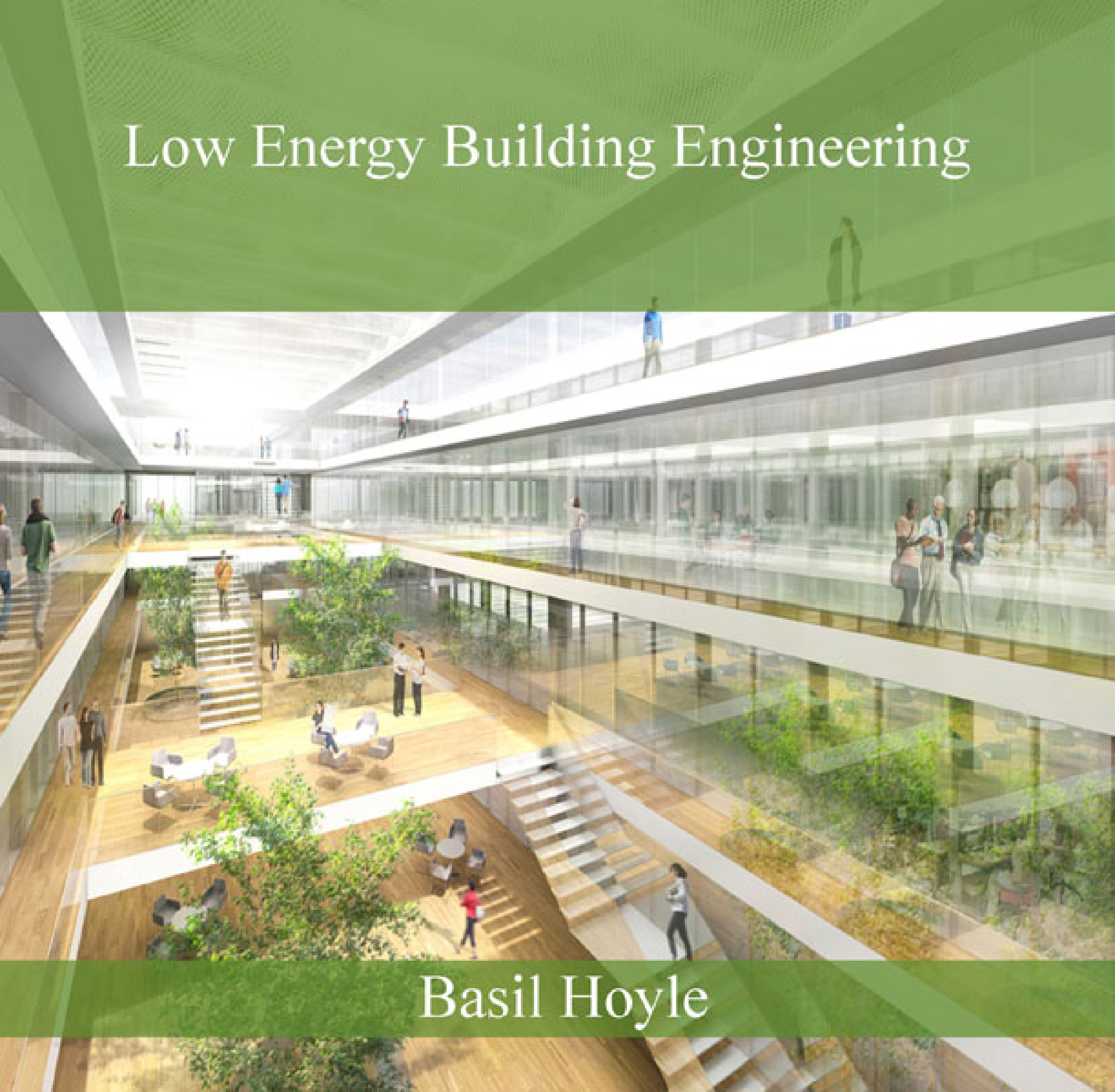
Low Energy Building Engineering



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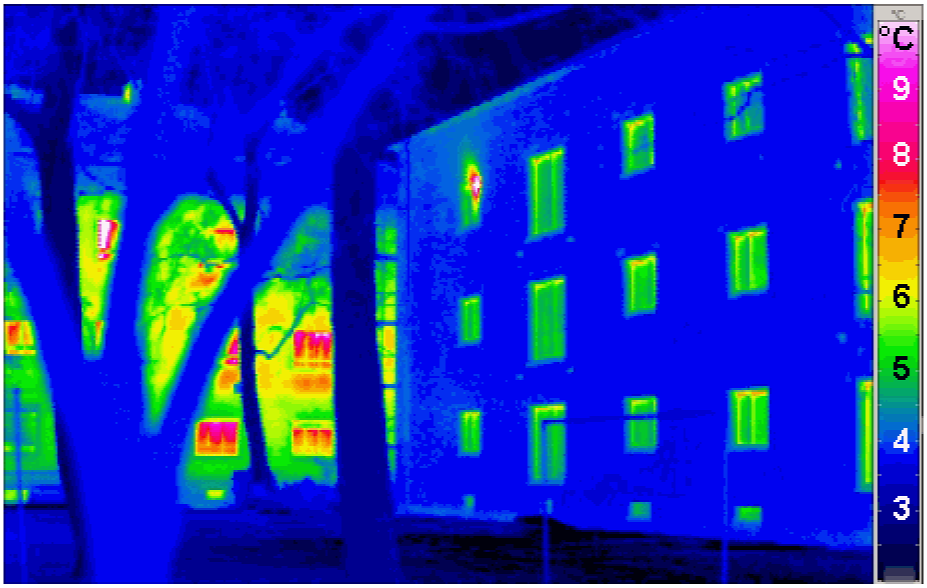
Low-Energy House



A Thermogram compares 2 buildings windows-walls "heat radiation" - with sustainable **Low-energy Passive house** on right; and conventional leaking house on left.

A **Low-energy house** is any type of house that from design, technologies, and building products and uses less energy, from any source, than a traditional or average contemporary house. They are the practice of Sustainable design, Sustainable architecture, Low energy building, Energy-efficient landscaping. They 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 & 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 could 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' ones 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 meter of room *for space heating* annually (50 kWh/m²a or 15,850 Btu/ft²/yr). In Switzerland the term is used in connection with the *MINERGIE* standard (42 kWh/m²a or 13,300 Btu/ft²/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/m²a or 4,755 Btu/ft²/yr.

A "Sub-10 Passive House" is under construction in Ireland which 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 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
- Geothermal heat pump
- Heat recovery ventilation
- Hot water heat recycling
- Passive cooling
- Renewable heat
- Seasonal thermal storage
- 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- 2

Zero-Energy Building

BedZED zero energy housing in the UK

A **zero energy building** (**ZEB**) or **net zero energy building** is a general term applied to a building's use with zero net energy consumption and zero carbon emissions annually. Zero energy buildings can be used autonomously from the energy grid supply – energy can be harvested on-site. The net zero design principle is overlaid on the requested comfort of the building occupant. Generally, the more extreme the exposure to the elements the more energy is needed to achieve a comfortable environment of human use.

The zero fossil energy consumption principle is gaining considerable interest as renewable energy harvesting is a means to cut greenhouse gas emissions. Traditional building use consumes 40% of the total fossil energy in the US and European Union. In developing countries many people have to live in zero-energy buildings out of necessity. Many people live in huts, yurts, tents and caves exposed to temperature extremes and without access to electricity. These conditions and the limited size of living quarters would be considered uncomfortable in the developed countries.

Modern evolution

The development of modern zero-energy buildings became possible not only through the progress made in new construction technologies and techniques, but it has also been significantly improved by academic research on traditional and experimental buildings, which collected precise energy performance data. Today's advanced computer models can show the efficacy of engineering design decisions.

Energy use can be measured in different ways (relating to cost, energy, or carbon emissions) and, irrespective of the definition used, different views are taken on the relative importance of energy harvest and energy conservation to achieve a net energy balance. Although zero energy buildings remain uncommon in developed countries, they are gaining in importance and popularity. The zero-energy approach has potential to reduce carbon emissions, and reduce dependence on fossil fuels. Most ZEB definitions do not include the emissions generated in the construction of the building and the embodied energy of the structure. So much energy is used in the construction of a new building that this can dwarf the operational energy savings over its useful life.

A building approaching net zero-energy use may be called a *near-zero energy building* or *ultra-low energy house*. Buildings that produce a surplus of energy during a portion of the year may be known as *energy-plus buildings*.

If the building is located in an area that requires heating or cooling throughout parts of the year, it is easier to achieve net zero-energy consumption when the available living space is kept small.

Definitions

Despite sharing the name **zero energy building**, there are several definitions of what ZEB means in practice, with a particular difference in usage between North America and Europe.

Net zero site energy use
: In this type of ZEB, the amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building. In the United States, "zero energy building" generally refers to this type of building.

Net zero source energy use
: This ZEB generates the same amount of energy as is used, including the energy used to transport the energy to the building. This type accounts for losses during electricity transmission. These ZEBs must generate more electricity than net zero site energy buildings.

Net zero energy emissions
: Outside the United States and Canada, a ZEB is generally defined as one with zero net energy emissions, also known as a *zero carbon building* or *zero emissions building*. Under this definition the carbon emissions generated from on-

site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production. Other definitions include not only the carbon emissions generated by the building in use, but also those generated in the construction of the building and the embodied energy of the structure. Others debate whether the carbon emissions of commuting to and from the building should also be included in the calculation.

Net zero cost

In this type of building, the cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site. Such a status depends on how a utility credits net electricity generation and the utility rate structure the building uses.

Net off-site zero energy use

A building may be considered a ZEB if 100% of the energy it purchases comes from renewable energy sources, even if the energy is generated off the site.

Off-the-grid

Off-the-grid buildings are stand-alone ZEBs that are not connected to an off-site energy utility facility. They require distributed renewable energy generation and energy storage capability (for when the sun is not shining, wind is not blowing, etc.). An energy autarkic house is a building concept where the balance of the own energy consumption and production can be made on an hourly or even smaller basis. Energy autarkic houses can be taken off-the-grid.

Design and construction

The most cost-effective steps toward a reduction in a building's energy consumption usually occurs during the design process. To achieve efficient energy use, zero energy design departs significantly from conventional construction practice. Successful zero energy building designers typically combine time tested passive solar, or natural conditioning, principles that work with the on site assets. Sunlight and solar heat, prevailing breezes, and the cool of the earth below a building, can provide daylighting and stable indoor temperatures with minimum mechanical means. ZEBs are normally optimized to use passive solar heat gain and shading, combined with thermal mass to stabilize diurnal temperature variations throughout the day, and in most climates are superinsulated. All the technologies needed to create zero energy buildings are available off-the-shelf today. Sophisticated 3D computer simulation tools are available to model how a building will perform with a range of design variables such as building orientation (relative to the daily and seasonal position of the sun), window and door type and placement, overhang depth, insulation type and values of the building elements, air tightness (weatherization), the efficiency of heating, cooling, lighting and other equipment, as well as local climate. These simulations help the designers predict how the building will perform before it is built, and enable them to model the economic and financial implications on building cost benefit analysis, or even more appropriate - life cycle assessment.

Zero-Energy Buildings are built with significant energy-saving features. The heating and cooling loads are lowered by using high-efficiency equipment, added insulation, high-efficiency windows, natural ventilation, and other techniques. These features vary depending on climate zones in which the construction occurs. Water heating loads can be lowered by using water conservation fixtures, heat recovery units on waste water, and by using solar water heating, and high-efficiency water heating equipment. In addition, daylighting with skylites or solartubes can provide 100% of daytime illumination within the home. Nighttime illumination is typically done with fluorescent and LED lighting that use 1/3 or less power then incandescent lights, without adding unwanted heat. And miscellaneous electric loads can be lessened by choosing efficient appliances and minimizing phantom loads or standby power. Other techniques to reach net zero (dependent on climate) are Earth sheltered building principles, superinsulation walls using straw-bale construction, Vitruvianbuilt pre-fabricated building panels and roof elements plus exterior landscaping for seasonal shading.

Zero-energy buildings are often designed to make dual use of energy including white goods; for example, using refrigerator exhaust to heat domestic water, ventilation air and shower drain heat exchangers, office machines and computer servers, and body heat to heat the building. These buildings make use of heat energy that conventional buildings may exhaust outside. They may use heat recovery ventilation, hot water heat recycling, combined heat and power, and absorption chiller units.

Energy harvest

ZEBs harvest available energy to meet their electricity and heating or cooling needs. In the case of individual houses, various microgeneration technologies may be used to provide heat and electricity to the building, using solar cells or wind turbines for electricity, and biofuels or solar collectors linked to seasonal thermal stores for space heating. To cope with fluctuations in demand, zero energy buildings are frequently connected to the electricity grid, export electricity to the grid when there is a surplus, and drawing electricity when not enough electricity is being produced. Other buildings may be fully autonomous.

Energy harvesting is most often more effective (in cost and resource utilization) when done on a local but combined scale, for example, a group of houses, co-housing, local district, village, etc. rather than an individual basis. An energy benefit of such localized energy harvesting is the virtual elimination of electrical transmission and electricity distribution losses. These losses amount to about 7.2%-7.4% of the energy transferred. Energy harvesting in commercial and industrial applications should benefit from the topography of each location. The production of goods under net zero fossil energy consumption requires locations of geothermal, microhydro, solar, and wind resources to sustain the concept.

Zero-energy neighborhoods, such as the BedZED development in the United Kingdom, and those that are spreading rapidly in California and China, may use distributed generation schemes. This may in some cases include district heating, community chilled water, shared wind turbines, etc. There are current plans to use ZEB technologies to build entire off-the-grid or net zero energy use cities.

The "energy harvest" versus "energy conservation" debate

One of the key areas of debate in zero energy building design is over the balance between energy conservation and the distributed point-of-use harvesting of renewable energy (solar energy and wind energy). Most zero energy homes use a combination of the two strategies.

As a result of significant government subsidies for photovoltaic solar electric systems, wind turbines, etc., there are those who suggest that a ZEB is a conventional house with distributed renewable energy harvesting technologies. Entire additions of such homes have appeared in locations where photovoltaic (PV) subsidies are significant, but many so called "Zero Energy Homes" still have utility bills. This type of energy harvesting without added energy conservation may not be cost effective with the current price of electricity generated with photovoltaic equipment (depending on the local price of power company electricity), and may also requires greater embodied energy and greater resources so be thus the less ecological approach.

Since the 1980s passive solar building design and passive house have demonstrated heating energy consumption reductions of 70% to 90% in many locations, without active energy harvesting. For new builds, and with expert design, this can be accomplished with little additional construction cost for materials over a conventional building. Very few industry experts have the skills or experience to fully capture benefits of the passive design. Such passive solar designs are much more cost effective than adding expensive photovoltaic panels on the roof of a conventional inefficient building. A few kilowatt-hours of photovoltaic panels (costing 2 to 3 dollars per annual kW-hr production, U.S. dollar equivalent) may only reduce external energy requirements by 15% to 30%. A 100,000 BTU (110 MJ) high seasonal energy efficiency ratio 14 conventional air conditioner requires over 7 kW of photovoltaic electricity while it is operating, and that does not include enough for off-the-grid night-time operation. Passive cooling, and superior system engineering techniques, can reduce the air conditioning requirement by 70% to 90%. Photovoltaic generated electricity becomes more cost-effective when the overall demand for electricity is lower.

Occupant behavior

The energy used in a building can vary greatly depending on the behavior of its occupants. The acceptance of what is considered comfortable varies widely. Studies of identical homes in the United States have shown dramatic differences in energy use, with some homes using more than twice the energy of others. Occupant behavior can vary from differences in setting and programming thermostats, varying levels of illumination and hot water, and the amount of miscellaneous electric devices used.

Development efforts

Wide acceptance of zero energy building technology may require more government incentives or building code regulations, the development of recognized standards, or significant increases in the cost of conventional energy.

The Google photovoltaic campus, and the Microsoft 480-kilowatt photovoltaic campus relied on U.S. Federal, and especially California, **subsidies** and financial incentives. California is now providing $3.2 billion USD in subsidies for residential-and-commercial near-zero-energy buildings, due to California's serious electricity shortage, frequent power outages, and air pollution problems. The details of other American states' renewable energy subsidies (up to $5.00 USD per watt) can be found in the Database of State Incentives for Renewables and Efficiency. The Florida Solar Energy Center has a slide presentation on recent progress in this area.

The **World Business Council for Sustainable Development** has launched a major initiative to support the development of ZEB. Led by the CEO of United Technologies and the Chairman of Lafarge, the organization has both the support of large global companies and the expertise to mobilize the corporate world and governmental support to make ZEB a reality. Their first report, a survey of key players in real estate and construction, indicates that the costs of building green are overestimated by 300 percent. Survey respondents estimated that greenhouse gas emissions by buildings are 19 percent of the worldwide total, in contrast to the actual value of roughly 40 percent.

Influential zero- and low-energy buildings

Those who commissioned construction of Passive Houses and Zero Energy Homes (over the last three decades) were essential to iterative, incremental, cutting-edge, technology innovations. Much has been learned from many significant successes, and a few expensive failures.

The zero energy building concept has been a progressive evolution from other low-energy building designs. Among these, the Canadian R-2000 and the German *passive house* standards have been internationally influential. Collaborative government demonstration projects, such as the superinsulated Saskatchewan House, and the International Energy Agency's *Task 13*, have also played their part.

Advantages and disadvantages

Advantages

- isolation for building owners from future energy price increases
- increased comfort due to more-uniform interior temperatures (this can be demonstrated with comparative isotherm maps)
- reduced requirement for energy austerity
- reduced total cost of ownership due to improved energy efficiency
- reduced total net monthly cost of living

- improved reliability - photovoltaic systems have 25-year warranties - seldom fail during weather problems - the 1982 photovoltaic systems on the Walt Disney World EPCOT Energy Pavilion are still working fine today, after going through 3 recent hurricanes
- extra cost is minimized for new construction compared to an afterthought retrofit
- higher resale value as potential owners demand more ZEBs than available supply
- the value of a ZEB building relative to similar conventional building should increase every time energy costs increase
- future legislative restrictions, and carbon emission taxes/penalties may force expensive retrofits to inefficient buildings

Disadvantages

- initial costs can be higher - effort required to understand, apply, and qualify for ZEB subsidies
- very few designers or builders have the necessary skills or experience to build ZEBs
- possible declines in future utility company renewable energy costs may lessen the value of capital invested in energy efficiency
- new photovoltaic solar cells equipment technology price has been falling at roughly 17% per year - It will lessen the value of capital invested in a solar electric generating system - Current subsidies will be phased out as photovoltaic mass production lowers future price
- challenge to recover higher initial costs on resale of building - appraisers are uninformed - their models do not consider energy
- climate-specific design may limit future ability to respond to rising-or-falling ambient temperatures (global warming)
- while the individual house may use an average of net zero energy over a year, it may demand energy at the time when peak demand for the grid occurs. In such a case, the capacity of the grid must still provide electricity to all loads. Therefore, a ZEB may not reduce the required power plant capacity.
- without an optimised thermal envelope the embodied energy, heating and cooling energy and resource usage is higher than needed. ZEB by definition do not mandate a minimum heating and cooling performance level thus allowing oversized renewable energy systems to fill the energy gap.
- solar energy capture using the house envelope only works in locations unobstructed from the South. The solar energy capture cannot be optimized in South facing shade or wooded surroundings.

Zero energy building versus green building

The goal of green building and sustainable architecture is to use resources more efficiently and reduce a building's negative impact on the environment. Zero energy buildings achieve one key green-building goal of completely or very significantly reducing energy use and greenhouse gas emissions for the life of the building. Zero energy buildings may or may not be considered "green" in all areas, such as reducing waste, using recycled building materials, etc. However, zero energy, or net-zero buildings do tend to have a much lower ecological impact over the life of the building compared with other 'green' buildings that require imported energy and/or fossil fuel to be habitable and meet the needs of occupants.

Because of the design challenges and sensitivity to a site that are required to efficiently meet the energy needs of a building and occupants with renewable energy (solar, wind, geothermal, etc.), designers must apply holistic design principles, and take advantage of the free naturally occurring assets available, such as passive solar orientation, natural ventilation, daylighting, thermal mass, and night time cooling.

Certification

Many Green building certification programs do not require a building to have net zero energy use, only to reduce energy use a few percentage points below the minimum required by law. The Leadership in Energy and Environmental Design (LEED) certification developed by the U.S. Green Building Council, and Green Globes, involve check lists that are measurement tools, not design tools. Inexperienced designers or architects may cherry-pick points to meet a target certification level, even though those points may not be the best design choices for a specific building or climate.

Worldwide

Canada

- In Canada the Net-Zero Energy Home Coalition is an industry association promoting net-zero energy home construction and the adoption of a near net-zero energy home (nNZEH), NZEH Ready and NZEH standard.
- The Canada Mortgage and Housing Corporation is sponsoring the EQuilibrium Sustainable Housing Competition that will see the completion of fifteen zero-energy and near-zero-energy demonstration projects across the country starting in 2008.
- The EcoTerra House in Eastman, Quebec, is Canada's first nearly net zero-energy housing built through the CMHC EQuilibrium Sustainable Housing Competition. The house was designed by Dr. Masa Noguchi of the Mackintosh School of Architecture for Alouette Homes and engineered by Prof. Dr. Andreas K. Athienitis of Concordia University.
- EcoPlusHome in Bathurst, New Brunswick. The Eco Plus Home is a prefabricated test house built by Maple Leaf Homes and with technology from Bosch Thermotechnology.

China

- One example of the new generation of zero energy office buildings is the 71-story Pearl River Tower, which opened in 2009, as the Guangdong Company headquarters. It uses both modest energy efficiency, and a big distributed renewable energy generation from both solar and wind. Designed by Skidmore Owings Merrill LLP in Guangzhou, China, the tower is receiving economic support from government subsidies that are now funding many significant conventional fossil-fuel (and nuclear energy) energy reduction efforts.

- Dongtan Eco-City near Shanghai

Germany

- Technische Universität Darmstadt won first place in the international zero energy design 2007 Solar Decathlon competition, with a passivhaus design (Passive house) + renewables, scoring highest in the Architecture, Lighting, and Engineering contests
- *Self-Sufficient Solar House* Fraunhofer Institute for Solar Energy Systems(ISE), Freiburg im Breisgau

Ireland

In 2005 *Scandinavian Homes* launched the worlds first standardised passive house in Ireland, this concept makes the design and construction of passive house a standardised process. Conventional low energy construction techniques have been refined and modelled on the PHPP (Passive House Design Package) to create the standardised passive house. Building offsite allows high precision techniques to be utilised and reduces the possibility of errors in construction.
In 2009 the same company started a project to use 23,000 liters of water in a *seasonal storage tank*, heated up by evacuated solar tubes throughout the year, with the aim to provide the house with enough heat throughout the winter months thus eliminating the need for any electrical heat to keep the house comfortably warm. 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.

Malaysia

In October 2007, the Malaysia Energy Centre (PTM) successfully completed the development and construction of the PTM Zero Energy Office (ZEO) Building. The building has been designed to be a super-energy-efficient building using only 286 kW·h/day. The renewable energy - photovoltaic combination is expected to result in a net zero energy requirement from the grid. The building is currently undergoing a fine tuning process by the local energy management team. Findings are expected to be published in a year.

Norway

In February 2009, the Research Council of Norway assigned The Faculty of Architecture and Fine Art at the Norwegian University of Science and Technology to host the Research Centre on Zero Emission Buildings (ZEB), which is one of eight new national Centres for Environment-friendly Energy Research (FME). The main objective of the

FME-centres is to contribute to the development of good technologies for environmentally friendly energy and to raise the level of Norwegian expertise in this area. In addition, they should help to generate new industrial activity and new jobs. Over the next eight years, the FME-Centre ZEB will develop competitive products and solutions for existing and new buildings that will lead to market penetration of zero emission buildings related to their production, operation and demolition.

Singapore

Singapore's First Zero Energy Building Launched at the Inaugural Singapore Green Building Week

United Arab Emirates

- Masdar City in Abu Dhabi

United Kingdom

In December 2006 the government announced that by 2016 all new homes in England will be zero energy buildings. To encourage this, an exemption from Stamp Duty Land Tax is planned. In Wales the plan is for the standard to be met earlier in 2011, although it is looking more likely that the actual implementation date will be 2012.

- BedZED development

United States

In the US, ZEB research is currently being supported by the US Department of Energy (DOE) Building America Program , including industry-based consortia and researcher organizations at the National Renewable Energy Laboratory (NREL), the Florida Solar Energy Center (FSEC), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). From fiscal year 2008 to 2012, DOE plans to award $40 million to four Building America teams, the Building Science Corporation; IBACOS; the Consortium of Advanced Residential Buildings; and the Building Industry Research Alliance, as well as a consortium of academic and building industry leaders. The funds will be used to develop net-zero-energy homes that consume at 50% to 70% less energy than conventional homes.

DOE is also awarding $4.1 million to two regional building technology application centers that will accelerate the adoption of new and developing energy-efficient technologies. The two centers, located at the University of Central Florida and Washington State University, will serve 17 states, providing information and training on commercially available energy-efficient technologies.

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 soon demonstrate multiple new technology innovations and mass production economies of scale.

Arizona

- Zero Energy House developed by the NAHB Research Center and John Wesley Miller Companies, Tucson.

California

- The IDeAs Z2 Design Facility is a net zero energy, zero carbon retrofit project occupied since 2007. It uses less than one fourth the energy of a typical U.S. office by applying strategies such as daylighting, radiant heating/cooling with a ground-source heat pump and high energy performance lighting and computing. The remaining energy demand is met with renewable energy from its building-integrated photovoltaic array. In 2009, building owner and occupant Integrated Design Associates (IDeAs) recorded actual measured energy use intensity of 21.17 kbtu/sf-year, with 21.72 kbtu/sf-year produced, for a net of -0.55 kbtu/sf-yr. The building is also carbon neutral, with no gas connection, and with carbon offsets purchased to cover the embodied carbon of the building materials used in the renovation.

- Googleplex, Google's headquarters in Mountain View, California, completed a 1.6 megawatt photovoltaic campus-wide renewable power generation system. Google (and others) have developed advanced technology for major reductions in computer-server energy consumption (which is becoming a major portion of modern zero-energy commercial building design, along with daylighting and efficient electrical lighting systems).

Florida

- The 1999 side-by-side Florida Solar Energy Center Lakeland Florida demonstration project was called the "Zero Energy Home." It was a first-generation university effort that significantly influenced the creation of the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Zero Energy Home program. George Bush's Solar America Initiative is funding research and development into widespread near-future development of cost-effective Zero Energy Homes in the amount of $148 million in 2008.

Michigan

- The Mission Zero House is the 110-year-old Ann Arbor home of Greenovation.TV host and Environment Report contributor Matthew Grocoff . As of 2011, the home is the oldest home in America to achieve net-zero energy.. The owners are chronicling their project on Greenovation.TV and the Environment Report on public radio.

- The Vineyard Project is a Zero Energy Home (ZEH) thanks to the Passive Solar Design, 3.3 Kws of Photovoltaics,Solar Hot Water and Geothermal Heating and Cooling. The home is pre-wired for a future wind turbine and only uses 600kwh of energy per month while a minimum of 20 kWh of electricity per day with many days net-metering backwards. The project also used ICF insulation throughout the entire house and is certified as Platinum under the LEED for Homes certification. This Project was awarded Green Builder Magazine Home of the Year 2009

New Jersey

- The 31 Tannery Project, located in Branchburg, New Jersey, serves as the corporate headquarters for Ferreira Construction, the Ferreira Group, and Noveda Technologies. The 42,000-square-foot (3,900 m^2) office and shop building was constructed in 2006 and is the 1st building in the state of New Jersey to meet New Jersey's Executive Order 54. The building is also the first Net Zero Electric Commercial Building in the United States.

Oklahoma

- The first 5,000-square-foot Zero Energy Design® home was built in 1979 with support from President Carter's new United States Department of Energy. It relied heavily on passive solar building design for space heat, water heat and space cooling. It heated and cooled itself effectively in a climate where the summer peak temperature was 110 degrees Fahrenheit, and the winter low temperature was -10 F. It did not use active solar systems. It is a double envelope house that uses a gravity-fed natural convection air flow design to circulate passive solar heat from 1,000 square feet of south-facing glass on its greenhouse through a thermal buffer zone in the winter. A swimming pool in the greenhouse provided thermal mass for winter heat storage. In the summer, air from two 24-inch 100-foot-long underground earth tubes is used to cool the thermal buffer zone and exhaust heat through 7200 cfm of outer-envelope roof vents.

Vermont

- The Putney School's net zero Field house was opened October 10, 2009.
- The Charlotte Vermont House designed by Pill - Maharam Architects is a verified net zero energy house completed in 2007. The project won the Northeast Sustainable Energy Association's Net Zero Energy award in 2009.

Chapter- 3

Passive House

One of the original 1990 **Passive Houses**, located in Darmstadt, Germany.

The term **Passive house** (***Passivhaus*** in German) refers to the rigorous, voluntary, *Passivhaus* standard for energy efficiency in a building, reducing its ecological footprint. It results in ultra-low energy buildings that require little energy for space heating or cooling. A similar standard, *MINERGIE-P*, is used in Switzerland. The standard is not confined only to residential properties; several office buildings, schools, kindergartens and a supermarket have also been constructed to the standard. Passive design is not the attachment or supplement of architectural design, but an integrated design process with the architectural design. Although it is mostly applied to new buildings, it has also been used for refurbishments.

Estimates on the number of Passivhaus buildings around the world in late 2008 ranged from 15,000 to 20,000 structures. As of August 2010, there were approximately 25,000 such certified structures of all types in Europe, while in the United States there were only 13, with a few dozens more under construction. The vast majority of Passive structures have been built in German-speaking countries and Scandinavia.

History

Prof. Bo Adamson of Sweden, co-originator of the **Passivhaus** concept.

Prof. Wolfgang Feist of Germany, co-originator of the **Passivhaus** concept, and founder of the **Passivhaus Institut**.

The Passivhaus standard originated from a conversation in May 1988 between Professors Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the *Institut für Wohnen und Umwelt* (Institute for Housing and the Environment, Germany). Their concept was developed through a number of research projects , aided by financial assistance from the German state of Hesse.

First examples

The eventual building of four row houses (terraced houses or town homes), was designed for four private clients by the Architectural firm of professors Bott, Ridder and Westermeyer. The first Passivhaus residences were built in Darmstadt, Germany in 1990, and occupied by the clients by the following year.

Further implementation and councils

In September 1996 the Passivhaus-Institut was founded, also in Darmstadt, to promote and control the standards. Since then, thousands of Passivhaus structures have been built, to an estimated 25,000+ as of 2010 Most are located in Germany and Austria, with others in various countries worldwide.

After the concept had been validated at Darmstadt, with space heating 90% less than required for a standard new building of the time, the 'Economical Passive Houses Working Group' was created in 1996. This developed the planning package and initiated the production of the novel components that had been used, notably the windows and the high-efficiency ventilation systems. Meanwhile further passive houses were built in Stuttgart (1993), Naumburg, Hesse, Wiesbaden, and Cologne (1997) .

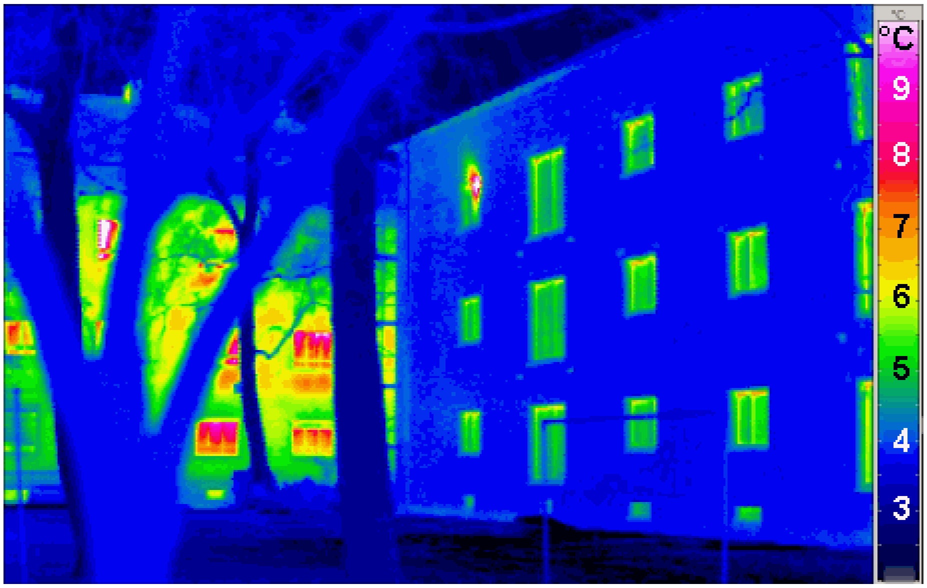
The products developed for the Passivhaus standard were further commercialised during and following the European Union sponsored CEPHEUS project, which proved the concept in five European countries over the winter of 2000-2001. In North America the first Passivhaus was built in Urbana, Illinois in 2003, and the first to be certified was built in 2006 near Bemidji, Minnesota in Camp Waldsee of the German Concordia Language Villages.
The first US *retrofit* project was certified in July of 2010, the remodeled 2,400 sf craftsman O'Neill house in the town of Sonoma, California.

The *world's first standardised "Passive prefabricated House* was built in Ireland in 2005 by *Scandinavian Homes* , a Swedish company that has since built more '"Passive houses" in England and Poland .

Present day

Estimates on the number of passive houses around the world range from 15,000 to 20,000. The vast majority have been built in German-speaking countries or Scandinavia.

Standards



The dark colours on this thermogram of a **Passive house**, at right, shows how little heat is escaping compared to a traditional building to the left.

While some techniques and technologies were specifically developed for the Passive House standard, others, such as superinsulation, already existed, and the concept of passive solar building design dates back to antiquity. There was also other previous experience with low-energy building standards, notably the German *Niedrigenergiehaus* (low-energy house) standard, as well as from buildings constructed to the demanding energy codes of Sweden and Denmark.

Requirements

The Passivhaus standard for central Europe requires that the building fulfills the following requirements:

- The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m^2 per year (4746 btu/ft^2 per year) in heating and 15 kWh/m^2 per year cooling energy OR to be designed with a peak heat load of 10W/m^2
- Total primary energy (source energy for electricity and etc.) consumption (primary energy for heating, hot water and electricity) must not be more than 120 kWh/m^2 per year (3.79×10^4 btu/ft^2 per year)
- The building must not leak more air than 0.6 times the house volume per hour ($n_{50} \leq 0.6$ / hour) at 50 Pa (N/m^2) as tested by a blower door,

Recommendations

- Further, the specific heat load for the heating source at design temperature is recommended, but not required, to be less than 10 W/m^2 (3.17 btu/ft^2 per hour).

These standards are much higher than houses built to most normal building codes.

National partners within the 'consortium for the Promotion of European Passive Houses' are thought to have some flexibility to adapt these limits locally.

Space heating requirement

By achieving the Passivhaus standards, qualified buildings are able to dispense with conventional heating systems. While this is an underlying objective of the Passivhaus standard, some type of heating will still be required and most Passivhaus buildings do include a system to provide supplemental space heating. This is normally distributed through the low-volume heat recovery ventilation system that is required to maintain air quality, rather than by a conventional hydronic or high-volume forced-air heating system, as described in the space heating section below.

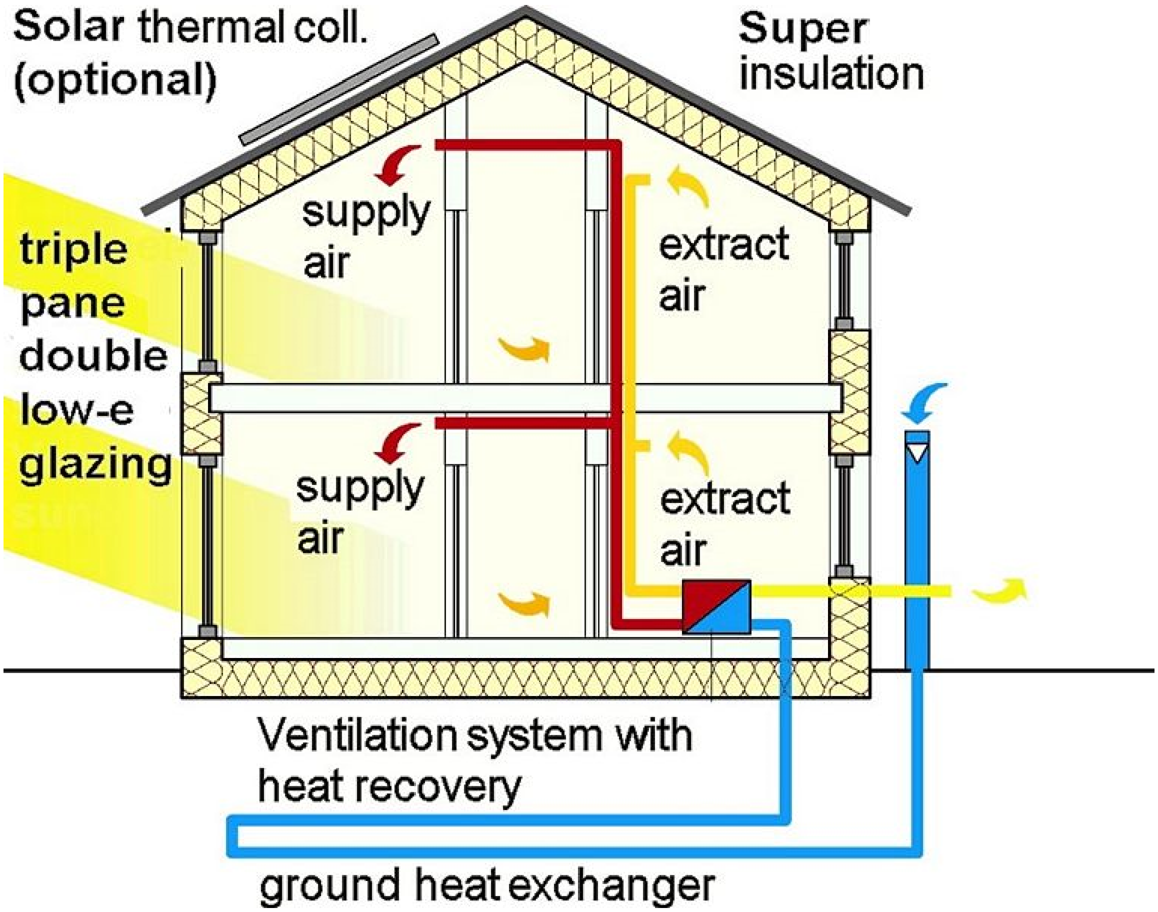
Construction costs

In Passivhaus buildings, the cost savings from dispensing with the conventional heating system can be used to fund the upgrade of the building envelope and the heat recovery ventilation system. With careful design and increasing competition in the supply of the specifically designed Passivhaus building products, in Germany it is now possible to construct buildings for the same cost as those built to normal German building standards, as was done with the Passivhaus apartments at Vauban, Freiburg. On average, however, passive houses are still up to 14% more expensive upfront than conventional buildings.

Evaluations have indicated that while it is technically possible, the costs of meeting the Passivhaus standard increase significantly when building in Northern Europe above 60° latitude. European cities at approximately 60° include Helsinki in Finland and Bergen in Norway. London is at 51°; Moscow is at 55°.

These facts have led a number of architects to construct buildings that use the ground under the building for massive heat storage to shift heat production from the winter to the summer. Some buildings can also shift cooling from the summer to the winter. At least one designer uses a passive thermosiphon carrying only air, so the process can be accomplished without expensive, unreliable machinery.

Design and construction



The **Passivhaus** uses a combination of low-energy building techniques and technologies.

Achieving the major decrease in heating energy consumption required by the standard involves a shift in approach to building design and construction. Design is carried out with the aid of the 'Passivhaus Planning Package' (PHPP) , and uses specifically designed computer simulations.

To achieve the standards, a number of techniques and technologies are used in combination:

Passive solar design and landscape

Passive solar building design and energy-efficient landscaping support the Passive house energy 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.

Passive 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.

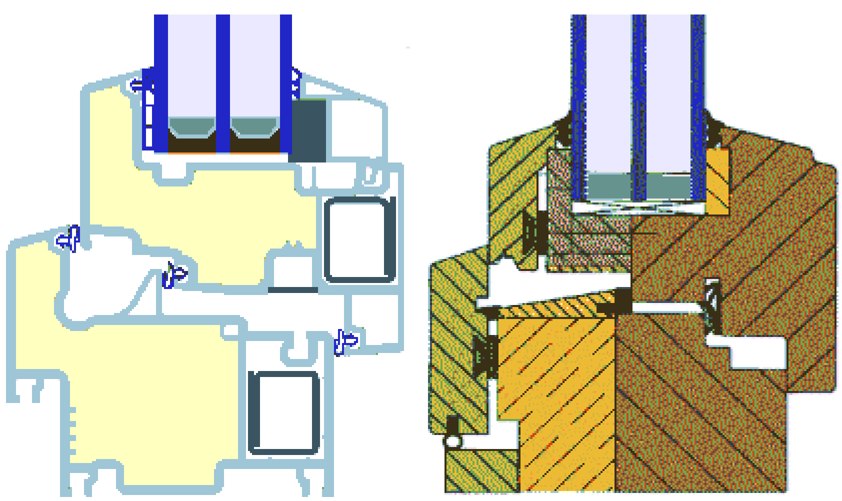
Superinsulation

Passivhaus buildings employ superinsulation to significantly reduce the heat transfer through the walls, roof and floor compared to conventional buildings. A wide range of thermal insulation materials can be used to provide the required high R-values (low U-values, typically in the 0.10 to 0.15 W/(m².K) range). Special attention is given to eliminating thermal bridges.

A disadvantage resulting from the thickness of wall insulation required is that, unless the external dimensions of the building can be enlarged to compensate, the internal floor area of the building may be less compared to traditional construction.

In Sweden, to achieve passive house standards, the insulation thickness would be 335 mm (about 13 in) (0.10 W/(m².K)) and the roof 500 mm (about 20 in) (U-value 0.066 W/(m².K)).

Advanced window technology



Typical **Passive House** windows

To meet the requirements of the Passivhaus standard, windows are manufactured with exceptionally high R-values (low U-values, typically 0.85 to 0.70 W/(m².K) for the entire window including the frame). These normally combine triple-pane insulated glazing (with a good solar heat-gain coefficient, low-emissivity coatings, sealed argon or krypton gas filled inter-pane voids, and 'warm edge' insulating glass spacers) with air-seals and specially developed thermally broken window frames.

In Central Europe and most of the United States, for unobstructed south-facing Passivhaus windows, the heat gains from the sun are, on average, greater than the heat losses, even in mid-winter.

Airtightness

Building envelopes under the Passivhaus standard are required to be extremely airtight compared to conventional construction. Air barriers, careful sealing of every construction joint in the building envelope, and sealing of all service penetrations through it are all used to achieve this.

Airtightness minimizes the amount of warm - or cool- air that can pass through the structure, enabling the mechanical ventilation system to recover the heat before discharging the air externally.

Ventilation

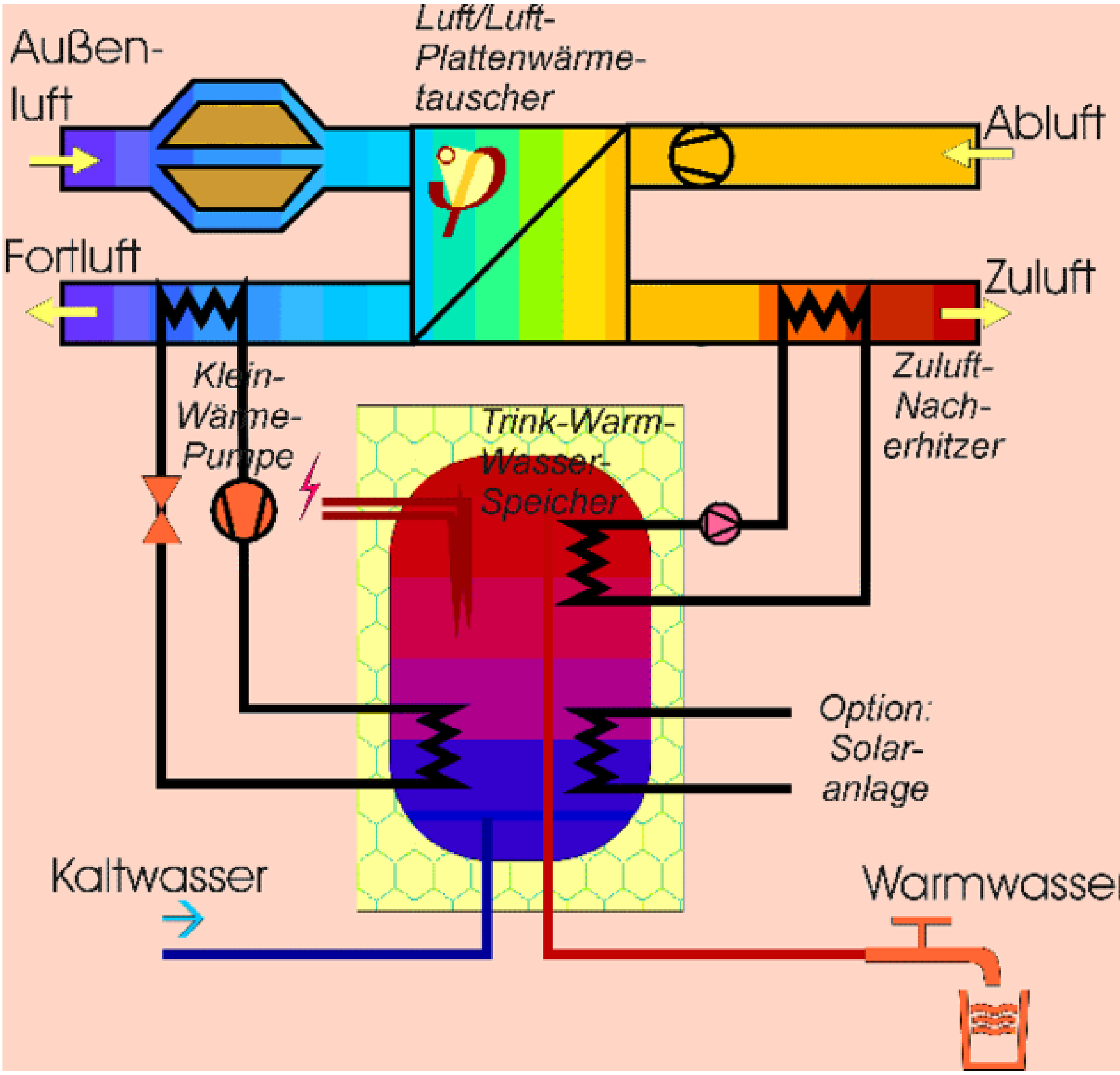
Passive methods of natural ventilation by singular or cross ventilation; by a simple opening or enhanced by the stack effect from smaller ingress - larger egress windows and/or clerestory-openable skylight use; is obvious when the exterior temperature is acceptable.

When not, mechanical heat recovery ventilation systems, with a heat recovery rate of over 80% and high-efficiency electronically commutated motors (ECM), are employed to maintain air quality, and to recover sufficient heat to dispense with a conventional central heating system. Since the building is essentially air-tight, the rate of air change can be optimized and carefully controlled at about 0.4 air changes per hour. All ventilation ducts are insulated and sealed against leakage.

Although not compulsory, earth warming tubes (typically ≈200 mm (~7,9 in) diameter, ≈40 m (~130 ft) long at a depth of ≈1.5 m (~5 ft)) are often buried in the soil to act as earth-to-air heat exchangers and pre-heat (or pre-cool) the intake air for the ventilation system. In cold weather the warmed air also prevents ice formation in the heat recovery system's heat exchanger.

Alternatively, an earth to air heat exchanger, can use a liquid circuit instead of an air circuit, with a heat exchanger (battery) on the supply air.

Space heating



Passivhaus: In addition to the heat exchanger (centre), a micro-heat pump extracts heat from the exhaust air (left) and hot water heats the ventilation air (right). The ability to control building temperature using only the normal volume of ventilation air is fundamental.

In addition to using passive solar gain, Passivhaus buildings make extensive use of their intrinsic heat from internal sources—such as waste heat from lighting, white goods (major appliances) and other electrical devices (but not dedicated heaters)—as well as body heat from the people and other animals inside the building. This is due to the fact that people, on average, emit heat equivalent to 100 watts each of radiated thermal energy.

Together with the comprehensive energy conservation measures taken, this means that a conventional central heating system is not necessary, although they are sometimes installed due to client skepticism.

Instead, Passive houses sometimes have a dual purpose 800 to 1,500 watt heating and/or cooling element integrated with the supply air duct of the ventilation system, for use during the coldest days. It is fundamental to the design that all the heat required can be transported by the normal low air volume required for ventilation. A maximum air temperature of 50 °C (122 °F) is applied, to prevent any possible smell of scorching from dust that escapes the filters in the system.

The air-heating element can be heated by a small heat pump, by direct solar thermal energy, annualized geothermal solar, or simply by a natural gas or oil burner. In some cases a micro-heat pump is used to extract additional heat from the exhaust ventilation air, using it to heat either the incoming air or the hot water storage tank. Small wood-burning stoves can also be used to heat the water tank, although care is required to ensure that the room in which stove is located does not overheat.

Beyond the recovery of heat by the heat recovery ventilation unit, a well designed Passive house in the European climate should not need any supplemental heat source if the heating load is kept under 10W/m² .

Because the heating capacity and the heating energy required by a passive house both are very low, the particular energy source selected has fewer financial implications than in a traditional building, although renewable energy sources are well suited to such low loads.

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 Passivhaus 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 Passive houses. The ecolabel certification marks of Energy Star and EKOenergy are examples.

Traits of passive houses

Due to their design, passive houses usually have the following traits:

- The air is fresh, and very clean. Note that for the parameters tested, and provided the filters (minimum F6) are maintained, HEPA quality air is provided. 0.3 air changes per hour (ACH) are recommended, otherwise the air can become "stale" (excess CO_2, flushing of indoor air pollutants) and any greater, excessively dry (less than 40% humidity). This implies careful selection of interior finishes and furnishings, to minimize indoor air pollution from VOC's (e.g., formaldehyde). The use of a mechanical venting system also implies higher positive ion values. This can be counteracted somewhat by opening a window for a very brief time, by plants, and by indoor fountains. However, failure to exchange air with the outside during occupied periods is not advisable.
- Because of the high resistance to heat flow (high R-value insulation), there are no "outside walls" which are colder than other walls.
- Inside temperature is homogeneous; it is impossible to have single rooms (e.g. the sleeping rooms) at a different temperature from the rest of the house. Note that the relatively high temperature of the sleeping areas is physiologically not considered desirable by some building scientists. Bedroom windows can be cracked open slightly to alleviate this when necessary.
- The temperature changes only very slowly - with ventilation and heating systems switched off, a passive house typically loses less than 0.5 °C (1 °F) per day (in winter), stabilizing at around 15 °C (59 °F) in the central European climate.
- Opening windows or doors for a short time has only a very limited effect; after the windows are closed, the air very quickly returns to the "normal" temperature.

International comparisons

- In the United States, a house built to the Passive House standard results in a building that requires space heating energy of 1 BTU per square foot per heating degree day, compared with about 5 to 15 BTUs per square foot per heating degree day for a similar building built to meet the 2003 Model Energy Efficiency Code. This is between 75 and 95% less energy for space heating and cooling than current new buildings that meet today's US energy efficiency codes. The Passivhaus in the German-language camp of Waldsee, Minnesota uses 85% less energy than a house built to Minnesota building codes.
- In the United Kingdom, an average new house built to the Passive House standard would use 77% less energy for space heating, compared to the Building Regulations.
- In Ireland, it is calculated that a typical house built to the Passive House standard instead of the 2002 Building Regulations would consume 85% less energy for space heating and cut space-heating related carbon emissions by 94%.

Comparison with zero energy buildings

A net zero-energy building (ZEB) is a building that over a year does not use more energy than it generates. The first 1979 Zero Energy Design ® building used passive solar heating and cooling techniques with air-tight construction and super insulation. Many recent ZEB's fail to fully exploit passive technology and use onsite active renewable energy technologies like photovoltaic to offset the building's primary energy consumption. Passive House and ZEB are complementary synergistic technology approaches, based on the same physics of thermal energy transfer and storage.

Tropical climate needs

In a tropical climate, it could be helpful for ideal internal conditions to use Energy Recovery Ventilation instead of Heat Recovery Ventilation to remove the excess humidity into the drains and excess heat into the hot water tank. Passive cooling, solar air conditioning, and other solutions in passive solar building design need to be studied to adapt the Passive house concept for use in more regions of the world.

There is a certified Passive House in the hot and humid climate of Lafayette, Louisiana, USA, which uses Energy Recovery Ventilation.

Chapter- 4

Heat Recovery Ventilation

Heat recovery ventilation, also known as **HRV**, **Mechanical ventilation heat recovery**, or **MVHR**, is an energy recovery ventilation system, using equipment known as a heat recovery ventilator, Heat exchanger, air exchanger or air-to-air exchanger, that employs a counter-flow heat exchanger (countercurrent heat exchange) between the inbound and outbound air flow. HRV provides fresh air and improved climate control, while also saving energy by reducing the heating (or cooling) requirements.

Energy recovery ventilators (ERVs) are closely related, however ERVs also transfer the humidity level of the exhaust air to the intake air.

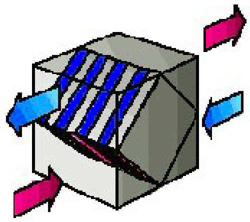
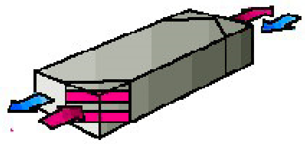
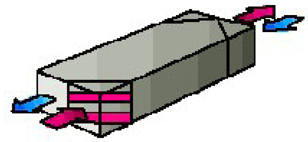
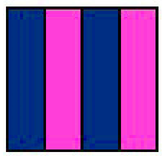
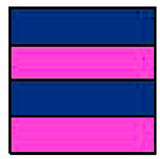
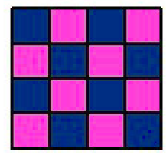
Benefits

As building efficiency is improved with insulation and weatherstripping, buildings are intentionally made more air-tight, and consequently less well ventilated. Since all buildings require a source of fresh air, the need for HRVs has become obvious. While opening a window does provide ventilation, the building's heat and humidity will then be lost in the winter and gained in the summer, both of which are undesirable for the indoor climate and for energy efficiency, since the building's HVAC systems must compensate. HRV technology offers an optimal solution: fresh air, better climate control, and Energy efficiency - Sustainability.

Technology

Heat recovery ventilation-HRVs and ERVs can be stand-alone devices that operate independently, or they can be built-in, or added to existing HVAC systems. For a small building in which nearly every room has an exterior wall, then the HRV/ERV device can be small and provide ventilation for a single room. A larger building would require either many small units, or a large central unit. The only requirements for the building are an air supply, either directly from an exterior wall or ducted to one, and an energy supply for air circulation, such as wind energy or electricity for a fan. When used with 'central' HVAC systems, then the system would be of the 'forced-air' type.

Air to air heat exchanger

Principle			www.paul-lueftung.de 
Profile			
Counter current Heat exchanger	Vertical flat plate	Horizontal flat plate	Cellular
Efficiency	50 - 70 %	70 - 80 %	85 - 99 %

A Heat exchanger.

There are a number of heat exchangers used in Heat recovery ventilation-HRV devices, as diagrammed to the right :

- cross flow heat exchanger up to 60% efficient (passive)
- countercurrent heat exchanger up to 99% efficient (passive)
- rotary heat exchanger (requires motor to turn wheel)
- heat pipes
- thin multiple heat wires (Fine wire heat exchanger)

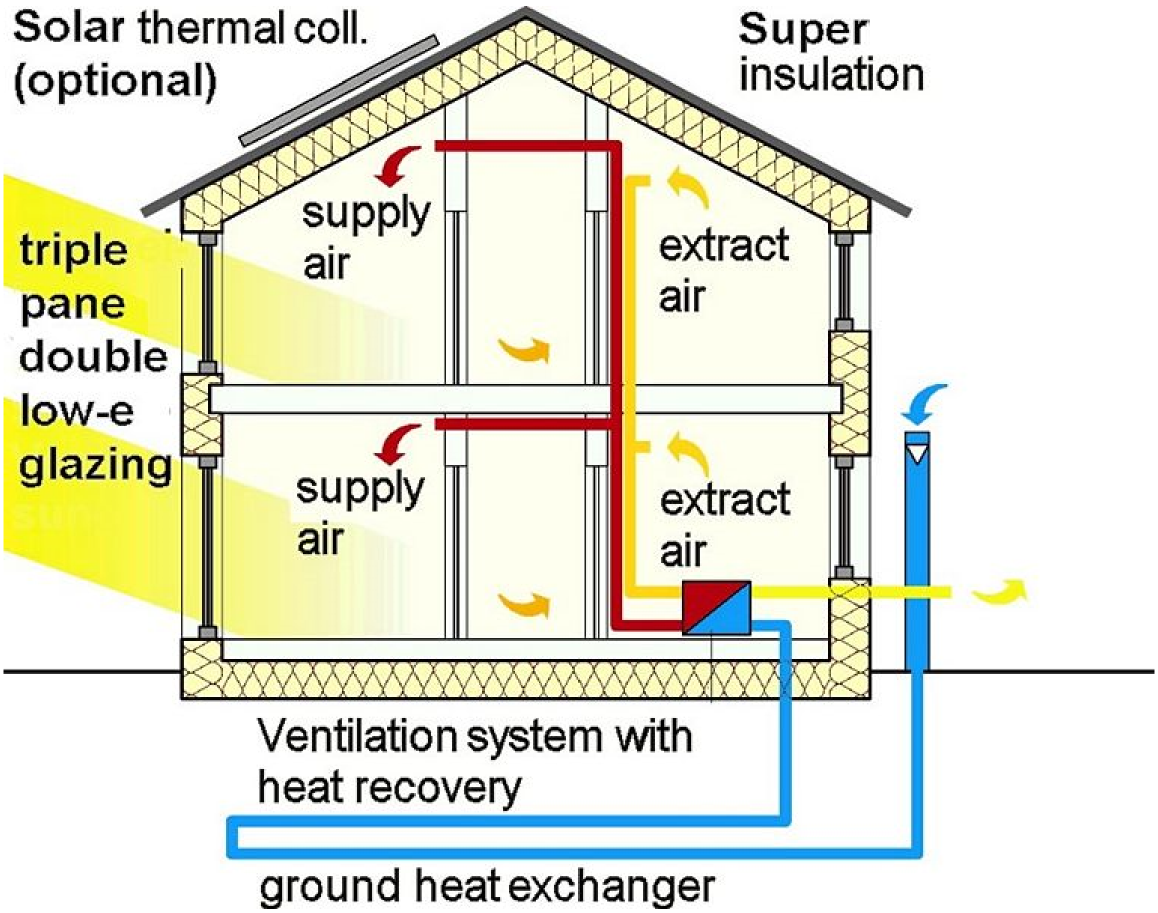
Incoming air

The air coming into the heat exchanger should be at least 0°C. Otherwise humidity in the outgoing air may condense, freeze and block the heat exchanger.

A high enough incoming air temperature can also be achieved by

- recirculating some of the exhaust air (causing loss of air quality) when required,
- by using a very small (1 kW) heat pump to warm the inlet air above freezing before it enters the HRV. (The 'cold' side of this heatpump is situated in the warm air outlet.)
- using a heating "battery" supplied by heat from a heat source eg hot water circuit from a wood fired boiler, etc.

Earth-to-air heat exchanger



Heat recovery ventilation, often with an earth-to-air heat exchanger, is essential to achieve German Passivhaus standards.

This can be done by an earth warming pipe ("ground-coupled heat exchanger"), usually about 30 m to 40 m long and 20 cm in diameter, typically buried about 1.5 m below ground level. In Germany and Austria this is a common configuration for earth to air heat exchangers.

In high humidity areas where internal condensation could lead to fungal / mould growth in the tube leading to contamination of the air, several measures exist to prevent this.

- Ensuring the tube drains of water.
- Regular cleaning
- Tubes with an imbedded bactericide coating such as silver ions (non-toxic for humans)
- Air filters F7 / EU7 (>0,4 micrometres) to traps mould (of a size between 2 & 20 micrometres).
- UV air purification

- Use a earth to "water" heat exchanger, see below.

The pipes may be either corrugated/slotted to enhance heat transfer and provide condensate drainage or smooth/solid to prevent gas/liquid transfer.

Air quality

This is highly site dependent.

Radon

One critical problem being located in soils with underlying rock strata which emit radon. In these situations the tube needs to be airtight from the surrounding soils, or an Air to Water heat exchanger be used.

Bacteria and fungi

Formal research indicates that Earth-Air Heat Exchangers reduce building ventilation air pollution. Rabindra (2004) states, “The Earth-Air Tunnel is found not to support the growth of bacteria and fungi; rather it is found to reduce the quantity of bacteria and fungi thus making the air safer for humans to inhale. It is therefore clear that the use of EAT (Earth-Air Tunnel) not only helps save the energy but also helps reduce the air pollution by reducing bacteria and fungi.”

Likewise, Flueckiger (1999) in a study of twelve Earth-Air Heat Exchangers varying in design, pipe material, size and age, stated, “This study was performed because of concerns of potential microbial growth in the buried pipes of 'ground-coupled' air systems. The results however demonstrate, that no harmful growth occurs and that the airborne concentrations of viable spores and bacteria, with few exceptions, even decreases after passage through the pipe-system”, and further stated, “Based on these investigations the operation of ground-coupled earth-to-air heat exchangers is acceptable as long as regular controls are undertaken and if appropriate cleaning facilities are available”.

Earth-to-Water heat exchanger

An alternative to the earth to air heat exchanger is the earth to "water" heat exchanger. This is typically similar to a geothermal heat pump tubing embedded horizontally in the soil (or could be a vertical pipe/sonde) to a similar depth of the EAHX. It uses approximately double the length of pipe Ø 35 mm ie around 80 metres compared to an EAHX. A heat exchanger coil is placed before the air inlet of the HRV. Typically a brine liquid (heavily salted water) is used as the heat exchange fluid which is slightly more efficient and environmentally friendly than polypropylene heat transfer liquids.

In temperate climates in an energy efficient building, such as a passivhaus, this is more than sufficient for comfort cooling during summer without resorting to an airconditioning system. In more extreme hot climates a very small air to air micro-heat pump in reverse (an air conditioner) with the evaporator (giving heat) on the air inlet after the HRV heat exchanger and the condensor (taking heat) from the air outlet after the heat exchanger will suffice.

Seasonal bypassing

At certain times of the year it is more thermally efficient to bypass the Heat recovery ventilation-HRV heat exchanger or the earth to air heat exchanger (EAHX).

For example, during the winter, the earth at the depth of the earth to air heat exchanger is ordinarily much warmer than the air temperature. The air becomes warmed by the earth before reaching the air heat exchanger.

In the summer, the opposite is true. The air becomes cooled in the earth to air exchanger. But after passing through the EAHX, the air is warmed by the heat recovery ventilator using the warmth of the outgoing air. In this case, the HRV can have an internal bypass such that the inflowing air bypasses the heat exchanger maximising the cooling potential of the earth.

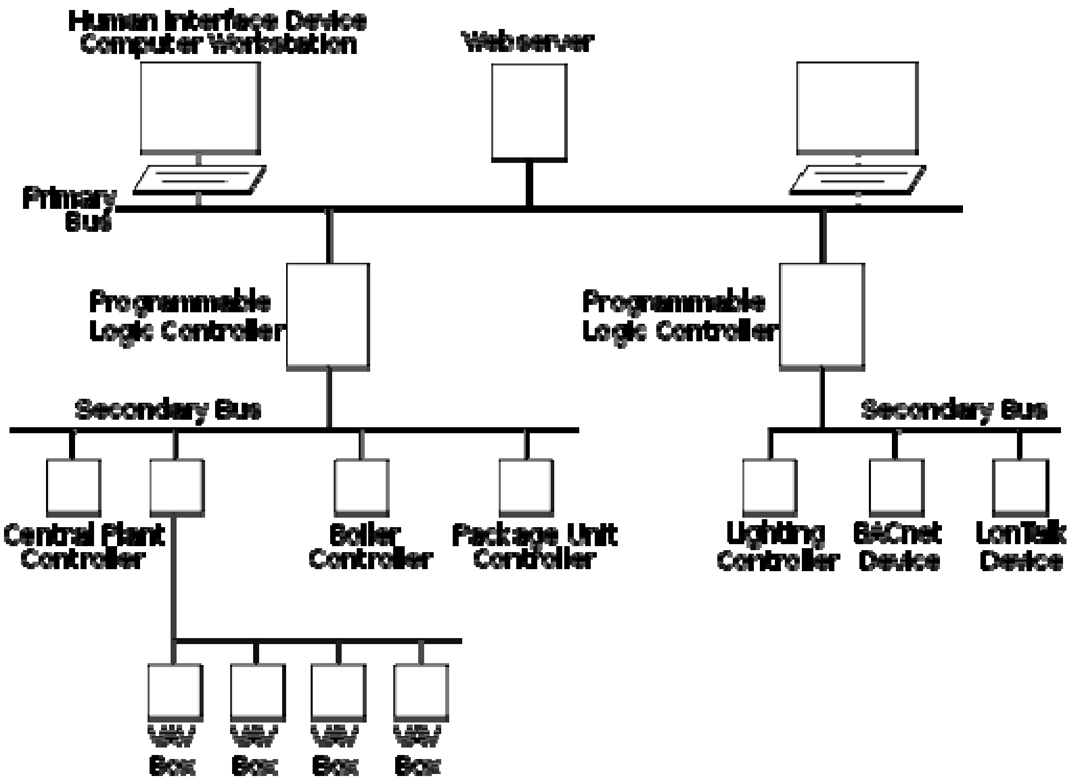
In autumn and spring there may be no thermal benefit from the EAHX—it may heat/cool the air too much and it will be better to use external air directly. In this case it is helpful to have a bypass such that the EAHX is disconnected and air taken directly from outside. A differential temperature sensor with a motorized valve can control the bypass function.

Chapter- 5

Building Automation

Building automation describes the functionality provided by the control system of a building. A building automation system (BAS) is an example of a distributed control system. The control system is a computerized, intelligent network of electronic devices, designed to monitor and control the mechanical and lighting systems in a building.

BAS core functionality keeps the building climate within a specified range, provides lighting based on an occupancy schedule, and monitors system performance and device failures and provides email and/or text notifications to building engineering staff. The BAS functionality reduces building energy and maintenance costs when compared to a non-controlled building. A building controlled by a BAS is often referred to as an intelligent building system.



Topology

Most building automation networks consist of a *primary* and *secondary* bus which connect high-level controllers (generally specialized for building automation, but may be generic programmable logic controllers) with lower-level controllers, input/output devices and a user interface (also known as a human interface device).

The primary and secondary bus can be BACnet, optical fiber, ethernet, ARCNET, RS-232, RS-485 or a wireless network.

Most controllers are proprietary. Each company has its own controllers for specific applications. Some are designed with limited controls: for example, a simple Packaged Roof Top Unit. Others are designed to be flexible. Most have proprietary software that will work with ASHRAE's open protocol BACnet or the open protocol LonTalk.

Some newer building automation and lighting control solutions use wireless mesh open standards (such as ZigBee. These systems can provide interoperability, allowing users to mix-and-match devices from different manufacturers, and to provide integration with other compatible building control systems.

Inputs and outputs are either analog or digital (some companies say binary).

Analog inputs are used to read a variable measurement. Examples are temperature, humidity and pressure sensor which could be thermistor, 4-20 mA, 0-10 volt or platinum resistance thermometer (resistance temperature detector), or wireless sensors.

A digital input indicates if a device is turned on or not. Some examples of an digital input would be a 24VDC/AC signal, an air flow switch, or a volta-free relay contact (Dry Contact).

Analog outputs control the speed or position of a device, such as a variable frequency drive, a I-P (current to pneumatics) transducer, or a valve or damper actuator. An example is a hot water valve opening up 25% to maintain a setpoint.

Digital outputs are used to open and close relays and switches. An example would be to turn on the parking lot lights when a photocell indicates it is dark outside.

Infrastructure

Controller

Controllers are essentially small, purpose-built computers with input and output capabilities. These controllers come in a range of sizes and capabilities to control devices commonly found in buildings, and to control sub-networks of controllers.

Inputs allow a controller to read temperatures, humidity, pressure, current flow, air flow, and other essential factors. The outputs allow the controller to send command and control signals to slave devices, and to other parts of the system. Inputs and outputs can be either digital or analog. Digital outputs are also sometimes called discrete depending on manufacturer.

Controllers used for building automation can be grouped in 3 categories. Programmable Logic Controllers (PLCs), System/Network controllers, and Terminal Unit controllers. However an additional device can also exist in order to integrate 3rd party systems (i.e. a stand-alone AC system) into a central Building automation system).

PLC's provide the most responsiveness and processing power, but at a unit cost typically 2 to 3 times that of a System/Network controller intended for BAS applications. Terminal Unit controllers are usually the least expensive and least powerful.

PLC's may be used to automate high-end applications such as clean rooms or hospitals where the cost of the controllers is a lesser concern.

In office buildings, supermarkets, malls, and other common automated buildings the systems will use System/Network controllers rather than PLC's. Most System controllers provide general purpose feedback loops, as well as digital circuits, but lack the millisecond response time that PLC's provide.

System/Network controllers may be applied to control one or more mechanical systems such as an Air Handler Unit (AHU), boiler, chiller, etc., or they may supervise a sub-network of controllers. In the diagram above, System/Network controllers are often used in place of PLCs.

Terminal Unit controllers usually are suited for control of lighting and/or simpler devices such as a package rooftop unit, heat pump, VAV box, or fan coil, etc. The installer typically selects 1 of the available pre-programmed personalities best suited to the device to be controlled, and does not have to create new control logic.

Occupancy

Occupancy is one of 2 or more operating modes for a building automation system. Unoccupied, Morning Warmup, and Night-time Setback are other common modes.

Occupancy is usually based on time of day schedules. In Occupancy mode, the BAS aims to provides a comfortable climate and adequate lighting, often with zone-based control so that users on one side of a building have a different thermostat (or a different system, or sub system) than users on the opposite side.

A temperature sensor in the zone provides feedback to the controller, so it can deliver heating or cooling as needed.

If enabled, Morning Warmup (MWU) mode occurs prior to Occupancy. During Morning Warmup the BAS tries to bring the building to setpoint just in time for Occupancy. The BAS often factors in outdoor conditions and historical experience to optimize MWU. This is also referred to as Optimised Start.

An override is a manually-initiated command to the BAS. For example, many wall-mounted temperature sensors will have a push-button that forces the system into Occupancy mode for a set number of minutes. Where present, web interfaces allow users to remotely initiate an override on the BAS.

Some buildings rely on occupancy sensors to activate lighting and/or climate conditioning. Given the potential for long lead times before a space becomes sufficiently cool or warm, climate conditioning is not often initiated directly by an occupancy sensor.

Lighting

Lighting can be turned on, off, or dimmed with a building automation or lighting control system based on time of day, or on occupancy sensors, photosensors and timers. One typical example is to turn the lights in a space on for a half hour since the last motion was sensed. A photocell placed outside a building can sense darkness, and the time of day, and modulate lights in outer offices and the parking lot.

Lighting is also a good candidate for Demand response, with many control systems providing the ability to dim (or turn off) lights to take advantage of DR incentives and savings. if occupancy sensors are present they can also be used as burglar alarms

Air handlers

Most air handlers mix return and outside air so less temperature change is needed. This can save money by using less chilled or heated water (not all AHUs use chilled/hot water circuits). Some external air is needed to keep the building's air healthy.

Analog or digital temperature sensors may be placed in the space or room, the return and supply air ducts, and sometimes the external air. Actuators are placed on the hot and chilled water valves, the outside air and return air dampers. The supply fan (and return if applicable) is started and stopped based on either time of day, temperatures, building pressures or a combination.

Constant volume air-handling units

The less efficient type of air-handler is a "constant volume air handling unit," or CAV. The fans in CAVs do not have variable-speed controls. Instead, CAVs open and close dampers and water-supply valves to maintain temperatures in the building's spaces. They heat or cool the spaces by opening or closing chilled or hot water valves that feed their internal heat exchangers. Generally one CAV serves several spaces, but large buildings may have many CAVs.

Variable volume air-handling units

A more efficient unit is a "variable air volume (VAV) air-handling unit," or VAV. VAVs supply pressurized air to VAV boxes, usually one box per room or area. A VAV air handler can change the pressure to the VAV boxes by changing the speed of a fan or blower with a variable frequency drive or (less efficiently) by moving inlet guide vanes to a fixed-speed fan. The amount of air is determined by the needs of the spaces served by the VAV boxes.

Each VAV box supply air to a small space, like an office. Each box has a damper that is opened or closed based on how much heating or cooling is required in its space. The more boxes are open, the more air is required, and a greater amount of air is supplied by the VAV air-handling unit.

Some VAV boxes also have hot water valves and an internal heat exchanger. The valves for hot and cold water are opened or closed based on the heat demand for the spaces it is supplying. These heated VAV boxes are sometimes used on the perimeter only and the interior zones are cooling only.

A minimum and maximum CFM must be set on VAV boxes to assure adequate ventilation and proper air balance.

VAV hybrid systems

Another variation is a hybrid between VAV and CAV systems. In this system, the interior zones operate as in a VAV system. The outer zones differ in that the heating is supplied by a heating fan in a central location usually with a heating coil fed by the building boiler. The heated air is ducted to the exterior dual duct mixing boxes and dampers controlled by the zone thermostat calling for either cooled or heated air as needed.

Central plant

A central plant is needed to supply the air-handling units with water. It may supply a chilled water system, hot water system and a condenser water system, as well as transformers and auxiliary power unit for emergency power. If well managed, these can often help each other. For example, some plants generate electric power at periods with peak demand, using a gas turbine, and then use the turbine's hot exhaust to heat water or power an absorptive chiller.

Chilled water system

Chilled water is often used to cool a building's air and equipment. The chilled water system will have chiller(s) and pumps. Analog temperature sensors measure the chilled water supply and return lines. The chiller(s) are sequenced on and off to chill the chilled water supply.

Condenser water system

Cooling tower(s) and pumps are used to supply cool condenser water to the chillers. Because the condenser water supply to the chillers has to be constant, variable speed drives are commonly used on the cooling tower fans to control temperature. Proper cooling tower temperature assures the proper refrigerant head pressure in the chiller. The cooling tower set point used depends upon the refrigerant being used. Analog temperature sensors measure the condenser water supply and return lines.

Hot water system

The hot water system supplies heat to the building's air-handling unit or VAV box heating coils, along with the domestic hot water heating coils (Calorifier). The hot water system will have a boiler(s) and pumps. Analog temperature sensors are placed in the hot water supply and return lines. Some type of mixing valve is usually used to control the heating water loop temperature. The boiler(s) and pumps are sequenced on and off to maintain supply.

Alarms and security

Many building automation systems have alarm capabilities. If an alarm is detected, it can be programmed to notify someone. Notification can be through a computer, pager, cellular phone, or audible alarm.

- Common temperature alarms are: space, supply air, chilled water supply and hot water supply.
- Differential pressure switches can be placed on the filter to determine if it is dirty.
- Status alarms are common. If a mechanical device like a pump is requested to start, and the status input indicates it is off. This can indicate a mechanical failure.
- Some valve actuators have end switches to indicate if the valve has opened or not.
- Carbon monoxide and carbon dioxide sensors can be used to alarm if levels are too high.
- Refrigerant sensors can be used to indicate a possible refrigerant leak.
- Current sensors can be used to detect low current conditions caused by slipping fan belts, or clogging strainers at pumps.

At sites with several buildings, momentary power failures can cause hundreds or thousands of alarms from equipment that has shut down. Some sites are programmed so that critical alarms are automatically re-sent at varying intervals. For example, a repeating critical alarm (of a uninterpretable power supply in 'by pass') might resound at 10 minutes, 30 minutes, and every 2 to 4 hours there after until the alarms are resolved.

Security systems can be interlocked to a building automation system. If occupancy sensors are present, they can also be used as burglar alarms.

Fire and smoke alarm systems can be hard-wired to override building automation. For example: if the smoke alarm is activated, all the outside air dampers close to prevent air coming into the building, and an exhaust system can isolate

Room automation

Room automation is a subset of Building automation and like it, is the consolidation of one or systems under centralised control but in this case in just one room.

The most common example of *room automation* is corporate boardroom, presentation suites, and lecture halls, where the operation of the large number of devices that define the room function (such as Videoconferencing equipment, Video projectors, lighting control systems, Public address systems etc.) would make manual operation of the room very complex. It is common for room automation systems to employ a touchscreen as the primary way of controlling each operation.

Chapter- 6

Over-Illumination

Over-illumination

This cosmetics store has lighting levels over twice recommended levels

Over-illumination is the presence of lighting intensity (illuminance) beyond that required for a specified activity. Over-illumination was commonly ignored between 1950 and 1995, especially in office and retail environments; only since then has the interior design community begun to reconsider this practice.

The concept of over-illumination encompasses two separate but related concerns:

- Use of more artificial illumination than required is expensive and energy-intensive. This includes consideration both of the appropriate level of illumination when spaces are in use, and when they are unoccupied.
- Clinical studies show that excessive levels of artificial light produce annoyance and health effects in a large fraction of the population. These effects may depend on the spectrum of the light as well as the overall brightness.

Lighting accounts for roughly 9% of U.S. residential electricity use and close to 40% of U.S. commercial building electricity use. Money and energy could be saved by, for example, turning off office building lights overnight, using natural light whenever possible, and taking full advantage of occupancy sensors or simply flipping manual light switches in unoccupied spaces. In response to these concerns, the design and architecture communities are making greater use of indirect sunlight in modern commercial buildings.

Numerical definition

Some big-box retail stores are over-illuminated.

Generally speaking, under-illumination occurs indoors when light levels fall below 320 lux for general office use. For comparison, the midday sun provides about 32,000 to 100,000 lux depending on latitude, time of year and cloud cover. The term over-illumination first came into reasonably broad use in the early 1990s, when the lighting, health and energy conservation fields realized its effects. Production of glare is a de facto indication of over-illumination, since that causes optical processing conflicts and confusion to the brain in processing optical inputs. Over-illumination is sometimes grouped with unnatural spectra because negative health effects may result from the excess illumination, and also because certain artificial lights (such as fluorescent lamps) provide intense illumination in certain frequency bands, unlike daylight, whose spectral power distribution is fairly even over the visible spectrum. The most desirable spectrum is that of natural light, which the body is attuned to and uses to set the circadian rhythms.

Related phenomena

Over-illumination can contribute to light pollution, where stray light illuminates the outdoors or others' property, where it is unwanted. Over-illumination is a topic normally addressed in the process of building design, whereas light pollution is normally addressed by zoning regulations.

Furthermore, over-illumination generally does not refer to the extreme conditions of snowblindness or arc eye, in which ultraviolet light can induce physical damage to the cornea.

Causes

Lighting unoccupied areas is a significant waste of energy. Many office buildings are illuminated overnight and on weekends. In some cases, this is so that janitors working overnight do not have to bother turning lights on and off. Lighting of unoccupied areas can be reduced by installation of occupancy sensors or timers.

Energy can also be wasted by operating outdoor lighting during daylight. In many cases this arises because the lights are controlled by timers, which must be reset periodically as the time of sunset varies throughout the year.

Forsaking use of sunlight

A fitness club that is illuminated mostly by natural light

Forsaking use of sunlight is often a design decision made by the architect or their subcontractor. Overlooking opportunities for skylights is a major defect of many building designs, but lack of coordination of interior light banks with indirect sunlight is an even more common error. At a minimum, the building design should offer sufficient independent light banks so that building occupants may select the most suitable combination of natural to augmented light. Very frequently entire floors of office buildings are designed with only one switch, so that perimeter areas near natural light are illuminated with the same level of artificial light as the dimmest interior zones. This lack of independent controls also would require an entire office floor of say 10,000 square feet (1,000 m^2) to be fully illuminated if one office worker stays late for evening work. This can occur with even the most eminent of architects. Frank Lloyd Wright designed Marin County Civic Center in 1957 with only one or two switches serving very large office pools. This cost Marin County several thousand of dollars per year in unneeded electricity costs.

Failure to use occupancy sensors

Occupancy sensors are used primarily for bathrooms, conference rooms and storage areas. This is an energy waste issue and not a health issue. The payback time of most occupancy sensors is in the range of two to five years, and yet first-cost economics prevent the installation of occupancy sensors in the majority of cases where they would save energy and lighting maintenance costs.

Failure to delamp or use available lighting controls

Failure to delamp or use available lighting controls is a common issue associated with over-illuminated buildings. Many instances of “designed in” over-illumination can be corrected by simple actions of building managers, following an illumination survey. In many instances over-illumination can be solved by removing a fraction of the lights or fixtures from a ceiling lighting system. In other cases a lighting retrofit can be conducted to replace older, less energy efficient fixtures with newer ones. Lighting retrofits can also be designed to reduce over-illumination; retrofits have typical payback periods of two to four years. In simpler cases many fluorescent ceiling illumination systems have multiple switch settings that allow tuning of the light intensity delivered, the most common version of this control being the "three-level switch", also called A/B switching. Much of the benefit of the excess illumination reduction comes from a better ratio of natural light to fluorescent light that can result from any of the above changes. Research has been conducted showing worker productivity gains in settings where each worker selects his or her own lighting level.

Health effects

Headaches, fatigue, stress and performance effects

Common T8 fluorescent lighting fixture frequently used in office environments

Health effects of over-illumination or improper spectral composition of light include increased headache incidence, worker fatigue, medically defined stress, decrease in sexual function and increase in anxiety. The health consequences are particularly significant of improperly matching the color spectrum of sunlight when illuminating the workplace.

Migraine headaches have been cited by some individuals as being caused by excessive light. In one survey over-illumination was listed as the number two trigger for migraines, with 47% of the respondents reporting bright light as the principal trigger of their migraine episode. Not only does bright light induce headache, but certain spectral distributions can increase the incidence of headache.

Fatigue is a common complaint from individuals exposed to over-illumination, especially with fluorescent media. Some studies have shown that the flicker and over-illumination combined in some fluorescent systems yield particularly high fatigue incidence. Research on circadian rhythm in humans indicates that one reason for fatigue stems from the incorrect color spectrum of fluorescent light.

Stress and anxiety are frequent outcomes from working in a setting of intense (especially fluorescent) lighting. Research has shown that annoyance from bright light leads to medical stress. It is clear that brighter, less spectrally correct light induces clinically measurable stress, and it is suggested that for children this over-illumination may interfere with the learning process. For example, children experiencing any form of stress are more likely to suffer from dysgraphia, a problem in learning to write. Task performance can also be compromised for people conducting work under artificial (e.g. fluorescent as opposed to natural light). The annoyance with purely artificial light and preference by office workers for natural light has been demonstrated by a number of studies spanning eastern and western cultures. Fluorescent lighting has also been linked to aggravating other psychological disorders such as agoraphobia.

Circulatory and circadian rhythm effects

Hypertension effects of over-illumination can lead to aggravation of cardiovascular disease and erectile dysfunction, which impacts are outcomes of long term cumulative exposure and associated systematic increases in blood pressure. The mechanism of this effect seems to be stress by related upregulation of adrenaline production akin to the fight-or-flight response. When adrenalin is released into the bloodstream it causes vasoconstriction, a known precursor to both hypertension and erectile dysfunction. Analogous female sexual side effects are thought to result in the female anatomy from reduced blood flows.

Circadian rhythm disruption is primarily caused by the wrong timing of light in reference to the circadian phase. It can also be affected by too much light, too little light, or incorrect spectral composition of light. This effect is driven by stimulus (or lack of stimulus) to photosensitive ganglion cells in the retina. The "time of day", the circadian phase, is signalled to the pineal gland, the body's photometer, by the suprachiasmatic nucleus. Bright light in the evening or in the early morning shifts the phase of the production of melatonin. An out-of-sync melatonin rhythm can worsen cardiac arrhythmias and increase oxidized lipids in the ischemic heart. Melatonin also reduces superoxide production and myeloperoxide (an enzyme in neutrophils which produces hypochlorous acid) during ischemia-reperfusion.

In practice, adverse outcomes seem to arise most commonly among workers subject to intense fluorescent light, which is poorly matched to the spectrum of sunlight. According to one set of researchers, the body translates this condition as "total darkness" and resets the circadian clock incorrectly. Not only does this result in fatigue, but also immuno-suppressive behavior that has been shown to be linked to increased cancers. The research indicates that increasing the ratio of natural light to artificial solves much of the problem, provided the total illumination level is not driven excessively high. Many of these health impacts may be primarily due to the spectrum of the light rather than the overall level of illumination, but more research is required to establish this.

Energy and economic considerations

Excessive energy use is often tolerated because the person who bears the cost is not the one making day to day decisions about lighting. Building managers and not building owners usually structure such things as janitorial use of lighting, setting or installation of timers, or the choice of lighting fixtures. Another contributor is a leasing structure, common in the U.S., where the tenant pays none of the electricity costs.

There are also myths which continue to propagate, occluding better lighting decisions. One such is the idea that it costs more to turn fluorescent lighting off and on again than to keep it running. According to the U.S. Department of Energy, the amount of electricity consumed in lighting up a fluorescent lamp is equal to a few seconds or less of normal operation. Taking into account the extra wear on the bulb caused by turning it off and on, the lamp has to not be needed for between five and fifteen minutes, depending on the type of lamp and other factors. Another myth is that more light is better, which is contradicted by health data.

Architectural design can identify technological aspects of window design where window angles can be calculated to minimize interior glare and reduce interior over-illumination, while at the same time reducing solar heat loading and subsequent demand for air conditioning as energy conservation techniques. For the Dakin Building in Brisbane, California the angled window projections effectively provide permanent sunscreens, obviating interior blinds or shades.

Building and lighting control systems

Building automation and lighting control solutions are now available to help reduce energy usage and cost by eliminating over-illumination. These solutions provide centralized control of all lighting within a home or commercial building, allowing easy implementation of scheduling, occupancy control, daylight harvesting and more. Many systems also support Demand response and will automatically dim or turn off lights to take advantage of DR incentives and cost savings.

Many newer control systems are using wireless mesh open standards (such as ZigBee), which provides benefits including easier installation (no need to run control wires) and interoperability with other standards-based building control systems (e.g. security).

Chapter- 7

Compact Fluorescent Lamp

The tubular-type compact fluorescent lamp is one of the most popular types in Europe.

A spiral-type integrated CFL. This style has slightly reduced efficiency compared to tubular fluorescent lamps, due to the thicker layer of phosphor on the lower side of the twist. It has been the most popular type in North America since the mid 1990s, when the final expiration of patents allowed its manufacture.

A **compact fluorescent lamp** (**CFL**), also known as a **compact fluorescent light** or **energy saving light** (or less commonly as a **compact fluorescent tube**), is a type of fluorescent lamp. Many CFLs are designed to replace an incandescent lamp and can fit into most existing light fixtures formerly used for incandescents.

Compared to general service incandescent lamps giving the same amount of visible light, CFLs use less power and have a longer rated life. In the United States, a CFL has a higher purchase price than an incandescent lamp, but can save over US$40 in electricity costs over the lamp's lifetime. Like all fluorescent lamps, CFLs contain mercury, which complicates their disposal.

CFLs radiate a different light spectrum from that of incandescent lamps. Improved phosphor formulations have improved the perceived color of the light emitted by CFLs such that some sources rate the best 'soft white' CFLs as subjectively similar in color to standard incandescent lamps.

History

An early compact fluorescent lamp

The parent to the modern fluorescent lamp was invented in the late 1890s by Peter Cooper Hewitt. The Cooper Hewitt lamps were used for photographic studios and industries.

Edmund Germer, Friedrich Meyer, and Hans Spanner then patented a high pressure vapor lamp in 1927. George Inman later teamed with General Electric to create a practical fluorescent lamp, sold in 1938 and patented in 1941. Circular and U-shaped lamps were devised to reduce the length of fluorescent light fixtures. The first fluorescent bulb and fixture were displayed to the general public at the 1939 New York World's Fair.

The spiral tube CFL was invented in 1976 by Edward E. Hammer, an engineer with General Electric, in response to the 1973 oil crisis. The design met its goals, and it would have cost GE only about US$25 million to build new factories to produce them, but the invention was shelved. The design was eventually copied by others. It was not until 1995 that spiral lamps manufactured in China were commercially available; spiral lamps have steadily increased in sales volume.

In 1980, Philips introduced its model SL, which was a screw-in lamp with integral ballast. The lamp used a folded T4 tube, stable tri-color phosphors, and a mercury amalgam. This was the first successful screw-in replacement for an incandescent lamp. In 1985 Osram started selling their model EL lamp which was the first CFL to include an electronic ballast.

Development of fluorescent lamps that could fit in the same volume as comparable incandescent lamps required the development of new, high-efficacy phosphors that could withstand more power per unit area than the phosphors used in older, larger fluorescent tubes.

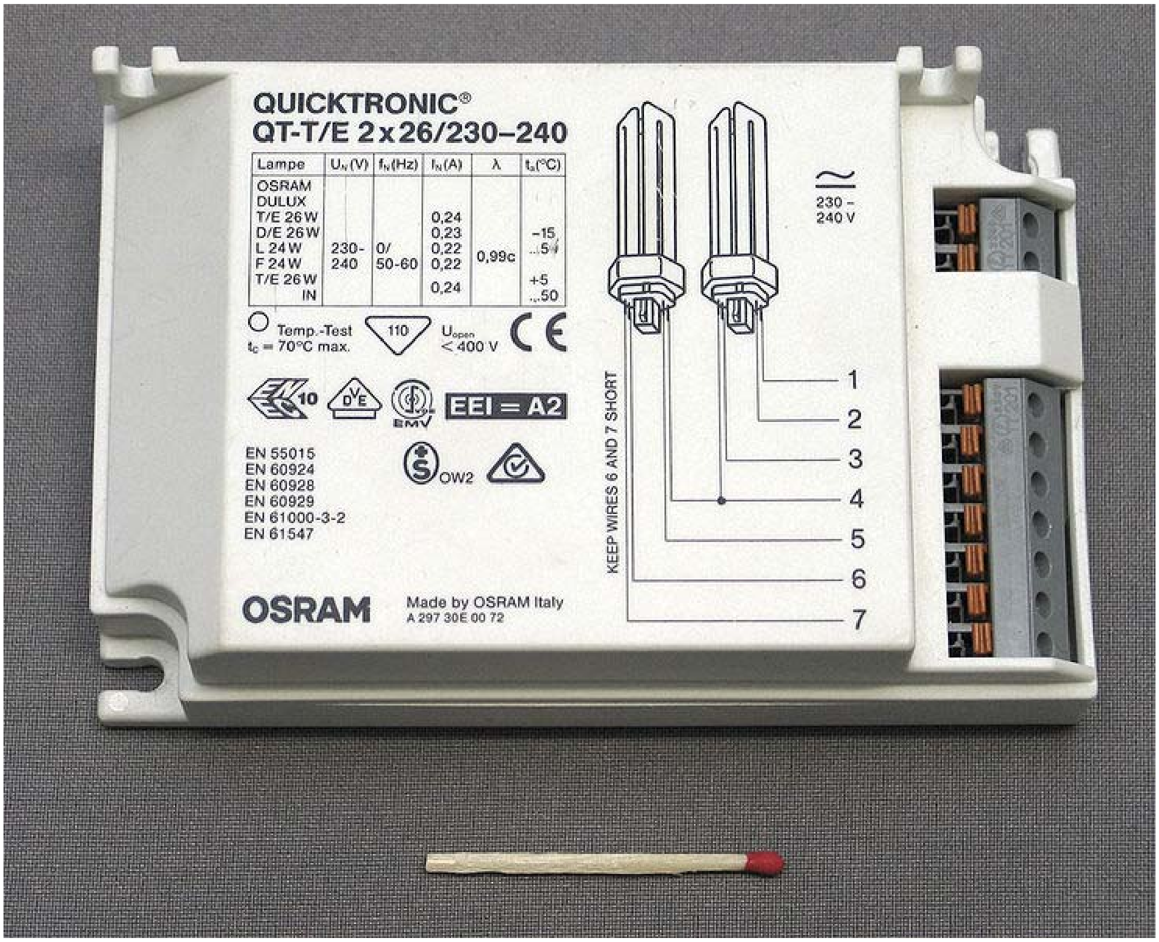
Construction

A compact fluorescent lamp used outside of a building.

The most important technical advance has been the replacement of electromagnetic ballasts with electronic ballasts; this has removed most of the flickering and slow starting traditionally associated with fluorescent lighting.

There are two types of CFLs: integrated and non-integrated lamps. Integrated lamps combine a tube, an electronic ballast and either an Edison screw or a bayonet fitting in a single unit. These lamps allow consumers to replace incandescent lamps easily with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, reducing the cost of converting to fluorescent. Special 3-way models and dimmable models with standard bases are available.

Non-integrated bi-pin double-turn compact fluorescent lamp

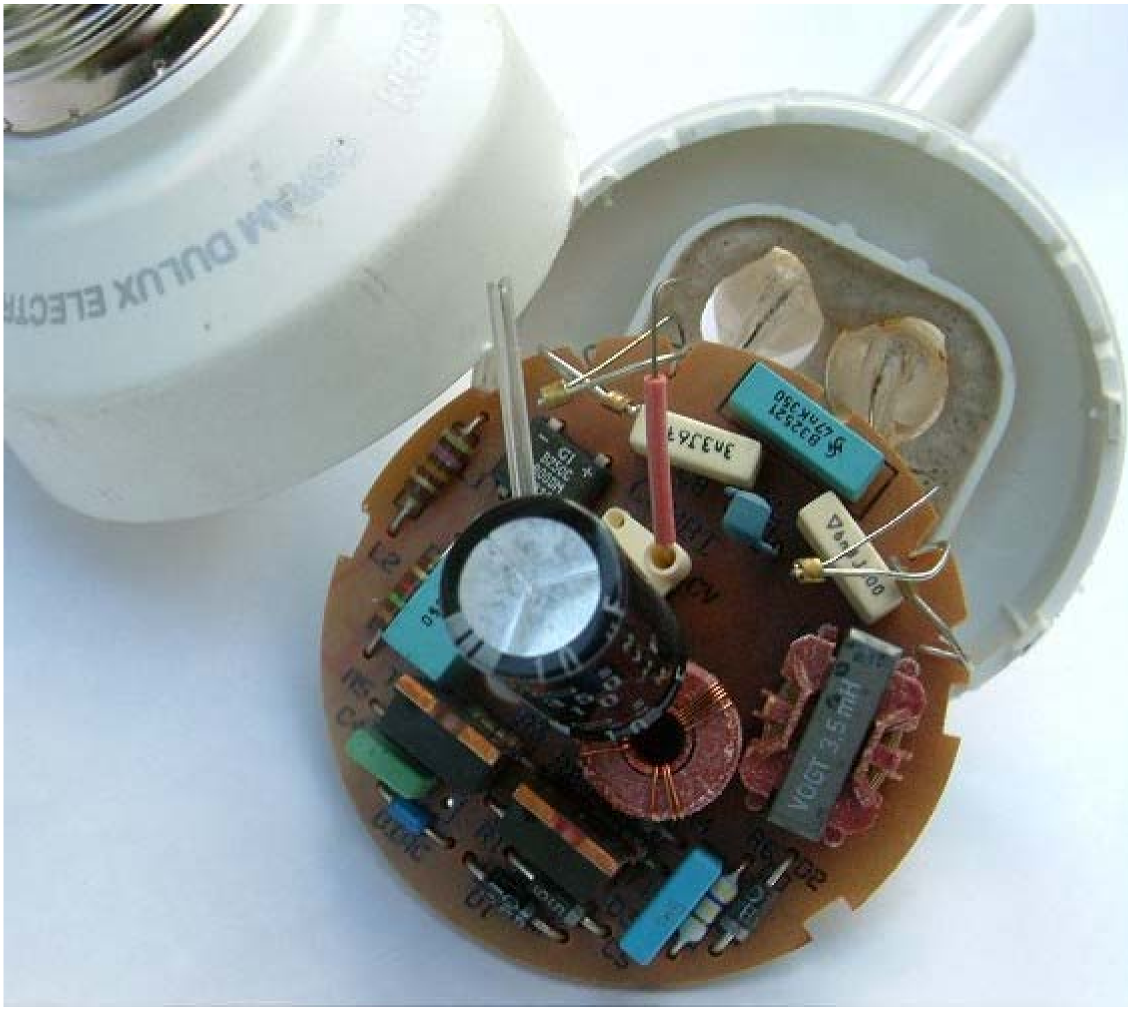


Non-integrated electronic ballast for compact fluorescent lamps

Non-integrated CFLs have the ballast permanently installed in the luminaire, and only the lamp bulb is usually changed at its end of life. Since the ballasts are placed in the light fixture they are larger and last longer compared to the integrated ones, and they don't need to be replaced when the bulb reaches its end-of-life. Non-integrated CFL housings can be both more expensive and sophisticated. They have two types of tubes: a bi-pin tube designed for a conventional ballast, and a quad-pin tube designed for an electronic ballast or a conventional ballast with an external starter. A bi-pin tube contains an integrated starter which obviates the need for external heating pins but causes incompatibility with electronic ballasts.

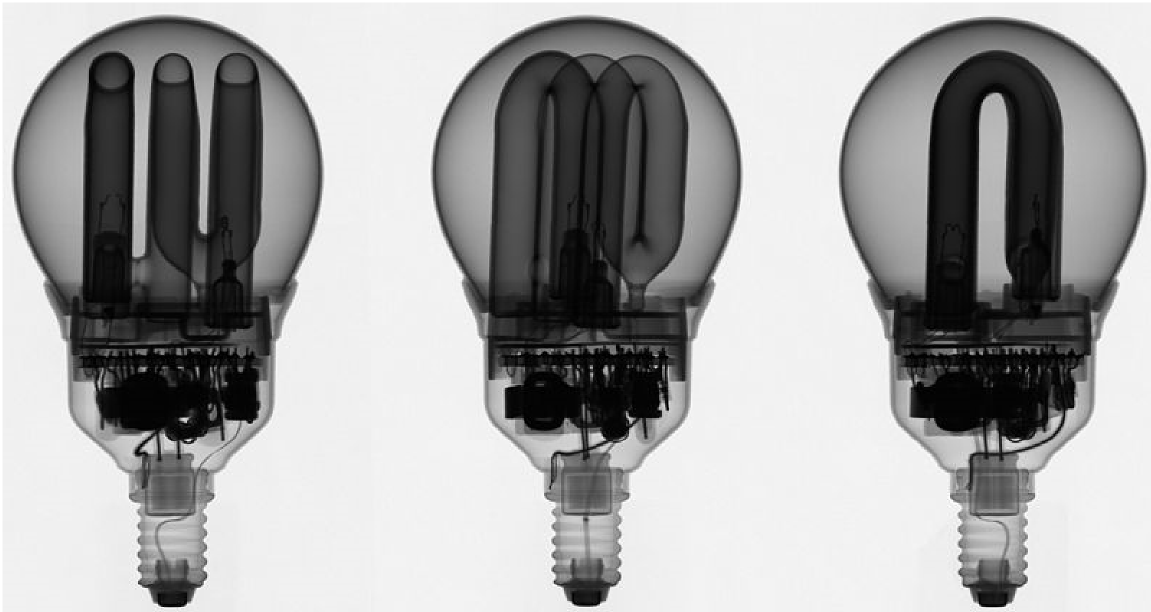
Components

CFLs have two main components: a gas-filled tube (also called bulb or burner) and a magnetic or electronic ballast.



An electronic ballast and permanently attached tube in an integrated CFL

Standard shapes of CFL tube are single-turn double helix, double-turn, triple-turn, quad-turn, circular, and butterfly.



Stitched X-ray image from three different angles (0°, 45°, 90°) of a defective IKEA compact fluorescent lamp. The burned through filament is visible in the left image.

Electronic ballasts contain a small circuit board with rectifiers, a filter capacitor and usually two switching transistors connected as a high-frequency resonant series DC to AC inverter. The resulting high frequency, around 40 kHz or higher, is applied to the lamp tube. Since the resonant converter tends to stabilize lamp current (and light produced) over a range of input voltages, standard CFLs do not respond well in dimming applications and special lamps are required for dimming service. CFLs that flicker when they start have magnetic ballasts; CFLs with electronic ballasts are now much more common.

CFL power sources

CFLs are produced for both alternating current (AC) and direct current (DC) input. DC CFLs are popular for use in recreational vehicles and off-the-grid housing. There are various aid agency led initiatives in developing countries to replace kerosene lanterns (with their associated health hazards) with DC CFLs (with car batteries and small solar panels or wind generators).

CFLs can also be operated with solar powered street lights, using solar panels located on the top or sides of a pole and light fixtures that are specially wired to use the lamps.

Comparison with incandescent lamps

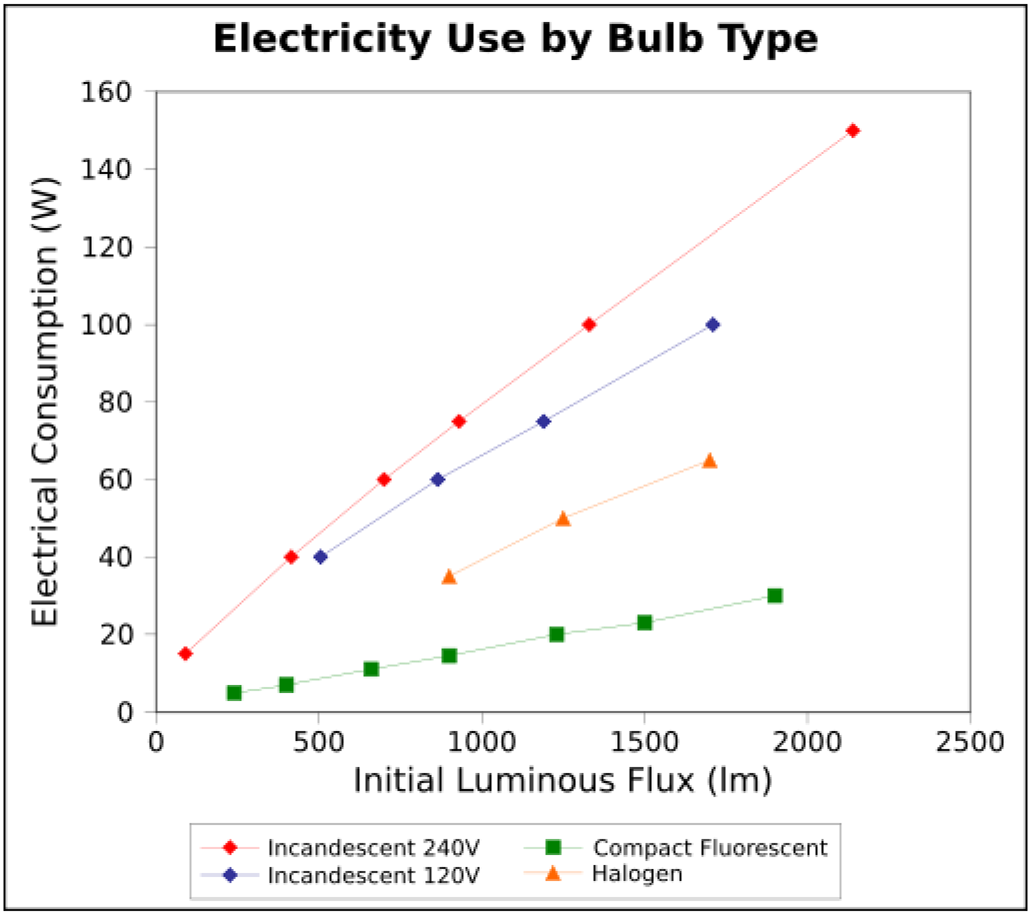
Lifespan

The average rated life of a CFL is between 8 and 15 times that of incandescents. CFLs typically have a rated lifespan of between 6,000 and 15,000 hours, whereas incandescent lamps are usually manufactured to have a lifespan of 750 hours or 1,000 hours.

The lifetime of any lamp depends on many factors including operating voltage, manufacturing defects, exposure to voltage spikes, mechanical shock, frequency of cycling on and off, lamp orientation, and ambient operating temperature, among other factors. The life of a CFL is significantly shorter if it is turned on and off frequently. In the case of a 5-minute on/off cycle the lifespan of a CFL can be reduced to "close to that of incandescent light bulbs". The US Energy Star program suggests that fluorescent lamps be left on when leaving a room for less than 15 minutes to mitigate this problem.

CFLs produce less light later in their lives than when they are new. The light output decay is exponential, with the fastest losses being soon after the lamp is first used. By the end of their lives, CFLs can be expected to produce 70–80% of their original light output. The response of the human eye to light is logarithmic (a photographic 'f-stop' reduction represents a halving in actual light, but is subjectively quite a small change). A 20–30% reduction over many thousands of hours represents a change of about half an f-stop. So, presuming the illumination provided by the lamp was ample at the beginning of its life, such a difference will be compensated for by the eyes, for most purposes.

Energy efficiency



The chart shows the energy usage for different types of light bulbs operating at different light outputs. Points lower on the graph correspond to lower energy use.

For a given light output, CFLs use 20 to 33 percent of the power of equivalent incandescent lamps. Since lighting accounted for approximately 9% of household electricity usage in the United States in 2001, widespread use of CFLs could save as much as 7% of total US household usage.

Yet, there is ongoing debate about energy efficiency and biased discussion assuming energy equals electric energy.

Electrical power equivalents for differing lamps

Electrical power consumption Watts (W)		**Minimum light output lumens (lm)**
Compact fluorescent	Incandescent	
8–9	40	450
9–15	60	800
15–20	75	1,100

20–25	100	1,600
25–45	150	2,600

Heating and cooling

If a building's indoor incandescent lamps are replaced by CFLs, the heat produced due to lighting is significantly reduced. In warm climates or in office or industrial buildings where air conditioning is often required, CFLs would reduce the load on the cooling system when compared to the use of incandescent lamps, resulting in savings in electricity, in addition to the energy efficiency savings of using CFLs instead of incandescent lamps. However, in cooler climates in which buildings require heating, the heating system will need to replace the inadvertently generated heat. While the CFLs are still saving electricity, total greenhouse gas emissions may increase in certain scenarios, such as the operation of a natural gas furnace to replace the unintended heating from CFLs running on low-GHG electricity. In Winnipeg, Canada, it is estimated that CFLs will only generate 17% savings in energy when switching from incandescent bulbs, as opposed to the 75% savings that can be expected if there were no heating or cooling considerations.

Efficacy and efficiency

Because the eye's sensitivity changes with the wavelength, the output of lamps is commonly measured in lumens, a measure of the power of light perceived by the human eye. The luminous efficacy of lamps refers to the number of lumens produced for each watt of electrical power used. A theoretically 100% efficient electric light source producing light only at the wavelength the human eye is most sensitive to would produce 680 lumens per watt.

The typical luminous efficacy of CFL lamps is 60 to 72 lumens per watt, and that of normal domestic incandescent lamps is 13 to 18 lm/W. Compared to the theoretical 100% efficient lamp, these figures are equivalent to lighting efficiency ranges of 9 to 11% for CFLs (60/680 and 72/680) and 1.9 to 2.6% for incandescents (13/680 and 18/680).

Embodied energy

While CFLs require more energy in manufacturing than incandescent lamps, this embodied energy is offset by their longer life and lower energy use than equivalent incandescent lamps.

Cost

While the purchase price of an integrated CFL is typically 3 to 10 times greater than that of an equivalent incandescent lamp, the extended lifetime and lower energy use will more than compensate for the higher initial cost. A US article stated "A household that invested $90 in changing 30 fixtures to CFLs would save $440 to $1,500 over the five-year life of the bulbs, depending on your cost of electricity. Look at your utility bill and imagine a 12% discount to estimate the savings."

CFLs are extremely cost-effective in commercial buildings when used to replace incandescent lamps. Using average U.S. commercial electricity and gas rates for 2006, a 2008 article found that replacing each 75 W incandescent lamp with a CFL resulted in yearly savings of $22 in energy usage, reduced HVAC cost, and reduced labor to change lamps. The incremental capital investment of $2 per fixture is typically paid back in about one month. Savings are greater and payback periods shorter in regions with higher electric rates and, to a lesser extent, also in regions with higher than U.S. average cooling requirements.

The current price of CFLs reflects the manufacturing of nearly all CFLs in China, where labor costs less. In September 2010, the Winchester, Virginia General Electric plant closed, leaving Osram Sylvania the last company to make standard incandescent bulbs in the United States. At that time, Ellis Yan, whose Chinese company made the majority of CFLs sold in the United States, was interested in building a United States factory to make CFL bulbs, but he needed $12.5 million to do so, and the U.S. government had not helped with this. Yan said stores wanted American-made bulbs, which would be 45 to 50 cents more each, but Yan said consumers were willing to pay this much.

General Electric had considered changing one of its bulb plants to make CFLs, but even after a $40 million investment, wage differences would mean the bulbs would cost one and a half times those made in China.

Comparison with alternative technologies

Solid-state lighting has already filled a few specialist niches such as traffic lights and may compete with CFLs for house lighting as well. LEDs providing over 200 lm/W have been demonstrated in laboratory tests and expected lifetimes of around 50,000 hours are typical. The luminous efficacy of available LED lamps does not typically exceed that of CFLs. DOE testing of commercial LED lamps designed to replace incandescent or CFL lamps showed that average efficacy was still about 31 lm/W in 2008 (tested performance ranged from 4 lm/W to 62 lm/W).

General Electric discontinued a 2007 development project intended to develop a high-efficiency incandescent bulb with the same lumens per watt as fluorescent lamps. Meanwhile other companies have developed and are selling halogen incandescents that use 70% of the energy of standard incandescents.

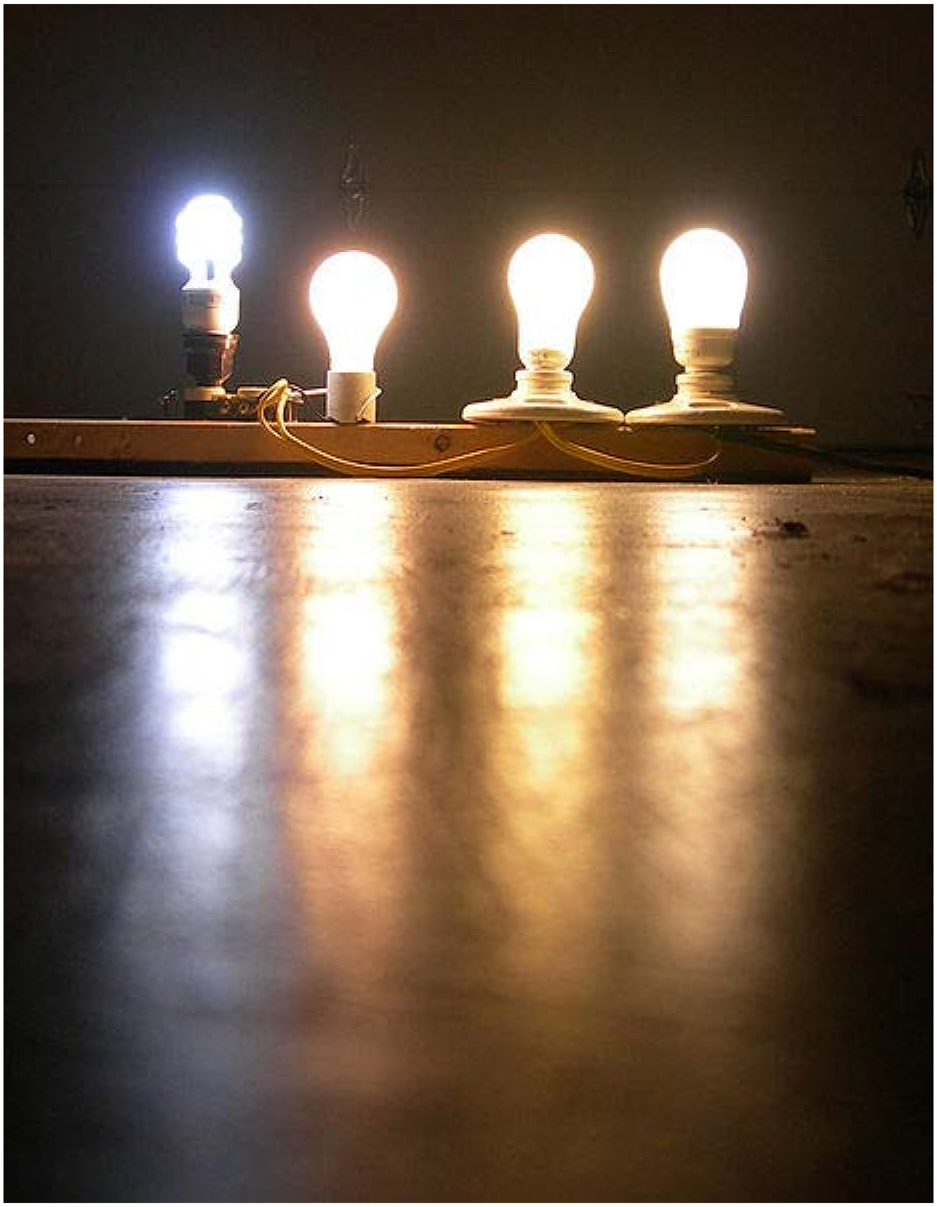
Other CFL technologies

Another type of fluorescent lamp is the electrodeless lamp, known as magnetic induction lamp, radiofluorescent lamp or fluorescent induction lamp. These lamps have no wire conductors penetrating their envelopes, and instead excite mercury vapor using a radio-frequency oscillator. Currently, this type of light source is struggling with a high cost of production, stability of the products produced by domestic manufacturers in China, establishing an internationally recognized standard and problems with EMC and RFI. Furthermore, induction lighting is excluded from Energy Star standard for 2007 by the EPA.

The cold cathode fluorescent lamp (CCFL) is one of the newest forms of CFL. CCFLs use electrodes without a filament. The voltage of CCFLs is about 5 times higher than CFLs, and the current is about 10 times lower. CCFLs have a diameter of about 3 millimeters. CCFLs were initially used for document scanners and also for backlighting LCD displays, but they are now also manufactured for use as lamps. The efficacy (lumens per watt) is about half that of CFLs. Their advantages are that they are instant-on, like incandescents, they are compatible with timers, photocells, and dimmers, and they have a long life of approximately 50,000 hours. CCFLs are a convenient transition technology for those who are not comfortable with the short lag time associated with the initial lighting of CFLs. They are also an effective and efficient replacement for lighting that is turned on and off frequently with little extended use (e.g. a bathroom or closet).

A few manufacturers make CFL-style bulbs with mogul Edison screw bases intended to replace 250 watt and 400 watt metal halide lamps, claiming a 50% energy reduction; however, these lamps require slight rewiring of the lamp fixtures to bypass the lamp ballast.

Spectrum of light

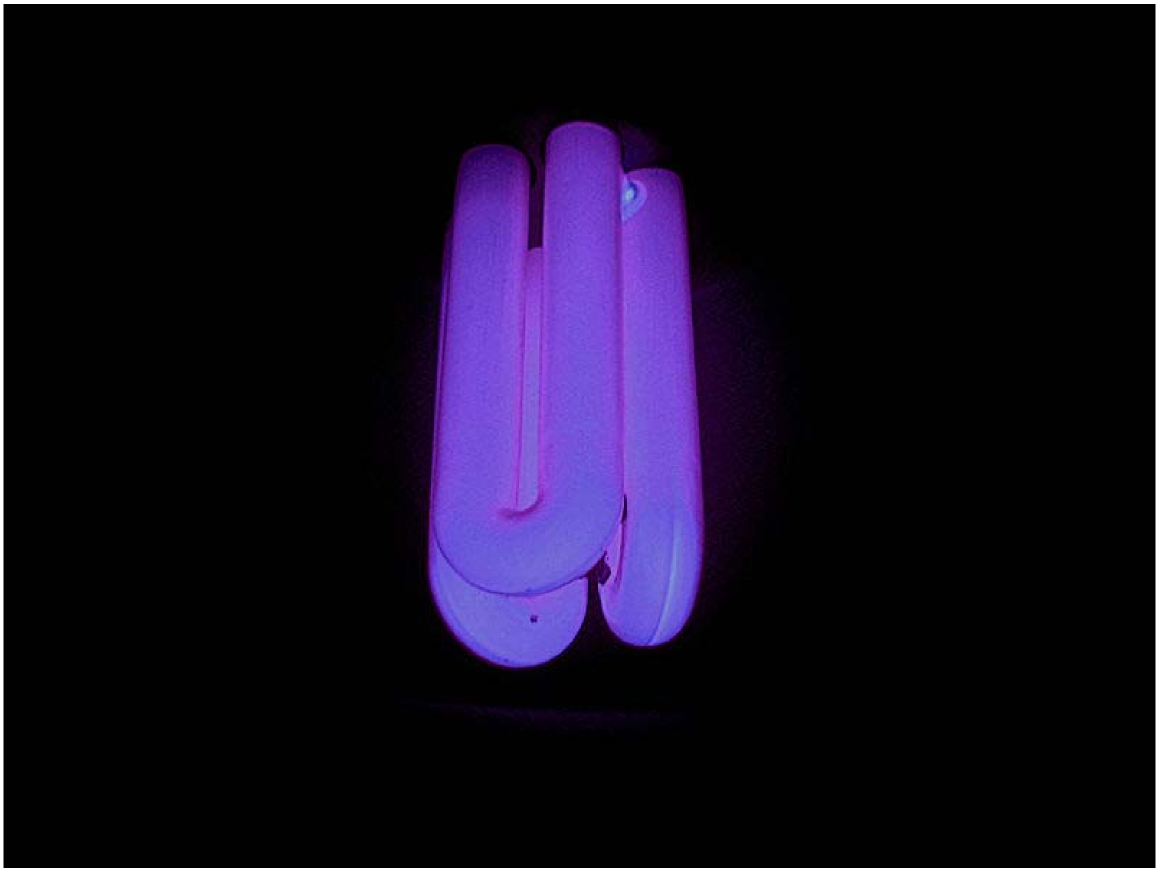


A photograph of various lamps illustrates the effect of color temperature differences (left to right):

1. Compact Fluorescent: General Electric, 13 W, 6,500 K
2. Incandescent: Sylvania 60 W Extra Soft White
3. Compact Fluorescent: Bright Effects, 15 W, 2,644 K
4. Compact Fluorescent: Sylvania, 14 W, 3,000 K

Color Temperature compared against a white ceiling.

Spectrum of a CFL bulb. The camera had a diffraction grating in front of the lens. The discrete images are produced by the different colors in the light, a line spectrum. An incandescent lamp would instead have a continuous band of color.



A blacklight CFL.

CFLs emit light from a mix of phosphors inside the bulb, each emitting one band of color. Modern phosphor designs are a compromise between the shade of the emitted light, energy efficiency, and cost. Every extra phosphor added to the coating mix causes a loss of efficiency and increased cost. Good quality consumer CFLs use three or four phosphors to achieve a 'white' light with a CRI (color rendering index) of around 80, where 100 represents the appearance of colors under daylight or a black-body (depending on the correlated color temperature).

Color temperature can be indicated in kelvins or mireds (1 million divided by the color temperature in kelvins).

Name	**Color temperature**	
	(K)	**(Mired)**
Warm/soft white	≤ 3,000	≥ 333
(Bright) white	3,500	286
Cool white	4,000	250

Daylight	≥ 5,000	≤ 200

Color temperature is a quantitative measure. The higher the number in kelvins, the more blue the shade. Color names associated with a particular color temperature are not standardized for modern CFLs and other triphosphor lamps like they were for the older-style halophosphate fluorescent lamps. Variations and inconsistencies exist among manufacturers. For example, Sylvania's Daylight CFLs have a color temperature of 3,500 K, while most other lamps with a *daylight* label have color temperatures of at least 5,000 K. Some vendors do not include the kelvin value on the package, but this is beginning to change now that the Energy Star criteria for CFLs is expected to require such labeling in its 4.0 revision.

Some manufacturers now label their CFLs with a 3 digit code to specify the color rendering index (CRI) and color temperature of the lamp. The first digit represents the CRI measured in tens of percent, while the second two digits represent the color temperature measured in hundreds of kelvins. For example, a CFL with a CRI of 83 and a color temperature of 2,700 K would be given a code of 827.

CFLs are also produced, less commonly, in other colors:

- Red, green, orange, blue, and pink, primarily for novelty purposes
- Blue for phototherapy
- Yellow, for outdoor lighting, because it does not attract insects
- Black light (UV light) for special effects

Black light CFLs, those with UVA generating phosphor, are much more efficient than incandescent black light lamps, since the amount of UV light that the filament of the incandescent lamp produces is only a fraction of the generated spectrum.

Disadvantages

Starting time

Incandescents reach full brightness a fraction of a second after being switched on. As of 2009, CFLs turn on within a second, but many still take time to warm up to full brightness. The light color may be slightly different immediately after being turned on. Some CFLs are marketed as "instant on" and have no noticeable warm-up period, but others can take up to a minute to reach full brightness, or longer in very cold temperatures. Some that use a mercury amalgam can take up to three minutes to reach full output. This and the shorter life of CFLs when turned on and off for short periods may make CFLs less suitable for applications such as motion-activated lighting.

Hybrid CFL

From November 2010 a Hybrid CFL as a solution for instant warm up time and brightness is commercially available. A second company announced a similar product to be available during 2011. These products combine a halogen lamp with a CFL. The halogen lights immediately, and once the CFL has warmed up the halogen lamp goes out.

Health issues

The cost effectiveness of battery-powered CFLs is enabling aid agencies to support initiatives to replace kerosene lamps, the fumes from which cause chronic lung disorders in typical homes and work places in third world countries.

According to the European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) in 2008, the only property of compact fluorescent lamps that could pose an added health risk is the ultraviolet and blue light emitted by such devices. The worst that can happen is that this radiation could aggravate symptoms in people who already suffer rare skin conditions that make them exceptionally sensitive to light. They also stated that more research is needed to establish whether compact fluorescent lamps constitute any higher risk than incandescent lamps.

If individuals are exposed to the light produced by some single-envelope compact fluorescent lamps for long periods of time at distances of less than 20 cm, it could lead to ultraviolet exposures approaching the current workplace limit set to protect workers from skin and retinal damage.

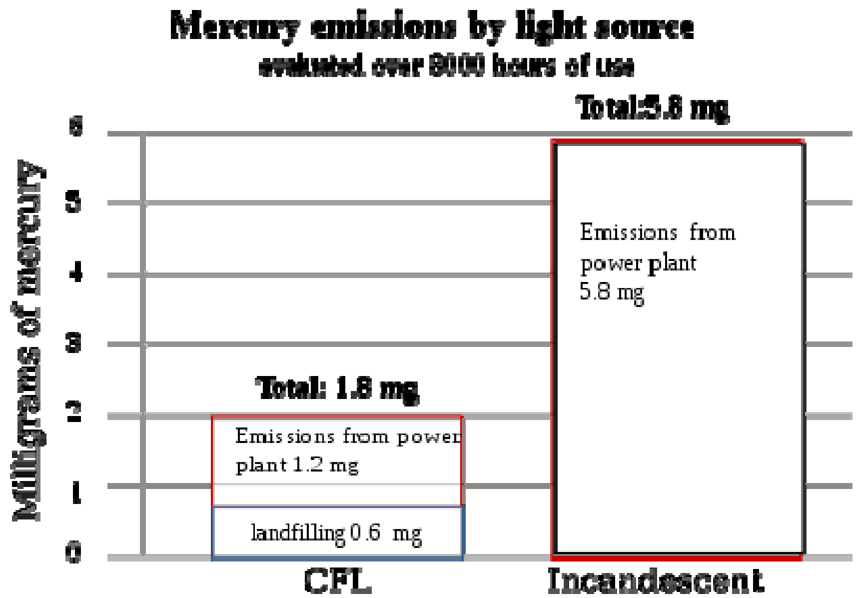
The UV radiation received from CFLs is too small to contribute to skin cancer and the use of double-envelope CFL lamps "largely or entirely" mitigates any other risks.

Environmental issues

Mercury emissions

CFLs, like all fluorescent lamps, contain small amounts of mercury as vapor inside the glass tubing. Most CFLs contain 3–5 mg per bulb, with the eco-friendly bulbs containing as little as 1 mg. Because mercury is poisonous, even these small amounts are a concern for landfills and waste incinerators where the mercury from lamps may be released and contribute to air and water pollution. In the U.S., lighting manufacturer members of the National Electrical Manufacturers Association (NEMA) have voluntarily capped the amount of mercury used in CFLs. In the EU the same cap is required by the RoHS law.

In areas with coal-fired power stations, the use of CFLs saves on mercury emissions when compared to the use of incandescent bulbs. This is due to the reduced electrical power demand, reducing in turn the amount of mercury released by coal as it is burned. In July 2008 the US EPA published a data sheet stating that the net system emission of mercury for CFL lighting was lower than for incandescent lighting of comparable lumen output. This was based on the average rate of mercury emission for US electricity production and average estimated escape of mercury from a CFL put into a landfill. Coal-fired plants also emit other heavy metals, sulfur, and carbon dioxide.



Net mercury emissions for CFL and incandescent lamps, based on EPA FAQ sheet, assuming average US emission of 0.012 mg of mercury per kilowatt-hour and 14% of CFL mercury contents escapes to environment after land fill disposal.

In the United States, the U.S. Environmental Protection Agency estimated that if all 270 million compact fluorescent lamps sold in 2007 were sent to landfill sites, that this would represent around 0.13 metric tons, or 0.1% of all U.S. emissions of mercury (around 104 metric tons that year).

Broken and discarded lamps

Health and environmental concerns about mercury have prompted many jurisdictions to require spent lamps to be properly disposed or recycled rather than being included in the general waste stream sent to landfills. It is unlawful to dispose of fluorescent bulbs as universal waste in the states of California, Minnesota, Ohio, Illinois, Indiana, Michigan, and Wisconsin. In the European Union, CFLs are one of many products subject to the WEEE recycling scheme. The retail price includes an amount to pay for recycling, and manufacturers and importers have an obligation to collect and recycle CFLs. Safe disposal requires storing the bulbs unbroken until they can be processed. In the US, The Home Depot is the first retailer to make CFL recycling options widely available.

Special handling instructions for breakage are currently not printed on the packaging of household CFL bulbs in many countries. The amount of mercury released by one bulb can temporarily exceed U.S. federal guidelines for chronic exposure. *Chronic* however, implies that the exposure continues constantly over a long period of time and the Maine DEP study noted that it remains unclear what the health risks are from short-term exposure to low levels of elemental mercury. The Maine DEP study also confirmed that, despite following EPA best-practice cleanup guidelines on broken CFLs, researchers were unable to remove mercury from carpet, and agitation of the carpet—such as by young children playing—created spikes as high as 25,000 ng/m^3 in air close to the carpet, even weeks after the initial breakage. Conventional tubular fluorescent lamps have been in commercial and domestic use since the 1930s with little public concern about their handling; these and other domestic products such as thermometers contain far more mercury than modern CFLs.

The U.S. Environmental Protection Agency (EPA) recommends that, in the absence of local guidelines, fluorescent bulbs be double-bagged in plastic before disposal. The Maine DEP study of 2008 compared clean-up methods, and warned that the EPA recommendation of plastic bags was the worst choice, as vapors well above safe levels continued to leach from the bags. The Maine DEP now recommends a sealed glass jar as the best repository for a broken bulb.

According to the Northwest Compact Fluorescent Lamp Recycling Project, because household users in the U.S. Northwest have the option of disposing of these products in the same way they dispose of other solid waste, in Oregon "a large majority of household CFLs are going to municipal solid waste". They also note the EPA's estimates for the percentage of fluorescent lamps' total mercury released when they are disposed of in the following ways: municipal waste landfill 3.2%, recycling 3%, municipal waste incineration 17.55% and hazardous waste disposal 0.2%.

Mercury poisoning of Chinese factory workers

In the past decade, hundreds of Chinese factory workers who manufacture CFLs for export to first world countries were being poisoned and hospitalized because of mercury exposure. Examples include workers at the Nanhai Feiyang lighting factory in Foshan where 68 out of 72 were so badly poisoned that they required hospitalization. At another CFL factory in Jinzhou, 121 out of 123 employees were found to have excessive mercury levels with one employee's mercury level 150 times the accepted standard.

Recycling

The first step of processing CFLs involves crushing the bulbs in a machine that uses negative pressure ventilation and a mercury-absorbing filter or cold trap to contain mercury vapor. Many municipalities are purchasing such machines. The crushed glass and metal is stored in drums, ready for shipping to recycling factories.

Design and application issues

Dimmable integrated spiral CFL that dims 2%-100%, comparable to regular light bulb dimming properties.

The primary objectives of CFL design are high electrical efficiency and durability. However, there are some other areas of CFL design and operation that are problematic:

Size

CFL light output is roughly proportional to phosphor surface area, and high output CFLs are often larger than their incandescent equivalents. This means that the CFL may not fit well in existing light fixtures.

End of life

In addition to the wear-out failure modes common to all fluorescent lamps, the electronic ballast may fail since it has a number of component parts. Ballast failures may be accompanied by discoloration or distortion of the ballast enclosure, odors, or smoke. The lamps are internally protected and are meant to fail safely at the end of their lives. Industry associations are working toward advising consumers of the different failure modes of CFLs compared to incandescent lamps, and to develop lamps with inoffensive failure modes. New North American technical standards aim to eliminate smoke or excess heat at the end of lamp life.

Incandescent replacement wattage inflation

An August 2009 newspaper report described that some manufacturers claim the CFL replaces a higher wattage incandescent lamp than justified by the light produced by the CFL. Equivalent wattage claims can be replaced by comparison of the lumens produced by the lamp.

Dimming

Only some CF lamps are labeled for dimming control. Using regular CFLs with a dimmer is ineffective at dimming, can shorten bulb life and will void the warranty of certain manufacturers. Dimmable CFLs are available. There is a need for the dimmer switch used in conjunction with a dimmable CFL to be matched to its power consumption range, many dimmers installed for use with incandescent bulbs do not yield acceptable results below 40W, whereas CFL applications commonly draw power in the range 7-20W. The marketing and availability of dimmable CFLs has preceded that of suitable dimmers. The dimming range of CFLs is usually between 20% and 90%. However, in many modern CFLs the dimmable range has been improved to be from 2% to 100%, more akin to regular lights. There are two types of dimmable CFL marketed: Regular dimmable CFLs, and "switch-dimmable" CFLs. The latter use a regular light switch, while the on-board electronics has a setting where the number of times the switch is turned on & off in quick succession sets a reduced light output mode. Dimmable CFLs are not a 100% replacement for incandescent fixtures that are dimmed for "mood scenes" such as wall sconces in a dining area. Below the 20% limit, the lamp remain at the approximate 20% level, in other cases it may flicker or the starter circuitry may stop and restart. Above the 80% dim limit, the bulb will generally glow at 100% brightness. However, these issues have been addressed with the latest units and some CFLs may perform more like regular lamps. Dimmable CFLs have a higher purchase cost than standard CFLs due to the additional circuitry required for dimming. A further limitation is that multiple dimmable CFLs on the same dimmer switch may not appear to be at the same brightness level. Cold Cathode CFLs can be dimmed to low levels, making them popular replacements for incandescent bulbs on dimmer circuits.

Perceived coldness of low intensity CFL

When a CFL is dimmed the colour temperature (warmth) stays the same. This is counter to most other light sources (such as the sun or incandescents) where colour gets warmer as the light source gets dimmer. Emotional response testing suggests that people find dim, bluish light sources to be cold or even sinister. This may explain the persistent lack of popularity for CFL's in bedrooms and other settings where a subdued light source is preferred.

Heat

Some CFLs are labeled not to be run base up, since heat will shorten the ballast's life. Such CFLs are unsuitable for use in pendant lamps and especially unsuitable for recessed light fixtures. CFLs for use in such fixtures are available. Current recommendations for fully enclosed, unventilated light fixtures (such as those recessed into insulated ceilings), are either to use 'reflector CFLs' (R-CFL), cold cathode CFLs or to replace such fixtures with those designed for CFLs. A CFL will thrive in areas that have good airflow, such as in a table lamp.

Power quality

The introduction of CFLs may affect power quality appreciably, particularly in large-scale installations. The input stage of a CFL is a rectifier, which presents a non-linear load to the power supply and introduces harmonic distortion on the current drawn from the supply. In such cases, CFLs with low (below 30 percent) total harmonic distortion (THD) and power factors greater than 0.9 should be used.

Infrared signals

Electronic devices operated by infrared remote control can interpret the infrared light emitted by CFLs as a signal, this limits the use of CFLs near televisions, radios, remote controls, or mobile phones.

Iridescence

Fluorescent lamps can cause window film to exhibit iridescence. This phenomenon usually occurs at night. The amount of iridescence may vary from almost imperceptible, to very visible and most frequently occurs when the film is constructed using one or more layers of sputtered metal. It can however occur in non-reflective films as well. When iridescence does occur in window film, the only way to stop it is to prevent the fluorescent light from illuminating the film.

Use with timers, motion sensors, light sensors, and other electronic controls

Some electronic (but not mechanical) timers can interfere with the electronic ballast in CFLs and can shorten their lifespan. Some timers rely on a connection to neutral through the bulb and so pass a tiny current through the bulb, charging the capacitors in the electronic ballast. They may not work with a CFL connected, unless an incandescent bulb is also connected. They may also cause the CFL to flash when off. This can also be true for illuminated wall switches and motion sensors. Also, most CFL's will not work with light sensor devices, as in a "dusk to dawn" device. Cold cathode CFLs avoid many of these problems. Timer manufacturers may make products compatible with CFL lamps.

Fire hazard

When the base of the bulb is not made to be flame-retardant, as required in the voluntary standard for CFLs, then the electrical components in the bulb can overheat which poses a fire hazard. The latest ENERGY STAR CFL specification (which went into effect December 2, 2008) requires all ENERGY STAR qualified CFLs to incorporate end-of-life requirements and higher safety standards. The Electrical Safety Authority of Canada has stated that certified bulbs do not pose a fire hazard as they use anti-fire plastics.

Outdoor use

CFLs are generally not designed for outdoor use and some will not start in cold weather. CFLs are available with cold-weather ballasts, which may be rated to as low as −23 °C (−10 °F). Light output drops at low temperatures. Cold cathode CFLs will start and perform in a wide range of temperatures due to their different design.

Differences among manufacturers

There are large differences among quality of light, cost, and turn-on time among different manufacturers, even for lamps that appear identical and have the same color temperature.

Lifetime brightness

Fluorescent lamps get dimmer over their lifetime, so what starts out as an adequate luminosity may become inadequate. In one test by the US Department of Energy of 'Energy Star' products in 2003–04, one quarter of tested CFLs no longer met their rated output after 40% of their rated service life.

UV emissions

Fluorescent bulbs can damage paintings and textiles which have light-sensitive dyes and pigments. Strong colours will tend to fade on exposure to UV light. Ultraviolet light can also cause polymer degradation with a loss in mechanical strength and yellowing of colourless products.

Efforts to encourage adoption

Due to the potential to reduce electric consumption and pollution, various organizations have encouraged the adoption of CFLs and other efficient lighting. Efforts range from publicity to encourage awareness, to direct handouts of CFLs to the public. Some electric utilities and local governments have subsidized CFLs or provided them free to customers as a means of reducing electric demand (and so delaying additional investments in generation).

More controversially, some governments are considering stronger measures to entirely displace incandescents. These measures include taxation, or bans on production of incandescent light bulbs that do not meet energy efficiency requirements.

In 2008, the European Union approved regulations progressively phasing out incandescent bulbs starting in 2009 and finishing at the end of 2012. By switching to energy saving bulbs, EU citizens will save almost 40 TW·h (almost the electricity consumption of 11 million European households), leading to a reduction of about 15 million metric tons of CO_2 emissions per year.

Australia, Canada, and the US have also announced plans for nationwide efficiency standards that would constitute an effective ban on most current incandescent bulbs.

Venezuela and Cuba have launched massive incandescent light bulbs replacement programs in order to save energy. In the case of Venezuela, the government was able to save 2000 MW of electricity in the first six months of the 2006 program called Mission Energy Revolution, which by 2007 replaced 20 million incandescent light bulbs with CFL from a total of an estimated 55 million light bulbs in the country. Cuba replaced all the 11 million light bulbs used in the island. Also, Venezuela signed an agreement with

Vietnam, one of the large producers of CFLs in the world, to establish a factory to supply the future demand and hand-outs of government light bulbs.

The United States Department of Energy reports that sales of CFLs have dropped between 2007 and 2008, and estimated only 11% of suitable domestic light sockets use CFLs.

In the USA, a subjective program called the Program for the Evaluation and Analysis of Residential Lighting (PEARL) was created to be a watchdog program. PEARL has evaluated the performance and ENERGY STAR compliance of more than 150 models of CFL bulbs.

Labeling programs

In the United States and Canada, the Energy Star program labels compact fluorescent lamps that meet a set of standards for starting time, life expectancy, color, and consistency of performance. The intent of the program is to reduce consumer concerns due to variable quality of products. Those CFLs with a recent Energy Star certification start in less than one second and do not flicker. There is ongoing work in improving the 'quality' (color rendering index) of the light.

In the United Kingdom a similar program is run by the Energy Saving Trust to identify lighting products that meet energy conservation and performance guidelines.

Chapter- 8

Cool Roof

In the world of industrial and commercial buildings, a roofing system that can deliver high solar reflectance (the ability to reflect the visible, infrared and ultraviolet wavelengths of the sun, reducing heat transfer to the building) and high thermal emittance (the ability to radiate absorbed, or non-reflected solar energy) is a **cool roof**. Most cool roofs are white or other light colors.

In tropical Australia, zinc-galvanized (silvery) sheeting (usually corrugated) do not reflect heat as well as the truly "cool" color of white, especially as metallic surfaces fail to emit infrared back to the sky. European fashion trends are now using darker-colored aluminium roofing, to pursue consumer fashions.

Cool roofs enhance roof durability and reduce both building cooling loads and the urban heat island effect.

Also known as albedo, solar reflectance is expressed either as a decimal fraction or a percentage. A value of 0 indicates that the surface absorbs all solar radiation, and a value of 1 represents total reflectivity. Thermal emittance is also expressed either as a decimal fraction between 0 and 1, or a percentage. Another method of evaluating coolness is the solar reflectance index (SRI), which incorporates both solar reflectance and emittance in a single value. SRI quantifies how hot a surface would get relative to standard black and standard white surfaces. It is defined such that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. The use of SRI as a combined measurement of reflectance has been disputed, since it has been shown that two different products with identical SRI numbers can yield significantly different energy savings results depending on what geographic region they are applied in, and the climatic conditions present in this region].

Cool roofs are an effective alternative to bulk attic insulation under roofs in humid tropical and subtropical climates. Bulk insulation can be entirely replaced by roofing systems that both reflect solar radiation and provide emission to the sky. This dual function is crucial, and relies on the performance of cool roof materials in both the visible spectrum (which needs to be reflected) and far infra-red which needs to be emitted.

Cool roof can also be used as a geoengineering technique to tackle global warming based on the principle of solar radiation management, provided that the materials used not only reflect solar energy, but also emit infra-red radiation to cool the planet. This technique can give between 0.01-0.19 W/m^2 of globally-averaged negative forcing, depending on whether cities or all settlements are so treated. This is generally small when compared to the 3.7 W/m^2 of positive forcing from a doubling of CO_2. However, in many cases it can be achieved at little or no cost by simply selecting different materials. Further, it can reduce the need for air conditioning, which causes CO_2 emissions which worsen global warming. For this reason alone it is still demonstrably worth pursuing as a geoengineering technique.

Benefits of cool roofs

Most of the roofs in the world (including over 90% of the roofs in the United States) are dark-colored. In the heat of the full sun, the surface of a black roof can increase in temperature as much as 50 °C (90 °F), reaching temperatures of 70 to 90 °C (150-190 °F). This heat increase can contribute to:

- Increased cooling energy use and higher utility bills;
- Higher peak electricity demand (the maximum energy load, in megawatts, an electric utility experiences to supply customers instantaneously, generally experienced in summer late afternoons as businesses and residences turn up their air conditioners), raised electricity production costs, and a potentially overburdened power grid;
- Reduced indoor comfort;
- Increased air pollution due to the intensification of the "heat island effect"
- Accelerated deterioration of roofing materials, increased roof maintenance costs, and high levels of roofing waste sent to landfills.

Any building with a dark colored roof, but particularly large buildings, will consume more energy for air conditioning than a “cooler” building – a strain on both operating costs and the electric power grid. Cool roofs offer both immediate and long-term savings in building energy costs. White reflective membranes, metal roofing with "cool roof" pigments, coated roofs and planted or green roofs can:

- Reduce building heat-gain, as a white or reflective roof typically increases only 5–14 °C (10–25 °F) above ambient temperature during the day.
- Create 15–30% savings on summertime air conditioning expenditures.
- Enhance the life expectancy of both the roof membrane and the building’s cooling equipment.
- Improve thermal efficiency of the roof insulation; this is because as temperature increases, the thermal conductivity of the roof’s insulation also increases.
- Reduce the demand for electric power by as much as 10 percent on hot days.
- Reduce resulting air pollution and greenhouse gas emissions.
- Provide energy savings, even in northern climates on sunny (not necessarily “hot”) days.

Note that today's "cool roof" pigments allow metal roofing products to be EnergyStar rated in dark colors, even black. They aren't as reflective as whites or light colors, but can still save energy over other paints.

Energy calculators

Calculating cost savings resulting from the use of cool roofs can be done using several tools developed by federal agencies.

U.S. Department of Energy (DOE) Cool Roof Calculator

This tool developed by DOE's Oak Ridge National Laboratory estimates cooling and heating savings for low slope roof applications with non-black surfaces.

ENERGY STAR Roofing Comparison Calculator

This tool developed by the U.S. EPA calculates the net savings accruing from installing an ENERGY STAR labeled roof product on an air conditioned building. In addition to cooling savings, the program considers any resulting differences in heating costs.

Cool roofs in cool climates

No matter where cool roofs are installed, they cut down on the urban heat island effect, however they do not always lower a building's carbon footprint. In climates where there are more heating days than cooling days, white reflective roofs are not typically a worthwhile investment in terms of energy efficiency or savings. The cooling benefits of a highly reflective roof surface do not outweigh the winter month heating benefits of a less reflective, or black, roof surface in cooler climates. Heating accounts for 29% of commercial buildings' yearly energy consumption, while air conditioning only accounts for 6% of that same yearly energy consumption. Therefore, in cooler climates, it is more beneficial to utilize a dark-colored roof surface to help lower heating costs, which far outweigh annual air conditioning expenses. Energy calculators generally show a yearly net savings for dark-colored roof systems in cool climates. Oftentimes, reflective roofing materials get dirty, and their reflective benefits diminish, after only a few short years. Without a proper maintenance program to keep the material clean, reflective roofing materials seldom provide the energy-saving benefits that could be fully experienced based on their initial SRI.

Additionally, higher R values for insulating materials can lessen the impact of roof surface color. Snow on roofs also provides insulation, but it also adds considerable weight to the roofing assembly, which may not have been accounted for in the initial design. For a medium density of snow the resistance per 25 mm is about 0.110 (m^2-°C)/W, 300 mm of snow cover can provide an equivalent of 50 mm of good insulating material. Cool roofs contribute to the retention of snow on roofs in moderate snow fall areas. Dark-colored roofs heat up more quickly and therefore help melt rooftop snow.

There can be a 26 °C differential in membrane temperature between areas having 300 mm of snow cover compared to areas having no snow.

Research and practical experience with the degradation of roofing membranes over a number of years have shown that heat from the sun is one of the most potent factors that affects durability. High temperatures and large variations; seasonally or daily, at the roofing level are detrimental to the longevity of roof membranes. Reducing the extremes of temperature change will reduce the incidence of damage to membrane systems. Covering membranes with materials that reflect ultraviolet and infrared radiation will reduce damage caused by u/v and heat degradation. White surfaces reflect more than half of the radiation that reaches them, while black surfaces absorb almost all. White or white coated roofing membranes, or white gravel cover would appear to be the best approach to control these problems where membranes must be left exposed to solar radiation.

There are some studies that have shown that reflective roofs are not always best in cool climates. Benchmark Inc. did a study in five different cities and used the energy star calculator and the DOE calculator to find the annual savings. Because the DOE calculator includes differences in heating losses, there were significant differences between the savings in all of the cities. However, in Chicago, the annual savings became slightly negative in one of the models because of heating costs. The following graph shows the results:

Calculations performed using the DOE Energy Star Calculator show that high-reflectivity, medium-emissivity roof coatings, such as aluminum roof coatings can yield greater savings in colder regions.

Miller-McCune published a blog article by Robert Reale expressing an opinion that areas where heating is more of a concern than cooling would not benefit, and so cool roofs are only appropriate in climate zones 1-3. ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers') position on reflective roofs falls in line with Mr. Reale's article. ASHRAE now promotes the use of reflective roofs only in climate zones 1-3. In zones 4 and above, darker-colored roofing materials are more beneficial. An article in ecobroker.com also does not recommend reflective roofs in cooler climates. This site is designed to aid real estate agents in finding their clients green homes.

Green roofs are another option to consider for flat roofs in cooler climates.

One issue that is rarely talked about in terms of cool/reflective roofing is "What happens to the heat/UV that is reflective from the roof surface?" Well, if it's coming from a lower building adjacent to taller buildings, the energy is likely transferred into the adjacent building. This negates the energy-saving benefits for the building with the reflective rooftop, however it increases the heat gain, and subsequent energy costs, for the adjacent building. Furthermore, studies show that heat gain through windows has more than 10x the impact on energy costs and consumption that heat gained through the roof assembly. So, the reduction in energy costs (and subsequent carbon emissions) from the building with a reflective roof is multiplied by the adjacent building that picked it up via the windows.

Types of cool roofs

Cool roofs for commercial and industrial buildings fall into one of three categories: roofs made from inherently cool roofing materials, roofs made of materials that have been coated with a solar reflective coating, or green planted roofs.

Inherently cool roofs

White vinyl roofs, which are inherently reflective, achieve some of the highest reflectance and emittance measurements of which roofing materials are capable. A roof made of thermoplastic white vinyl, for example, can reflect 80 percent or more of the sun's rays and emit at least 70% of the solar radiation that the building absorbs. An asphalt roof only reflects between 6 and 26% of solar radiation, resulting in greater heat transfer to the building interior and greater demand for air conditioning – a strain on both operating costs and the electric power grid.

Coated roofs

One of the way to make an existing or new roof reflective is by applying a solar reflective coating on its surface. These coatings are specially engineered to reflect heat, regular white paint is not enough.
Ceramic coatings are the most well known in this domain, they provide an average reflectance of 75% to 85%. They have several limitations such as color (usually white only), which is why they are used by industrial applications mainly (warehouses, factories, ...). Their application is done by trained professionals only and may require specialized equipment and appropriate safety precautions.
High performance *nanotechnology heat reflective paints* are the most innovative in this field. They can reflect up to almost 95% of solar radiations, reducing a roof's heat load by an average of 30% in hot weather with as little as 200 micrometres (0.2 mm) in thickness . Working at nanotechnology levels allows thermal barrier paints like Planet Supra, for example, to offer an unlimited choice of colors in matte or glossy finish (the lighter the color, the higher the performance), easy application like any regular water-based paint and additional benefits such as self-cleaning properties thanks to Titanium Dioxide in the formulation.
Reflectivity and emissivity ratings for some reflective roof products can be found in the CRRC (Cool Roofs Rating Council) website.

Green roofs

A green roof typically consist of an insulation layer; a waterproof membrane; a drainage layer, usually made of lightweight gravel, clay, or plastic; a geotextile or filter mat that allows water to soak through but prevents erosion of fine soil particles; a growing medium; plants; and, sometimes, a wind blanket. Green roofs are classified as either intensive or extensive; some green roof designs incorporate both intensive and extensive elements.

Intensive green roofs require at least one foot of soil and appear as a traditional garden with trees, shrubs and other attractive landscapes. They are multi-layer constructions with elaborate irrigation and drainage systems. These roofs are often designed for recreational purposes and accommodate foot traffic. Intensive green roofs add considerable load to a structure and require intensive maintenance, so they are more common with large businesses or government buildings rather than free-standing homes.

Extensive roofs usually require less maintenance. The soil is shallower (less than 6 inches) and home to smaller, lighter plants such as mosses or wildflowers.

Both types of green roofs offer a variety of benefits including:

- Improved air quality as the plants absorb and convert carbon dioxide to oxygen
- Long lifespan - some green roofs in Europe have lasted more than 40 years
- Excellent insulation
- Cooled surrounding environment
- Potentially increases the area of habitat for wildlife such as birds and insects

A cool roof case study

In a 2001 federal study, the Lawrence Berkeley National Laboratory (LBNL) measured and calculated the reduction in peak energy demand associated with a cool roof's surface reflectivity. LBNL found that, compared to the original black rubber roofing membrane on the Texas retail building studied, a retrofitted vinyl membrane delivered an average decrease of 24 °C (43 °F) in surface temperature, an 11 percent decrease in aggregate air conditioning energy consumption, and a corresponding 14 percent drop in peak hour demand. The average daily summertime temperature of the black roof surface was 75 °C (168 °F), but once retrofitted with a white reflective surface, it measured 52 °C (125 °F). Without considering any tax benefits or other utility charges, annual energy expenditures were reduced by $7,200 or $0.07/sq. ft.

Instruments measured weather conditions on the roof, temperatures inside the building and throughout the roof layers, and air conditioning and total building power consumption. Measurements were taken with the original black rubber roofing membrane and then after replacement with a white vinyl roof with the same insulation and HVAC systems in place.

Programs promoting the use of cool roofs

Across the U.S. Federal Government

USDOE has announced a series of initiatives to more broadly implement cool roof technologies on DOE facilities and buildings across the country. As part of the new efforts, DOE will install a cool roof, whenever cost effective over the lifetime of the roof, during construction of a new roof or the replacement of an old one at a DOE facility.

Energy Star

ENERGY STAR is a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy designed to reduce greenhouse gas emissions and help businesses and consumers save money by making energy-efficient product choices.

For low slope roof applications, a roof product qualifying for the ENERGY STAR label under its Roof Products Program must have an initial solar reflectivity of at least 0.65, and weathered reflectance of at least 0.50, in accordance with EPA testing procedures. Warranties for reflective roof products must be equal in all material respects to warranties offered for comparable non-reflective roof products, either by a given company or relative to industry standards.

Cool Roof Rating Council (CRRC)

CRRC has created a rating system for measuring and reporting the solar reflectance and thermal emittance of roofing products. This system has been put into an online directory of more than 850 roofing products and is available for energy service providers, building code bodies, architects and specifiers, property owners and community planners. CRRC conducts random testing each year to ensure the credibility of its rating directory.

CRRC's rating program allows manufacturers and sellers to appropriately label their roofing products according to specific CRRC measured properties. The program does not, however, specify minimum requirements for solar reflectance or thermal emittance.

Green Globes

The Green Globes system is used in Canada and the United States. In the U.S., Green Globes is owned and operated by the Green Building Initiative (GBI). In Canada, the version for existing buildings is owned and operated by BOMA Canada under the brand name 'Go Green' (Visez vert).

Green Globes uses performance benchmark criteria to evaluate a building's likely energy consumption, comparing the building design against data generated by the EPA's Target Finder, which reflects real building performance. Buildings may earn a rating of between one and four globes. This is an online system; a building's information is verified by a Green Globes-approved and trained licensed engineer or architect. To qualify for a rating, roofing materials must have a solar reflectance of at least .65 and thermal emittance of at least .90. As many as 10 points may be awarded for 1-100 percent roof coverage with either vegetation or highly reflective materials or both.

LEED

The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system is a voluntary, continuously evolving national standard for developing high performance sustainable buildings. LEED provides standards for choosing products in designing buildings, but does not certify products.

In the area of roofing, to receive LEED Sustainable Sites Credit 7.2, at least 75% of the surface of a roof must use materials having a Solar Reflective Index (SRI) of at least 78. This criterion may also be met by installing a vegetated roof for at least 50% of the roof area, or installing a high albedo and vegetated roof that, in combination, meets this formula: (Area of SRI Roof/0.75)+(Area of vegetated roof/0.5) = Total Roof Area.

As of August 2008, various LEED initiatives including legislation, executive orders, resolutions, ordinances, policies, and incentives are in place in 98 cities, 29 counties, 25 towns, 31 states, 12 federal agencies or departments, 15 public school jurisdictions and 38 institutions of higher education across the United States.

Examples of LEED-certified buildings with white reflective roofs are:

Building Name	Owner	Location	LEED Level
Donald Bren School of Environmental Science & Management	University of California, Santa Barbara	Santa Barbara, California	Platinum
Frito-Lay Jim Rich Service Center	Frito-Lay, Inc.	Rochester, New York	Gold
Edifice Multifunction	Travaux Public et Services Gouvernementaux Canada	Montreal, Quebec	Gold
Seattle Central Library	City of Seattle	Seattle, Wash.	Silver
National Geography Society Headquarters Complex	National Geographic Society	Washington, D.C.	Silver
Utah Olympic Oval	Salt Lake City Olympic Winter Games 2002 Organizing Committee	Salt Lake City, Utah	Certified
Premier Automotive Group North American Headquarters	Ford Motor Company	Irvine, California	Certified

COOL ROOFS EUROPE

This project is co-financed by the European Union in the framework of the Intelligent Energy Europe Programme.

The aim of the proposed action is to create and implement an Action Plan for the cool roofs in EU. The specific objectives are: to support policy development by transferring experience and improving understanding of the actual and potential contributions by cool roofs to heating and cooling consumption in the EU; to remove market barriers and simplify the procedures for cool roofs integration in construction and building's stock; to change the behaviour of decision-makers and stakeholders so to improve acceptability of the cool roofs; to disseminate and promote the development of innovative legislation, codes, permits and standards, including application procedures, construction and planning permits concerning cool roofs. The work will be developed in four axes, technical, market, policy and end-users.

The urban heat island effect

For hundreds of millions to perhaps billions of people living in and near cities, urban heat islands are a growing concern. An urban heat island occurs where the combination of heat-absorbing infrastructure such as dark asphalt parking lots and road pavement and expanses of black rooftops, coupled with sparse vegetation, raises air temperature by several degrees Celsius higher than the temperature in the surrounding countryside.

Green building programs advocate the use of cool roofing to mitigate the urban heat island effect and the resulting poorer air quality (in the form of smog) the effect causes. By reflecting sunlight, light-colored roofs minimize the temperature rise and reduce smog formation. In some densely populated areas, a quarter of the land cover may be roof surface alone.

To best combat the urban heat island effect, a combined strategy that maximizes the amount of vegetation by planting trees along streets and in open spaces, as well as by building green roofs and painting buildings with solar reflective coatings, offers more potential cooling than any individual strategy. Abating the urban heat island effect even has worthwhile effects in cooler climates. An LBNL study showed that, if strategies to mitigate this effect, including cool roofs, were widely adopted, the Greater Toronto metropolitan area could save more than $11 million annually on energy costs.

Chapter- 9

Green Roof

Traditional sod roofs can be seen in many places in the Faroe Islands.

Green roof of City Hall in Chicago, Illinois.

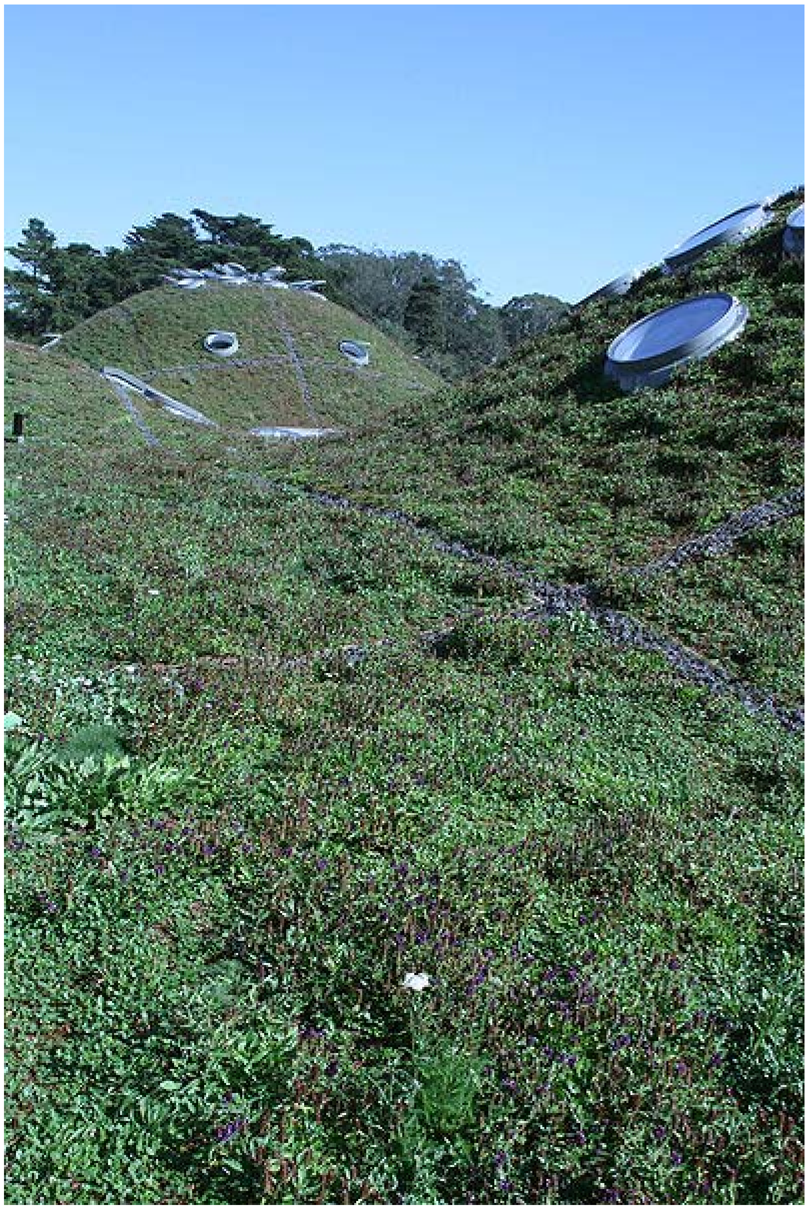
A **green roof** is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. (The use of “green” refers to the growing trend of environmentalism and does not refer to roofs which are merely colored green, as with green roof tiles or roof shingles.)

Container gardens on roofs, where plants are maintained in pots, are not generally considered to be true green roofs, although this is an area of debate. Rooftop ponds are another form of green roofs which are used to treat greywater.

Also known as “**living roofs**”, green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, and helping to lower urban air temperatures and combat the heat island effect. There are two types of green roofs: intensive roofs, which are thicker and can support a wider variety of plants but are heavier and require more maintenance, and extensive roofs, which are covered in a light layer of vegetation and are lighter than an intensive green roof.

The term *green roof* may also be used to indicate roofs that use some form of "green" technology, such as a cool roof, a roof with solar thermal collectors or photovoltaic modules. Green roofs are also referred to as *eco-roofs*, *oikosteges*, *vegetated roofs*, *living roofs*, and *greenroofs*.

Environmental benefits



A modern green roof (California Academy of Sciences). Constructed for low maintenance by intentionally avoiding many native plant species, with only the hardiest surviving varieties selected for installation on the roof.

Green roofs are used to:

- Reduce heating (by adding mass and thermal resistance value)

A 2005 study by Brad Bass of the University of Toronto showed that green roofs can also reduce heat loss and energy consumption in winter conditions.

- Reduce cooling (by evaporative cooling) loads on a building by fifty to ninety percent
- especially if it is glassed in so as to act as a terrarium and passive solar heat reservoir — a concentration of green roofs in an urban area can even reduce the city's average temperatures during the summer
- Reduce stormwater run off
- Natural Habitat Creation
- Filter pollutants and carbon dioxide out of the air which helps lower disease rates such as asthma
- Filter pollutants and heavy metals out of rainwater
- Help to insulate a building for sound; the soil helps to block lower frequencies and the plants block higher frequencies
- If installed correctly many living roofs can contribute to LEED points
- Agricultural space

Financial benefits

- Increase roof life span dramatically
- Increase real estate value

A green roof is often a key component of an autonomous building.

Several studies have been carried out in Germany since the 1970s. Berlin is one of the most important centers of green roof research in Germany. Particularly in the last 10 years, much more research has begun. About ten green roof research centers exists in the US and activities exist in about 40 countries. In a recent study on the impacts of green infrastructure, in particular green roofs in the Greater Manchester area, researchers found that adding green roofs can help keep temperatures down, particularly in urban areas: “adding green roofs to all buildings can have a dramatic effect on maximum surface temperatures, keeping temperatures below the 1961-1990 current form case for all time periods and emissions scenarios. Roof greening makes the biggest difference…where the building proportion is high and the evaporative fraction is low. Thus, the largest difference was made in the town centers.”

Types

An intensive roof garden in Manhattan

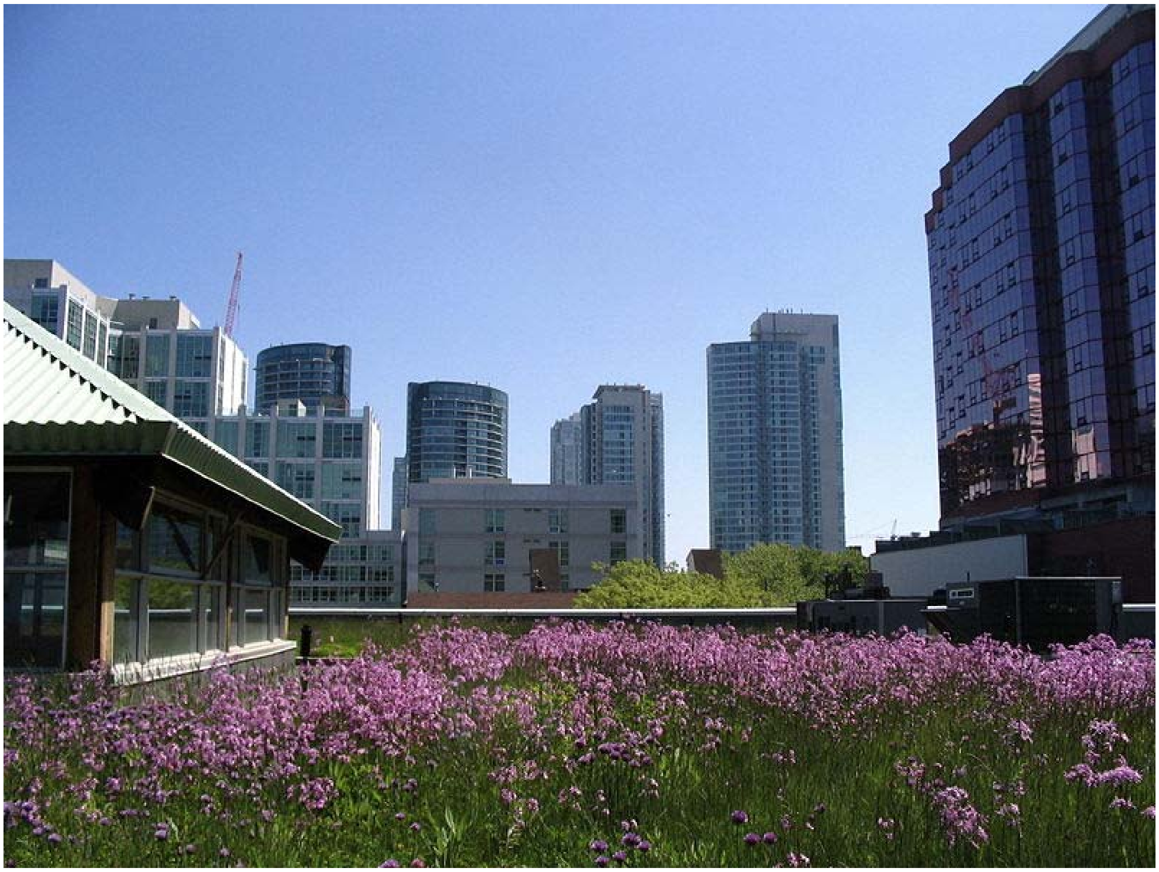
Green roofs can be categorized as intensive, "semi-intensive", or extensive, depending on the depth of planting medium and the amount of maintenance they need. Traditional roof gardens, which require a reasonable depth of soil to grow large plants or conventional lawns, are considered "intensive" because they are labour-intensive, requiring irrigation, feeding and other maintenance. Intensive roofs are more park-like with easy access and may include anything from kitchen herbs to shrubs and small trees. "Extensive" green roofs, by contrast, are designed to be virtually self-sustaining and should require only a minimum of maintenance, perhaps a once-yearly weeding or an application of slow-release fertiliser to boost growth. Extensive roofs are usually only accessed for maintenance. They can be established on a very thin layer of "soil" (most use specially formulated composts): even a thin layer of rockwool laid directly onto a watertight roof can support a planting of *Sedum* species and mosses.

Another important distinction is between pitched green roofs and flat green roofs. Pitched sod roofs, a traditional feature of many Scandinavian buildings, tend to be of a simpler design than flat green roofs. This is because the pitch of the roof reduces the risk of water penetrating through the roof structure, allowing the use of fewer waterproofing and drainage layers.

History

Re-creation of Viking houses in Newfoundland

Sod roofs on 18th century farm buildings in Heidal, Norway.



On the green roof of the Mountain Equipment Co-op store in Toronto, Canada.

Green Roofs have a centuries-long history.

Modern green roofs, which are made of a system of manufactured layers deliberately placed over roofs to support growing medium and vegetation, are a relatively new phenomenon. However, green roofs or sod roofs in Northern Scandinavia have been around for centuries. The modern "trend" started when green roofs were developed in Germany in the 1960s, and have since spread to many countries. Today, it is estimated that about 10% of all German roofs have been “greened”. Green roofs are also becoming increasingly popular in the United States, although they are not as common as in Europe.

A number of European Countries have very active associations promoting green roofs, including Germany, Switzerland, the Netherlands, Norway, Italy, Austria, Hungary, Sweden, the UK and Greece. The City of Linz in Austria has been paying developers to install green roofs since 1983 and in Switzerland it has been a federal law since the late 1990s. In the UK their up-take has been slow but a number of cities have developed policies to encourage their use, notably in London and Sheffield.

Many green roofs are installed to comply with local regulations and government fees, often regarding stormwater runoff management. In areas with combined sewer-stormwater systems, heavy storms can overload the wastewater system and cause it to flood, dumping raw sewage into the local waterways. Green roofs decrease the total amount of runoff and slow the rate of runoff from the roof. It has been found that they can retain up to 75% of rainwater, gradually releasing it back into the atmosphere via condensation and transpiration, while retaining pollutants in their soil. Elevation 314, a new development in Washington D.C., uses green roofs to filter and store some of its stormwater on site, avoiding the need for expensive underground sand filters to meet D.C. Department of Health stormwater regulations.

Combating the urban heat island effect is another reason for creating a green roof. Traditional building materials soak up the sun's radiation and re-emit it as heat, making cities at least 4 degrees Celsius (7 °F) hotter than surrounding areas. On Chicago's City Hall, by contrast, which features a green roof, roof temperatures on a hot day are typically 14–44 degrees Celsius (25–80 °F) cooler than they are on traditionally roofed buildings nearby.

Green roofs are becoming common in Chicago, as well as Atlanta, Portland, and other United States cities, where their use is encouraged by regulations to combat the urban heat island effect. In the case of Chicago, the city has passed codes offering incentives to builders who put green roofs on their buildings. The Chicago City Hall green roof is one of the earliest and most well-known examples of green roofs in the United States; it was planted as an experiment to determine the effects a green roof would have on the microclimate of the roof. Following this and other studies, it has now been estimated that if all the roofs in a major city were "greened", urban temperatures could be reduced by as much as 7 degrees Celsius.

Green roofs have also been found to dramatically improve a roof’s insulation value. A study conducted by Environment Canada found a 26% reduction in summer cooling needs and a 26% reduction in winter heat losses when a green roof is used. In addition, greening a roof is expected to lengthen a roof’s lifespan by two or three times, according to Penn State University’s Green Roof Research Center.

Rooftop water purification is also being implemented in green roofs. These forms of green roofs are actually treatment ponds built into the rooftops. They are built either from a simple substrate (as being done in Dongtan) or with plant-based ponds (as being done by WaterWorks UK Grow System and Waterzuiveren.be Plants used include calamus, Menyanthes trifoliata, Mentha aquatica, etc.)

Green roofs also provide habitats for plants, insects, and animals that otherwise have limited natural space in cities. Even in high-rise urban settings as tall as 19 stories, it has been found that green roofs can attract beneficial insects, birds, bees and butterflies. Rooftop greenery complements wild areas by providing "stepping stones" for songbirds, migratory birds and other wildlife facing shortages of natural habitat.

Brown roofs

Industrial brownfield sites can be valuable ecosystems, supporting rare species of plants, animals and invertebrates. Increasingly in demand for redevelopment, these habitats are under threat. "Brown roofs", also known as "biodiverse roofs", can partly mitigate this loss of habitat by covering the flat roofs of new developments with a layer of locally sourced material. Construction techniques for brown roofs are typically similar to those used to create flat green roofs, the main difference being the choice of growing medium (usually locally sourced rubble, gravel, spoil etc...) to meet a specific biodiversity objective. In Switzerland it is common to use alluvial gravels from the foundations; in London a mix of brick rubble and some concrete has been used. Although the original idea was to allow the roofs to self-colonise with plants, they are sometimes seeded to increase their biodiversity potential in the short term, although such practices are derided by purists. The roofs are colonised by spiders and insects (many of which are becoming extremely rare in the UK as such sites are developed) and provide a feeding site for insectivorous birds. Laban, a centre for contemporary dance in London, has a brown roof specifically designed to encourage the nationally rare black redstart. (In 2003 Laban won the RIBA Stirling Prize.) A green roof, 160m above ground level, and claimed to be the highest in the UK and Europe "and probably in the world" to act as nature reserve, is on the Barclays Bank HQ in Canary Wharf. Designed combining the principles of green and brown roofs, it is already home to a range of rare invertebrates.

Examples by country

Green roof planted with native species at L'Historial de la Vendée, a new museum in western France

Switzerland

Switzerland has one of Europe's oldest green roofs, created in 1914 at the Moos lake water-treatment plant, Wollishofen, Zürich. Its filter-tanks have 30,000 square metres (320,000 sq ft) of flat concrete roofs. To keep the interior cool and prevent bacterial growth in the filtration beds, a drainage layer of gravel and a 15 cm (6 in) layer of soil was spread over the roofs, which had been waterproofed with asphalt. A meadow developed from seeds already present in the soil; it is now a haven for many plant species, some of which are now otherwise extinct in the district, most notably 6,000 *Orchis morio* (green-winged orchid). More recent Swiss examples can be found at Klinikum 1 and Klinikum 2, the Cantonal Hospitals of Basel, and the Sihlpost platform at Zürich's main railway station.

Sweden

What is claimed to be the world's first green roof botanical garden was set up in Augustenborg, a suburb of Malmö, in May 1999. The International Green Roof Institute (IGRI) opened to the public in April 2001 as a research station and educational facility. (It has since been renamed the Scandinavian Green Roof Institute (SGRI), in view of the increasing number of similar organisations around the world.) Green roofs are well-established in Malmö: the Augustenborg housing development near the SGRI botanical garden incorporates green roofs and extensive landscaping of streams, ponds and soakaways between the buildings to deal with storm water run-off.

The new Bo01 urban residential development (in the Västra Hamnen (Western Harbour) close to the foot of the Turning Torso office and apartment block, designed by Santiago Calatrava) is built on the site of old shipyards and industrial areas, and incorporates many green roofs.

Germany

Long-held green roof traditions since the early industrialization about 100 years ago exist in Germany. Since the 1970s, a vibrant green roof industry also exists. Building codes developed by the *Fachvereinigung Bauwerksbegrünung,* have existed since the 1980s. The current issue was published in 2008. Since the 1980s, environmental mitigation regulations have helped to push green roofs to reduce the ecological footprint of buildings. Now, about 10,000,000 m^2 of new green roofs are be constructed each year. About 3/4 of these are extensive, the last 1/4 are roof gardens. The two cities with the most green roofs in Germany are Berlin and Stuttgart. Surveys about the status of regulation are done by the FBB (Fachvereinigung Bauwerksbegrünung = German organization for green building technologies). Nearly one third of all cities have regulations to support green roof and rain water technology. Green roof research institutions in Germany are located in several cities as including Hannover, Berlin, Geisenheim and Neubrandenburg.

Iceland

Sod roof Church at Hof, Iceland

Sod roofs are frequently found on traditional farmhouses and farm buildings in Iceland.

United Kingdom

British examples can be found at the University of Nottingham Library, and in London at the Horniman Museum and Canary Wharf. The Ethelred Estate, close to the River Thames in central London, is the British capital's largest roof-greening project to date. Toxteth in Liverpool is also a candidate for a major roof-greening project.

In the United Kingdom, green roofs are often used in built-up city areas where residents and workers often do not have access to gardens or local parks. They have also been used by companies such as Rolls-Royce Motor Cars, who have one of the biggest green roofs in Europe (covering more than 32,000m² to help their factory, at Goodwood, West Sussex, blend into its rural surroundings.

Canada

The city of Toronto approved a by-law in May 2009, mandating green roofs on residential and industrial buildings. There is criticism from Green Roofs for Healthy Cities that the new laws are not stringent enough, since they will only apply to residential building that are a minimum of six storeys high. By 31 January 2011, industrial buildings will be required to render 10% or 2,000m² of their roofs green. In 2008, the Vancouver

Convention Center installed a six-acre living roof of indigenous plants and grasses on its West building, making it the largest green roof in Canada.

France

In France, a huge green roof of roughly 8,000 square metres (86,000 sq ft) has been incorporated into the new museum L'Historial de la Vendée which opened in June 2006 at Les Lucs-sur-Boulogne.

Greece

The *oikostegi*, a green roof on the Treasury building in Athens

The Greek Ministry of Finance has now installed a green roof on the Treasury in Constitution Square in Athens. The so called "oikostegi" (Greek - *oiko*, pronounced *eeko*, meaning building-ecological, and *stegi*, pronounced *staygee*, meaning roof-abode-shelter) was inaugurated in September, 2008. Studies of the thermodynamics of the roof in September 2008 concluded that the thermal performance of the building was significantly affected by the installation. In further studies, in August 2009, energy savings of 50% were observed for air conditioning in the floor directly below the installation. The ten-floor building has a total floor space of 1.4 hectares. The oikostegi covers 650m², equalling 52% of the roof space and 8% of the total floor space. Despite this, energy savings totalling €5,630 per annum were recorded, which translates to a 9% saving in air conditioning and a 4% saving in heating bills for the whole building. An additional observation and conclusion of the study was that the thermodynamic performance of the oikostegi had improved as biomass was added over the 12 months between the first and second study. This suggests that further improvements will be observed as the biomass increases still further. The study also stated that while measurements were being made by thermal cameras, a plethora of beneficial insects were observed on the roof, such as butterflies, honey bees and ladybirds. Obviously this was not the case before installation. Finally, the study suggested that both the micro-climate and biodiversity of Constitution Square, in Athens, Greece had been improved by the oikostegi.

Spain

The roof to Banco Santander's headquarters in Madrid, Spain is currently home to Europe's biggest green roof at just over 100,000sqm in size. The roof was made using a mix of both extensive and intensive planting systems.

Egypt

In Egypt, soil-less agriculture is used to grow plants on the roofs of buildings. No soil is placed directly on the roof itself, thus eliminating the need for an insulating layer; instead, plants are grown on wooden tables. Vegetables and fruit are the most popular candidates, providing a fresh, healthy source of food that is free from pesticides.

A more advanced method (aquaponics), being used experimentally in Egypt, is farming fish next to plants in a closed cycle. This allows the plants to benefit from the ammonia excreted by the fish, helping the plants to grow better and at the same time eliminating the need for changing the water for the fish, because the plants help to keep it clean by absorbing the ammonia. The fish also get some nutrients from the roots of the plants.

United States of America

The undulating green roof of the California Academy of Sciences, under construction in San Francisco.

One of the largest expanses of extensive green roof is to be found in the US, at Ford Motor Company's River Rouge Plant, Dearborn, Michigan, where 42,000 square metres (450,000 sq ft) of assembly plant roofs are covered with sedum and other plants, designed by William McDonough. Built over Millennium Park Garage, Chicago's 24.5-acre (99,000 m^2) Millennium Park is considered one of the largest intensive green roofs. Other well-known American examples include Chicago’s City Hall and the Gap headquarters in San Bruno, CA. Recently, the American Society of Landscape Architects retrofitted their existing headquarters building in Washington, D.C. with a green roof designed by landscape architect Michael Van Valkenburgh.

Another example of a green roof in the United States is the Ballard Library in Seattle. The landscape architect was Swift & Co. and the building architect was Bohlin Cywinski Jackson. This green roof has over 18,000 plants to help with insulation and reduce runoff. The plants used on the roof include *Achillea tomentosa* (woolly yarrow), *Armeria maritima* (sea pink, sea thrift), *Carex inops pensylvanica* (long-stoloned sedge), *Eriphyllum lanatum* (Oregon sunshine), *Festuca rubra* (red creeping fescue), *Festuca idahoensis* (Idaho fescue), *Phlox subulata* (creeping phlox), *Saxifrage cespitosa* (tufted saxifrage), *Sedum oreganum* (Oregon stonecrop), *Sedum album* (white stonecrop), *Sedum spurium* (two-row stonecrop), *Sisyrinchium idahoensis* (blue-eyed grass), *Thymus serpyllum* (wild thyme), *Triteleia hyacintha* (fool's onion).

The new California Academy of Sciences building in San Francisco's Golden Gate Park has a green roof that provides 2.5 acres (10,000 m^2) of native vegetation designed as a habitat for indigenous species, including the threatened Bay checkerspot butterfly. According to the Academy's fact sheet on the building, the building consumes 30-35% less energy than required by code.

An early green roofed building (completed in 1971) is the 358,000 sq ft (33,300 m^2) Weyerhaeuser Corporate Headquarters building in Federal Way, Washington. Its 5 story office roof system comprises a series of stepped back terraces covered in greenery. From the air, the building blends into the landscape.

Australia

Green roofs have been increasing in popularity in Australia over the past 10 years. Some of the early examples include the Freshwater Place residential tower in Melbourne (2002) with its Level 10 rooftop Half Acre Garden, CH2 building housing the Melbourne City Council (2006) - Australia's first 6-star Green Star Design commercial office building as certified by the Green Building Council of Australia, and Condor Tower (2005) with a 75 square metre lawn on the 4th floor.

In 2010, the largest Australian green roof project was announced. The Victorian Desalination Project will have a "living tapestry" of 98,000 Australian indigenous plants over a roof area spanning more than 26,000 square metres. The roof will form part of the desalination plant's sophisticated roof system, designed to blend the building into the landscape, provide acoustic protection, corrosion resistance, thermal control and reduced maintenance. The green roof will be installed by Fytogreen Australia

Since 2008 City Councils and influential business groups in Australia have become active promoting the benefits of green roofs. "The Blueprint to Green Roof Melbourne" is one program being run by the Committee for Melbourne.

Costs

A properly designed and installed green roof system can cost 15 to 20 dollars per square foot as a total cost, not including the roof's waterproof layers according to Green Roofs for Healthy Cities, the green roof not-for-profit advocacy group of North America. <http://greenroofs.org/> In Europe a well-designed and professionally installed fully integrated green roof can cost anywhere between 100 to 200 euros per square meter. The cost depends on what kind of roof it is, the structure of the building, and what plants can grow on the material that is on top of the roof. In the Spring 2007 issue of the Green Roof Infrastructure Monitor (Green Roofs for Healthy Cities web site), Jörg Breuning reflects the wind and fire loads of green roofs and how German insurance companies handle extensive green roofs.

Some cost can also be attributed to maintenance. Extensive green roofs have low maintenance requirements but they are generally not maintenance free. German research has quantified the need to remove unwanted seedlings to approximately 0,1 min/(m^2*year). Maintenance of green roofs often includes fertilization to increase flowering and succulent plant cover. If aesthetics is not an issue, fertilization and maintenance is generally not needed. Extensive green roofs should only be fertilized with controlled release fertilizers in order to avoid pollution of the storm-water. Conventional fertilizers should never be used on extensive vegetated roofs. German studies have approximated the nutrient requirement of vegetated roofs to 5gN/m^2. It is also important to use a substrate that does not contain too much available nutrients. The FLL-guidelines specify maximum allowable nutrient content of substrates.

Disadvantages

The main disadvantage of green roofs is the higher initial cost. Some types of green roofs do have more demanding structural standards especially in seismic regions of the world. Some existing buildings cannot be retrofitted with certain kinds of green roof because of the weight load of the substrate and vegetation exceeds permitted static loading. Depending on what kind of green roof it is, the maintenance costs could be higher, but some types of green roof have little or no ongoing cost. Some kinds of green roofs also place higher demands on the waterproofing system of the structure both because water is retained on the roof and due to the possibility of roots penetrating the waterproof membrane. "However, a sedum covering doesn't need water to be retained on the roof as these plants can tolerate long periods without rainfall, so a drainage layer will combat this particular problem" (Chris Sorrell). Moreover, properly designed and installed systems include root barriers. It is true that installing adequate waterproofing systems and root barriers can increase the initial cost of the roof, however, due to the fact that a green roof protects the waterproofing membrane from the elements, particularly UV light, the life expectancy of the membranes is doubled or even tripled, leading to recovered initial cost differentials.

Chapter- 10

Daylighting

A skylight providing internal illumination

Daylighting is the practice of placing windows or other openings and reflective surfaces so that during the day natural light provides effective internal lighting. Particular attention is given to daylighting while designing a building when the aim is to maximize visual comfort or to reduce energy use. Energy savings can be achieved either from the reduced use of artificial (electric) lighting or from passive solar heating or cooling. Artificial lighting energy use can be reduced by simply installing fewer electric lights because daylight is present, or by dimming/switching electric lights automatically in response to the presence of daylight, a process known as daylight harvesting.

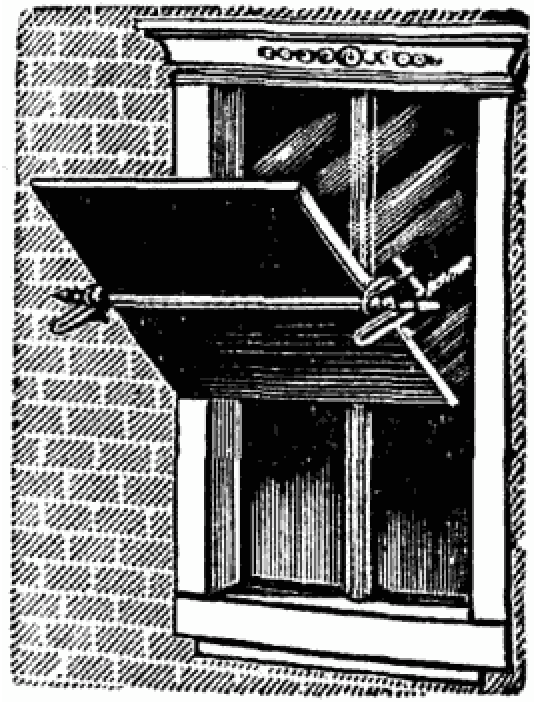
Daylighting is a technical term given to a common centuries-old, geography and culture independent design basic when "rediscovered" by 20th century architects.

There is no direct sunlight on the polar-side wall of a building from the autumnal equinox to the spring equinox. Traditionally, houses were designed with minimal windows on the polar side but more and larger windows on the equatorial-side. Equatorial-side windows receive at least some direct sunlight on any sunny day of the year (except in tropical latitudes in summertime) so they are effective at daylighting areas of the house adjacent to the windows. Even so, during mid-winter, light incidence is highly directional and casts deep shadows. This may be partially ameliorated through light diffusion and through somewhat reflective internal surfaces. In fairly low latitudes in summertime, windows that face east and west and sometimes those that face toward the pole receive more sunlight than windows facing toward the equator.

Windows

Windows are the most common way to admit daylight into a space. Their vertical orientation means that they selectively admit sunlight and diffuse daylight at different times of the day and year. Therefore windows on multiple orientations must usually be combined to produce the right mix of light for the building, depending on the climate and latitude. There are three ways to improve the amount of light available from a window:

- Place window close to a light colored wall.
- Slant the sides of window openings so the inner opening is larger than the outer opening.
- Use a large light colored window sill to project light into the room.



Reflektor von W. Hanisch & Co., Berlin.

Adjustable light reflector

Different types and grades of glass and different window treatments can also affect the amount of light transmission through the windows.

Light reflectors

Once used extensively in office buildings, the manually adjustable **light reflector** is seldom in use today having been supplanted by a combination of other methods in concert with artificial illumination. The reflector had found favor where the choices of artificial light provided poor illumination compared to modern electric lighting.

Heliostats

A heliostat. The mirror rotates on a computer-controlled, motor-driven alt-azimuth mount.

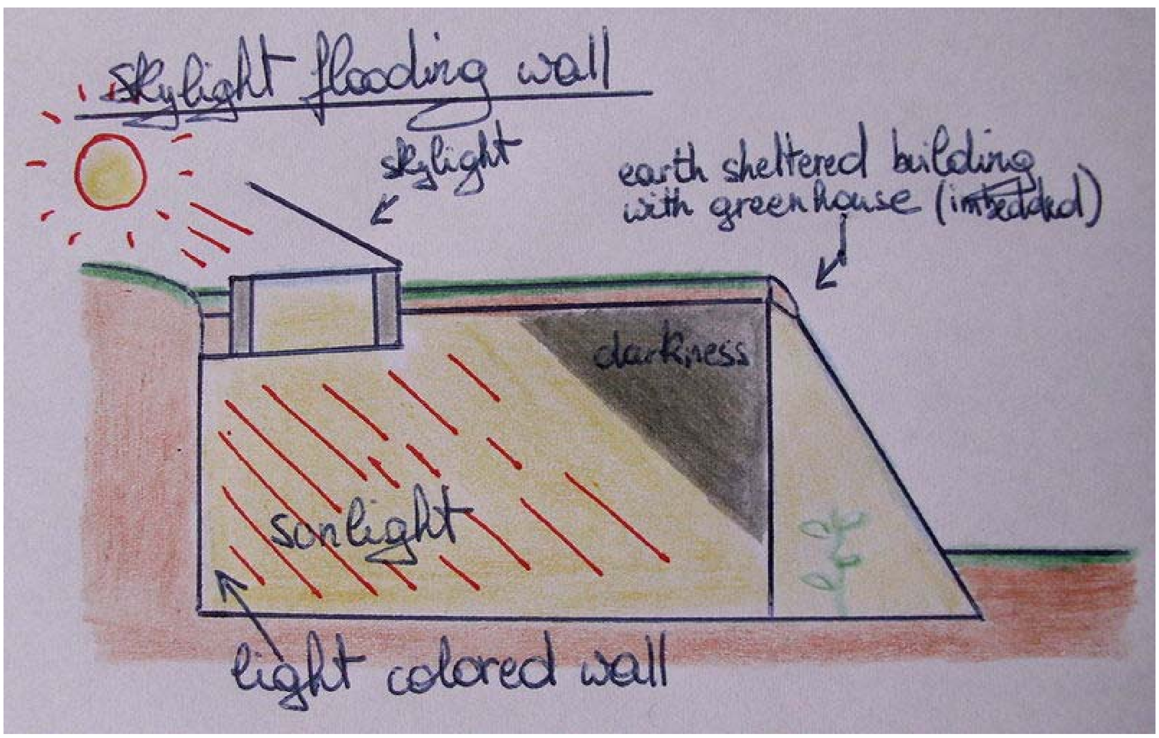
The use of **heliostats**, mirrors which are moved automatically to reflect sunlight in a constant direction as the sun moves across the sky, is gaining popularity as an energy-efficient method of lighting. A heliostat can be used to shine sunlight directly through a window or skylight, or into any arrangement of optical elements, for example **light tubes**, that distribute the light where it is needed.

Light shelves

Light shelves are an effective way to enhance the lighting from windows on the equator-facing side of a structure, this effect being obtained by placing a white or reflective metal light shelf outside the window. Usually the window will be protected from direct summer season sun by a projecting eave. The light shelf projects beyond the shadow created by the eave and reflects sunlight upward to illuminate the ceiling. This reflected light can contain little heat content and the reflective illumination from the ceiling will typically reduce deep shadows, reducing the need for general illumination.

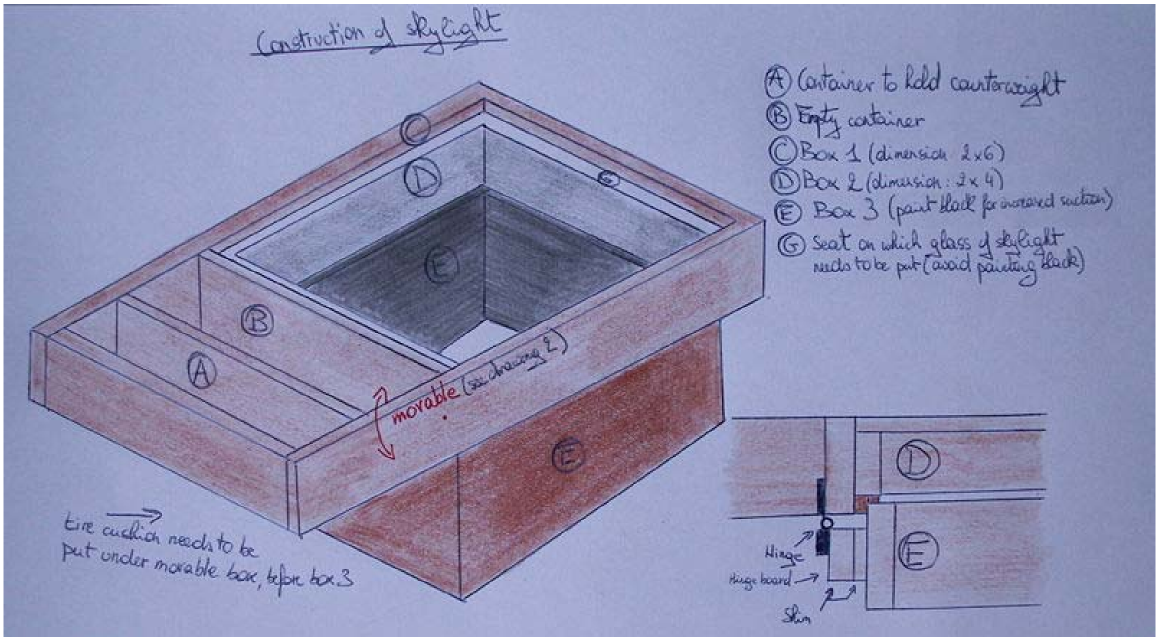
In the cold winter, a natural light shelf is created when there is snow on the ground. As the outside temperature drops below freezing, moisture in the atmosphere precipitates out, often in the form of snow (or freezing rain). This makes the ground highly reflective. Low winter sun reflects off the snow and increases solar gain through equator-facing glass by one-to-two thirds which brightly lights the ceiling of these rooms. Glare control (drapes) may be required.

Skylights



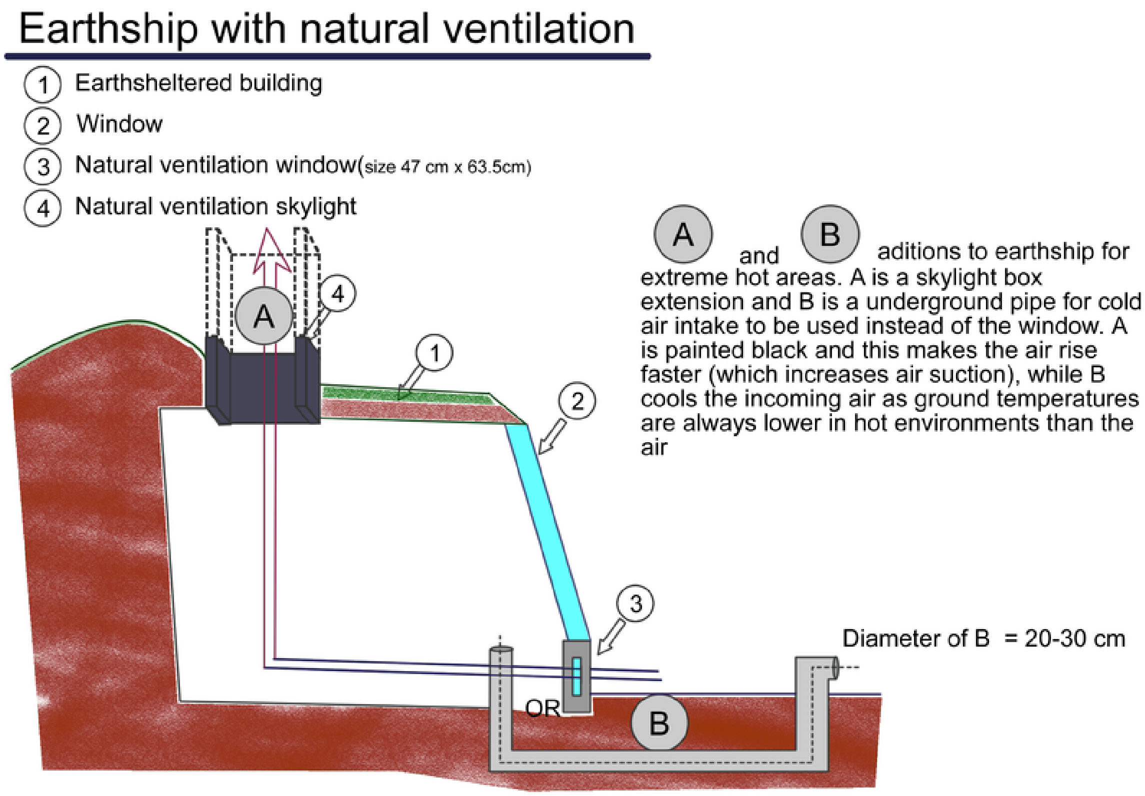
A skylight and the optimal placement thereof

Skylight is any horizontal window, Roof lantern or Oculus, placed at the roof of the building, often used for daylighting. White translucent acrylic is a 'Lambertian Diffuser' meaning transmitted light is perfectly diffused and distributed evenly over affected areas. This means, among other advantages, that light source quality standards are measured relative to white acrylic transmission. White acrylic domes provide even light distribution throughout the day. Skylights admit more light per unit area than windows, and distribute it more evenly over a space.



Construction of a DIY skylight

The optimal area of skylights (usually quantified as "effective aperture") varies according to climate, latitude, and the characteristics of the skylight, but is usually 4-8% of floor area. The thermal performance of skylights is affected by stratification, i.e. the tendency of warm air to collect in the skylight wells, which in cool climates increases the rate of heat loss. During warm seasons, skylights with transparent glazings will cause internal heat problems, which is best treated by placing white translucent acrylic over or under the transparent skylight glazing.

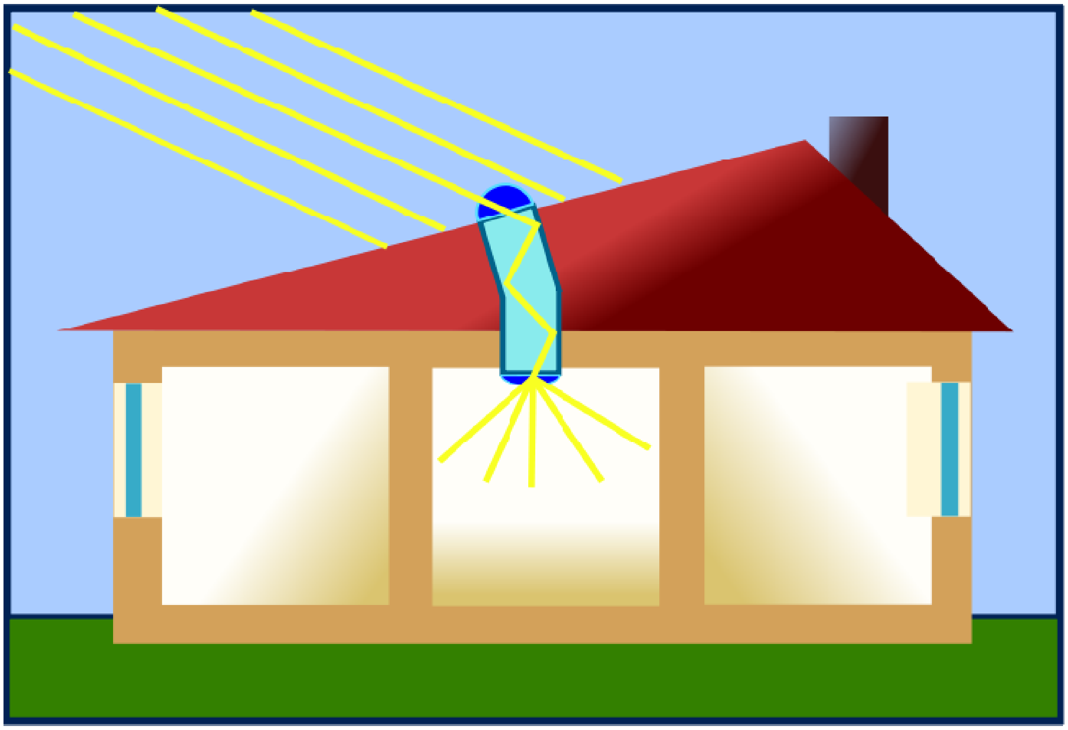


Skylights can also double for natural ventilation systems

With proper skylight design, there can be significant energy savings in commercial and industrial applications. Savings from daylighting can cut lighting energy use by up to 80 percent according to the US Department of Energy's Federal Energy Management Program. In terms of cost savings, the DOE reported that many commercial buildings can reduce total energy costs by up to one-third through the optimal use of daylighting.

Poorly constructed or installed skylights may have leaking problems and single-paned skylights may weep with condensation. Using modern designs with proper installation will eliminate issues with leaks and provide greater energy efficiency.

Light tubes



Light tube illustrated

Another type of device used is the **light tube**, also called a **solar tube**, which is placed into a roof and admits light to a focused area of the interior. These somewhat resemble recessed ceiling light fixtures. They do not allow as much heat transfer as skylights because they have less surface area.

Tubular Daylighting Devices (TDDs) use modern technology to transmit visible light through opaque walls and roofs. The tube itself is a a passive component consisting of either a simple reflective interior coating or a light conducting fiber optic bundle. It is frequently capped with a transparent, roof-mounted dome 'light collector' and terminated with a diffuser assembly that admits the daylight into interior spaces and distributes the available light energy evenly (or else efficiently if the use of the lit space is reasonably fixed, and the user desired one or more 'bright-spots').

Clerestory windows

Another important element in creating daylighting is the use of **clerestory windows**. These are high, vertically-placed windows. They can be used to increase direct solar gain when oriented towards the equator. When facing toward the sun, clerestories and other windows may admit unacceptable glare. In the case of a passive solar house, clerestories may provide a direct light path to polar-side (north in the northern hemisphere; south in the southern hemisphere) rooms that otherwise would not be illuminated. Alternatively, clerestories can be used to admit diffuse daylight (from the north in the northern hemisphere) that evenly illuminates a space such as a classroom or office.

Often, clerestory windows also shine onto interior wall surfaces painted white or another light color. These walls are placed so as to reflect indirect light to interior areas where it is needed. This method has the advantage of reducing the directionality of light to make it softer and more diffuse, reducing shadows.

Sawtooth Roof

Another roof-angled glass alternative is a "**sawtooth roof**" (found on older factories). Sawtooth roofs have vertical roof glass facing away from the equator side of the building to capture diffused light (not harsh direct equator-side solar gain). The angled portion of the glass-support structure is opaque and well insulated with a cool roof and radiant barrier. The sawtooth roof's lighting concept partially reduces the summer "solar furnace" skylight problem, but still allows warm interior air to rise and touch the exterior roof glass in the cold winter, with significant undesirable heat transfer.

Solarium

In a well-designed isolated solar gain building with a **solarium**, **sunroom**, **greenhouse**, etc., there is usually significant glass on the equator side. A large area of glass can also be added between the sun room and your interior living quarters. Low-cost high-volume-produced patio door safety glass is an inexpensive way to accomplish this goal.

The doors used to enter a room, should be opposite the sun room interior glass, so that a user can see outside immediately when entering most rooms. Halls should be minimized with open spaces used instead. If a hall is necessary for privacy or room isolation, inexpensive patio door safety glass can be placed on both sides of the hall. Drapes over the interior glass can be used to control lighting. Drapes can optionally be automated with sensor-based electric motor controls that are aware of room occupancy, daylight, interior temperature, and time of day. Passive solar buildings with no central air conditioning system need control mechanisms for hourly, daily, and seasonal, temperature-and-daylight variations. If the temperature is correct, and a room is unoccupied, the drapes can automatically close to reduce heat transfer in either direction.

To help distribute sun room daylight to the sides of rooms that are farthest from the equator, inexpensive ceiling-to-floor mirrors can be used.

Building codes require a second means of egress, in case of fire. Most designers use a door on one side of bedrooms, and an outside window, but west-side windows provide very-poor summer thermal performance. Instead of a west-facing window, designers use an R-13 foam-filled solid energy-efficient exterior door. It may have a glass storm door outside with the inner door allowing light to pass through when opened. East/west glass doors and windows should be fully shaded top-to-bottom or a spectrally-selective coating can be used to reduce solar gain.

Fiber-optic concrete wall

Another way to make a secure structural concrete wall translucent is to embed optical fiber cables in it. Daylight (and shadow images) can then pass directly through a thick solid-concrete wall.

Hybrid solar lighting

Oak Ridge National Laboratory (ORNL) has developed a new alternative to skylights called **Hybrid Solar Lighting**. This design uses a roof-mounted light collector, large-diameter optical fiber, and modified efficient fluorescent lighting fixtures that have transparent rods connected to the optical fiber cables. Essentially no electricity is needed for daytime natural interior lighting.

Field tests conducted in 2006 and 2007 of the new HSL technology were promising, but the low-volume equipment production is still expensive. HSL should become more cost effective in the near future. A version that can withstand windstorms could begin to replace conventional commercial fluorescent lighting systems with improved implementations in 2008 and beyond. The U.S. 2007 Energy Bill provides funding for HSL R&D, and multiple large commercial buildings are ready to fund further HSL application development and deployment.

At night, ORNL HSL uses variable-intensity fluorescent lighting electronic control ballasts. As the sunlight gradually decreases at sunset, the fluorescent fixture is gradually turned up to give a near-constant level of interior lighting from daylight until after it becomes dark outside.

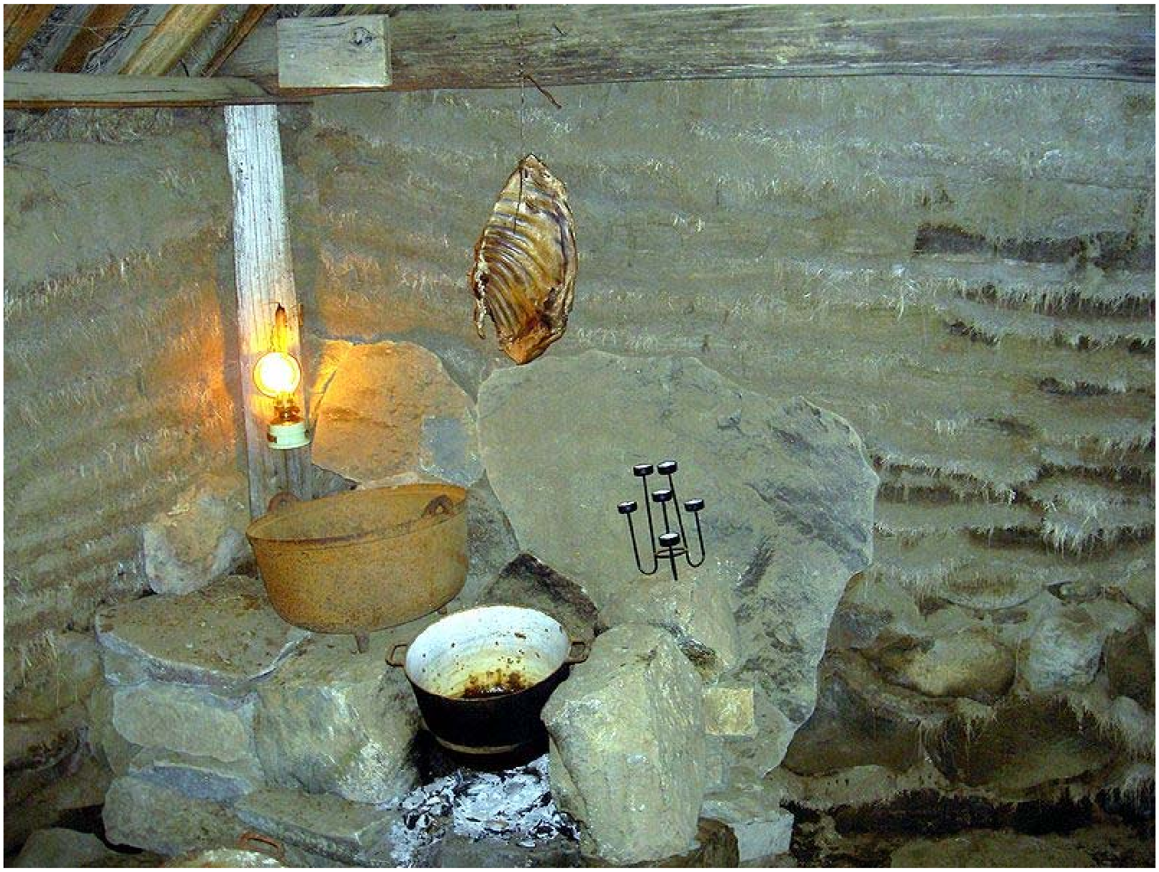
HSL may soon become an option for commercial interior lighting. It can transmit about half of the direct sunlight it receives.

Chapter- 11

Earth Sheltering

Turf houses in Keldur, Iceland.

Turf house in Sænautasel, Iceland.



Turf house in Sænautasel, Iceland. Inside view showing the turf layers on the walls.

Earth sheltering is the architectural practice of using earth against building walls for external thermal mass, to reduce heat loss, and to easily maintain a steady indoor air temperature. Earth sheltering is popular in modern times among advocates of passive solar and sustainable architecture, but has been around for nearly as long as humans have been constructing their own shelter.

Background

Living within earth shelters has been a large part of human history. The connection to earth shelter dwellings began with the utilization of caves, and over time evolving technologies led to the construction of customized earth dwellings. Today, earth shelter construction is a rare practice, especially in the U.S.A. During the energy crisis and the 1973 Oil Crisis, along with the back-to-the-land movement, there was a surge of interest in earth shelter/underground home construction in an effort toward self-sufficient living. However, progress has been slow, and earth shelter construction is often viewed by architects, engineers, and the public alike as an unconventional method of building. Techniques of earth sheltering have not yet become common knowledge, and much of society still remains unaware of the process or benefits of this type of building construction.

Types of construction

- **Earth berming:** Earth is piled up against exterior walls and packed, sloping down away from the house. The roof may, or may not be, fully earth covered, and windows/openings may occur on one or more sides of the shelter. Due to the building being above ground, fewer moisture problems are associated with earth berming in comparison to underground/fully recessed construction.
- **In-hill construction:** The house is set into a slope or hillside. The most practical application is using a hill facing towards the equator (south in the Northern Hemisphere and north in the Southern Hemisphere). There is only one exposed wall in this type of earth sheltering, the wall facing out of the hill, all other walls are embedded within the earth/hill.
- **Underground/fully recessed construction:** The ground is excavated, and the house is set in below grade. It can also be referred to as an Atrium style due to the common atrium/courtyard constructed in the middle of the shelter to provide adequate light and ventilation.

Benefits

The benefits of earth sheltering are numerous. They include: taking advantage of the earth as a thermal mass, offering extra protection from the natural elements, energy savings, providing substantial privacy, efficient use of land in urban settings, shelters have low maintenance requirements, and earth sheltering commonly takes advantage of passive solar building design.

The Earth's mass absorbs and retains heat. Over time, this heat is released to surrounding areas, such as an earth shelter. Because of the high density of the earth, change in the earth's temperature occurs slowly. This is known as 'thermal lag.' Because of this principle, the earth provides a fairly constant temperature for the underground shelters, even when the outdoor temperature undergoes great fluctuation. In most of the United States, the average temperature of the earth once below the frost line is between 55 and 57 degrees Fahrenheit (13 to 14 degrees Celsius). Frost line depths vary from region to region. In the USA frost lines can range from roughly 20 inches to more than 40 inches. Thus, at the base of a deep earth berm, the house is heated against an exterior temperature gradient of perhaps ten to fifteen degrees, instead of against a steeper temperature grade where air is on the outside of the wall instead of earth. During the summer, the temperature gradient helps to cool the house.

The reduction of air infiltration within an earth shelter can be highly profitable. Because three walls of the structure are mainly surrounded by earth, very little surface area is exposed to the outside air. This alleviates the problem of warm air escaping the house through gaps around windows and door. Furthermore, the earth walls protect against cold winter winds which might otherwise penetrate these gaps. However, this can also become a potential indoor air quality problem. Healthy air circulation is key.

As a result of the increased thermal mass of the structure, the thermal lag of the earth, the protection against unwanted air infiltration and the combined use of passive solar techniques, the need for extra heating and cooling is minimal. Therefore, there is a drastic reduction in energy consumption required for the home compared to homes of typical construction.

Earth shelters also provide privacy from neighbours, as well as soundproofing. The ground provides acoustic protection against outside noise. This can be a major benefit in urban areas or near highways. In urban areas, another benefit of underground sheltering is the efficient use of land. Many houses can sit below grade without spoiling the habitat above ground. Each site can contain both a house and a lawn/garden.

Potential problems

Problems of water seepage, internal condensation, bad acoustics, and poor indoor air quality can occur if an earth shelter has not been properly designed.

Issues also include the sustainability of building materials. Earth sheltering often requires heavier construction than conventional building techniques, and many construction companies have limited or no experience with earth sheltered construction, potentially compromising the physical construction of even the best designs.

The threat of water seepage occurs around areas where the waterproofing layers have been penetrated. Vents and ducts emerging from the roof can cause specific problems due to the possibility of movement. Precast concrete slabs can have a deflection of 1/2 inch or more when the earth/soil is layered on top of it. If the vents or ducts are held rigidly in place during this deflection, the result is usually the failure of the waterproofing layer. To avoid this difficulty, vents can be placed on other sides of the building (besides the roof), or separate segments of pipes can be installed. A narrower pipe in the roof that fits snugly into a larger segment within the building can also be used. The threat of water seepage, condensation, and poor indoor air quality can all be overcome with proper waterproofing and ventilation.

The building materials for earth sheltered construction tend to be of non-biodegradable substances. Because the materials must keep water out, they are often made of plastics. Concrete is another material that is used in great quantity. More sustainable products are being tested to replace the cement within concrete (such as fly ash), as well as alternatives to reinforced concrete. The excavation of a site is also drastically time- and labor-consuming. Overall, the construction is comparable to conventional construction, because the building requires minimal finishing and significantly less maintenance.

Condensation and poor quality indoor air problems can be solved by using earthtubes, or what is known as a geothermal heat pump - a concept different from earth sheltering. With modification, the idea of earthtubes can be used for underground buildings: instead of looping the earthtubes, leave one end open downslope to draw in fresh air using the chimney effect by having exhaust vents placed high in the underground building.

Landscape and site planning

The site planning for an earth sheltered building is an integral part of the overall design; investigating the landscape of a potential building site is crucial. There are many factors to assess when surveying a site for underground construction. The topography, regional climate, vegetation, water table and soil type of varying landscapes all play dynamic roles in the design and application of earth shelters.

Topography

On land that is relatively flat, a fully recessed house with an open courtyard is the most appropriate design. On a sloping site, the house is set right into the hill. The slope will determine the location of the window wall; a south facing exposed wall is the most practical in the Northern hemisphere (and north facing in the southern hemisphere) due to solar benefits.

Regional climate

Depending on the region and site selected for earth sheltered construction, the benefits and objectives of the earth shelter construction vary. For cool and temperate climates, objectives consist of retaining winter heat, avoiding infiltration, receiving winter sun, using thermal mass, shading and ventilating during the summer, and avoiding winter winds and cold pockets. For hot, arid climates objectives include maximizing humidity, providing summer shade, maximizing summer air movement, and retaining winter heat. For hot, humid climates objective include avoiding summer humidity, providing summer ventilation, and retaining winter heat.

Regions with extreme daily and seasonal temperatures emphasize the value of earth as a thermal mass. In this way, earth sheltering is most effective in regions with high cooling and heating needs, and high temperature differentials. In regions such as the south eastern United States, earth sheltering may need additional care in maintenance and construction due to condensation problems in regard to the high humidity. The ground temperature of the region may be too high to permit earth cooling if temperatures fluctuate only slightly from day to night. Preferably, there should be adequate winter solar radiation, and sufficient means for natural ventilation. Wind is a critical aspect to evaluate during site planning, for reasons regarding wind chill and heat loss, as well as ventilation of the shelter. In the Northern Hemisphere, south facing slopes tend to avoid cold winter winds typically blown in from the north. Fully recessed shelters also offer adequate protection against these harsh winds. However, atriums within the structure have the ability to cause minor turbulence depending on the size. In the summer, it is helpful to take advantage of the prevailing winds. Because of the limited window arrangement in most earth shelters, and the resistance to air infiltration, the air within a structure can become stagnant if proper ventilation is not provided. By making use of the wind, natural ventilation can occur without the use of fans or other active systems. Knowing the direction, and intensity, of seasonal winds is vital in promoting cross ventilation. Vents are commonly placed in the roof of bermed or fully recessed shelters to achieve this effect.

Vegetation

The plant cover of the landscape is another important factor. Adding plants can be both positive and negative. Nearby trees may be valuable in wet climates because their roots remove water. However a prospective builder should know what types of trees are in the area and how large and rapidly they tend to grow, due to possible solar-potential compromise with their growth. Vegetation can provide a windbreak for houses exposed to winter winds. The growth of small vegetation, especially those with deep roots, also helps in the prevention of erosion, on the house and in the surrounding site.

Soil and drainage

The soil type is one of the most essential factors during site planning. The soil needs to provide adequate bearing capacity and drainage, and help to retain heat. With respects to drainage, the most suitable type of soil for earth sheltering is a mixture of sand and gravel. Well graded gravels have a large bearing capacity (about 8,000 pounds per square foot), excellent drainage and a low frost heave potential. Sand and clay, however, do not compact well and can be susceptible to erosion as a result. Clay soils, while least susceptible to erosion, often do not allow for proper drainage, and have a higher potential for frost heaves. Clay soils are more susceptible to thermal shrinking and expanding. Being aware of the moisture content of the soil and the fluctuation of that content throughout the year will help prevent potential heating problems. Frost heaves can also be problematic in some soil. Fine grain soils retain moisture the best and are most susceptible to heaving. A few ways to protect against capillary action responsible for frost heaves are placing foundations below the freezing zone or insulating ground surface around shallow footings, replacement of frost sensitive soils with granular material, and interrupting capillary draw of moisture by putting a drainage layer of coarser material in the existing soil.

Water can cause potential damage to earth shelters if it ponds around the shelter. Avoiding sites with a high water table is crucial. Drainage, both surface and subsurface, must be properly dealt with. Waterproofing applied to the building is essential.

Atrium designs have an increased risk of flooding, so the surrounding land should slope away from the structure on all sides. A drain pipe at the perimeter of the roof edge can help collect and remove additional water. For bermed homes, an interceptor drain at the crest of the berm along the edge of the roof top is recommended. An interceptor drainage swale in the middle of the berm is also helpful or the back of the berm can be terraced with retaining walls. On sloping sites runoff may cause problems. A drainage swale or gully can be build to divert water around the house, or a gravel filled trench with a drain tile can be installed along with footing drains.

Soil stability should also be considered, especially when evaluating a sloping site. These slopes may be inherently stable when left alone, but cutting into them can greatly compromise their structural stability. Retaining walls and backfills may have to be constructed to hold up the slope prior to shelter construction.

Construction methods

Current methods

In earth sheltered construction there is often extensive excavation done on the building site. An excavation several feet larger than the walls' planned perimeter is made to allow for access to the outside of the wall for waterproofing and insulation. Once the site is prepared and the utility lines installed, a foundation of reinforced concrete is poured. The walls are then installed. Usually they are either poured in place or formed either on or off site and then moved into place. Reinforced concrete is the most common choice. The process is repeated for the roof structure. If the walls, floor and roof are all to be poured in place, it is possible to make them with a single pour. This can reduce the likelihood of there being cracks or leaks at the joints where the concrete has cured at different times.

On the outside of the concrete a waterproofing system is applied. The most frequently used waterproofing system includes a layer of liquid asphalt onto which a heavy grade waterproof membrane is affixed, followed by a final liquid water sealant which may be sprayed on. It is very important to make sure that all of the seams are carefully sealed. It is very difficult to locate and repair leaks in the waterproofing system after the building is completed.

One or more layers of insulation board or foam are added on the outside of the waterproofing. If the insulation chosen is porous a top layer of waterproofing is added. After everything is complete, earth is backfilled into the remaining space at the exterior of the wall and sometimes over the roof to accommodate a green roof. Any exposed walls and the interior are finished according to the owners' preferences.

Materials

Structural

Reinforced concrete is the most commonly used structural material in earth shelter construction. It is strong and readily available. Untreated wood rots within five years of use in earth shelter construction. Steel can be used, but needs to be encased by concrete to keep it from direct contact with the soil which corrodes the metal. Bricks and CMUs (concrete masonry units) are also possible options in earth shelter construction but must be reinforced to keep them from shifting under vertical pressure unless the building is constructed with arches and vaults.

Unfortunately, reinforced concrete is not the most environmentally sustainable material. The concrete industry is working to develop products that are more earth-friendly in response to consumer demands. Products like Grancrete and Hycrete are becoming more readily available. They claim to be environmentally friendly and either reduce or eliminate the need for additional waterproofing. However, these are new products and have not been extensively used in earth shelter construction yet.

Some unconventional approaches are also proposed. One such method is a PSP method proposed by Mike Oehler. The PSP method uses, wooden posts, plastic sheeting and non-conventional ideas that allow more windows and ventilation. This design also reduces some runoff problems associated with conventional designs. The method uses wood posts, a frame that acts like a rib to distribute settling forces, specific construction methods which rely on fewer pieces of heavy equipment, plastic sheeting, and earth floors with plastic and carpeting.

Waterproofing

Several layers are used for waterproofing in earth shelter construction. The first layer is meant to seal any cracks or pores in the structural materials, also working as an adhesive for the waterproof membrane. The membrane layer is often a thick flexible polyethylene sheeting called EPDM. EPDM is the material usually used in water garden, pond and swimming pool construction. This material also prevents roots from burrowing through the waterproofing. EPDM is very heavy to work with, and can be chewed through by some common insects like fire ants. It is also made from petrochemicals, making it less than perfect environmentally.

There are various cementitious coatings that can be used as waterproofing. The product is sprayed directly onto the unprotected surface. It dries and acts like a huge ceramic layer between the wall and earth. The challenge with this method is, if the wall or foundation shifts in any way, it cracks and water is able to penetrate through it easily.

Bituthene (Registered name) is very similar to the three coat layering process only in one step. It comes already layered in sheets and has a self adhesive backing. The challenge with this is the same as with the manual layering method, in addition it is sun sensitive and must be covered very soon after application.

Eco-Flex is an environmentally friendly waterproofing membrane that seems to work very well on foundations, but not much is known about its effectiveness in earth sheltering. It is among a group of liquid paint-on waterproofing products. The main challenges with these are they must be carefully applied, making sure that every area is covered to the right thickness, and that every crack or gap is tightly sealed.

Bentonite clay is the alternative that is closest to optimum on the environmental scale. It is naturally occurring and self-healing. The drawback to this system is that it is very heavy and difficult for the owner/builder to install.

Insulation

Unlike conventional building, earth shelters require the insulation on the exterior of the building rather than inside the wall. One reason for this is that it provides protection for the waterproof membrane against freeze damage, another is that the earth shelter is able to better retain its desired temperature. There are two types of insulation used in earth shelter construction. The first is close-celled extruded polystyrene sheets. Two to three inches glued to the outside of the waterproofing is generally sufficient. The second type of insulation is a spray on foam. This works very well were the shape of the structure is unconventional, rounded or difficult to get to. Foam insulation requires an additional protective top coat such as foil to help it resist water penetration.

In some low budget earth shelters, insulation may not be applied to the walls. These methods rely on the U factor or thermal heat storage capacity of the earth itself below the frost layer. These designs are the exception however and risk frost heave damage in colder climates. The theory behind no insulation designs relies on using the thermal mass of the earth to store heat, rather than relying on a heavy masonry or cement inner structures that exist in a typical passive solar house. This is the exception to the rule and cold temperatures may extend down into the earth above the frost line making insulation necessary for higher efficiencies.

Design for energy conservation

Earth sheltered homes are often constructed with energy conservation and savings in mind. Specific designs of earth shelters allow for maximum savings. For bermed or in-hill construction, a common plan is to place all the living spaces on the side of the house facing the equator. This provides maximum solar radiation to bedrooms, living rooms, and kitchen spaces. Rooms that do not require natural daylight and extensive heating such as the bathroom, storage and utility room are typically located on the opposite (or in hill) side of the shelter. This type of layout can also be transposed to a double level house design with both levels completely underground. This plan has the highest energy efficiency of earth sheltered homes because of the compact configuration as well as the structure being submerged deeper in the earth. This provides it with a greater ratio of earth cover to exposed wall than a one story shelter would.

With an atrium earth shelter the living spaces are concentrated around the atrium. The atrium arrangement provides a much less compact plan than that of the one or two story bermed/inhill design; therefore it is commonly less energy efficient, in terms of heating needs. This is one of the reasons why atrium designs are classically applied to warmer climates. However, the atrium does tend to trap air within it which is then heated by the sun and helps reduce heat loss.

Earth sheltering with solar heating

Earth sheltering is often combined with solar heating systems. Most commonly, the utilization of passive solar design techniques is used in earth shelters. A south facing structure with the north, east, and west sides covered with earth, is the most effective application for passive solar systems. A large double glazed window, triple glazed or Zomeworks beadwall (vacuum/blower pumps that filled your double pane solar windows with styrofoam balls at night for extra insulation and vacuumed the beads out in the morning, patent now expired), spanning most of the length of the south wall is critical for solar heat gain. It is helpful to accompany the window with insulated drapes to protect against heat loss at night. Also, during the summer months, providing an overhang, or some sort of shading device, is useful to block out excess solar gain. Combining solar heating with earth sheltering is referred to as "annualized geo solar design", "Passive annual heat storage", or sometimes as an "Umbrella house." In the umbrella house, Polystyrene insulation extends around 23 feet radius from underground walls. A plastic film covers the insulation (for waterproofing), and soil is layer on top. The materials slope downward, like an umbrella. It sheds excess water while keeping the soil temperature warm and dry.

Passive cooling which pulls air with a fan or convection from a near constant temperature air into buried Earth cooling tubes and then into the house living space. This also provides fresh air to occupants and the air exchange required by ASHRAE.

Earth shelter construction: history and examples

Berming

Historically, earth berming was a common building practice that combined heavy timber framing and rough stone work with stacking thick layers of sod or peat against the walls and on the roof. This served as excellent protection from the elements. In a relatively short period of time the earth layers grow together leaving the structure with an appearance of a hill with a door.

Earth Sheltered rest area along Interstate 77 in Ohio

In these early structures, the heavy timber framing acted as structural support and added comfort and warmth to the interior. Rough stone was often stacked along the outer walls with a simple lime mortar for structural support and often serves as an exterior facing wall and foundation. There is a greater use of stone work in earth shelter structures in areas where timber is scarce. These are the most sustainable of the earth shelters as far as materials go because they are able to decompose and return to earth. This is why there are few remaining example like Hvalsey Church in Greenland where only the stacked stones remain. One of the oldest examples of berming, dating back some 5,000 years, can be found at Skara Brae in the Orkney Islands off northern Scotland.

Today's bermed earth structures are built quite differently from those of the past. Common construction employs large amounts of steel reinforced concrete acting as structural support and building shell. Bulldozers or bobcats are used to pile earth around the building and on the roof instead of stacking earth in place. A community of 5 bermed earth structures can be found in Hockerton in Nottinghamshire,UK.

In-hill

One historical example of in-hill earth shelters would be Mesa Verde, in the southwest United States. These building are constructed directly onto the ledges and caves on the face of the cliffs. The front wall is built up with local stone and earth to enclose the structure. Similarly today, in-hill earth shelter construction utilizes the natural formation of a hillside for two to three of the exterior walls and sometimes the roof of a structure. Alternative builders craft a type of in-hill structure known as an Earthship. In Earthship construction, tires rammed with earth are used as structural materials for three of the walls and generally have a front façade of windows to capture passive solar energy.

The most famous and probably the largest earth-sheltered home is the residence of Bill Gates, who had it built over a period of several years on a heavily wooded site on the shore of Lake Washington. It is an excellent example of the lack of obtrusiveness of this kind of home, since it appears much smaller than it actually is, when seen from the lake.

Underground

Though underground construction is relatively uncommon in the US, successful examples can be found in Australia where the ground is so hard that there is little to no need for structural supports and a pick ax and shovel are the tools of the builder/remodeler.

In the early 1970s, China undertook the construction of Dixia Cheng, a city underneath Beijing. It was primarily a complex of bomb shelters that could house 40% of the population at that time. It was a response to the fear of Soviet attack. Parts of it are now used in more commercial ventures.

Chapter- 12

Techniques & Practices of Low Energy Building Engineering

Active daylighting

Active daylighting is a system of collecting sunlight using a mechanical device to increase the efficiency of light collection for a given lighting purpose. Active daylighting systems are different from passive daylighting systems in that passive systems are stationary and do not actively follow or track the sun.

Types of active daylighting control systems

There are two types of active daylighting control systems: 'closed loop' solar tracking, and 'open loop' solar tracking systems.

Closed loop systems track the sun by relying on a set of lenses or sensors with a limited field of view, directed at the sun, and are fully illuminated by sunlight at all times. As the sun moves, it begins to shade one or more sensors, which the system detect and activates motors or actuators to move the device back into a position where all sensors are once again equally illuminated.

Open loop systems track the sun without physically following the sun via sensors (although sensors may be used for calibration). These systems typically employ electronic logic which controls device motors or actuators to follow the sun based on a mathematical formula. This formula is typically a pre-programmed sun path chart, detailing where the sun will be at a given latitude and at a given date and time for each day.

Companies or products that utilize active daylighting systems

- Himawari Daylight Collector
- Heliostats
- Sunflower Corporation

Barra system

The **Barra system** is a passive solar building technology developed by Horazio Barra in Italy. It uses a collector wall to capture solar radiation in the form of heat. It also uses the thermosiphon effect to distribute the warmed air through channels incorporated into the reinforced concrete floors, warming the floors and hence the building. Alternatively, in hot weather, cool nighttime air can be drawn through the floors to chill them in a form of air conditioning.

Barra's are said to have more uniform north-south temperature distributions than other passive solar houses. Many successful systems were built in Europe, but Barra seems fairly unknown elsewhere.

Passive solar collector

To convert the sun's light into heat indirectly, a separate insulated space is constructed on the sunny side of the house walls. Looking at the outside, and moving through a cross section there is an outside clear layer. This was traditionally built using glass, but with the advent of cheap, robust Polycarbonate glazing most designs use twin- or triple-wall polycarbonate greenhouse sheeting. Typically the glazing is designed to pass visible light, but block IR to reduce losses, and block UV to protect building materials.

The next layer is an absorption space. This absorbs most of the light entering the collector. It usually consists of an air gap of around 10cm thickness with one or more absorption meshs suspended vertically in the space. Often window fly screen mesh is used, or horticultural shade cloth. The mesh itself can hold very little heat and warms up rapidly in light. The heat is absorbed by air passing around and through the mesh, and so the mesh is suspended with an air gap on both the front and back sides.

Finally a layer of insulation sits between the absorption space and the house. Usually this is normal house insulation, using materials such as polyisocyanurate foam, rock wool, foil and polystyrene.

This collector is very agile - in the sun it heats up rapidly and the air inside starts to convect. If the collector were to be directly connected to the building using a hole near the floor and a hole near the ceiling an indirect solar gain system would be created. One problem with this that, like Trombe walls, the heat would radiate back out at night, and a convection current would chill the room during the night. Instead, the air movement can be stopped using automatic dampers, similar to those used for ventilating foundation spaces in cold climates, or plastic film dampers, which work by blocking air flow in one direction with a very lightweight flap of plastic. The addition of the damper makes the design an efficient isolated solar gain system.

Thermal store

To store the thermal energy from the collector, the Barra system suspends a "spancrete" slab of concrete as a ceiling to store heat. This is fairly expensive and requires strong support. An alternative is to use water, which can store 5 times as much heat for a given weight. A simple, cheap and effective way is to store the water in sealed 100 mm diameter PVC storm pipe with end caps.

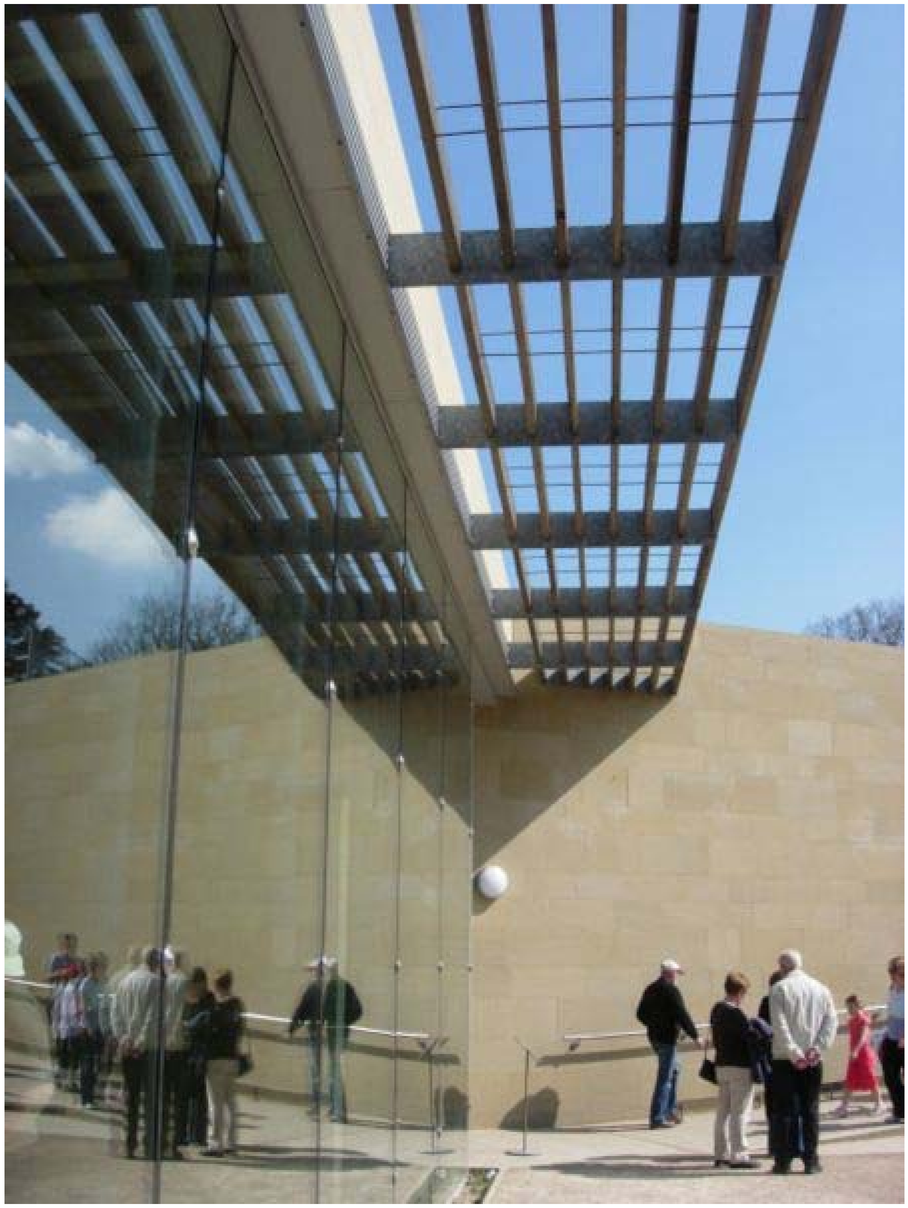
Whether water or concrete is used, the heat is transferred from the air in the collector into the storage material during the day, and released on demand using a ceiling fan into the room at night.

Where "spancrete" slabs are used, the ceiling also heats the house by radiation. Some houses are fitted with louvres (similar to those used on satellites) to adjust the radiation transfer. Warm air travels through the slab tunnels from south to north, where it exits and travels back north through the bulk of the room to the air heater inlet near the floor.

Intermediate thermal store

In most places a system designed for 5 successive days of no sun provides enough storage for all but a few days in a hundred years. Heat can be stored over a number of days using a large container of water. An 8 foot cube of water in the basement might store 15 kL of water, which is heated using a copper tube with fins in the collector. The performance of this can be further improved by putting the finned tube inside another layer of glazing at the back of the main collector, allowing the temperature to build up more than the surrounding air stream. On cloudy days the heat is transferred back out of the store to heat the house.

Brise soleil



A basic brise soleil at the Underground gallery at the Yorkshire Sculpture Park. This photo was taken at noon in April, a little after the vernal equinox. Note how the top of the glazing is in shade. As the passage of summer continues, the noon shading on the glass will be greater.

Brise soleil, sometimes **brise-soleil**, in architecture refers to a variety of permanent sun-shading techniques, ranging from the simple patterned concrete walls popularized by Le Corbusier to the elaborate wing-like mechanism devised by Santiago Calatrava for the Milwaukee Art Museum or the mechanical, pattern-creating devices of the Institut du Monde Arabe by Jean Nouvel.

In the typical form, a horizontal projection extends from the sunside facade of a building. This is most commonly used to prevent facades with a large amount of glass from overheating during the summer. Often louvers are incorporated into the shade to prevent the high-angle summer sun falling on the facade, but also to allow the low-angle winter sun to provide some passive solar heating.

Energy-plus-house

An **energy-plus-house** produces more energy from renewable energy sources, on average over the course of a year, than it imports from external sources. This is achieved using some combination microgeneration technology and low-energy building techniques such as passive solar building design, insulation and careful site selection and placement.

It may involve a reduction of modern conveniences, preferring those with low-energy requirements. However, many energy-plus houses are almost indistinguishable from a traditional home, since they simply use the most energy-efficient solutions (i.e. appliances, fixtures, etc) throughout the house.

Passive daylighting

Passive daylighting is a system of both: collecting sunlight using static, non-moving, and non-tracking systems such as Windows, Sliding glass doors, most skylights, light tubes, and reflecting the collected daylight deeper inside with elements such as light shelves. Passive daylighting systems are different from active daylighting systems in that active systems track and/or follow the sun, and rely on mechanical mechanisms to do so.

Collecting

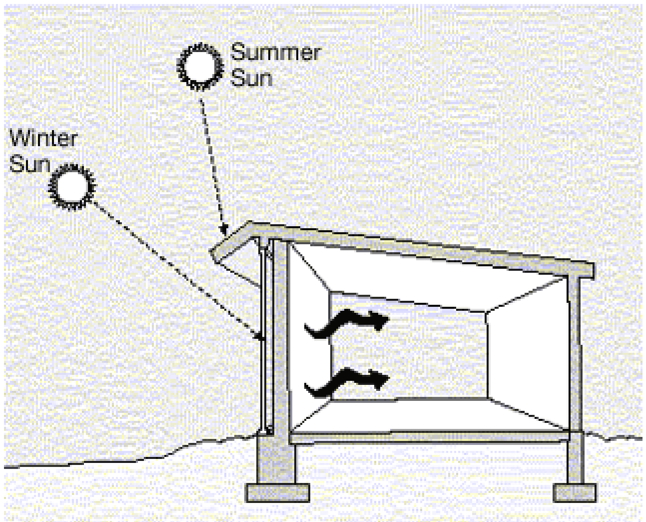
Collecting devices rely on their position to most effectively capture sunlight. A building's position as well as architectural considerations are critical in the effectiveness of passive daylighting. Passive daylight systems are typically non-mechanical, and optimal daylighting efficiency is achieved by proper building and system orientation. A southern facing orientation is optimal if a building or system is located in the northern hemisphere, and a northern facing orientation is optimal if located in the southern hemisphere.

Reflecting

Reflecting elements such as light shelves, lighter wall colors, mirrored wall sections, interior walls with upper glass panels, and clear or translucent glassed hinged doors and Sliding glass doors take the captured light and passively reflect it further inside. The light can be from passive vertical windows or overhead skylights-tubes or active daylighting sources. In traditional Japanese architecture the Shōji sliding panel doors, with translucent Washi screens, are an original precedent. International style, Modernist and Mid-century modern architecture were earlier innovators of this passive penetration and reflection in industrial, commercial, and residential applications.

The use of all these passive daylighting methods reduces energy consumption from artificial lighting use, creating a more sustainable architecture. They are some of the components in designing for LEED - Leadership in Energy and Environmental Design certification.

Trombe wall

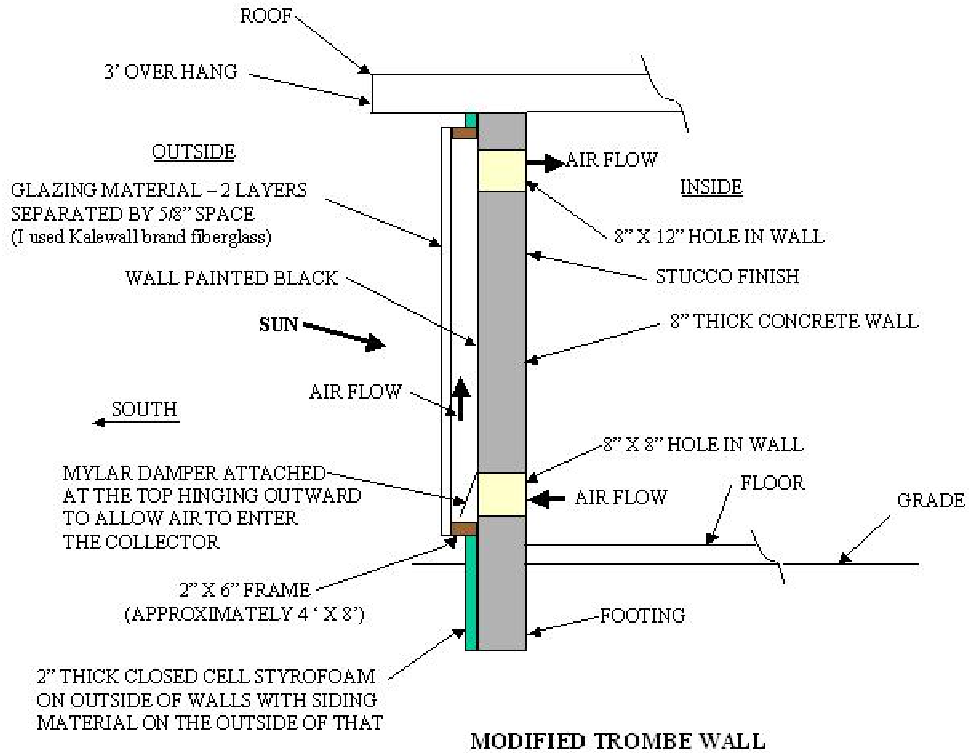


Passive solar design using an unvented trombe wall and summer shading

A **Trombe wall** is a sun-facing wall patented in 1881 by its inventor, Edward Morse, and popularized in 1964 by French engineer Félix Trombe and architect Jacques Michel. It is a massive wall separated from the outdoors by glazing and an air space, which absorbs solar energy and releases it selectively towards the interior at night.

Even single-pane glass works for this process, because glass is transparent to visible light, but less so to infra-red radiation (heat). Modern variations include insulating glass to retain more of the stored solar heat and high and low — sometimes operable — vents to allow convective heat transfer to the indoors.

Current basic design



A Trombe wall

Rammed earth trombe wall built by the Design Build Bluff organization

Modern Trombe walls have vents added to the top and bottom of the air gap between the glazing and the thermal mass. Heated air flows via convection into the building interior. The vents have one-way flaps which prevent convection at night, thereby making heat flow strongly directional. This kind of design is an indirect passive thermal collector. By moving the heat away from the collection surface, it greatly reduces thermal losses at night and improves net heat gain. Generally, the vents to the interior are closed in summer months when heat gain is not wanted.

Because temperature variations tend to propagate through dense masonry materials (thermal diffusion) at a rate of approximately 1 inch per hour, daytime heat gain will be available at the interior surface of the thermal mass in the early evening when it's needed. This time lag property of thermal mass, combined with its thermal decrement (dampening of temperature variations), allows the use of fluctuating daytime solar energy as a more uniform night-time heat source.

Common variations

Common modifications to the Trombe wall include:

- Exhaust vent near the top that is opened to vent to the outside during the summer. Such venting makes the Trombe wall act as a solar chimney pumping fresh air through the house during the day, even if there is no breeze.

- Windows in the trombe wall. This lowers the efficiency but may be done for natural lighting or aesthetic reasons. If the outer glazing has high ultraviolet transmittance, and the window in the trombe wall is normal glass, this allows efficient use of the ultraviolet light for heating. At the same time, it protects people and furnishings from ultraviolet radiation more than do windows with high ultraviolet transmittance.
- Electric blowers controlled by thermostats, to improve air and heat flow.
- Fixed or movable shades, which can reduce night-time heat losses.
- Trellises to shade the solar collector during summer months.
- Insulating covering used at night on the glazing surface.
- Tubes or water tanks as part of a solar hot water system.
- Fish tanks as thermal mass.
- Using a selective surface to increase the absorption of solar radiation by the thermal mass.

Application in developing regions

In Ladakh, India, the Ladakh Project is designing Trombe walls that complement Ladakh's traditional architecture and has promoted building them in Ladakhi homes. This has shown Ladhakis a clean, reliable alternative to fire as a source of heat. The traditional fuel, dung, burns poorly and offers poor relief from the bitter winter temperatures. The smoldering dung produces significant amounts of smoke that fouls the air and causes many health problems. Trombe walls offer relief from both the cold and the smoke. Ladakh receives about 320 days of sun annually, and the traditional building materials — stone and mud brick — provide the thermal mass needed for heat collection in a Trombe wall.

The Druk White Lotus School in Ladakh uses Trombe walls and as part of "a model of appropriate design and development".

Windcatcher

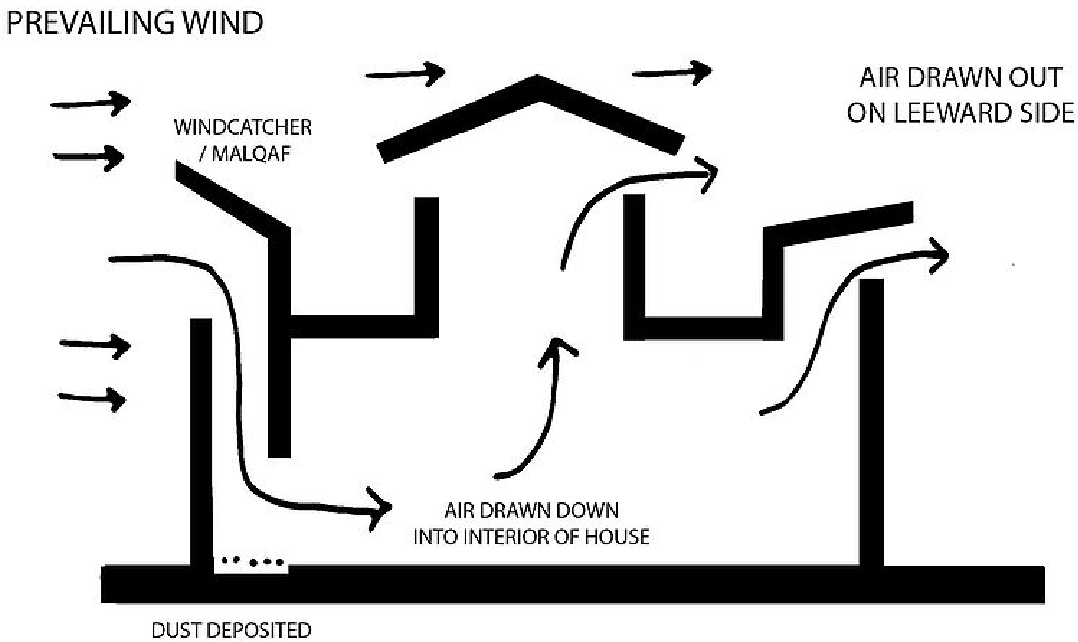
An ab anbar with double domes and windcatchers in the central desert city of Naeen, near Yazd.

A **windcatcher** (Persian: بادگیر *Bâdgir*, or *Malqaf* / *Malgaf* or "Barjeel" بارجيل in Arabic) is a traditional Persian architectural device used for many centuries to create natural ventilation in buildings. It is not known who first invented the windcatcher, but it still can be seen in many countries today. Windcatchers come in various designs: uni-directional, bi-directional, and multi-directional. Examples of windcatchers can be found in traditional Persian-influenced architecture throughout the Middle East, Pakistan and Afghanistan.

Background

Central Iran has a very large day-night temperature difference, ranging from cool to extremely hot, and the air tends to be very dry all day long. Most buildings are constructed of very thick ceramics with extremely high insulation values. Furthermore, towns centered on desert oases tend to be packed very closely together with high walls and ceilings relative to Western architecture, maximizing shade at ground level. The heat of direct sunlight is minimized with small windows that do not face the sun.

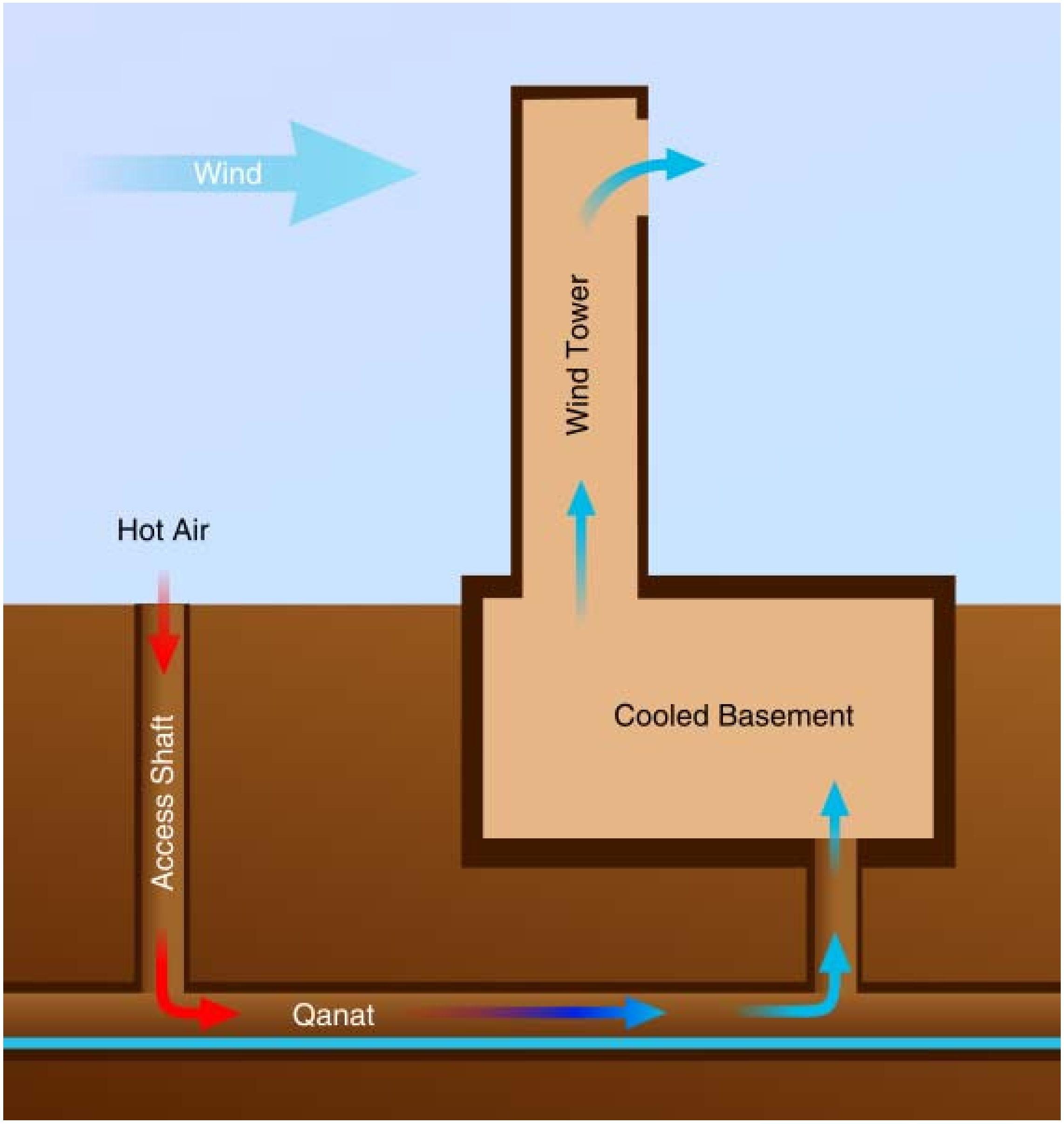
Function



A windcatcher or malqaf used in traditional persian / arabic architecture.

The windcatcher or malqaf can function by several methods:

One of the most common uses of the badgir is as an architectural feature to cool the inside of the dwelling, and is often used in combination with courtyards and domes as an overall ventilation / heat management strategy. The malqaf is essentially a tall, capped tower with one face open at the top. This open side faces the prevailing wind, thus 'catching' it, and bringing it down the tower into the heart of the building to maintain air flow, thus cooling the interior of the building. This is the most direct way of drawing air into the building, but importantly it does not necessarily cool the air, but relies on a rate of air flow to provide a cooling effect. This use of the malqaf or windcatcher has been employed in this manner for thousands of years, as detailed by contemporary Egyptian architect Hassan Fathy.



A windcatcher and qanat used for cooling.

The second usage is in combination with a qanat, or underground canal. In this method however, the open side of the tower faces away from the direction of the prevailing wind. (This can be adjusted by having directional ports at the top). By closing all but the one facing away from the incoming wind, air is drawn upwards using the Coandă effect, similar to how opening the one facing towards the wind would pull air down into the shaft.

As there is now a pressure differential on one side of the building, air is drawn down into the passage on the other side. This hot air is brought down into the qanat tunnel, and is cooled by the combination of coming into contact with the cold earth (as it is several meters below ground, the earth stays continuously cool) as well as the cold water running through the qanat. The air is therefore cooled significantly, and is then drawn up through the windcatcher by the same Coandă effect. This therefore brings cool air up through the building, cooling the structure overall, with the additional benefit that the water vapour from the qanat has an added cooling effect.

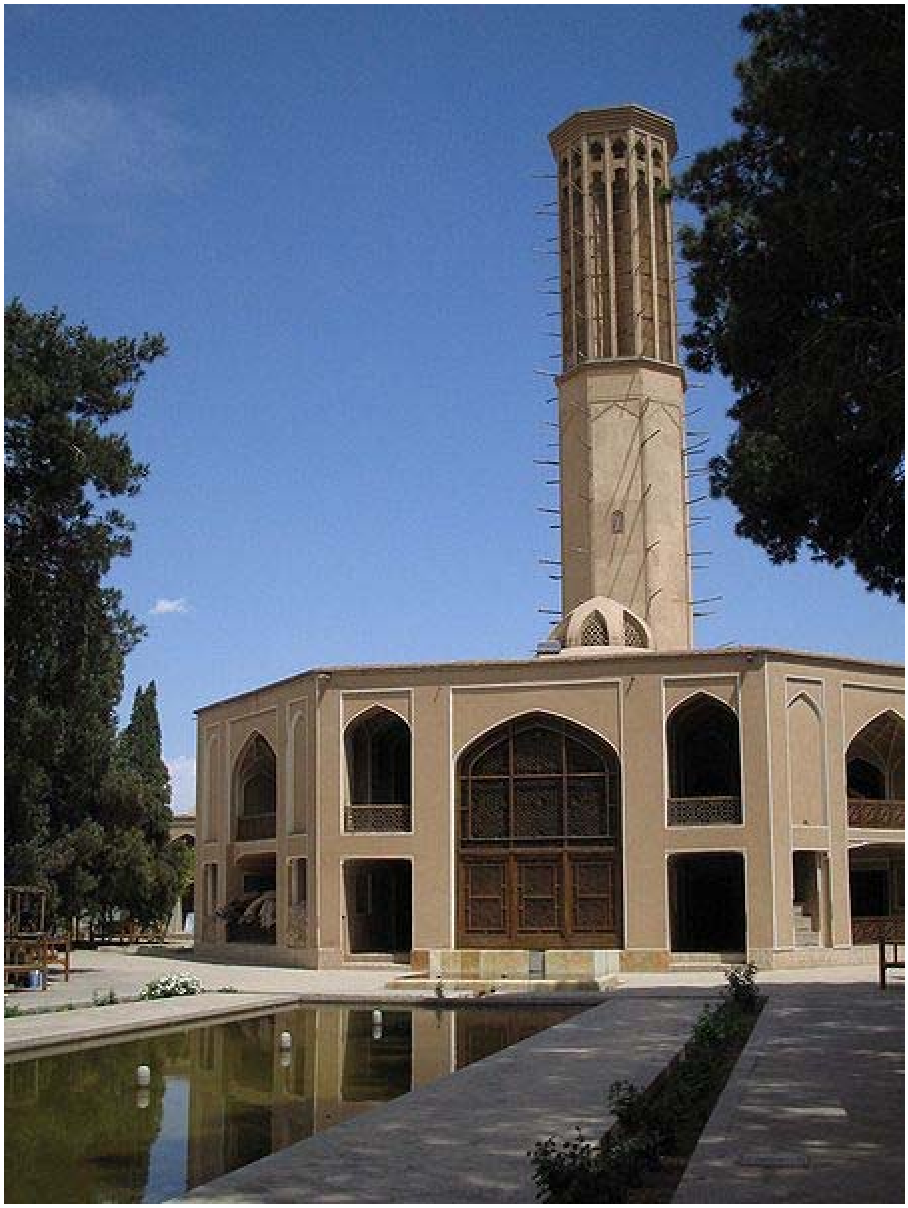
Finally, in a windless environment or waterless house, a windcatcher functions as a solar chimney. It creates a pressure gradient which allows less dense hot air to travel upwards and escape out the top. This is also compounded significantly by the day-night cycle mentioned above, trapping cool air below. The temperature in such an environment cannot drop below the nightly low temperature. These last two functions have gained some ground in Western architecture, and there are several commercial products using the name *windcatcher*.

When coupled with thick adobe that exhibits high heat transmission resistance qualities, the windcatcher is able to chill lower level spaces in mosques and houses (e.g. shabestan) in the middle of the day to frigid temperatures.

So effective has been the windcatcher in Persian architecture that it has been routinely used as a refrigerating device (yakhchal) for ages. Many traditional water reservoirs (ab anbars) are built with windcatchers that are capable of storing water at near freezing temperatures for months in summer. The evaporative cooling effect is strongest in the driest climates, such as on the Iranian plateau, hence the ubiquitous use of these devices in drier areas such as Yazd, Kerman, Kashan, Sirjan, Nain, and Bam. This is especially visible in ab anbars that use windcatchers.

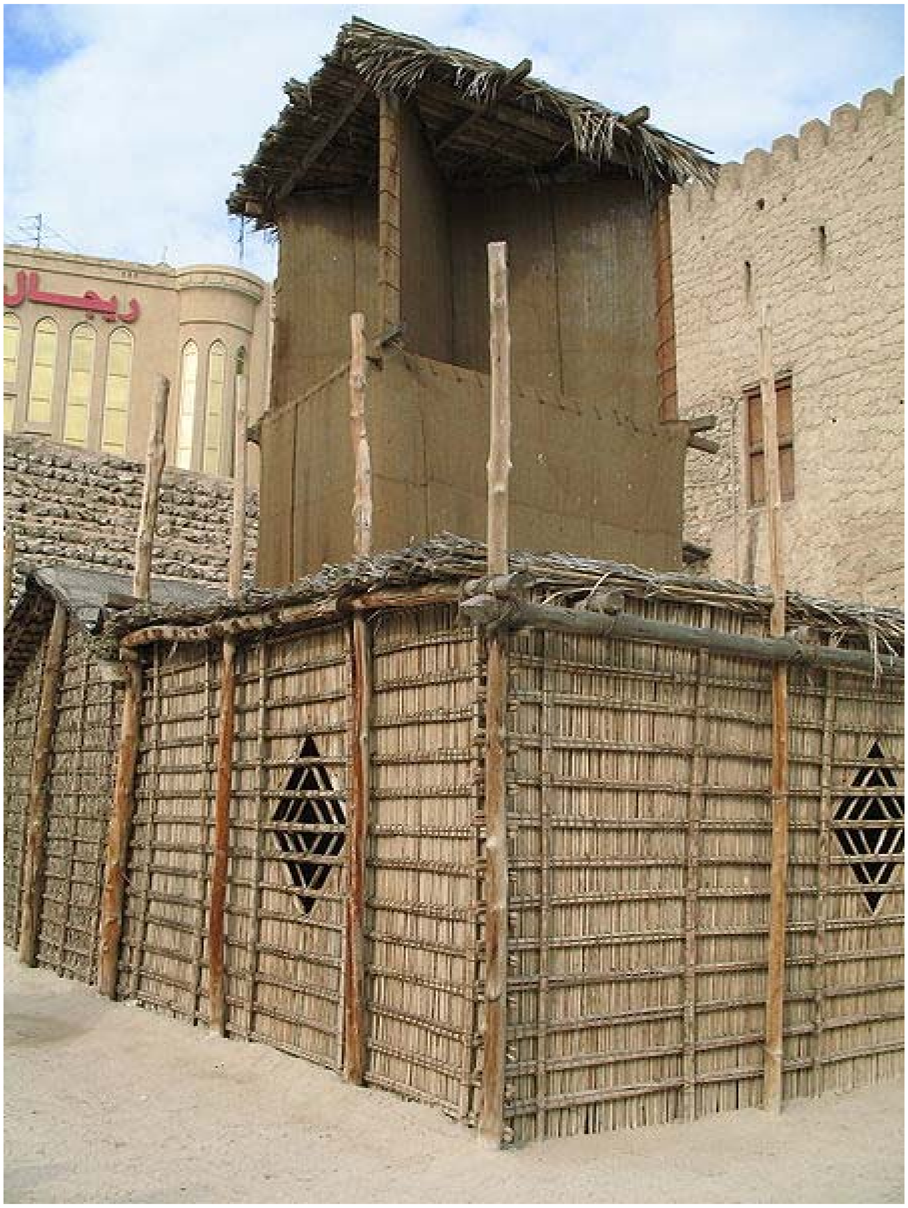
A small windcatcher (badgir) is called a "shish-khan" in traditional Persian architecture. Shish-khans can still be seen on top of ab anbars in Qazvin, and other northern cities in Iran. These seem to be more designed as a pure ventilating device, as opposed to temperature regulators as are their larger cousins in the central deserts of Iran.

Gallery



The windcatcher of "Dowlat-abad" in Yazd, is one of the tallest extant windcatchers.

Borujerdi ha House, in central Iran. Built in 1857, it is an excellent example of ancient Persian desert architecture. The two tall windcatchers cool the **andaruni** section of the house.



The tower on this Barasti made (Palm Fronds) house catches the wind in the same way as a normal wind tower and cools the interior

Windcatchers in the Persian Gulf

Windtower of Isa bin Ali House, in Muharraq, Bahrain

The emergence of a traditional Bahraini and Persian Gulf style of architecture arose as people migrated to Bahrain with the growth of the pearl trade. With newfound wealth, the merchants built houses of note in the 18th and 19th centuries. The people of Fars in Iran, for example, came and brought with them their Persian architectural designs, including the distinctive wind tower which can be seen so prominently in the Awadhiya area (after their hometown Evaz in Iran and elsewhere in Bahrain. This distinguishing feature was adapted locally with its own distinctive decorative motifs. The wind tower, an early and very effective form of air conditioning, has in fact been around for about 500 years and was developed from early wind scoops first built about 2,000 years ago in Iran.

In Muharraq and also in parts of Manama there are many buildings, which are no more than two stories high and houses built with natural ventilation, using wind towers and *badghirs*, the devices for speeding up the flow of air and which consists of horizontal slats in the lower part of the walls. *Badghir* means ‘wind trap’ and is also the word used to describe the wind tower.