appear to be "geothermal heat pump" by laymen and "ground-source heat pump" by experts, but even these are broad, barely understood terms about which there is no consensus.

Builders may try to smooth out the indoor climate over surface temperature variations resulting from the day-night cycle, variations due to short-term weather patterns, or variations due to entire seasons. The amount of thermal mass incorporated is on a spectrum, so one cannot say their system addresses any of these cycles specifically – a system sized for day-night cycling will still help somewhat in a week-long blizzard. Such a system requires power to pump the coolant, but can be operated indefinitely.

To further complicate things, even though most home-sized systems termed "geothermal" operate primarily on the former principle, the thermal mass in such systems is rarely perfectly finite and closed. Groundwater flows through the area, and heat leaks out and warms/cools the surrounding area. True geothermal heat may play a small or large role in such systems.

When trying to explain this subject, experts may go through a series of explanations and divisions.

First, people separate out terms for geothermal electricity generation:

- geothermal power

Then, they split out geothermal heating, which is commonly used in tectonically or volcanically active regions:

- geothermal heating

Then, they explain the traditional concept of a heat pump which uses only inside and outside air:

- heat pump

After that, they try to identify simple systems in which the coolant is air which is pumped directly out of and back into the building, going through a simple hole in the ground:

- earth tube or earth air heat exchanger
- ground-coupled heat exchanger

After that, they remove systems which depend on large quantities of water or wet ground, primarily for cooling:

- lake water cooling
- deep water source cooling

At this point they may explain the concept of a seasonal thermal store or a thermal mass climate control strategy:

- trombe wall
- seasonal thermal store
- thermal mass

Then, they may try to figure out the size of the system. Is it targeted at a home? A larger residential or commercial building? Is it a full-scale district heating system?

Then they go into the specifics of the system. First, is the coolant water, and if so is it "open loop" – exposed to groundwater – or "closed loop" – not exposed.

Are other energy sources helping? Is solar absorbed from the house or from a dedicated thermal collector?

- annualized geothermal solar or annualized geo solar
- geosolar or solar combisystem

After this they concentrate on the specific form factor of the system. Is it a grid of pipes buried 3 feet (0.91 m) underneath the owner's garden? Does it consist of a hundred-foot borehole? A thousand-foot borehole? Dozens of 8-foot (2.4 m) boreholes?

- downhole heat exchanger or borehole heat exchanger

Finally they may try to decide what the locals call the system, as identical systems are often called different things in different countries, and in some countries generic terms may be trademarked in others:

- Geoexchange is a trademarked product in the US, but is a standards coalition in Canada.
- Earth tubes, Air-earth heat exchangers and "heat exchanger" in general, appear to be primarily used in the UK.

History

The heat pump was described by Lord Kelvin in 1853 and developed by Peter Ritter von Rittinger in 1855. After experimenting with a freezer, Robert C. Webber built the first direct exchange ground-source heat pump in the late 1940s. The first successful commercial project was installed in the Commonwealth Building (Portland, Oregon) in 1946, and has been designated a National Historic Mechanical Engineering Landmark by ASME. The technology became popular in Sweden in the 1970s, and has been growing slowly in worldwide acceptance since then. Open loop systems dominated the market until the development of polybutylene pipe in 1979 made closed loop systems economically viable. As of 2004, there are over a million units installed worldwide providing 12 GW of thermal capacity. Each year, about 80,000 units are installed in the USA (geothermal energy is used in all 50 U.S. states today, with great potential for near-term market growth and savings) and 27,000 in Sweden.

Ground heat exchanger

Loop field for a 12-ton system (unusually large for most residential applications)

Heat pumps provide wintertime heating by extracting heat from a source and transferring it to the building. In theory, heat can be extracted from any source, no matter how cold, but a warmer source allows higher efficiency. A ground source heat pump uses the shallow ground as a source of heat, thus taking advantage of its seasonally moderate temperatures.

In the summer, the process can be reversed so the heat pump extracts heat from the building and transfers it to the ground. Transferring heat to a cooler space takes less energy, so the cooling efficiency of the heat pump gain benefits from the lower ground temperatures.

Shallow horizontal heat exchangers experience seasonal temperature cycles due to solar gains and transmission losses to ambient air at ground level. These temperature cycles lag behind the seasons because of thermal inertia, so the heat exchanger can harvest heat deposited by the sun several months earlier. Deep vertical systems rely heavily on migration of heat from surrounding geology, unless they are recharged annually by exhaust heat from air conditioning.

Ground source heat pumps must have a heat exchanger in contact with the ground or groundwater to extract or dissipate heat. This component accounts for a third to a half of the total system cost. Several major design options are available for these, which are classified by fluid and layout. Direct exchange systems circulate refrigerant underground, closed loop systems use a mixture of anti-freeze and water, and open loop systems use natural groundwater.

Direct exchange

The Direct exchange geothermal heat pump is the oldest type of geothermal heat pump technology. It is also the simplest and easiest to understand. The ground-coupling is achieved through a single loop circulating refrigerant in direct thermal contact with the ground (as opposed to a combination of a refrigerant loop and a water loop). The refrigerant leaves the heat pump appliance cabinet, circulates through a loop of copper tube buried underground, and exchanges heat with the ground before returning to the pump. The name "direct exchange" refers to heat transfer between the refrigerant and the ground without the use of an intermediate fluid. There is no direct interaction between the fluid and the earth; only heat transfer through the pipe wall. Direct exchange heat pumps are not to be confused with "water-source heat pumps" or "water loop heat pumps" since there is no water in the ground loop. ASHRAE defines the term *ground-coupled heat pump* to encompass closed loop and direct exchange systems, while excluding open loops.

Direct exchange systems are significantly more efficient and have potentially lower installation costs than closed loop water systems. Copper's high thermal conductivity contributes to the higher efficiency of the system, but heat flow is predominantly limited by the thermal conductivity of the ground, not the pipe. The main reasons for the higher efficiency are the elimination of the water pump (which uses electricity), the elimination of the water heat exchanger (which is a source of heat losses), and most importantly, the latent heat phase change of the refrigerant in the ground itself.

While they require much more refrigerant and their tubing is more expensive per foot, a direct exchange loop is shorter than a closed water loop for a given capacity. A direct exchange system requires only 15 to 30% of the length of tubing and half the diameter of drilled holes, and the drilling or excavation costs are therefore lower. Refrigerant loops are less tolerant of leaks than water loops because gas can leak out through smaller imperfections. This dictates the use of brazed copper tubing, even though the pressures are similar to water loops. The copper loop must be protected from corrosion in acidic soil through the use of a sacrificial anode or cathodic protection.

Closed loop

Most installed systems have two loops on the ground side: the primary refrigerant loop is contained in the appliance cabinet where it exchanges heat with a secondary water loop that is buried underground. The secondary loop is typically made of High-density polyethylene pipe and contains a mixture of water and anti-freeze (propylene glycol, denatured alcohol or methanol). After leaving the internal heat exchanger, the water flows through the secondary loop outside the building to exchange heat with the ground before returning. The secondary loop is placed below the frost line where the temperature is more stable, or preferably submerged in a body of water if available. Systems in wet ground or in water are generally more efficient than drier ground loops since it is less work to move heat in and out of water than solids in sand or soil. If the ground is naturally dry, soaker hoses may be buried with the ground loop to keep it wet.

An installed liquid pump pack

Closed loop systems need a heat exchanger between the refrigerant loop and the water loop, and pumps in both loops. Some manufacturers have a separate ground loop fluid pump pack, while some integrate the pumping and valving within the heat pump. Expansion tanks and pressure relief valves may be installed on the heated fluid side. Closed loop systems have lower efficiency than direct exchange systems, so they require longer and larger pipe to be placed in the ground, increasing excavation costs.

Closed loop tubing can be installed horizontally as a loop field in trenches or vertically as a series of long U-shapes in wells(see below). The size of the loop field depends on the soil type and moisture content, the average ground temperature and the heat loss and or gain characteristics of the building being conditioned. A rough approximation of the initial soil temperature is the average daily temperature for the region.

Vertical

A vertical closed loop field is composed of pipes that run vertically in the ground. A hole is bored in the ground, typically 75 to 500 feet (23–150 m) deep. Pipe pairs in the hole are joined with a U-shaped cross connector at the bottom of the hole. The borehole is commonly filled with a bentonite grout surrounding the pipe to provide a thermal connection to the surrounding soil or rock to improve the heat transfer. Thermally enhanced grouts are available to improve this heat transfer. Grout also protects the ground water from contamination, and prevents artesian wells from flooding the property. Vertical loop fields are typically used when there is a limited area of land available. Bore holes are spaced at least 5–6 m apart and the depth depends on ground and building characteristics. For illustration, a detached house needing 10 kW (3 ton) of heating capacity might need three boreholes 80 to 110 m (260 to 360 ft) deep. (A ton of heat is 12,000 British thermal units per hour (BTU/h) or 3.5 kilowatts.) During the cooling season, the local temperature rise in the bore field is influenced most by the moisture travel in the soil. Reliable heat transfer models have been developed through sample bore holes as well as other tests.

Horizontal

A 3-ton slinky loop prior to being covered with soil. The three slinky loops are running out horizontally with three straight lines returning the end of the slinky coil to the heat pump

A horizontal closed loop field is composed of pipes that run horizontally in the ground. A long horizontal trench, deeper than the frost line, is dug and U-shaped or slinky coils are placed horizontally inside the same trench. Excavation for horizontal loop fields is about half the cost of vertical drilling, so this is the most common layout used wherever there is adequate land available. For illustration, a detached house needing 10 kW (3 ton) of heating capacity might need 3 loops 120 to 180 m (390 to 590 ft) long of NPS 3/4 (DN 20) or NPS 1.25 (DN 32) polyethylene tubing at a depth of 1 to 2 m (3.3 to 6.6 ft).

A slinky (also called coiled) closed loop field is a type of horizontal closed loop where the pipes overlay each other (not a recommended method). The easiest way of picturing a slinky field is to imagine holding a slinky on the top and bottom with your hands and then move your hands in opposite directions. A slinky loop field is used if there is not adequate room for a true horizontal system, but it still allows for an easy installation. Rather than using straight pipe, slinky coils, use overlapped loops of piping laid out horizontally along the bottom of a wide trench. Depending on soil, climate and your heat pump's run fraction, slinky coil trenches can be anywhere from one third to two thirds shorter than traditional horizontal loop trenches. Slinky coil ground loops are essentially a more economic and space efficient version of a horizontal ground loop.

Radial/Directional drilling

As an alternative to trenching, loops may be laid by mini horizontal directional drilling. (mini-HDD) This technique can lay piping under yards, driveways, gardens or other structures without disturbing them, with a cost between those of trenching and vertical drilling. This system also differs from horizontal & vertical drilling as the loops are installed from one central chamber, further reducing the ground space needed. Radial drilling is often installed retrospectively (after the property has been built) due to the small nature of the equipment used and the ability to bore beneath existing constructions.

Pond

12-ton pond loop system being sunk to the bottom of a pond

A closed pond loop is not common because it depends on proximity to a body of water, where an open loop system is usually preferable. A pond loop may be advantageous where poor water quality precludes an open loop, or where the system heat load is small. A pond loop consists of coils of pipe similar to a slinky loop attached to a frame and located at the bottom of an appropriately sized pond or water source.

Open loop

In an open loop system (also called a groundwater heat pump), the secondary loop pumps natural water from a well or body of water into a heat exchanger inside the heat pump. ASHRAE calls open loop systems *groundwater heat pumps* or *surface water heat pumps*, depending on the source. Heat is either extracted or added by the primary refrigerant loop, and the water is returned to a separate injection well, irrigation trench, tile field or body of water. The supply and return lines must be placed far enough apart to ensure thermal recharge of the source. Since the water chemistry is not controlled, the appliance may need to be protected from corrosion by using different metals in the heat exchanger and pump. Limescale may foul the system over time and require periodic acid cleaning. Also, as fouling decreases the flow of natural water, it becomes difficult for the heat pump to exchange building heat with the groundwater. If the water contains high levels of salt, minerals, iron bacteria or hydrogen sulfide, a closed loop system is usually preferable.

Deep lake water cooling uses a similar process with an open loop for air conditioning and cooling. Open loop systems using ground water are usually more efficient than closed systems because they are better coupled with ground temperatures. Closed loop systems, in comparison, have to transfer heat across extra layers of pipe wall and dirt.

A growing number of jurisdictions have outlawed open-loop systems that drain to the surface because these may drain aquifers or contaminate wells. This forces the use of more environmentally sound injection wells.

Standing column well

A standing column well system is a specialized type of open loop system. Water is drawn from the bottom of a deep rock well, passed through a heat pump, and returned to the top of the well, where traveling downwards it exchanges heat with the surrounding bedrock. The choice of a standing column well system is often dictated where there is near-surface bedrock and limited surface area is available. A standing column is typically not suitable in locations where the geology is mostly clay, silt, or sand. If bedrock is deeper than 200 feet (61 m) from the surface, the cost of casing to seal off the overburden may become prohibitive.

A multiple standing column well system can support a large structure in an urban or rural application. The standing column well method is also popular in residential and small commercial applications. There are many successful applications of varying sizes and well quantities in the many boroughs of New York City, and is also the most common application in the New England states. This type of ground source system has some heat storage benefits, where heat is rejected from the building and the temperature of the well is raised, within reason, during the Summer cooling months which can then be harvested for heating in the Winter months, thereby increasing the efficiency of the heat pump system. As with closed loop systems, sizing of the standing column system is critical in reference to the heat loss and gain of the existing building. As the heat exchange is actually with the bedrock, using water as the transfer medium, a large amount of production capacity (water flow from the well) is not required for a standing column system to work. However, if there is adequate water production, then the thermal capacity of the well system can be enhanced by discharging a small percentage of system flow during the peak Summer and Winter months.

Since this is essentially a water pumping system, standing column well design requires critical considerations to obtain peak operating efficiency. Should a standing column well design be misapplied, leaving out critical shut-off valves for example, the result could be an extreme loss in efficiency and thereby cause operational cost to be higher than anticipated.

Building distribution

Liquid-to-air heat pump

The heat pump is the central unit that becomes the heating and cooling plant for the building. Some models may cover space heating, space cooling, (space heating via conditioned air, hydronic systems and / or radiant heating systems), domestic or pool water preheat (via the desuperheater function, demand hot water, and driveway ice melting all within one appliance with a variety of options with respect to controls, staging and zone control. The heat may be carried to its end use by circulating water or forced air. Almost all types of heat pumps are produced for commercial and residential applications.

Liquid-to-air heat pumps (also called *water-to-air*) output forced air, and are most commonly used to replace legacy forced air furnaces and central air conditioning systems. There are variations that allow for split systems, high-velocity systems, and ductless systems. Heat pumps cannot achieve as high of a fluid temperature as a conventional furnace, so they require a higher volume flow rate of air to compensate. When retrofitting a residence, the existing duct work may have to be enlarged to reduce the noise from the higher air flow.

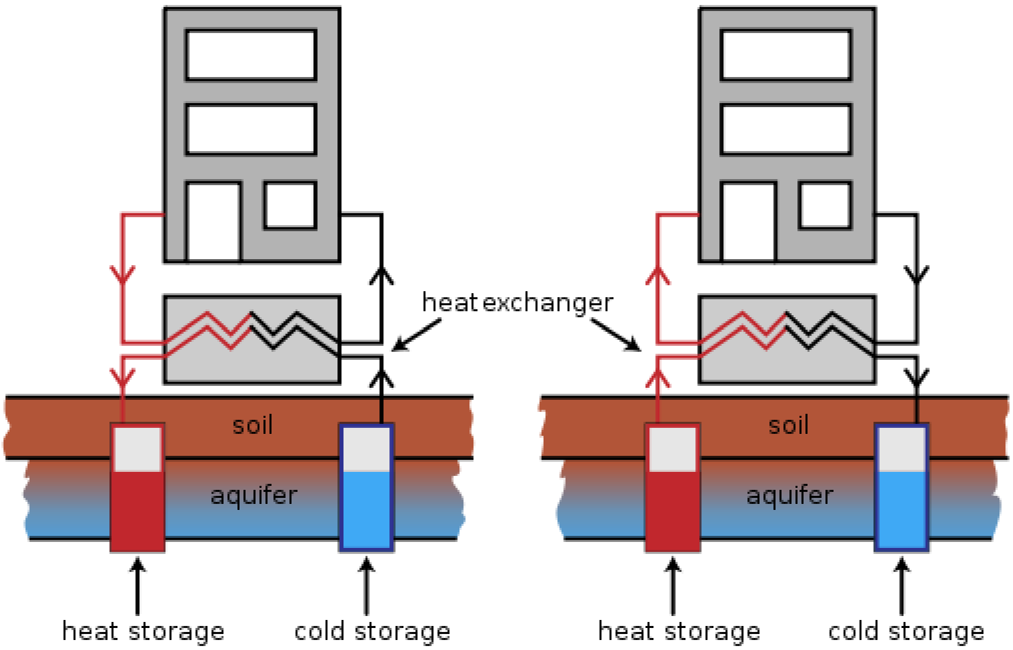
Liquid-to-water heat pump

Liquid-to-water heat pumps (also called *water-to-water*) are hydronic systems that use water to carry heating or cooling through the building. Systems such as radiant underfloor heating, baseboard radiators, conventional cast iron radiators would use a liquid-to-water heat pump. These heat pumps are preferred for pool heating or domestic hot water pre-heat. Heat pumps can only heat water to about 50 °C (122 °F) efficiently, whereas a boiler normally reaches 65–95 °C (149–203 °F). Legacy radiators designed for these higher temperatures may have to be doubled in numbers when retrofitting a home. A hot water tank will still be needed to raise water temperatures above the heat pump's maximum, but pre-heating will save 25-50% of hot water costs.

Ground source heat pumps are especially well matched to underfloor heating and baseboard radiator systems which only require warm temperatures (40 °C) to work well. Thus they are ideal for open plan offices. Using large surfaces such as floors, as opposed to radiators, distributes the heat more uniformly and allows for a lower water temperature. Wood or carpet floor coverings dampen this effect because the thermal transfer efficiency of these materials is lower than that of masonry floors (tile, concrete). Underfloor piping, ceiling or wall radiators can also be used for cooling in dry climates, although the temperature of the circulating water must be above the dew point to ensure that atmospheric humidity does not condense on the radiator.

Combination heat pumps are available that can produce forced air and circulating water simultaneously and individually. These systems are largely being used for houses that have a combination of air and liquid conditioning needs, for example central air conditioning and pool heating.

Seasonal thermal storage



A heat pump in combination with heat and cold storage

The efficiency of ground source heat pumps can be improved by using seasonal thermal storage. If heat loss from the ground source is sufficiently low, the heat pumped out of the building in the summer can be retrieved in the winter. Heat storage efficiency increases with scale, so this advantage is most significant in commercial or district heating systems. Geosolar combisystems further augment this efficiency by collecting extra solar energy during the summer (more than is needed for air conditioning) and concentrating it in the store.

Such a system has been used to heat and cool a greenhouse using an aquifer for thermal storage. In summer, the greenhouse is cooled with cold ground water. This heats the water in the aquifer which can become a warm source for heating in winter. The combination of cold and heat storage with heat pumps can be combined with water/humidity regulation. These principles are used to provide renewable heat and renewable cooling to all kinds of buildings.

Also the efficiency of existing small heat pump installations can sometimes be improved a lot by adding large, cheap, water filled solar collectors. These may be integrated into a to be overhauled parking lot, or in walls or roof constructions simply by putting lots of one inch PE pipes into the outer layer. A very simple option is to add a large mechanically ventilated out door water-air heat exchanger (like the one that is in front of your car engine, but larger). In the summer they allow to pump lots of heat, almost free of running cost, into the ground. This only works well when ground water mobility is not too high, and it works better when more houses install this system next to each other. (In the winter such outdoor components have to be drained of water.)

Thermal efficiency

The net thermal efficiency of a heat pump should take into account the efficiency of electricity generation and transmission, typically about 40%. Since a heat pump moves 3 to 5 times more heat energy than the electric energy it consumes, the total energy output is much greater than the input. This results in net thermal efficiencies greater than 100% for most electricity sources. Traditional combustion furnaces and electric heaters can never exceed 100% efficiency, but heat pumps provide extra energy by extracting it from the ground.

Geothermal heat pumps can reduce energy consumption— and corresponding air pollution emissions—up to 44% compared to air source heat pumps and up to 72% compared to electric resistance heating with standard air-conditioning equipment.

The dependence of net thermal efficiency on the electricity infrastructure tends to be an unnecessary complication for consumers and is not applicable to hydroelectric power, so performance of heat pumps is usually expressed as the ratio of heating output or heat removal to electricity input. Cooling performance is typically expressed in units of BTU/hr/watt as the Energy Efficiency Ratio, (EER) while heating performance is typically reduced to dimensionless units as the Coefficient of Performance. (COP) The conversion factor is 3.41 BTU/hr/watt. Performance is influenced by all components of the installed system, including the soil conditions, the ground-coupled heat exchanger, the heat pump appliance, and the building distribution, but is largely determined by the "lift" between the input temperature and the output temperature.

For the sake of comparing heat pump appliances to each other, independently from other system components, a few standard test conditions have been established by the American Refrigerant Institute (ARI) and more recently by the International Organization for Standardization. Standard ARI 330 ratings were intended for closed loop ground-source heat pumps, and assumes secondary loop water temperatures of 77 °F (25 °C) for air conditioning and 32 °F (0 °C) for heating. These temperatures are typical of installations in the northern USA. Standard ARI 325 ratings were intended for open loop ground-source heat pumps, and include two sets of ratings for groundwater temperatures of 50 °F (10 °C) and 70 °F (21 °C). ARI 325 budgets more electricity for water pumping than ARI 330. Neither of these standards attempt to account for seasonal variations. Standard ARI 870 ratings are intended for direct exchange ground-source heat pumps. ASHRAE transitioned to ISO 13256-1 in 2001, which replaces ARI 320, 325 and 330. The new ISO standard produces slightly higher ratings because it no longer budgets any electricity for water pumps.

Efficient compressors, variable speed compressors and larger heat exchangers all contribute to heat pump efficiency. Residential ground source heat pumps on the market today have standard COPs ranging from 2.4 to 5.0 and EERs ranging from 10.6 to 30. To qualify for an Energy Star label, heat pumps must meet certain minimum COP and EER ratings which depend on the ground heat exchanger type. For closed loop systems, the ISO 13256-1 heating COP must be 3.3 or greater and the cooling EER must be 14.1 or greater.

Actual installation conditions may produce better or worse efficiency than the standard test conditions. COP improves with a lower temperature difference between the input and output of the heat pump, so the stability of ground temperatures is important. If the loop field or water pump is undersized, the addition or removal of heat may push the ground temperature beyond standard test conditions, and performance will be degraded. Similarly, an undersized blower may allow the plenum coil to overheat and degrade performance.

Soil without artificial heat addition or subtraction and at depths of several meters or more remains at a relatively constant temperature year round. This temperature equates roughly to the average annual air-temperature of the chosen location, usually 7–12 °C (45–54 °F) at a depth of six meters in the northern USA. Because this temperature remains more constant than the air temperature throughout the seasons, geothermal heat pumps perform with far greater efficiency during extreme air temperatures than air conditioners and air-source heat pumps.

Standards ARI 210 and 240 define Seasonal Energy Efficiency Ratio (SEER) and Heating Seasonal Performance Factors (HSPF) to account for the impact of seasonal variations on air source heat pumps. These numbers are normally not applicable and should not be compared to ground source heat pump ratings. However, Natural Resources Canada has adapted this approach to calculate typical seasonally adjusted HSPFs for ground-source heat pumps in Canada. The NRC HSPFs ranged from 8.7 to 12.8 BTU/hr/watt (2.6 to 3.8 in nondimensional factors, or 255% to 375% seasonal average electricity utilization efficiency) for the most populated regions of Canada. When combined with the thermal efficiency of electricity, this corresponds to net average thermal efficiencies of 100% to 150%.

Environmental impact

The U.S. Environmental Protection Agency (EPA) has called ground source heat pumps the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available. Heat pumps offer significant emission reductions potential, particularly where they are used for both heating and cooling and where the electricity is produced from renewable resources.

Ground-source heat pumps have unsurpassed thermal efficiencies and produce zero emissions locally, but their electricity supply includes components with high greenhouse gas emissions, unless the owner has opted for a 100% renewable energy supply. Their environmental impact therefore depends on the characteristics of the electricity supply.

Annual greenhouse gas savings from using a ground source heat pump instead of a high-efficiency furnace in a detached residence (assuming no specific supply of renewable energy)

Country	Electricity CO_2 Emissions Intensity	GHG savings relative to		
		natural gas	heating oil	electric heating
Canada	223 ton/GWh	2.7 ton/yr	5.3 ton/yr	3.4 ton/yr
Russia	351 ton/GWh	1.8 ton/yr	4.4 ton/yr	5.4 ton/yr
USA	676 ton/GWh	-0.5 ton/yr	2.2 ton/yr	10.3 ton/yr
China	839 ton/GWh	-1.6 ton/yr	1.0 ton/yr	12.8 ton/yr

The GHG emissions savings from a heat pump over a conventional furnace can be calculated based on the following formula:

$$GHG\ Savings = HL\left(\frac{FI}{AFUE \times 1000\frac{kg}{ton}} - \frac{EI}{COP \times 3600\frac{sec}{hr}}\right)$$

- HL = seasonal heat load ≈ 80 GJ/yr for a modern detached house in the northern USA
- FI = emissions intensity of fuel = 50 kg(CO_2)/GJ for natural gas, 73 for heating oil, 0 for 100% renewable energy such as wind, hydro, photovoltaic or solar thermal
- AFUE = furnace efficiency ≈ 95% for a modern condensing furnace
- COP = heat pump coefficient of performance ≈ 3.2 seasonally adjusted for northern USA heat pump
- EI = emissions intensity of electricity ≈ 200-800 ton(CO_2)/GWh, depending on region

Ground-source heat pumps always produce less greenhouse gases than air conditioners, oil furnaces, and electric heating, but natural gas furnaces may be competitive depending on the greenhouse gas intensity of the local electricity supply. In countries like Canada and Russia with low emitting electricity infrastructure, a residential heat pump may save 5 tons of carbon dioxide per year relative to an oil furnace, or about as much as taking an average passenger car off the road. But in countries like China or USA that are highly reliant on coal for electricity production, a heat pump may result in 1 or 2 tons more carbon dioxide emissions than a natural gas furnace.

The fluids used in closed loops may be designed to be biodegradable and non-toxic, but the refrigerant used in the heat pump cabinet and in direct exchange loops was, until recently, chlorodifluoromethane, which is an ozone depleting substance. Although harmless while contained, leaks and improper end-of-life disposal contribute to enlarging the ozone hole. This refrigerant is being phased out in favor of ozone-friendly R410A for new construction. The EcoCute water heater is an air-source heat pump that uses Carbon Dioxide as its working fluid instead of Chlorofluorocarbons.

Open loop systems that draw water from a well and drain to the surface may contribute to aquifer depletion, water shortages, groundwater contamination, and subsidence of the soil. A geothermal heating project in Staufen im Breisgau, Germany, is suspected to have caused considerable damage to buildings in the city center. The ground has subsided by up to eight millimeters under the city hall while other areas have been uplifted by a few millimeters.

Ground-source heat pump technology, like building orientation, is a natural building technique (bioclimatic building).

Economics

Ground source heat pumps are characterized by high capital costs and low operational costs compared to other HVAC systems. Their overall economic benefit depends primarily on the relative costs of electricity and fuels, which are highly variable over time and across the world. Based on recent prices, ground-source heat pumps currently have lower operational costs than any other conventional heating source almost everywhere in the world. Natural gas is the only fuel with competitive operational costs, and only in a handful of countries where it is exceptionally cheap, or where electricity is exceptionally expensive. In general, a homeowner may save anywhere from 20% to 60% annually on utilities by switching from an ordinary system to a ground-source system. However, many family size installations are reported to use much more electricity then their owners had expected from advertisements. This is often partly due to bad design or installation: Heat exchange capacity with groundwater is often too small, heating pipes in house floors are often too thin and too few, or heated floors are covered with wooden panels or carpets.

Capital costs and system lifespan have received much less study, and the return on investment is highly variable. One study found the total installed cost for a system with 10 kW (3 ton) thermal capacity for a detached rural residence in the USA averaged $8000–$9000 in 1995 US dollars. More recent studies found an average cost of $14,000 in 2008 US dollars for the same size system. The US Department of Energy estimates a price of $7500 on its website, last updated in 2008. Prices over $20,000 are quoted in Canada, with one source placing them in the range of $30,000-$34,000 Canadian dollars. The rapid escalation in system price has been accompanied by rapid improvements in efficiency and reliability. Capital costs are known to benefit from economies of scale, particularly for open loop systems, so they are more cost-effective for larger commercial buildings and harsher climates. The initial cost can be two to five times that of a conventional heating system in most residential applications, new construction or existing. In retrofits, the cost of installation is affected by the size of living area, the home's age, insulation characteristics, the geology of the area, and location of the home/property. Proper duct system design and mechanical air exchange should be considered in the initial system cost.

Payback period for installing a ground source heat pump in a detached residence

Country	Payback period for replacing natural gas	Payback period for replacing heating oil	Payback period for replacing electric heating
Canada	13 years	3 years	6 years
USA	12 years	5 years	4 years
Germany	net loss	8 years	2 years

Notes:

- Highly variable with energy prices.
- Government subsidies not included.
- Climate differences not evaluated.

Capital costs may be offset by substantial subsidies from many governments, for example totaling over $7000 in Ontario for residential systems installed in the 2009 fiscal year. Some electric companies offer special rates to customers who install a ground-source heat pump for heating/cooling their building. This is due to the fact that electrical plants have the largest loads during summer months and much of their capacity sits idle during winter months. This allows the electric company to use more of their facility during the winter months and sell more electricity. It also allows them to reduce peak usage during the summer (due to the increased efficiency of heat pumps), thereby avoiding costly construction of new power plants. For the same reasons, other utility companies have started to pay for the installation of ground-source heat pumps at customer residences. They lease the systems to their customers for a monthly fee, at a net overall savings to the customer.

The lifespan of the system is longer than conventional heating and cooling systems. Good data on system lifespan is not yet available because the technology is too recent, but many early systems are still operational today after 25–30 years with routine maintenance. Most loop fields have warranties for 25 to 50 years and are expected to last at least 50 to 200 years. Ground-source heat pumps use electricity for heating the house. The higher investment above conventional oil, propane or electric systems may be returned in energy savings in 2–10 years for residential systems in the USA. If compared to natural gas systems, the payback period can be much longer or non-existent. The payback period for larger commercial systems in the USA is 1–5 years, even when compared to natural gas.

Ground source heat pumps are recognized as one of the most efficient heating and cooling systems on the market. They are often the second-most cost effective solution in extreme climates, (after co-generation), despite reductions in thermal efficiency due to ground temperature. (The ground source is warmer in climates that need strong air conditioning, and cooler in climates that need strong heating.)

Commercial systems maintenance costs in the USA have historically been between \$0.11 to \$0.22 per m^2 per year in 1996 dollars, much less than the average \$0.54 per m^2 per year for conventional HVAC systems.

Governments that promote renewable energy will likely offer incentives for the consumer (residential), or industrial markets. For example, in the United States, incentives are offered both on the state and federal levels of government.

Seasonal thermal store

A **seasonal thermal store** (also known as a **seasonal heat store** or **inter-seasonal thermal store**) is a store designed to retain heat deposited during the hot summer months for use during colder winter weather. The heat is typically captured using solar collectors, although other energy sources are sometime used separately or in parallel.

Types of seasonal thermal storage system

Seasonal (or "annualized") thermal storage can be divided into three broad categories:

- Low-temperature systems use the soil adjoining the building as a low-temperature seasonal heat store (reaching temperatures similar to average annual air temperature), drawing upon the stored heat for space heating. Such systems can also be seen as an extension to the building design (normally passive solar building design), as the design involves some simple but significant differences when compared to 'traditional' buildings.

- Warm-temperature interseasonal heat stores also use soil to store heat, but employ active mechanisms of solar collection in summer to heat thermal banks in advance of the heating season.

- High-temperature seasonal heat stores are essentially an extension of the building's HVAC and water heating systems. Water is normally the storage medium, stored in tanks at temperatures that can approach boiling point. Phase change materials (which are expensive but which require much smaller tanks) and high-tech soil heating systems (remote from the building) are occasionally used instead. For systems installed in individual buildings, additional space is required to accommodate the size of the storage tanks.

In all cases, very effective above-ground insulation / superinsulation of the building structure is required to minimize heat-loss from the building, and hence the amount of heat that needs to be stored and used for space heating.

Despite the differences in design that they involve, low-temperature systems tend to offer simple and relatively inexpensive implementations which are less vulnerable to equipment failure. They do, however, require the site of the building to be clear of the water table, bedrock and existing buildings, and are limited to temperate (or warmer) climate zones and to space heating only. High-temperature systems share the same vulnerabilities as conventional space and water heating systems due to their 'active' mechanical and electrical components, as well as their advantage of enabling greater control. They can also be employed in colder climates.

Low-temperature seasonal heat stores

One of the original motivations of early man's movement into caves was probably the ability of the earth to naturally even out variations in temperature. At depths of about 20 feet (6m) temperature is naturally "annualised" at a stable year-round temperature.

With the development of modern passive solar building design, during the 1970s and 1980s a number of techniques were developed in the US that enabled thermally and moisture-protected soil to be used as an effective seasonal storage medium for space heating, with direct conduction as the heat return method.

Two basic techniques can be employed:

- In the Passive Annual Heat Storage (PAHS) and similar direct solar gain systems, solar heat is directly captured by the structure's spaces (through windows and other surfaces) in summer and then passively transferred (by conduction) through its floors, walls (and, sometimes, roof) into adjoining thermally-buffered soil. It is then *passively* returned (by conduction and radiation) as those spaces cool in winter. These techniques were advocated in Daniel Geery's 1982 book *Solar Greenhouses: Underground* and John Hait's 1983 *Passive Annual Heat Storage - Improving the Design of Earth Shelters*.

- The Annualized Geothermal Solar (AGS) concept involves the capture of heat by isolated solar gain devices (rather than the building structure). From here it is deposited in the earth (or other storage masses or mediums) adjoining the building using active or passive technology. The depth at which the heat is deposited is calculated (according to soil type) to provide a controlled 6-month heat-return time-lag to the building through conduction as the building cools. This alternative was posed by Don Stephens.

Warm-temperature seasonal heat stores

Warm-temperature heat stores are a development of low-temperature stores in that solar collectors are used to capture surplus heat in summer and actively raise the temperature of large thermal banks of soil so that heat can be extracted more easily (and more cheaply) in winter. Interseasonal Heat Transfer uses water circulating in pipes embedded in asphalt solar collectors to transfer heat to Thermal Banks beneath the insulated foundation of buildings. A ground source heat pump is used in winter to extract the warmth from the Thermal Bank to provide space heating via underfloor heating. A high Coefficient of Performance is obtained because the heat pump starts with a warm temperature of 25°C (77°F) from the thermal store, instead of a cold temperature of 10°C (50°F) from the ground.

High-temperature seasonal thermal stores

High-temperature seasonal thermal stores are found on a variety of scales, from those installed in individual houses to those serving neighbourhoods via district heating.

Individual structures

Although the use of high-temperature seasonal thermal stores within individual buildings dates back to at least 1939 (MIT Solar House #1), the United States, Switzerland and Germany have all been notable pioneers in this field.

One example of this active approach is the experimental "Jenni-Haus" built in 1989 in Oberburg, Switzerland. This has three tanks storing a total of 118m³ (4,100 cubic feet) providing far more heat than is required to heat the building.

The more recent "Zero Heating Energy House", completed in 1997 in Berlin as part of the IEA Task 13 low energy housing demonstration project, stores water at temperatures up to 90 °C (195 °F) inside a 20m³ (700 cubic feet) tank in the basement and is now one of a growing number of similar properties.

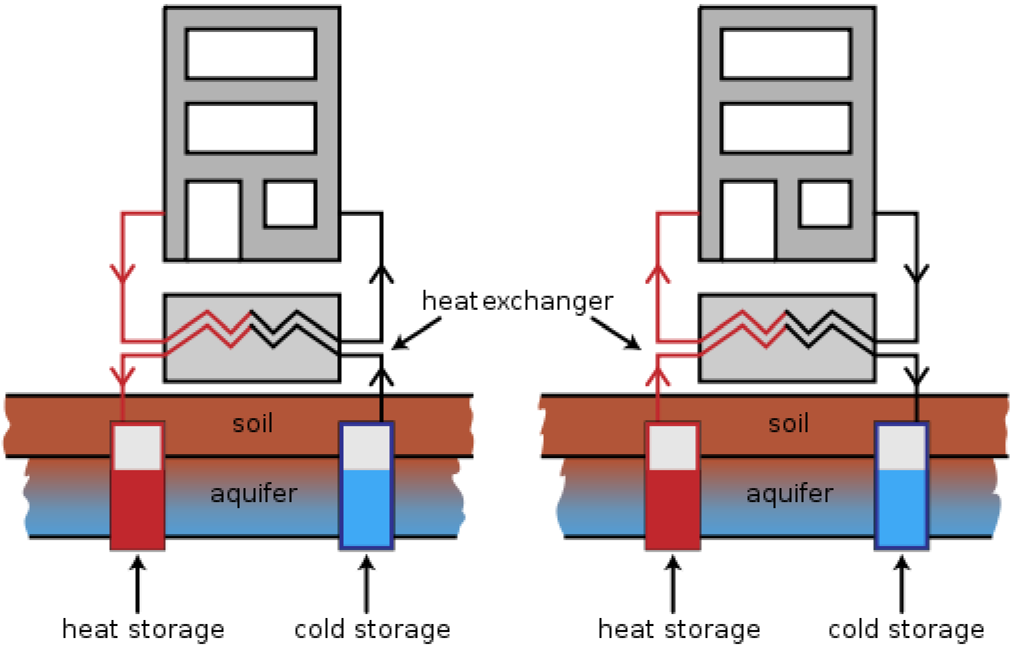
Another similar example was set up in Ireland in 2009. The *solar seasonal store* consists of a 23m³ (23,000 liters) tank, filled with water, which was installed in the ground, heavily insulated all around, to store heat from evacuated solar tubes during the year. The system was installed as an experiment to heat the *world's first standardised pre-fabricated passive house* in Galway, Ireland. The aim was to find out if this heat would be sufficient to eliminate the need for any electricity in the already highly efficient home during the winter months. The system is monitored and documented by a research team from The University of Ulster and the results will be included in part of a PhD thesis.

Neighbourhoods

At the neighbourhood level, the Wiggenhausen-Süd solar development at Friedrichshafen has received international attention. This features a 12,000 m³ (424,000 cubic feet) reinforced concrete thermal store linked to 4,300m² (46,000 square feet) of solar collectors, which will supply the 570 houses with around 50% of their heating and hot water.

A different approach is illustrated by the Drake Landing Solar Community development in Okotoks, Alberta. This community consists of 52 houses built to the stringent R-2000 building code. Here the store is created from the ground itself, with solar heated water pumped into a Borehole Thermal Energy Storage (BTES) system. It consists of 144 boreholes, each 37 m (121 ft) deep, which heat the ground to a maximum of around 90 °C (195 °F). During the winter, the hot water flows from the BTES field to the houses through a distribution network. Once inside the house, it flows through coil units, over which air is blown. The hot air then heats the house. Each house also has an independent solar thermal system installed on its sloped roof to provide domestic hot water. This system has a 90% solar fraction, meaning 90% of the energy required to heat the air and water within the community is provided by the sun. This results in a reduction of over 5 tonnes of CO_2 equivalent, per house.

Greenhouses



A heat pump in combination with heat and cold storage

Thermal storage (sometimes referred to as heat and cold storage) is also used extensively for applications as the heating of greenhouses. In summer, the greenhouse is cooled with ground water, pumped from an aquifer, which is the cold source. This heats the water, which is then stored by the system in a warm source. In winter, the warm water is pumped up to supply heat. The now cooled water is returned to the cold source. The combination of cold and heat storage with heat pumps has an additional benefit for greenhouses, as it may be combined with humidification. In the (closed circuit) system, the hot water is stored in one aquifer, while the cold water is stored in another. The water is used to heat or cool the air, which is moved by fans. Such a system can be completely automated.

Solar air conditioning

Solar air conditioning refers to any air conditioning (cooling) system that uses solar power.

This can be done through passive solar, solar thermal energy conversion and photovoltaic conversion (sun to electricity). The U.S. Energy Independence and Security Act of 2007 created 2008 through 2012 funding for a new solar air conditioning research and development program, which should develop and demonstrate multiple new technology innovations and mass production economies of scale. Solar air conditioning will play an increasing role in zero energy and energy-plus buildings design.

Solar Open Loop A/C using desiccants

Air can be passed over common, solid desiccants (like silica gel or zeolite) to draw moisture from the air to allow an efficient evaporative cooling cycle. The desiccant is then regenerated by using solar thermal energy to dry it out, in a cost-effective, low-energy-consumption, continuously repeating cycle. A photovoltaic system can power a low-energy air circulation fan, and a motor to slowly rotate a large disk filled with desiccant.

Energy recovery ventilation systems provide a controlled way of ventilating a home while minimizing energy loss. Air is passed through an "enthalpy wheel" (often using silica gel) to reduce the cost of heating ventilated air in the winter by transferring heat from the warm inside air being exhausted to the fresh (but cold) supply air. In the summer, the inside air cools the warmer incoming supply air to reduce ventilation cooling costs. This low-energy fan-and-motor ventilation system can be cost-effectively powered by photovoltaics, with enhanced natural convection exhaust up a solar chimney - the downward incoming air flow would be forced convection (advection).

A desiccant like calcium chloride can be mixed with water to create an attractive recirculating waterfall, that dehumidifies a room using solar thermal energy to regenerate the liquid, and a PV-powered low-rate water pump

The potential for near-future exploitation of this type of innovative solar-powered desiccant air conditioning technology is great.

Active solar cooling wherein solar thermal collectors provide input energy for a desiccant cooling system: A packed column air-liquid contactor has been studied in application to air dehumidification and regeneration in solar air conditioning with liquid desiccants. A theoretical model has been developed to predict the performance of the device under various operating conditions. Computer simulations based on the model are presented which indicate the practical range of air to liquid flux ratios and associated changes in air humidity and desiccant concentration. An experimental apparatus has been constructed and experiments performed with monoethylene glycol (MEG) and lithium bromide as desiccants. MEG experiments have yielded inaccurate results and have pointed out some practical problems associated with the use of glycols. LiBr experiments show very good agreement with the theoretical model. Preheating of the air is shown to greatly enhance desiccant regeneration. The packed column yields good results as a dehumidifier/regenerator, provided pressure drop can be reduced with the use of suitable packing.

Passive solar cooling

In this type of cooling solar thermal energy is not used directly to create a cold environment or drive any direct cooling processes. Instead, solar building design aims at slowing the rate of heat transfer into a building in the summer, and improving the removal of unwanted heat. It involves a good understanding of the mechanisms of heat transfer: heat conduction, convective heat transfer, and thermal radiation, the latter primarily from the sun.

For example, a sign of poor thermal design is an attic that gets hotter in summer than the peak outside air temperature. This can be significantly reduced or eliminated with a cool roof or a green roof, which can reduce the roof surface temperature by 70 °F (40 °C) in summer. A radiant barrier and an air gap below the roof will block about 97% of downward radiation from roof cladding heated by the sun.

Passive solar cooling is much easier to achieve in new construction than by adapting existing buildings. There are many design specifics involved in passive solar cooling. It is a primary element of designing a zero energy building in a hot climate.

Solar Closed Loop Absorption & Adsorption Cooling

The following are common technologies in use for solar thermal closed loop air conditioning.

- Absorption: NH3/H2O or Ammonia/Water
- Absorption: Water/Lithium Bromide
- Absorption: Water/Lithium Chloride
- Adsorption: Water/Silica Gel or Water/Zeolite
- Adsorption: Methanol/Activated Carbon

Active solar cooling uses solar thermal collectors to provide thermal energy to drive thermally driven chillers (usually adsorption or absorption chillers). The Sopogy concentrating solar thermal collector, for example, provides solar thermal heat by concentrating the sun's energy on a collection tube and heating the recirculated heat transfer fluid within the system. The generated heat is then used in conjunction with absorption chillers to provide a renewable source of industrial cooling.

There are multiple alternatives to compressor-based chillers that can reduce energy consumption, with less noise and vibration. Solar thermal energy can be used to efficiently cool in the summer, and also heat domestic hot water and buildings in the winter. Single, double or triple iterative absorption cooling cycles are used in different solar-thermal-cooling system designs. The more cycles, the more efficient they are.

Efficient absorption chillers require water of at least 190 °F (88 °C). Common, inexpensive flat-plate solar thermal collectors only produce about 160 °F (71 °C) water. In large scale installations there are several projects successful both technical and economical in operation world wide including e.g. on the headquarters of Caixa Geral de Depósitos in Lisbon with 1579m² solar collectors and 545 kW cooling power or on the Olympic Sailing Village in Qingdao/China. In 2011 the most powerful plant at Singapore's new constructed United World College will be commissioned (1500 kW).

These projects have shown that flat plate solar collectors specially developed for temperatures over 200 °F (featuring double glazing, increased backside insulation, etc.) can be effective and cost efficient. Evacuated-tube solar panels can be used as well. Concentrating solar collectors required for absorption chillers are less effective in hot humid, cloudy environments, especially where the overnight low temperature and relative humidity are uncomfortably high. Where water can be heated well above 190 °F (88 °C), it can be stored and used when the sun is not shining.

The Audubon Environmental Center in Los Angeles has an example solar air conditioning installation. The Southern California Gas Co. (The Gas Company), and its sister utility, San Diego Gas & Electric (SDG&E), are also testing the practicality of solar thermal cooling systems at their Energy Resource Center (ERC) in Downey, California. Solar Collectors from Sopogy and HelioDynamics were installed on the rooftop at the ERC and are producing cooling for the building’s air conditioning system.

In the late 19th century, the most common phase change refrigerant material for absorption cooling was a solution of ammonia and water. Today, the combination of lithium and bromide is also in common use. One end of the system of expansion/condensation pipes is heated, and the other end gets cold enough to make ice. Originally, natural gas was used as a heat source in the late 19th century. Today, propane is used in recreational vehicle absorption chiller refrigerators. Innovative hot water solar thermal energy collectors can also be used as the modern "free energy" heat source.

For 150 years, absorption chillers have been used to make ice (before the electric light bulb was invented). This ice can be stored and used as an "ice battery" for cooling when the sun is not shining, as it was in the 1995 Hotel New Otani in Tokyo Japan. Mathematical models are available in the public domain for ice-based thermal energy storage performance calculations.

The ISAAC Solar Icemaker is an intermittent solar ammonia-water absorption cycle. The ISAAC uses a parabolic trough solar collector and a compact and efficient design to produce ice with no fuel or electric input, and with no moving parts.

Makers include SOLID and Mirroxx for commercial installations and ClimateWell, Fagor-Rotartica, Sopogy, SorTech and Daikin mostly for residential systems.

Photovoltaic (PV) solar cooling

Photovoltaics can provide the power for any type of electrically powered cooling be it **conventional** compressor-based or adsorption/absorption-based, though the most common implementation is with compressors which is the least efficient form of electrical cooling methods.

For small residential and small commercial cooling (less than 5 MWh/yr) PV-powered cooling has been the most frequently implemented solar cooling technology. The reason for this is debated, but commonly suggested reasons include incentive structuring, lack of residential-sized equipment for other solar-cooling technologies, the advent of more efficient electrical coolers, or ease of installation compared to other solar-cooling technologies (like radiant cooling).

Since PV cooling's cost effectiveness depends largely on the cooling equipment and given the poor efficiencies in electrical cooling methods until recently it has not been **cost effective** without subsidies. Pairing PV with 14 SEER and less coolers is the least efficient of all solar cooling methods. Using more efficient electrical cooling methods and allowing longer payback schedules is changing that scenario.

For example, a 100,000 BTU U.S. Energy Star rated air conditioner with a high seasonal energy efficiency ratio (SEER) of 14 requires around 7 kW of electric power for full cooling output on a hot day. This would require over a 7 kW solar photovoltaic electricity generation system (with morning-to-evening, and seasonal solar tracker capability to handle the 47-degree summer-to-winter difference in solar altitude). The photovoltaics would only produce full output during the sunny part of clear days.

A solar-tracking 7 kW photovoltaic system would probably have an installed price well over $20,000 USD (with PV equipment prices currently falling at roughly 17% per year). Infrastructure, wiring, mounting, and NEC code costs may add up to an additional cost; for instance a 3120 watt solar panel grid tie system has a panel cost of $0.99/watt hour peak, but still costs ~$2.2/watt hour peak. Other systems of different capacity cost even more, let alone battery backup systems, which cost even more. Due to the advent of net metering allowed by utility companies, your photovoltaic system can produce enough energy in the course of the year to completely offset the cost of the electricity used to run air conditioning, depending on the amount of your electric costs you wish to offset.

A more efficient air conditioning system would require a smaller, less-expensive photovoltaic system. A high-quality geothermal heat pump installation can have a SEER in the range of 20 (+/-). A 100,000 BTU SEER 20 air conditioner would require less than 5 kW while operating.

Newer and lower power technology including reverse inverter DC heat pumps can achieve SEER ratings up to 26, the Fujitsu Halycon line being one notable example, but its requirements of 200-250v AC input makes its use in the USA in smaller grids newer.

There are new non-compressor-based electrical air conditioning systems with a SEER above 20 coming on the market. New versions of phase-change indirect evaporative coolers use nothing but a fan and a supply of water to cool buildings without adding extra interior humidity (such as at McCarran Airport Las Vegas Nevada). In dry arid climates with relative humidity below 45% (about 40% of the continental U.S.) indirect evaporative coolers can achieve a SEER above 20, and up to SEER 40. A 100,000 BTU indirect evaporative cooler would only need enough photovoltaic power for the circulation fan (plus a water supply).

A less-expensive partial-power photovoltaic system can reduce (but not eliminate) the monthly amount of electricity purchased from the power grid for air conditioning (and other uses). With American state government subsidies of $2.50 to $5.00 USD per photovoltaic watt, the amortized cost of PV-generated electricity can be below $0.15 per kWh. This is currently cost effective in some areas where power company electricity is now $0.15 or more. Excess PV power generated when air conditioning is not required can be sold back to the power grid in many locations, which can reduce (or eliminate) annual net electricity purchase requirement.

The key to solar air conditioning cost effectiveness is in lowering the cooling requirement for the building. Superior energy efficiency can be designed into new construction (or retrofitted to existing buildings). Since the U.S. Department of Energy was created in 1977, their Weatherization Assistance Program has reduced heating-and-cooling load on 5.5 million low-income affordable homes an average of 31%. A hundred million American buildings still need improved weatherization. Careless conventional construction practices are still producing inefficient new buildings that need weatherization when they are first occupied.

It is fairly simple to reduce the heating-and-cooling requirement for new construction by one half. This can often be done at no additional net cost, since there are cost savings for smaller air conditioning systems and other benefits.

Since U.S. President Carter created the Solar Energy Tax Incentives in 1978, hundreds of thousands of passive solar and zero energy buildings have demonstrated 70% to 90% heating-and-cooling load reductions (and even 100% reduction in some climates). In contrast, well over 25 million new conventional U.S. buildings have ignored well-documented energy efficiency techniques since 1978. As a result, U.S. buildings waste more energy (39%) than transportation or industry. If their architects and builders had listened to the U.S. Department Of Energy presentations at the National Energy Expositions three decades ago, American buildings could be using $200 billion USD less energy per year today.

Geothermal cooling

Earth sheltering or Earth cooling tubes can take advantage of the ambient temperature of the Earth to reduce or eliminate conventional air conditioning requirements. In many climates where the majority of humans live, they can greatly reduce the build up of undesirable summer heat, and also help remove heat from the interior of the building. They increase construction cost, but reduce or eliminate the cost of conventional air conditioning equipment.

Earth cooling tubes are not cost effective in hot humid tropical environments where the ambient Earth temperature approaches human temperature comfort zone. A solar chimney or photovoltaic-powered fan can be used to exhaust undesired heat and draw in cooler, dehumidified air that has passed by ambient Earth temperature surfaces. Control of humidity and condensation are important design issues.

A geothermal heat pump uses ambient Earth temperature to improve SEER for heat and cooling. A deep well recirculates water to extract ambient Earth temperature (typically at 6 to 10 gallons per minute). Ambient earth temperature is much lower than peak summer air temperature. And, much higher than the lowest extreme winter air temperature. Water is 25 times more thermally conductive than air, so it is much more efficient than an outside air heat pump, (which become less effective when the outside temperature drops).

The same type of geothermal well can be used without a heat pump but with greatly diminished results. Ambient Earth temperature water is pumped through a shrouded radiator (like an automobile radiator). Air is blown across the radiator, which cools without a compressor-based air conditioner. Photovoltaic solar electric panels produce electricity for the water pump and fan—eliminating conventional air-conditioning utility bills. This concept is cost-effective, as long as the location has ambient Earth temperature below the human thermal comfort zone. (Not the tropics)

Zero energy buildings

Goals of zero energy buildings include sustainable, green building technologies that can significantly reduce, or eliminate, net annual energy bills. The supreme achievement is the totally off the grid autonomous building that does not have to be connected to utility companies. In hot climates with significant degree days of cooling requirement, leading-edge solar air conditioning will be an increasingly important critical success factor.