Solar Energy Home Design
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Introduction

Passive solar building design

In **passive solar building design**, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices.

The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".

As a science

The scientific basis for passive solar building design has been developed from a combination of climatology, thermodynamics (particularly heat transfer), and human thermal discomfort (for buildings to be inhabited by humans and animals). Specific attention is dissected to the site and location of the dwelling, the prevailing level of rain, design and construction, solar orientation, placement of walls, and incorporation of biomass. While these considerations may be directed to any building, achieving an ideal solution requires careful integration of these principles. Modern refinements through computer modeling and application of other technology can achieve significant energy savings without necessarily sacrificing functionality or aesthetics.\[1\] [2] In fact it is for this reason that this newly coined term, known as Architectural Science or Architectural Technology, has become an upcoming subject area in most schools of Architecture worldwide.
The solar path in passive design

The ability to achieve these goals simultaneously is fundamentally dependent on the seasonal variations in the sun's path throughout the day.

This occurs as a result of the inclination of the Earth's axis of rotation in relation to its orbit. The sun path is unique for any given latitude.

In Northern Hemisphere non-tropical latitudes farther than 23.5 degrees from the equator:

- The sun will reach its highest point toward the South (in the direction of the equator)
- As winter solstice approaches, the angle at which the sun rises and sets progressively moves further toward the South and the daylight hours will become shorter
- The opposite is noted in summer where the sun will rise and set further toward the North and the daylight hours will lengthen[3]

The converse is observed in the Southern Hemisphere, but the sun rises to the east and sets toward the west regardless of which hemisphere you are in.

In equatorial regions at less than 23.5 degrees, the position of the sun at solar noon will oscillate from north to south and back again during the year.[4]

In regions closer than 23.5 degrees from either north-or-south pole, during summer the sun will trace a complete circle in the sky without setting whilst it will never appear above the horizon six months later, during the height of winter.[5]

The 47-degree difference in the altitude of the sun at solar noon between winter and summer forms the basis of passive solar design. This information is combined with local climatic data (degree day) heating and cooling requirements to determine at what time of the year solar gain will be beneficial for thermal comfort, and when it should be blocked with shading. By strategic placement of items such as glazing and shading devices, the percent of solar gain entering a building can be controlled throughout the year.

One passive solar sun path design problem is that although the sun is in the same relative position six weeks before, and six weeks after, the solstice, due to "thermal lag" from the thermal mass of the Earth, the temperature and solar gain requirements are quite different before and after the summer or winter solstice. Movable shutters, shades, shade screens, or window quilts can accommodate day-to-day and hour-to-hour solar gain and insulation requirements.

Careful arrangement of rooms completes the passive solar design. A common recommendation for residential dwellings is to place living areas facing solar noon and sleeping quarters on the opposite side.[6] A heliodon is a traditional movable light device used by architects and designers to help model sun path effects. In modern times, 3D computer graphics can visually simulate this data, and calculate performance predictions.[1]
Passive solar thermodynamic principles

Personal thermal comfort is a function of personal health factors (medical, psychological, sociological and situational), ambient air temperature, mean radiant temperature, air movement (wind chill, turbulence) and relative humidity (affecting human evaporative cooling). Heat transfer in buildings occurs through convection, conduction, and thermal radiation through roof, walls, floor and windows. [7]

Convective heat transfer

Convective heat transfer can be beneficial or detrimental. Uncontrolled air infiltration from poor weatherization / weatherstripping / draft-proofing can contribute up to 40% of heat loss during winter,[8] however strategic placement of operable windows or vents can enhance convection, cross-ventilation, and summer cooling when the outside air is of a comfortable temperature and relative humidity. [9] Filtered energy recovery ventilation systems may be useful to eliminate undesirable humidity, dust, pollen, and microorganisms in unfiltered ventilation air.

Natural convection causing rising warm air and falling cooler air can result in an uneven stratification of heat. This may cause uncomfortable variations in temperature in the upper and lower conditioned space, serve as a method of venting hot air, or be designed in as a natural-convection air-flow loop for passive solar heat distribution and temperature equalization. Natural human cooling by perspiration and evaporation may be facilitated through natural or forced convective air movement by fans, but ceiling fans can disturb the stratified insulating air layers at the top of a room, and accelerate heat transfer from a hot attic, or through near by windows. In addition, high relative humidity inhibits evaporative cooling by humans.

Radiative heat transfer

The main source of heat transfer is radiant energy, and the primary source is the sun. Solar radiation occurs predominantly through the roof and windows (but also through walls). Thermal radiation moves from a warmer surface to a cooler one. Roofs receive the majority of the solar radiation delivered to a house. A cool roof, or green roof in addition to a radiant barrier can help prevent your attic from becoming hotter than the peak summer outdoor air temperature[10] (see albedo, absorptivity, emissivity, and reflectivity).

Windows are a ready and predictable site for thermal radiation.[11] Energy from radiation can move into a window in the day time, and out of the same window at night. Radiation uses photons to transmit electromagnetic waves through a vacuum, or translucent medium. Solar heat gain can be significant even on cold clear days. Solar heat gain through windows can be reduced by insulated glazing, shading, and orientation. Windows are particularly difficult to insulate compared to roof and walls. Convective heat transfer through and around window coverings also degrade its insulation properties.[11] When shading windows, external shading is more effective at reducing heat gain than internal window coverings.[11]

Western and eastern sun can provide warmth and lighting, but are vulnerable to overheating in summer if not shaded. In contrast, the low midday sun readily admits light and warmth during the winter, but can be easily shaded with appropriate length overhangs or angled louvres during summer. The amount of radiant heat received is related to the location latitude, altitude, cloud cover, and seasonal / hourly angle of incidence (see Sun path and Lambert's cosine law).

Another passive solar design principle is that thermal energy can be stored in certain building materials and released again when heat gain eases to stabilize diurnal (day/night) temperature variations. The complex interaction of thermodynamic principles can be counterintuitive for first-time designers. Precise computer modeling can help avoid costly construction experiments.
Site specific considerations during design

- Latitude and sun path
- Seasonal variations in solar gain e.g. cooling or heating degree days, solar insolation, humidity
- Diurnal variations in temperature
- Micro-climate details related to breezes, humidity, vegetation and land contour
- Obstructions / Over-shadowing - to solar gain or local cross-winds

Design elements for residential buildings in temperate climates

- Placement of room-types, internal doors & walls, & equipment in the house.
- Orienting the building to face the equator (or a few degrees to the East to capture the morning sun)\(^6\)
- Extending the building dimension along the east/west axis
- Adequately sizing windows to face the midday sun in the winter, and be shaded in the summer.
- Minimising windows on other sides, especially western windows\(^{11}\)
- Erecting correctly sized, latitude-specific roof overhangs,\(^{12}\) or shading elements (shrubbery, trees, trellises, fences, shutters, etc.)\(^{13}\)
- Using the appropriate amount and type of insulation including radiant barriers and bulk insulation to minimise seasonal excessive heat gain or loss
- Using thermal mass to store excess solar energy during the winter day (which is then re-radiated during the night)\(^{14}\)

The precise amount of equator-facing glass and thermal mass should be based on careful consideration of latitude, altitude, climatic conditions, and heating/cooling degree day requirements.

Factors that can degrade thermal performance:

- Deviation from ideal orientation and north/south/east/west aspect ratio
- Excessive glass area ('over-glazing') resulting in overheating (also resulting in glare and fading of soft furnishings) and heat loss when ambient air temperatures fall
- Installing glazing where solar gain during the day and thermal losses during the night cannot be controlled easily e.g. West-facing, angled glazing, skylights\(^{15}\)
- Thermal losses through non-insulated or unprotected glazing
- Lack of adequate shading during seasonal periods of high solar gain (especially on the West wall)
- Incorrect application of thermal mass to modulate daily temperature variations
- Open staircases leading to unequal distribution of warm air between upper and lower floors as warm air rises
- High building surface area to volume - Too many corners
- Inadequate weatherization leading to high air infiltration
- Lack of, or incorrectly installed, radiant barriers during the hot season. (See also cool roof and green roof)
- Insulation materials that are not matched to the main mode of heat transfer (e.g. undesirable convective/conductive/radiant heat transfer)
Efficiency and economics of passive solar heating

Technically, PSH is highly efficient. Direct-gain systems can utilize (i.e. convert into "useful" heat) 65-70% of the energy of solar radiation that strikes the aperture or collector. To put this in perspective relative to another energy conversion process, the photosynthetic efficiency theoretical limit is around 11%.

Passive solar fraction (PSF) is the percentage of the required heat load met by PSH and hence represents potential reduction in heating costs. RETScreen International has reported a PSF of 20-50%. It must be noted that within the field of sustainability, energy conservation even of the order of 15% is considered substantial.

Other sources report the following PSFs:

- 5-25% for modest systems
- 40% for "highly optimized" systems
- Up to 75% for "very intense" systems

In favorable climates such as the southwest United States, highly optimized systems can exceed 75% PSF.[16]

Key passive solar building design concepts

There are six primary passive solar energy configurations:[17]

- direct solar gain
- indirect solar gain
- isolated solar gain
- heat storage
- insulation and glazing
- passive cooling

Direct solar gain

Direct gain attempts to control the amount of direct solar radiation reaching the living space. This direct solar gain is a critical part of passive solar house designation as it imparts to a direct gain.

The cost effectiveness of these configurations are currently being investigated in great detail and are demonstrating promising results.[18]

Indirect solar gain

Indirect gain attempts to control solar radiation reaching an area adjacent but not part of the living space. Heat enters the building through windows and is captured and stored in thermal mass (e.g. water tank, masonry wall) and slowly transmitted indirectly to the building through conduction and convection. Efficiency can suffer from slow response (thermal lag) and heat losses at night. Other issues include the cost of insulated glazing and developing effective systems to redistribute heat throughout the living area.

Isolated solar gain

Isolated gain involves utilizing solar energy to passively move heat from or to the living space using a fluid, such as water or air by natural convection or forced convection. Heat gain can occur through a sunspace, solarium or solar closet. These areas may also be employed usefully as a greenhouse or drying cabinet. An equator-side sun room may have its exterior windows higher than the windows between the sun room and the interior living space, to allow the low winter sun to penetrate to the cold side of adjacent rooms. Glass placement and overhangs prevent solar gain during the summer. Earth cooling tubes or other passive cooling techniques can keep a solarium cool in the summer.

Measures should be taken to reduce heat loss at night e.g. window coverings or movable window insulation

Examples:
Passive solar building design

- Thermosiphon
- Barra system
- Double envelope house
- Thermal buffer zone\(^{[19]}\)
- Solar space heating system
- Solar chimney

**Heat Storage**

The sun doesn’t shine all the time. Heat storage, or thermal mass keeps the building warm when the sun can’t heat it.

In diurnal solar houses, the storage is designed for one or a few days. The usual method is a custom-constructed thermal mass. These include a Trombe wall, a ventilated concrete floor, a cistern, water wall or roof pond.

In subarctic areas, or areas that have long terms without solar gain (e.g. weeks of freezing fog), purpose-built thermal mass is very expensive. Don Stephens pioneered an experimental technique to use the ground as thermal mass large enough for annualized heat storage. His designs run an isolated thermosiphon 3m under a house, and insulate the ground with a 6m waterproof skirt.\(^{[20]}\)

**Insulation**

Thermal insulation or superinsulation (type, placement and amount) reduces unwanted leakage of heat.\(^{[7]}\) Some passive buildings are actually constructed of insulation.

**Special glazing systems and window coverings**

The effectiveness of direct solar gain systems is significantly enhanced by insulative (e.g. double glazing), spectrally selective glazing (low-e), or movable window insulation (window quilts, bifold interior insulation shutters, shades, etc.).\(^{[21]}\)

Generally, Equator-facing windows should not employ glazing coatings that inhibit solar gain.

There is extensive use of super-insulated windows in the German Passive House standard. Selection of different spectrally selective window coating depends on the ratio of heating versus cooling degree days for the design location.

**Glazing selection**

**Equator-facing glass**

The requirement for vertical equator-facing glass is different from the other three sides of a building. Reflective window coatings and multiple panes of glass can reduce useful solar gain. However, direct-gain systems are more dependent on double or triple glazing to reduce heat loss. Indirect-gain and isolated-gain configurations may still be able to function effectively with only single-pane glazing. Nevertheless, the optimal cost-effective solution is both location and system dependent.
Roof-angle glass / Skylights

Skylights admit sunlight either horizontally (a flat roof) or pitched at the same angle as the roof slope. In most cases, horizontal skylights are used with reflectors to increase the intensity of solar radiation depending on the angle of incidence. Large skylights should be provided with shading devices to prevent heat loss at night and heat gain during the summer months.

Skylights on roofs that face away from the equator provide fairly constant but cool illumination. Those on east-facing roofs provide maximum light and solar heat gain in the morning. West-facing skylights provide afternoon sunlight and heat gain. Equatorial-facing skylights provide the greatest potential for desirable winter passive solar heat gain than any other location, but often allow unwanted heat gain in the summer. You can prevent unwanted solar heat gain by installing the skylight in the shade of deciduous (leaf-shedding) trees or adding a movable window covering on the inside or outside of the skylight. Some modern designs have special glazing that can help control solar heat gain while still allowing high levels of visible light transmittance. Skylights are often the only method to bring passive solar into the core of a commercial or industrial application.

Angle of incident radiation

The amount of solar gain transmitted through glass is also affected by the angle of the incident solar radiation. Sunlight striking glass within 20 degrees of perpendicular is mostly transmitted through the glass, whereas sunlight at more than 35 degrees from perpendicular is mostly reflected[22].

All of these factors can be modeled more precisely with a photographic light meter and a heliodon or optical bench, which can quantify the ratio of reflectivity to transmissivity, based on angle of incidence.

Alternatively, passive solar computer software can determine the impact of sun path, and cooling-and-heating degree days on energy performance. Regional climatic conditions are often available from local weather services.

Operable shading and insulation devices

A design with too much equator-facing glass can result in excessive winter, spring, or fall day heating, uncomfortably bright living spaces at certain times of the year, and excessive heat transfer on winter nights and summer days.

Although the sun is at the same altitude 6-weeks before and after the solstice, the heating and cooling requirements before and after the solstice are significantly different. Heat storage on the Earth's surface causes "thermal lag." Variable cloud cover influences solar gain potential. This means that latitude-specific fixed window overhangs, while important, are not a complete seasonal solar gain control solution.

Control mechanisms (such as manual-or-motorized interior insulated drapes, shutters, exterior roll-down shade screens, or retractable awnings) can compensate for differences caused by thermal lag or cloud cover, and help control daily / hourly solar gain requirement variations.

Home automation systems that monitor temperature, sunlight, time of day, and room occupancy can precisely control motorized window-shading-and-insulation devices.
**Exterior colors reflecting - absorbing**

Materials and colors can be chosen to reflect or absorb solar thermal energy. Using information on a Color for electromagnetic radiation to determine its thermal radiation properties of reflection or absorption can assist the choices.

See Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory: "Cool Colors" [23]

**Landscaping and gardens**

Energy-efficient landscaping materials for careful passive solar choices include hardscape building material and "softscape" plants. The use of landscape design principles for selection of trees, hedges, and trellis-pergola features with vines; all can be used to create summer shading. For winter solar gain it is desirable to use deciduous plants that drop their leaves in the autumn gives year round passive solar benefits. Non-deciduous evergreen shrubs and trees can be windbreaks, at variable heights and distances, to create protection and shelter from winter wind chill. Xeriscaping with 'mature size appropriate' native species of-and drought tolerant plants, drip irrigation, mulching, and organic gardening practices reduce or eliminate the need for energy-and-water-intensive irrigation, gas powered garden equipment, and reduces the landfill waste footprint. Solar powered landscape lighting and fountain pumps, and covered swimming pools and plunge pools with solar water heaters can reduce the impact of such amenities.

- Sustainable gardening
- Sustainable landscaping
- Sustainable landscape architecture

**Other passive solar principles**

**Passive solar lighting**

Passive solar lighting techniques enhance taking advantage of natural illumination for interiors, and so reduce reliance on artificial lighting systems.

This can be achieved by careful building design, orientation, and placement of window sections to collect light. Other creative solutions involve the use of reflecting surfaces to admit daylight into the interior of a building. Window sections should be adequately sized, and to avoid over-illumination can be shielded with a Brise soleil, awnings, well placed trees, glass coatings, and other passive and active devices. [17]

Another major issue for many window systems is that they can be potentially vulnerable sites of excessive thermal gain or heat loss. Whilst high mounted clerestory window and traditional skylights can introduce daylight in poorly oriented sections of a building, unwanted heat transfer may be hard to control. [24] [25] Thus, energy that is saved by reducing artificial lighting is often more than offset by the energy required for operating HVAC systems to maintain thermal comfort.

Various methods can be employed to address this including but not limited to window coverings, insulated glazing and novel materials such as aerogel semi-transparent insulation, optical fiber embedded in walls or roof, or hybrid solar lighting at Oak Ridge National Laboratory [26].

**Interior reflecting**

Reflecting elements, from active and passive daylighting collectors, such as light shelves, lighter wall and floor 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 windows or skylights and solar light tubes or from 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,
Passive solar building design

Passive solar water heating
There are many ways to use solar thermal energy to heat water for domestic use. Different active-and-passive solar hot water technologies have different location-specific economic cost benefit analysis implications. Fundamental passive solar hot water heating involves no pumps or anything electrical. It is very cost effective in climates that do not have lengthy sub-freezing, or very-cloudy, weather conditions. Other active solar water heating technologies, etc. may be more appropriate for some locations.

It is possible to have active solar hot water which is also capable of being "off grid" and qualifies as sustainable. This is done by the use of a photovoltaic cell which uses energy from the sun to power the pumps.

Comparison to the Passive House standard in Europe
There is growing momentum in Europe for the approach espoused by the Passive House Institute in Germany. Rather than relying solely on traditional passive solar design techniques, this approach seeks to make use of all passive sources of heat, minimises energy usage, and emphasises the need for high levels of insulation reinforced by meticulous attention to detail in order to address thermal bridging and cold air infiltration. Most of the buildings built to the Passive House standard also incorporate an active heat recovery ventilation unit with or without a small (typically 1 kW) incorporated heating component.

The energy design of Passive House buildings is developed using a spreadsheet-based modeling tool called the Passive House Planning Package (PHPP) which is updated periodically. The current version is PHPP2007, where 2007 is the year of issue. A building may be certified as a 'Passive House' when it can be shown that it meets certain criteria, the most important being that the annual specific heat demand for the house should not exceed 15kWh/m²a.

Design tools
Traditionally a heliodon was used to simulate the altitude and azimuth of the sun shining on a model building at any time of any day of the year. In modern times, computer programs can model this phenomenon and integrate local climate data (including site impacts such as overshadowing and physical obstructions) to predict the solar gain potential for a particular building design over the course of a year. This provides the designer the ability to evaluate design elements and orientation prior to building works commencing. Energy performance optimization normally requires an iterative-refinement design-and-evaluate process.

Levels of application

Pragmatic
Many detached suburban houses can achieve reductions in heating expense without obvious changes to their appearance, comfort or usability. This is done using good siting and window positioning, small amounts of thermal mass, with good-but-conventional insulation, weatherization, and an occasional supplementary heat source, such as a central radiator connected to a (solar) water heater. Sunrays may fall on a wall during the daytime and raise the temperature of its thermal mass. This will then radiate heat into the building in the evening. This can be a problem in the summer, especially on western walls in areas with high degree day cooling requirements. External shading, or a radiant barrier plus air gap, may be used to reduce undesirable summer solar gain.
Annualised

An extension of the "passive solar" approach to seasonal solar capture and storage of heat and cooling. These designs attempt to capture warm-season solar heat, and convey it to a seasonal thermal store for use months later during the cold season ("annualised passive solar.") Increased storage is achieved by employing large amounts of thermal mass or earth coupling. Anecdotal reports suggest they can be effective but no formal study has been conducted to demonstrate their superiority. The approach also can move cooling into the warm season.

Examples:
- Passive Annual Heat Storage (PAHS) - by John Hait
- Annualized Geothermal Solar (AGS) heating - by Don Stephen
- Earthed-roof

Minimum machinery

A "purely passive" solar-heated house would have no mechanical furnace unit, relying instead on energy captured from sunshine, only supplemented by "incidental" heat energy given off by lights, computers, and other task-specific appliances (such as those for cooking, entertainment, etc.), showering, people and pets. The use of natural convection air currents (rather than mechanical devices such as fans) to circulate air is related, though not strictly solar design.

Passive solar building design sometimes uses limited electrical and mechanical controls to operate dampers, insulating shutters, shades, awnings, or reflectors. Some systems enlist small fans or solar-heated chimneys to improve convective air-flow. A reasonable way to analyse these systems is by measuring their coefficient of performance. A heat pump might use 1 J for every 4 J it delivers giving a COP of 4. A system that only uses a 30 W fan to more-evenly distribute 10 kW of solar heat through an entire house would have a COP of 300.

Zero Energy Building

Passive solar building design is often a foundational element of a cost-effective zero energy building. Although a ZEB uses multiple passive solar building design concepts, a ZEB is usually not purely passive, having active mechanical renewable energy generation systems such as: wind turbine, photovoltaics, micro hydro, geothermal, and other emerging alternative energy sources.

References

Passive solar building design

[27] (http://www.heliodon.com.mx/productos/heliodon/gal/helio_u_u_c_colon.JPG)

External links

- Direct space heating and daylighting (http://www.practicalsolar.com/photos/photos.html) with heliostats (photos)
- www.FSEC.UCF.edu (http://www.FSEC.UCF.edu) - Florida Solar Energy Center
- http://www.solarroof.org/wiki
- Calculation of insolation (houses, garden, roof, apartment...) (http://www.sun-time.org/english)
- www.gaisma.com (http://www.gaisma.com)- Sun path calculator for selected cites
- http://sunposition.info/sunposition/spc/locations.php (http://sunposition.info/sunposition/spc/locations.php) - Sun path by location and date
Zero-energy building

A zeronet energy building (ZNE) is a popular term to describe a building's use with zero net energy consumption and zero carbon emissions annually. ZeroNet Energy buildings can be used autonomously from the energy grid supply — energy can be harvested on-site usually in combination with energy producing technologies like Solar and Wind while reducing the overall use of energy with extremely efficient HVAC and Lighting technologies. The ZeroNet design principle is becoming more practical in adopting due to the increasing costs of traditional fossil fuels and their negative impact on the planet's climate and ecological balance.

The ZNE consumption principle is gaining considerable interest as renewable energy harvesting as a means to cut greenhouse gas emissions. Traditional building use consumes 40% of the total fossil energy in the US and European Union.\(^1\) \(^2\) 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 ZeroNet Energy (ZNE) 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 importance and popularity. The ZeroNet Energy approach has potential to reduce carbon emissions, and reduce dependence on fossil fuels.

A building approaching ZeroNet 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 ZeroNet Energy consumption when the available living space is kept small.
Definitions

Despite sharing the name zeronet energy, there are several definitions of what ZNE means in practice, with a particular difference in usage between North America and Europe.\[^3\]

ZeroNet site energy use

In this type of ZNE, 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, “zeronet energy building” generally refers to this type of building.

ZeroNet source energy use

This ZNE 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 ZNEs must generate more electricity than ZeroNet 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.\[^4\] 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.\[^5\] 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, Vitruvian built 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 100000 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[18]
• 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.\[27\]
- Self-Sufficient Solar House \[28\] Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg im Breisgau

Ireland

In 2005 Scandinavian Homes \[29\] launched the world’s 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*,\[30\] 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.\[31\]

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,[32] 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.[33]

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.[33]

The U.S. Energy Independence and Security Act of 2007[34] 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[35] 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[36] 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[37] (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). Not ZEB/NZE. Remove this paragraph.

**Florida**
- The 1999 side-by-side Florida Solar Energy Center Lakeland Florida demonstration project[38] 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[^41][^42][^43] is the 110-year-old Ann Arbor home of Greenovation.TV host and Environment Report contributor Matthew Grocoff.[^44] As of 2011, the home is the oldest home in America to achieve net-zero energy.[^45][^46] The owners are chronicling their project on Greenovation.TV[^47] 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[^48]

Missouri

- In 2010, architectural firm HOK worked with energy and daylighting consultant The Weidt Group to design a 170,735-square-foot net zero carbon emissions Class A office building prototype in St. Louis, Missouri.[^49] The team chronicled its process and results on Netzerocourt.com.[^50]

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 m²) 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 5000-square-foot (460 m²) Zero Energy Design®[^51] 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 1000 square feet (93 m²) 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 (30 m)-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. In use for a over a year, as of December, 2010, the Field House used 48,374 kWh and produced a total of 51,371 kWh during the first 12 months of operation, thus performing at slightly better than net-zero[^52]. Also in December, the building won an AIA-Vermont Honor Award[^53].
References


[14] Database of State Incentives for Renewables & Efficiency (http://www.dsireusa.org/)


[27] DOE Solar Decathlon: Final Results:First Place: Technische Universität Darmstadt (http://www.solardecathlon.org/scores_standings.html#first)


[29] Scandinavian Homes Ltd (http://www.scanhome.ie)


[37] http://www.idealabs.com

Zero-energy building


External links

- U.S. Department of Energy Building America (http://www.eere.energy.gov/buildings/building_america)
- Oak Ridge National Laboratory Building Technologies and Integration Center (http://www.ornl.gov/sci/ees/etsd/btric)
- Zero Energy Building Database from U.S. Department of Energy's Building Technologies Program (http://zeb.buildinggreen.com/)

Further reading

Passive house

The term passive house (Passivhaus in German) refers to the rigorous, voluntary, Passivhaus standard for energy efficiency in a building, reducing its ecological footprint.[1] It results in ultra-low energy buildings that require little energy for space heating or cooling.[2] [3] A similar standard, MINERGIE-P, is used in Switzerland.[4] The standard is not confined to residential properties; several office buildings, schools, kindergartens and a supermarket have also been constructed to the standard. Passive design is not an attachment or supplement to architectural design, but a design process that is integrated with architectural design.[5] Although it is mostly applied to new buildings, it has also been used for refurbishments.

Estimates of the number of Passivhaus buildings around the world in late 2008 ranged from 15,000 to 20,000 structures.[6] [7] 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.[1] The vast majority of passive structures have been built in German-speaking countries and Scandinavia. [6]

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
Their concept was developed through a number of research projects, aided by financial assistance from the German state of Hessen.

**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 group 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 passive retrofit project was certified in July 2010: the remodeled 2,400 sf craftsman O’Neill house in 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**
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:[19] [20]

- The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year (4746 btu/ft² per year) in heating and 15 kWh/m² per year cooling energy OR to be designed with a peak heat load of 10W/m²
- 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/m² per year \( (3.79 \times 10^4 \text{ btu/ft}^2 \text{ per year}) \)
- The building must not leak more air than 0.6 times the house volume per hour \( (n_{50} \leq 0.6 \text{ / hour}) \) at 50 Pa \( (\text{N/m}^2) \) 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/m² \( (3.17 \text{ btu/ft}^2 \text{ per hour}) \).

These standards are much higher than houses built to most normal building codes. For comparisons, see the international comparisons section below.

National partners within the 'consortium for the Promotion of European Passive Houses' are thought to have some flexibility to adapt these limits locally.[21]

**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.[22] On average, however, passive houses are still up to 14% more expensive upfront than conventional buildings.[23]
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.[24][25] 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.[26](See also Annualized geo solar)

**Design and construction**

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)[27], and uses specifically designed computer simulations.

To achieve the standards, a number of techniques and technologies are used in combination:[2]

**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

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**

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.\[31\]

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\[32\].

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 CO₂, 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.[33]
• 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.[34]
• 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%.[35]

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. A few ZEB’s fail to fully exploit more affordable conservation technology and all 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: ZEBs drive the annual energy consumption down to 0 kWh/m2 from the already low PassiveHaus criteria of 120 kWh/m2 with help from on-site renewable energy sources. Energy Plus houses Energy-plus-house are similar to both PassivHaus and ZEB but emphasize the production of more energy per year than they consume, e.g., annual energy performance of -25 kWh/m2 is an Energy Plus house.

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 reduce the humidity load of ventilation on the mechanical dehumidification system. Although dehumidifiers might be used, heat pump hot water heaters also will act to cool and condense interior humidity (where it can be dumped into drains ) and dump the 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 and an efficient one ton air-conditioner to provide cooling and dehumidification. [36]

References
Notes
[8] Institute for Housing and the Environment (http://www.iwu.de/homep_e.htm)
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Bibliography


External links

- The international Passive House Magazine (iPHM) (http://the-passive-house-magazine.info/)
- Passivhaus Germany (http://www.energiesparhaus.info/passivhaus/)
- Passivhaus Institut (http://www.passiv.de/)
- Passivhaus Infos (http://www.muellersbuero.com/de/infos/passivhaus.html)
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Green building

Green building (also known as green construction or sustainable building) refers to a structure and using process that is environmentally responsible and resource-efficient throughout a building’s life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort.[1]

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation[1]

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally.[2] Other related topics include sustainable design and green architecture. Green building does not specifically address the issue of the retrofitting existing homes.

Reducing environmental impact

Green building practices aim to reduce the environmental impact of new buildings. Buildings account for a large amount of land

Goals of green building

The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s.[3] The green building movement in the U.S. originated from the need and desire for more energy efficient and environmentally friendly construction practices. There are a number of motives to building green, including environmental, economic, and social benefits. However, modern sustainability initiatives call for an integrated and synergistic design to both new construction and in the retrofitting of an existing structure. Also known as sustainable design, this approach integrates the building life-cycle with each green practice employed with a design-purpose to create a synergy amongst the practices used.

Green building brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of new buildings on the environment and human health. It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off. Many other techniques, such as using packed gravel or permeable concrete instead of conventional concrete or asphalt to enhance replenishment of ground water, are used as well.
While the practices, or technologies, employed in green building are constantly evolving and may differ from region to region, there are fundamental principles that persist from which the method is derived: Siting and Structure Design Efficiency, Energy Efficiency, Water Efficiency, Materials Efficiency, Indoor Environmental Quality Enhancement, Operations and Maintenance Optimization, and Waste and Toxics Reduction. The essence of green building is an optimization of one or more of these principles. Also, with the proper synergistic design, individual green building technologies may work together to produce a greater cumulative effect.

On the aesthetic side of green architecture or sustainable design is the philosophy of designing a building that is in harmony with the natural features and resources surrounding the site. There are several key steps in designing sustainable buildings: specify 'green' building materials from local sources, reduce loads, optimize systems, and generate on-site renewable energy.

**Siting and structure design efficiency**

The foundation of any construction project is rooted in the concept and design stages. The concept stage, in fact, is one of the major steps in a project life cycle, as it has the largest impact on cost and performance. In designing environmentally optimal buildings, the objective is to minimize the total environmental impact associated with all life-cycle stages of the building project. However, building as a process is not as streamlined as an industrial process, and varies from one building to the other, never repeating itself identically. In addition, buildings are much more complex products, composed of a multitude of materials and components each constituting various design variables to be decided at the design stage. A variation of every design variable may affect the environment during all the building's relevant life-cycle stages.

**Energy efficiency**

Green buildings often include measures to reduce energy use. To increase the efficiency of the building envelope, (the barrier between conditioned and unconditioned space), they may use high-efficiency windows and insulation in walls, ceilings, and floors. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (daylighting) can provide more natural light and lessen the need for electric lighting during the day. Solar water heating further reduces energy loads.

Onsite generation of renewable energy through solar power, wind power, hydro power, or biomass can significantly reduce the environmental impact of the building. Power generation is generally the most expensive feature to add to a building.

**Water efficiency**

Reducing water consumption and protecting water quality are key objectives in sustainable building. One critical issue of water consumption is that in many areas, the demands on the supplying aquifer exceed its ability to replenish itself. To the maximum extent feasible, facilities should increase their dependence on water that is collected, used, purified, and reused on-site. The protection and conservation of water throughout the life of a building may be accomplished by designing for dual plumbing that recycles water in toilet flushing. Waste-water may be minimized by utilizing water conserving fixtures such as ultra-low flush toilets and low-flow shower heads. Bidets help eliminate the use of toilet paper, reducing sewer traffic and increasing possibilities of re-using water on-site. Point of use water treatment and heating improves both water quality and energy efficiency while reducing the amount of water in circulation. The use of non-sewage and greywater for on-site use such as site-irrigation will minimize demands on the local aquifer.
**Materials efficiency**

Building materials typically considered to be 'green' include (Expanded polystyrene) rapidly renewable plant materials like bamboo (because bamboo grows quickly) and straw, lumber from forests certified to be sustainably managed, insulated concrete forms, dimension stone, recycled stone, recycled metal, and other products that are non-toxic, reusable, renewable, and/or recyclable (e.g. Trass, Linoleum, sheep wool, panels made from paper flakes, compressed earth block, adobe, baked earth, rammed earth, clay, vermiculite, flax linen, sisal, seagrass, cork, expanded clay grains, coconut, wood fibre plates, calcium sand stone, concrete (high and ultra high performance, roman self-healing concrete\(^{[10]} \)) , etc.\(^{[11]} [12] \) The EPA (Environmental Protection Agency) also suggests using recycled industrial goods, such as coal combustion products, foundry sand, and demolition debris in construction projects \(^{[13]} \) Building materials should be extracted and manufactured locally to the building site to minimize the energy embedded in their transportation. Where possible, building elements should be manufactured off-site and delivered to site, to maximise benefits of off-site manufacture including minimising waste, maximising recycling (because manufacture is in one location), high quality elements, better OHS management, less noise and dust.

**Indoor environmental quality enhancement**

The Indoor Environmental Quality (IEQ) category in LEED standards, one of the five environmental categories, was created to provide comfort, well-being, and productivity of occupants. The LEED IEQ category addresses design and construction guidelines especially: indoor air quality (IAQ), thermal quality, and lighting quality.\(^{[14]} \)

Indoor Air Quality seeks to reduce volatile organic compounds, or VOC's, and other air impurities such as microbial contaminants. Buildings rely on a properly designed HVAC system to provide adequate ventilation and air filtration as well as isolate operations (kitchens, dry cleaners, etc.) from other occupancies. During the design and construction process choosing construction materials and interior finish products with zero or low emissions will improve IAQ. Many building materials and cleaning/maintenance products emit toxic gases, such as VOCs and formaldehyde. These gases can have a detrimental impact on occupants' health and productivity as well. Avoiding these products will increase a building's IEQ.

Personal temperature and airflow control over the HVAC system coupled with a properly designed building envelope will also aid in increasing a building's thermal quality. Creating a high performance luminous environment through the careful integration of natural and artificial light sources will improve on the lighting quality of a structure.\(^{[9]} [15] \)

**Operations and maintenance optimization**

No matter how sustainable a building may have been in its design and construction, it can only remain so if it is operated responsibly and maintained properly. Ensuring operations and maintenance (O&M) personnel are part of the project's planning and development process will help retain the green criteria designed at the onset of the project.\(^{[16]} \)

Every aspect of green building is integrated into the O&M phase of a building's life. The addition of new green technologies also falls on the O&M staff. Although the goal of waste reduction may be applied during the design, construction and demolition phases of a building's life-cycle, it is in the O&M phase that green practices such as recycling and air quality enhancement take place.

**Waste reduction**

Green architecture also seeks to reduce waste of energy, water and materials used during construction. For example, in California nearly 60% of the state's waste comes from commercial buildings\(^{[17]} \) During the construction phase, one goal should be to reduce the amount of material going to landfills. Well-designed buildings also help reduce the amount of waste generated by the occupants as well, by providing on-site solutions such as compost bins to reduce matter going to landfills.
To reduce the impact on wells or water treatment plants, several options exist. "Greywater", wastewater from sources such as dishwashing or washing machines, can be used for subsurface irrigation, or if treated, for non-potable purposes, e.g., to flush toilets and wash cars. Rainwater collectors are used for similar purposes.

Centralized wastewater treatment systems can be costly and use a lot of energy. An alternative to this process is converting waste and wastewater into fertilizer, which avoids these costs and shows other benefits. By collecting human waste at the source and running it to a semi-centralized biogas plant with other biological waste, liquid fertilizer can be produced. This concept was demonstrated by a settlement in Lubeck Germany in the late 1990s. Practices like these provide soil with organic nutrients and create carbon sinks that remove carbon dioxide from the atmosphere, offsetting greenhouse gas emission. Producing artificial fertilizer is also more costly in energy than this process.\(^{[18]}\)

**Cost and payoff**

The most criticized issue about constructing environmentally friendly buildings is the price. Photo-voltaics, new appliances, and modern technologies tend to cost more money. Most green buildings cost a premium of <2%, but yield 10 times as much over the entire life of the building.\(^{[19]}\) The stigma is between the knowledge of up-front cost\(^{[20]}\) vs. life-cycle cost. The savings in money come from more efficient use of utilities which result in decreased energy bills. It is projected that different sectors could save $130 Billion on energy bills.\(^{[21]}\) Also, higher worker or student productivity can be factored into savings and cost deductions.

Studies have shown over a 20 year life period, some green buildings have yielded $53 to $71 per square foot back on investment.\(^{[22]}\) Confirming the rentability of green building investments, further studies of the commercial real estate market have found that LEED and Energy Star certified buildings achieve significantly higher rents, sale prices and occupancy rates as well as lower capitalization rates potentially reflecting lower investment risk.\(^{[23]}\)\(^{[24]}\)\(^{[25]}\)

**Regulation and operation**

Many countries have developed their own standards for green building or energy efficiency for buildings. Some of the major building environmental assessment tools currently in use include:

- Australia: Nabers [26] / Green Star [27]
- Brazil: AQUA [28] / LEED Brasil [29]
- China: GBAS [32]
- Finland: PromisE [33]
- France: HQE [34]
- Hong Kong: HKBEAM [37]
- India: Indian Green Building Council (IGBC)[38] / GRIHA [39]
- Italy: Protocollo Itaca [40] / Green Building Counsil Italia [41]
- Japan: CASBEE [42]
- Korea: KGBC [43]
- Malaysia: GBI Malaysia [44]
- Mexico: LEED Mexico [45]
- Netherlands: BREEAM Netherlands [46]
- New Zealand: Green Star NZ [47]
- Portugal: Lider A [50]
- Republic of China(Taiwan):Green Building Label [51]
- Singapore: Green Mark [52]
International frameworks and assessment tools

IPCC Fourth Assessment Report

Climate Change 2007, the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC), is the fourth in a series of such reports. The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio-economic information concerning climate change, its potential effects and options for adaptation and mitigation.\[61\]

UNEP and Climate change [62]

UNEP works to facilitate the transition to low-carbon societies, support climate proofing efforts, improve understanding of climate change science, and raise public awareness about this global challenge.

GHG Indicator[63]

The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organizations

Agenda 21[64]

Agenda 21 is a programme run by the United Nations (UN) related to sustainable development. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the UN, governments, and major groups in every area in which humans impact on the environment. The number 21 refers to the 21st century.

FIDIC’s PSM[65]

FIDIC’s Project Sustainability Management Guidelines were created in order to assist project engineers and other stakeholders in setting sustainable development goals for their projects that are recognized and accepted by as being in the interests of society as a whole. The process is also intended to allow the alignment of project goals with local conditions and priorities and to assist those involved in managing projects to measure and verify their progress.

The PSM Guidelines are structured with Themes and Sub-Themes under the three main sustainability headings of Social, Environmental and Economic. For each individual Sub-Theme a core project indicator is defined along with guidance as to the relevance of that issue in the context of an individual project.

The Sustainability Reporting Framework provides guidance for organizations to use as the basis for disclosure about their sustainability performance, and also provides stakeholders a universally applicable, comparable framework in which to understand disclosed information.

The Reporting Framework contains the core product of the Sustainability Reporting Guidelines, as well as Protocols and Sector Supplements. The Guidelines are used as the basis for all reporting. They are the foundation upon which all other reporting guidance is based, and outline core content for reporting that is broadly relevant to all organizations regardless of size, sector, or location. The Guidelines contain principles and guidance as well as standard disclosures – including indicators – to outline a disclosure framework that organizations can voluntarily, flexibly, and incrementally, adopt.
Protocols underpin each indicator in the Guidelines and include definitions for key terms in the indicator, compilation methodologies, intended scope of the indicator, and other technical references.

Sector Supplements respond to the limits of a one-size-fits-all approach. Sector Supplements complement the use of the core Guidelines by capturing the unique set of sustainability issues faced by different sectors such as mining, automotive, banking, public agencies and others.

**IPD Environment Code**

The IPD Environment Code was launched in February 2008. The Code is intended as a good practice global standard for measuring the environmental performance of corporate buildings. Its aim is to accurately measure and manage the environmental impacts of corporate buildings and enable property executives to generate high quality, comparable performance information about their buildings anywhere in the world. The Code covers a wide range of building types (from offices to airports) and aims to inform and support the following:

- Creating an environmental strategy
- Inputting to real estate strategy
- Communicating a commitment to environmental improvement
- Creating performance targets
- Environmental improvement plans
- Performance assessment and measurement
- Life cycle assessments
- Acquisition and disposal of buildings
- Supplier management
- Information systems and data population
- Compliance with regulations
- Team and personal objectives

IPD estimate that it will take approximately three years to gather significant data to develop a robust set of baseline data that could be used across a typical corporate estate.

**ISO 21931**

ISO/TS 21931:2006, Sustainability in building construction—Framework for methods of assessment for environmental performance of construction works—Part 1: Buildings, is intended to provide a general framework for improving the quality and comparability of methods for assessing the environmental performance of buildings. It identifies and describes issues to be taken into account when using methods for the assessment of environmental performance for new or existing building properties in the design, construction, operation, refurbishment and deconstruction stages. It is not an assessment system in itself but is intended be used in conjunction with, and following the principles set out in, the ISO 14000 series of standards.

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Green building


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Daylight harvesting

**Daylight Harvesting** is the term used in sustainable architecture and the building controls and active daylighting industries for a control system that reduces the use of artificial lighting with electric lamps in building interiors when natural daylight is available, in order to reduce energy consumption.

**System design and components**

Daylight harvesting systems are typically designed to maintain a minimum recommended light level. This light level will vary according to the needs and use of the space; for example, the commonly recommended light level for offices in North America is 500 Lux (or around 50 footcandles) on the desktop.\(^1\)

**Photosensors**

All daylight harvesting systems use a light level sensor, a photosensor, to detect the prevailing light level, luminance or brightness, in open-loop or closed-loop systems. Photosensors are used to integrate an electric lighting system with a daylighting system so lights operate only when daylighting is insufficient.\(^2\)\(^3\) In an open-loop system, the photosensor detects the amount of available daylight only, and can be positioned on the building’s exterior wall or roof, or inside the building facing the window or skylight. In a closed-loop system, the photosensor detects the total photometric amount of light, from both daylight and electric sources in the space. For example, in an office a closed-loop photosensor can be positioned on the ceiling facing the desktops in order to detect the amount of light on the work surface, as placing the sensor on the desktop itself would be impractical. In both the open- and closed-loop configurations, the signal from the photosensor must be carefully calibrated to accurately indicate the effect of exterior daylight variations on the light level on ‘important functions’ areas in the space.\(^4\)

**Control modules and dimming**

The signal from the photosensor is interpreted by a lighting control system module, an automated light switching device, in the electric lighting system which can reduce the electric lighting, by shutting off or dimming fixtures as appropriate.\(^5\)\(^6\) If the electric lighting is dimmable, then the artificial lighting may be continuously adjusted in proportion to the amount of daylight available. If the electric lighting is on-off only, then an electric lighting fixture or lamp must remain on at full output until daylight can meet the entire recommended light level for the space. Non-dimming variants include having multiple non-adjacent light fixtures such as alternate units in the ceiling ‘grid layout,’ or daylight source adjacent fixtures near windows or skylights, linked for module on-off switching. Another variant of on-off switching is step switching (sometimes referred to as “bi-level switching”), in which multiple lamps...
in a single light fixture can be switched on and off independent of each other. This allows for typically one or two steps between full output and zero.[7] [8]

Dimming systems are generally more expensive than on-off systems. They have the potential to save more energy, because they can reduce electric light output when daylight can only partially meet the needs of the space. However, dimming systems may also require a little more energy for their basic operation. If a dimming system is well-calibrated, the occupants of the space will not notice changes in electric lighting due to daylight harvesting, whereas they are very likely to notice the changes due to on-off or step switching.

**Energy Savings**

Several studies have recorded the energy savings due to daylight harvesting. Energy savings for electric lighting in the range of 20-60% are common. [9] Savings are very dependent on the type of space the light harvesting control system is deployed in, and its usage.[10] Clearly, savings can only accrue in spaces with substantial daylight where electric lighting would have been otherwise used. Therefore daylight harvesting works best in spaces with access to conventional or clerestory windows, skylights, light tube groups, glass block walls, and other passive daylighting sources from sunlight; and where electric lighting would otherwise be left on for long periods. Such spaces have included offices, atria, interior public multistory plazas and shopping mall courts, and schools.

It is too simplistic to try to increase energy savings by increasing the size of windows. Daylight over-illumination may cause glare for occupants, causing them to deploy blinds or other window shading devices, and compromising the daylight harvesting system. Even partially-deployed venetian blinds can cut energy savings in half. [11]

Impressive energy savings estimates may not be realized in practice due to poor system design, calibration, or commissioning. Systems that dim or switch electric lighting in a distracting manner, or that produce overall light levels that are perceived as too low, can be sabotaged by occupants. [12] (For example, simply taping over a sensor will create constant electric lighting at maximum output.)

The adoption of daylight harvesting technologies has been hampered by high costs and imperfect performance of the technologies. However, studies have shown that by using daylight harvesting technologies, owners can see an average annual energy savings of 24%. [13]

One method of predicting energy savings it to use commercially-available software programs, such as the (freeware) DOE-2, which considers thermal loads. [14]

**Payback, and Drivers for Adoption**

There is an incremental cost to daylight harvesting systems. Dividing this cost by the annual energy savings provides a "simple payback", the number of years for the system to pay for itself. The shorter the calculated payback period, the more likely it is that a building owner will invest in the system. Costs vary for a whole host of local factors, but generally if energy costs rise, or the cost of the control hardware and installation falls, the payback period will be reduced.

**Sustainability**

The green building-sustainable building movement encourages sustainable architecture design and building practices. Various green building ecolabel certification marks exist around the world, such as LEED, BOMA Best, BREEAM, HKBeam, and Green Star. All of these programs offer points for various building design features that promote sustainability, and certification at various levels is awarded for reaching a given number of points. One of the principal ways to gain points is through energy saving measures. [15] Therefore, daylight harvesting is a common feature of green buildings. [16] Thus green building practices are increasing the production of daylight harvesting components, leading to lower prices.

Many electric utilities provide financial incentives for their customers to save energy. One such incentive is rebates
on daylight harvesting systems \[17\], which also reduces payback periods.

In addition, energy codes and standards are beginning to address daylight harvesting. For example the California Energy Code Title 24-2008 recognizes primary and secondary daylight zones. At least 50\% of the general lighting in primary zones must be controlled separately from other lighting, with automatic control required for larger zones. The code encourages automatic daylight harvesting in secondary zones by awarding power adjustment factor credits that can be applied to the lighting design.\[18\] The 2009 International Energy Conservation Code (IECC) recognizes daylight zones around vertical fenestration and skylights, and requires that the lighting in these zones be controlled separately from the general lighting in the space. The 2010 ASHRAE 90.1 energy standard, expected to be published in 2010, is also expected to address daylight harvesting. Meanwhile, ASHRAE 189.1, the first of a generation of sustainable construction codes, defines daylight zones and requires daylight harvesting control.

References

**External links**

- Cost Effective Simplified Controls for Daylight Harvesting (http://cltc.ucdavis.edu/images/_projects/research/simplified_daylight_harvesting/aceee_cost_effective_simplified_controls_for_daylight_harvesting.pdf) California Lighting Technology Center, University of California, Davis
- Harvest Daylight and Reap Rewards (http://www.daintree.net/downloads/whitepapers/daylighting.pdf) by Daintree Networks
- Dayswitch technology (http://www.lrc.rpi.edu/programs/daylighting/pdf/14005DayswitchReport.pdf)
- Daylight Dividends, a research organization (http://www.lrc.rpi.edu/programs/daylighting/about.asp)
- Welch Allyn Headquarters Renovations (http://www.lrc.rpi.edu/programs/designWorks/projects/WelchAllyn/index.asp) a renovation project utilizing daylight harvesting technology

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**Daylighting**

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.

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**

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 (see Sun path) 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**

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.

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.
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**

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 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.\(^3\)

**References**

1. Sun/Earth Buffering and Superinsulation page 68 ISBN 0960442243

**External links**

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- Sun Light Redirecting Devices (http://www.arch.hawaii.edu/site/fileadmin/user_upload/Files/arch316_Steve/Daylight/Dayltg_intermed_4.pdf) - examples of geometrical set-up of light shelves etc.
- Solar control façades (http://gaia.lbl.gov/hpbf/techno_a.htm) and Daylighting façades (http://gaia.lbl.gov/hpbf/techno_b.htm), University of California, Berkeley
- MIT, Building Technology Program, Daylighting Lab (http://daylighting.mit.edu/home.php)
- Photos of a small-scale heliostat system in action (http://www.practicalsolar.com/photos/photos.html)
Solar thermal energy

Solar thermal energy (STE)\(^1\) is a technology for harnessing solar energy for thermal energy (heat). Solar thermal collectors are classified by the USA Energy Information Administration as low-, medium-, or high-temperature collectors. Low temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production. STE is different from photovoltaics, which convert solar energy directly into electricity. While only 600 megawatts of solar thermal power is up and running worldwide in October 2009 according to Dr David Mills of Ausra, another 400 megawatts is under construction and there are 14,000 megawatts of the more serious concentrating solar thermal (CST) projects being developed.\(^2\)

Low-temperature collectors

Of the 21000000 square feet (m\(^2\)) of solar thermal collectors produced in the United States in 2006, 16000000 square feet (m\(^2\)) were of the low-temperature variety.\(^3\) Low-temperature collectors are generally installed to heat swimming pools, although they can also be used for space heating. Collectors can use air or water as the medium to transfer the heat to their destination.

Heating, cooling, and ventilation

In the United States, heating, ventilation, and air conditioning (HVAC) systems account for over 25 percent (4.75 EJ) of the energy used in commercial buildings and nearly half (10.1 EJ) of the energy used in residential buildings.\(^4\)\(^5\) Solar heating, cooling, and ventilation technologies can be used to offset a portion of this energy.

Thermal mass materials store solar energy during the day and release this energy during cooler periods. Common thermal mass materials include stone, concrete, and water. The proportion and placement of thermal mass should consider several factors such as climate, daylighting, and shading conditions. When properly incorporated, thermal mass can passively maintain comfortable temperatures while reducing energy consumption. A solar chimney (or thermal chimney) is a passive solar ventilation system composed of a hollow thermal mass connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. These systems have been in use since Roman times and remain common in the Middle East.

Solar space heating with solar air heat collectors is more popular in the USA and Canada than heating with solar liquid collectors since most buildings already have a ventilation system for heating and cooling. The two main types of solar air panels are glazed and unglazed.
Glazed Solar Collectors are designed primarily for space heating and they recirculate building air through a solar air panel where the air is heated and then directed back into the building. These solar space heating systems require at least two penetrations into the building and only perform when the air in the solar collector is warmer than the building room temperature. Most glazed collectors are used in the residential sector.

Unglazed, "transpired" air collectors

Unglazed Solar Collectors are primarily used to pre-heat make-up ventilation air in commercial, industrial and institutional buildings with a high ventilation load. They turn building walls or sections of walls into low cost, high performance, unglazed solar collectors. Also called, "transpired solar panels", they employ a painted perforated metal solar heat absorber that also serves as the exterior wall surface of the building. Heat conducts from the absorber surface to the thermal boundary layer of air 1 mm thick on the outside of the absorber and to air that passes behind the absorber. The boundary layer of air is drawn into a nearby perforation before the heat can escape by convection to the outside air. The heated air is then drawn from behind the absorber plate into the building's ventilation system.

A Trombe wall is a passive solar heating and ventilation system consisting of an air channel sandwiched between a window and a sun-facing thermal mass. During the ventilation cycle, sunlight stores heat in the thermal mass and warms the air channel causing circulation through vents at the top and bottom of the wall. During the heating cycle the Trombe wall radiates stored heat.\(^6\)

Solar roof ponds are unique solar heating and cooling systems developed by Harold Hay in the 1960s. A basic system consists of a roof-mounted water bladder with a movable insulating cover. This system can control heat exchange between interior and exterior environments by covering and uncovering the bladder between night and day. When heating is a concern the bladder is uncovered during the day allowing sunlight to warm the water bladder and store heat for evening use. When cooling is a concern the covered bladder draws heat from the building's interior during the day and is uncovered at night to radiate heat to the cooler atmosphere. The Skytherm house in Atascadero, California uses a prototype roof pond for heating and cooling.\(^7\)

Active solar cooling can be achieved via absorption refrigeration cycles, desiccant cycles, and solar mechanical processes. In 1878, Auguste Mouchout pioneered solar cooling by making ice using a solar steam engine attached to a refrigeration device.\(^8\) Thermal mass, smart windows and shading methods can also be used to provide cooling. The leaves of deciduous trees provide natural shade during the summer while the bare limbs allow light and warmth into a building during the winter. The water content of trees will also help moderate local temperatures.

### Process heat

**Solar process heating** systems are designed to provide large quantities of hot water or space heating for nonresidential buildings.\(^9\)

Evaporation ponds are shallow ponds that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from sea water is one of the oldest applications of solar energy. Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams. Altogether, evaporation ponds represent one of the largest commercial applications of solar energy in use today.\(^10\)

Unglazed transpired collectors (UTC) are perforated sun-facing walls used for preheating ventilation air. UTCs can raise the incoming air temperature up to 22 °C and deliver outlet temperatures of 45-60 °C. The short payback period
of transpired collectors (3 to 12 years) make them a more cost-effective alternative to glazed collection systems. As of 2009, over 1500 systems with a combined collector area of 300,000 m² had been installed worldwide. Representatives include an 860 m² collector in Costa Rica used for drying coffee beans and a 1300 m² collector in Coimbatore, India used for drying marigolds.\cite{11} \cite{12}

A food processing facility in Modesto, California uses parabolic troughs to produce steam used in the manufacturing process. The 5,000 m² collector area is expected to provide 4.3 GJ per year.\cite{13}

Medium-temperature collectors

These collectors could be used to produce approximately 50% and more of the hot water needed for residential and commercial use in the United States.\cite{14} In the United States, a typical system costs $4000–$6000 retail ($1400 to $2200 wholesale for the materials) and 30% of the system qualifies for a federal tax credit + additional state credit exists in about half of the states. Labor for a simple open loop system in southern climates can take 3–5 hours for the installation and 4–6 hours in Northern areas. Northern system require more collector area and more complex plumbing to protect the collector form freezing. With this incentive, the payback time for a typical household is four to nine years, depending on the state. Similar subsidies exist in parts of Europe. A crew of one solar plumber and two assistants with minimal training can install a system per day. Thermosiphon installation have negligible maintenance costs (costs rise if antifreeze and mains power are used for circulation) and in the US reduces a households' operating costs by $6 per person per month. Solar water heating can reduce CO₂ emissions of a family of four by 1 ton/year (if replacing natural gas) or 3 ton/year (if replacing electricity).\cite{15} Medium-temperature installations can use any of several designs: common designs are pressurized glycol, drain back, batch systems and newer low pressure freeze tolerant systems using polymer pipes containing water with photovoltaic pumping. European and International standards are being reviewed to accommodate innovations in design and operation of medium temperature collectors. Operational innovations include "permanently wetted collector" operation. This innovation reduces or even eliminates the occurrence of no-flow high temperature stresses called stagnation which would otherwise reduce the life expectancy of collectors.

Solar drying

Solar thermal energy can be useful for drying wood for construction and wood fuels such as wood chips for combustion. Solar is also used for food products such as fruits, grains, and fish. Crop drying by solar means is environmentally friendly as well as cost effective while improving the quality. The less money it takes to make a product, the less it can be sold for, pleasing both the buyers and the sellers. Technologies in solar drying include ultra low cost pumped transpired plate air collectors based on black fabrics. Solar thermal energy is helpful in the process of drying products such as wood chips and other forms of biomass by raising the heat while allowing air to pass through and get rid of the moisture.\cite{16}
Cooking

Solar cookers use sunlight for cooking, drying and pasteurization. Solar cooking offsets fuel costs, reduces demand for fuel or firewood, and improves air quality by reducing or removing a source of smoke.

The simplest type of solar cooker is the box cooker first built by Horace de Saussure in 1767. A basic box cooker consists of an insulated container with a transparent lid. These cookers can be used effectively with partially overcast skies and will typically reach temperatures of 50–100 °C.[17] [18]

Concentrating solar cookers use reflectors to concentrate light on a cooking container. The most common reflector geometries are flat plate, disc and parabolic trough type. These designs cook faster and at higher temperatures (up to 350 °C) but require direct light to function properly.

The Solar Kitchen in Auroville, India uses a unique concentrating technology known as the solar bowl. Contrary to conventional tracking reflector/fixed receiver systems, the solar bowl uses a fixed spherical reflector with a receiver which tracks the focus of light as the Sun moves across the sky. The solar bowl's receiver reaches temperature of 150 °C that is used to produce steam that helps cook 2,000 daily meals.[19]

Many other solar kitchens in India use another unique concentrating technology known as the Scheffler reflector. This technology was first developed by Wolfgang Scheffler in 1986. A Scheffler reflector is a parabolic dish that uses single axis tracking to follow the Sun's daily course. These reflectors have a flexible reflective surface that is able to change its curvature to adjust to seasonal variations in the incident angle of sunlight. Scheffler reflectors have the advantage of having a fixed focal point which improves the ease of cooking and are able to reach temperatures of 450-650 °C.[20] Built in 1999, the world's largest Scheffler reflector system in Abu Road, Rajasthan India is capable of cooking up to 35,000 meals a day.[21] By early 2008, over 2000 large cookers of the Scheffler design had been built worldwide.

Distillation

Solar stills can be used to make drinking water in areas that clean water is not common. Solar distillation is necessary in these situations to provide people with purified water. Solar energy heats up the water in the still. The water then evaporates and condenses on the bottom of the covering glass.[16]

High-temperature collectors

Where temperatures below about 95 °C are sufficient, as for space heating, flat-plate collectors of the nonconcentrating type are generally used. Because of the relatively high heat losses through the glazing, flat plate collectors will not reach temperatures much above 200 °C even when the heat transfer fluid is stagnant. Such temperatures are too low for efficient conversion to electricity.

The efficiency of heat engines increases with the temperature of the heat source. To achieve this in solar thermal energy plants, solar radiation is concentrated by mirrors or lenses to obtain higher temperatures – a technique called Concentrated Solar Power (CSP).
The practical effect of high efficiencies is to reduce the plant's collector size and total land use per unit power generated, reducing the environmental impacts of a power plant as well as its expense.

As the temperature increases, different forms of conversion become practical. Up to 600 °C, steam turbines, standard technology, have an efficiency up to 41%. Above 600 °C, gas turbines can be more efficient. Higher temperatures are problematic because different materials and techniques are needed. One proposal for very high temperatures is to use liquid fluoride salts operating between 700 °C to 800 °C, using multi-stage turbine systems to achieve 50% or more thermal efficiencies.[22] The higher operating temperatures permit the plant to use higher-temperature dry heat exchangers for its thermal exhaust, reducing the plant's water use – critical in the deserts where large solar plants are practical. High temperatures also make heat storage more efficient, because more watt-hours are stored per unit of fluid.

Since the CSP plant generates heat first of all, it can store the heat before conversion to electricity. With current technology, storage of heat is much cheaper and more efficient than storage of electricity. In this way, the CSP plant can produce electricity day and night. If the CSP site has predictable solar radiation, then the CSP plant becomes a reliable power plant. Reliability can further be improved by installing a back-up system that uses fossil energy. The back-up system can reuse most of the CSP plant, which decreases the cost of the back-up system.

With reliability, unused desert, no pollution, and no fuel costs, the obstacles for large deployment for CSP are cost, aesthetics, land use and similar factors for the necessary connecting high tension lines. Although only a small percentage of the desert is necessary to meet global electricity demand, still a large area must be covered with mirrors or lenses to obtain a significant amount of energy. An important way to decrease cost is the use of a simple design.

**System designs**

During the day the sun has different positions. If the mirrors or lenses do not move, then the focus of the mirrors or lenses changes. Therefore it seems unavoidable that there needs to be a tracking system that follows the position of the sun (for solar photovoltaic a solar tracker is only optional). The tracking system increases the cost and complexity. With this in mind, different designs can be distinguished in how they concentrate the light and track the position of the sun.

**Parabolic trough designs**
Parabolic trough power plants use a curved, mirrored trough which reflects the direct solar radiation onto a glass tube containing a fluid (also called a receiver, absorber or collector) running the length of the trough, positioned at the focal point of the reflectors. The trough is parabolic along one axis and linear in the orthogonal axis. For change of the daily position of the sun perpendicular to the receiver, the trough tilts east to west so that the direct radiation remains focused on the receiver. However, seasonal changes in the in angle of sunlight parallel to the trough does not require adjustment of the mirrors, since the light is simply concentrated elsewhere on the receiver. Thus the trough design does not require tracking on a second axis.

The receiver may be enclosed in a glass vacuum chamber. The vacuum significantly reduces convective heat loss.

A fluid (also called heat transfer fluid) passes through the receiver and becomes very hot. Common fluids are synthetic oil, molten salt and pressurized steam. The fluid containing the heat is transported to a heat engine where about a third of the heat is converted to electricity.

Andasol 1 in Gaudix, Spain uses the Parabolic Trough design which consists of long parallel rows of modular solar collectors. Tracking the sun from East to West by rotation on one axis, the high precision reflector panels concentrate the solar radiation coming directly from the sun onto an absorber pipe located along the focal line of the collector. A heat transfer medium, a synthetic oil like in car engines, is circulated through the absorber pipes at temperatures up to 400 °C and generates live steam to drive the steam turbine generator of a conventional power block.

Full-scale parabolic trough systems consist of many such troughs laid out in parallel over a large area of land. Since 1985 a solar thermal system using this principle has been in full operation in California in the United States. It is called the SEGS system. Other CSP designs lack this kind of long experience and therefore it can currently be said that the parabolic trough design is the most thoroughly proven CSP technology.

The Solar Energy Generating System (SEGS) is a collection of nine plants with a total capacity of 350MW. It is currently the largest operational solar system (both thermal and non-thermal). A newer plant is Nevada Solar One plant with a capacity of 64MW. Under construction are Andasol 1 and Andasol 2 in Spain with each site having a capacity of 50MW. Note however, that those plants have heat storage which requires a larger field of solar collectors relative to the size of the steam turbine-generator to store heat and send heat to the steam turbine at the same time. Heat storage enables better utilization of the steam turbine. With day and some nighttime operation of the steam-turbine Andasol 1 at 50MW peak capacity produces more energy than Nevada Solar One at 64 MW peak capacity, due to the former plant's thermal energy storage system and larger solar field.

553MW new capacity is proposed in Mojave Solar Park, California. Furthermore, 59MW hybrid plant with heat storage is proposed near Barstow, California. Near Kuraymat in Egypt, some 40MW steam is used as input for a gas powered plant. Finally, 25MW steam input for a gas power plant in Hassi R’mel, Algeria.
**Power tower designs**

Power towers (also known as 'central tower' power plants or 'heliostat' power plants) capture and focus the sun's thermal energy with thousands of tracking mirrors (called heliostats) in roughly a two square mile field. A tower resides in the center of the heliostat field. The heliostats focus concentrated sunlight on a receiver which sits on top of the tower. Within the receiver the concentrated sunlight heats molten salt to over 1000 °F (538 °C). The heated molten salt then flows into a thermal storage tank where it is stored, maintaining 98% thermal efficiency, and eventually pumped to a steam generator. The steam drives a standard turbine to generate electricity. This process, also known as the "Rankine cycle" is similar to a standard coal-fired power plant, except it is fueled by clean and free solar energy.

The advantage of this design above the parabolic trough design is the higher temperature. Thermal energy at higher temperatures can be converted to electricity more efficiently and can be more cheaply stored for later use. Furthermore, there is less need to flatten the ground area. In principle a power tower can be built on a hillside. Mirrors can be flat and plumbing is concentrated in the tower. The disadvantage is that each mirror must have its own dual-axis control, while in the parabolic trough design one axis can be shared for a large array of mirrors.

*Some or all of the following reads like a press release or commercial promotion, please assist by rewriting, simplifying, and trimming as needed*

SolarReserve, a Santa Monica, CA-based solar developer, uses this technology for the development of its concentrated solar thermal plants with storage. The plants were designed by United Technologies Corporation. United Technologies' subsidiary, Rocketdyne, demonstrated the technology at the Solar One (1982–1986) and Solar Two (1995–1999) power tower plants in Southern California, although these plants were designed by the Department of Energy (DOE), Southern California Edison, LA Dept of Water and Power, and California Energy Commission. United Technologies has granted SolarReserve an exclusive worldwide license to develop such power plants.

In November 2009, SolarReserve and a Madrid-based renewable energy developer, Preneal, received the key environmental permit that is necessary for the construction of their 50 megawatt solar plant in Spain. This project will generate more than 300,000 megawatt hours of electricity per year, or enough electricity to power almost 70,000 houses in the region. The Alcazar Solar Thermal Power Project will use molten salt as a coolant, which is exclusively licensed to SolarReserve by United Technologies Corporation (UTC).

In December 2009, SolarReserve announced two power contracts in the United States. The first was with Pacific Gas and Electric (PG&E) for the sale of electricity from SolarReserve's Rice Solar Energy Project. The 150-megawatt solar energy project will be located 30 miles (48 km) northwest of the city of Blythe in eastern Riverside County, California. When completed, SolarReserve's facility will supply approximately 450,000 megawatt-hours annually of clean, reliable electricity – enough to power up to 68,000 homes during peak electricity
periods – and will use thermal energy storage for nighttime power generation. The second power contract was a 25-year power purchase agreement with NV Energy for the sale of electricity from SolarReserve's Crescent Dunes Solar Energy Project. Developed and owned by SolarReserve's subsidiary, Tonopah Solar Energy, LLC, the project will be located near the town of Tonopah in Nye County, Nevada. When completed, Tonopah Solar Energy's facility will supply approximately 480,000 megawatt hours annually.

In June 2008, eSolar, a Pasadena, CA-based company founded by Idealab CEO Bill Gross with funding from Google, announced a power purchase agreement (PPA) with the utility Southern California Edison to produce 245 megawatts of power. Also, in February 2009, eSolar announced it had licensed its technology to two development partners, the Princeton, N.J.-based NRG Energy, Inc., and the India-based ACME Group. In the deal with NRG, the companies announced plans to jointly build 500 megawatts of concentrating solar thermal plants throughout the United States. The target goal for the ACME Group was nearly double; ACME plans to start construction on its first eSolar power plant this year, and will build a total of 1 gigawatt over the next 10 years.

eSolar's proprietary sun-tracking software coordinates the movement of 24,000 1 meter-square mirrors per 1 tower using optical sensors to adjust and calibrate the mirrors in real time. This allows for a high density of reflective material which enables the development of modular concentrating solar thermal (CSP) power plants in 46 megawatt (MW) units on approximately π square mile parcels of land, resulting in a land-to-power ratio of 4 acres (16000 m²) per 1 megawatt.

BrightSource Energy entered into a series of power purchase agreements with Pacific Gas and Electric Company in March 2008 for up to 900MW of electricity, the largest solar power commitment ever made by a utility. BrightSource is currently developing a number of solar power plants in Southern California, with construction of the first plant planned to start in 2009.

In June 2008, BrightSource Energy dedicated its 4-6 MW Solar Energy Development Center (SEDC) in Israel's Negev Desert. The site, located in the Rotem Industrial Park, features more than 1,600 heliostats that track the sun and reflect light onto a 60 meter-high tower. The concentrated energy is then used to heat a boiler atop the tower to 550 degrees Celsius, generating superheated steam.

A working tower power plant is PS10 in Spain with a capacity of 11MW. The 15MW Solar Tres plant with heat storage is under construction in Spain. In South Africa, a 100MW solar power plant is planned with 4000 to 5000 heliostat mirrors, each having an area of 140 m². A 10MW power plant in Cloncurry, Australia (with purified graphite as heat storage located on the tower directly by the receiver).

Out of commission are the 10MW Solar One (later redeveloped and made into Solar Two) and the 2MW Themis plants.

A cost/performance comparison between power tower and parabolic trough concentrators was made by the NREL which estimated that by 2020 electricity could be produced from power towers for 5.47 $/kWh and for 6.21 $/kWh from parabolic troughs. The capacity factor for power towers was estimated to be 72.9% and 56.2% for parabolic troughs. There is some hope that the development of cheap, durable, mass producible heliostat power plant components could bring this cost down.
Dish designs

A dish system uses a large, reflective, parabolic dish (similar in shape to satellite television dish). It focuses all the sunlight that strikes the dish up onto a single point above the dish, where a receiver captures the heat and transforms it into a useful form. Typically the dish is coupled with a Stirling engine in a Dish-Stirling System, but also sometimes a steam engine is used. These create rotational kinetic energy that can be converted to electricity using an electric generator.

The advantage of a dish system is that it can achieve much higher temperatures due to the higher concentration of light (as in tower designs). Higher temperatures leads to better conversion to electricity and the dish system is very efficient on this point. However, there are also some disadvantages. Heat to electricity conversion requires moving parts and that results in maintenance. In general, a centralized approach for this conversion is better than the decentralized concept in the dish design. Second, the (heavy) engine is part of the moving structure, which requires a rigid frame and strong tracking system. Furthermore, parabolic mirrors are used instead of flat mirrors and tracking must be dual-axis.

In 2005 Southern California Edison announced an agreement to purchase solar powered Stirling engines from Stirling Energy Systems over a twenty year period and in quantities (20,000 units) sufficient to generate 500 megawatts of electricity. Stirling Energy Systems announced another agreement with San Diego Gas & Electric to provide between 300 and 900 megawatts of electricity. In January 2010, Stirling Energy Systems and Tessera Solar commissioned the first demonstration 1.5-megawatt power plant ("Maricopa Solar") using Stirling technology in Peoria, Arizona.

Fresnel reflectors

A linear Fresnel reflector power plant uses a series of long, narrow, shallow-curvature (or even flat) mirrors to focus light onto one or more linear receivers positioned above the mirrors. On top of the receiver a small parabolic mirror can be attached for further focusing the light. These systems aim to offer lower overall costs by sharing a receiver between several mirrors (as compared with trough and dish concepts), while still using the simple line-focus geometry with one axis for tracking. This is similar to the trough design (and different from central towers and dishes with dual-axis). The receiver is stationary and so fluid couplings are not required (as in troughs and dishes). The mirrors also do not need to support the receiver, so they are structurally simpler. When suitable aiming strategies are used (mirrors aimed at different receivers at different times of day), this can allow a denser packing of mirrors on available land area.

Recent prototypes of these types of systems have been built in Australia (CLFR) and by Solarmundo in Belgium. The Solarmundo research and development project, with its pilot plant at Liège, was closed down after successful proof of concept of the Linear Fresnel technology. Subsequently, Solar Power Group GmbH (SPG), based in Munich, Germany, was founded by some Solarmundo team members. A Fresnel-based prototype with direct steam generation was built by SPG in conjunction with the German Aerospace Center (DLR).
Based on the Australian prototype, a 177MW plant had been proposed near San Luis Obispo in California and would be built by Ausra. But Ausra sold its planned California solar farm to First Solar. First Solar will not build the Carrizo project, and the deal has resulted in the cancellation of Ausra's contract to provide 177 megawatts to P.G.& E. Small capacity plants are an enormous economical challenge with conventional parabolic trough and drive design – few companies build such small projects. There are plans for SHP Europe, former Ausra subsidiary, to build a 6.5 MW combined cycle plant in Portugal. The German company SK Energy ) has plans to build several small 1-3 MW plants in Southern Europe (esp. in Spain) using Fresnel mirror and steam drive technology (Press Release ).

In May 2008, the German Solar Power Group GmbH and the Spanish Laer S.L. agreed the joint execution of a solar thermal power plant in central Spain. This will be the first commercial solar thermal power plant in Spain based on the Fresnel collector technology of the Solar Power Group. The planned size of the power plant will be 10 MW a solar thermal collector field with a fossil co-firing unit as backup system. The start of constructions is planned for 2009. The project is located in Gotarrendura, a small renewable energy pioneering village, about 100 km northwest of Madrid, Spain.

A Multi-Tower Solar Array (MTSA) concept, that uses a point-focus Fresnel reflector idea, has also been developed, but has not yet been prototyped.

Since March 2009, the Fresnel solar power plant PE 1 of the German company Novatec Biosol is in commercial operation in southern Spain. The solar thermal power plant is based on linear Fresnel collector technology and has an electrical capacity of 1.4 MW. Beside a conventional power block, PE 1 comprises a solar boiler with mirror surface of around 18,000m². The steam is generated by concentrating direct solar irradiation onto a linear receiver which is 7.40m above the ground. An absorber tube is positioned in the focal line of the mirror field in which water is evaporated directly into saturated steam at 270 °C and at a pressure of 55 bar by the concentrated solar energy.

**Linear Fresnel reflector technologies**

Rival single axis tracking technologies include the relatively new linear Fresnel reflector (LFR) and compact-LFR (CLFR) technologies. The LFR differs from that of the parabolic trough in that the absorber is fixed in space above the mirror field. Also, the reflector is composed of many low row segments, which focus collectively on an elevated long tower receiver running parallel to the reflector rotational axis.

This system offers a lower cost solution as the absorber row is shared among several rows of mirrors. However, one fundamental difficulty with the LFR technology is the avoidance of shading of incoming solar radiation and blocking of reflected solar radiation by adjacent reflectors. Blocking and shading can be reduced by using absorber towers elevated higher or by increasing the absorber size, which allows increased spacing between reflectors remote from the absorber. Both these solutions increase costs, as larger ground usage is required.

The CLFR offers an alternate solution to the LFR problem. The classic LFR has only one linear absorber on a single linear tower. This prohibits any option of the direction of orientation of a given reflector. Since this technology would be introduced in a large field, one can assume that there will be many linear absorbers in the system. Therefore, if the linear absorbers are close enough, individual reflectors will have the option of directing reflected solar radiation to at least two absorbers. This additional factor gives potential for more densely packed arrays, since patterns of alternative reflector inclination can be set up such that closely packed reflectors can be positioned without shading and blocking.

CLFR power plants offer reduced costs in all elements of the solar array. These reduced costs encourage the advancement of this technology. Features that enhance the cost effectiveness of this system compared to that of the
parabolic trough technology include minimized structural costs, minimized parasitic pumping losses, and low maintenance. Minimized structural costs are attributed to the use of flat or elastically curved glass reflectors instead of costly sagged glass reflectors are mounted close to the ground. Also, the heat transfer loop is separated from the reflector field, avoiding the cost of flexible high pressure lines required in trough systems. Minimized parasitic pumping losses are due to the use of water for the heat transfer fluid with passive direct boiling. The use of glass-evacuated tubes ensures low radiative losses and is inexpensive. Studies of existing CLFR plants have been shown to deliver tracked beam to electricity efficiency of 19% on an annual basis as a preheater.[57]

Fresnel lenses

Prototypes of Fresnel lens concentrators have been produced for the collection of thermal energy by International Automated Systems.[59] No full-scale thermal systems using Fresnel lenses are known to be in operation, although products incorporating Fresnel lenses in conjunction with photovoltaic cells are already available.[60]

The advantage of this design is that lenses are cheaper than mirrors. Furthermore, if a material is chosen that has some flexibility, then a less rigid frame is required to withstand wind load. A new concept of a lightweight, 'non-disruptive' solar concentrator technology using asymmetric Fresnel lenses that occupies minimal ground surface area and allows for large amounts of concentrated solar energy per concentrator is seen in the 'Desert Blooms'[61] project, though a prototype has yet to be made.

MicroCSP

"MicroCSP"[62] references solar thermal technologies in which concentrating solar power (CSP) collectors are based on the designs used in traditional Concentrating Solar Power systems found in the Mojave Desert[64] but are smaller in collector size, lighter and operate at lower thermal temperatures usually below 315 °C (600 °F). These systems are designed for modular field or rooftop installation where they are easy to protect from high winds, snow and humid deployments.[65] Solar manufacturer Sopogy completed construction on a 1MW CSP plant at the Natural Energy Laboratory of Hawaii.[66]

MicroCSP is used for community-sized power plants (1MW to 50MW), for industrial, agricultural and manufacturing 'process heat' applications, and when large amounts of hot water are needed, such as resort swimming pools, water parks, large laundry facilities, sterilization, distillation and other such uses.

Heat exchange

Heat in a solar thermal system is guided by five basic principles: heat gain; heat transfer; heat storage; heat transport; and heat insulation.[67] Here, heat is the measure of the amount of thermal energy an object contains and is determined by the temperature, mass and specific heat of the object. Solar thermal power plants use heat exchangers that are designed for constant working conditions, to provide heat exchange.

Heat gain is the heat accumulated from the sun in the system. Solar thermal heat is trapped using the greenhouse effect; the greenhouse effect in this case is the ability of a reflective surface to transmit short wave radiation and reflect long wave radiation. Heat and infrared radiation (IR) are produced when short wave radiation light hits the absorber plate, which is then trapped inside the collector. Fluid, usually water, in the absorber tubes collect the trapped heat and transfer it to a heat storage vault.

Heat is transferred either by conduction or convection. When water is heated, kinetic energy is transferred by conduction to water molecules throughout the medium. These molecules spread their thermal energy by conduction and occupy more space than the cold slow moving molecules above them. The distribution of energy from the rising hot water to the sinking cold water contributes to the convection process. Heat is transferred from the absorber plates of the collector in the fluid by conduction. The collector fluid is circulated through the carrier pipes to the heat transfer vault. Inside the vault, heat is transferred throughout the medium through convection.
Heat storage enables solar thermal plants to produce electricity during hours without sunlight. Heat is transferred to a thermal storage medium in an insulated reservoir during hours with sunlight, and is withdrawn for power generation during hours lacking sunlight. Thermal storage mediums will be discussed in a heat storage section. Rate of heat transfer is related to the conductive and convection medium as well as the temperature differences. Bodies with large temperature differences transfer heat faster than bodies with lower temperature differences.

Heat transport refers to the activity in which heat from a solar collector is transported to the heat storage vault. Heat insulation is vital in both heat transport tubing as well as the storage vault. It prevents heat loss, which in turn relates to energy loss, or decrease in the efficiency of the system.

Heat storage

Heat storage allows a solar thermal plant to produce electricity at night and on overcast days. This allows the use of solar power for baseload generation as well as peak power generation, with the potential of displacing both coal and natural gas fired power plants. Additionally, the utilization of the generator is higher which reduces cost.

Heat is transferred to a thermal storage medium in an insulated reservoir during the day, and withdrawn for power generation at night. Thermal storage media include pressurized steam, concrete, a variety of phase change materials, and molten salts such as sodium and potassium nitrate.\[68\] [69]

Steam accumulator

The PS10 solar power tower stores heat in tanks as pressurized steam at 50 bar and 285 °C. The steam condenses and flashes back to steam, when pressure is lowered. Storage is for one hour. It is suggested that longer storage is possible, but that has not been proven yet in an existing power plant.\[70\]

Molten salt storage

A variety of fluids have been tested to transport the sun's heat, including water, air, oil, and sodium, but molten salt was selected as best. Molten salt is used in solar power tower systems because it is liquid at atmosphere pressure, it provides an efficient, low-cost medium in which to store thermal energy, its operating temperatures are compatible with today's high-pressure and high-temperature steam turbines, and it is non-flammable and nontoxic. In addition, molten salt is used in the chemical and metals industries as a heat-transport fluid, so experience with molten-salt systems exists in non-solar settings.

The molten salt is a mixture of 60 percent sodium nitrate and 40 percent potassium nitrate, commonly called saltpeter. New studies show that calcium nitrate could be included in the salts mixture to reduce costs and with technical benefits. The salt melts at 220 °C (430 °F) and is kept liquid at 290 °C (550 °F) in an insulated storage tank. The uniqueness of this solar system is in de-coupling the collection of solar energy from producing power, electricity can be generated in periods of inclement weather or even at night using the stored thermal energy in the hot salt tank. Normally tanks are well insulated and can store energy for up to a week. As an example of their size, tanks that provide enough thermal storage to power a 100-megawatt turbine for four hours would be about 9 m (30 ft) tall and 24 m (80 ft) in diameter.

The Andasol power plant in Spain is the first commercial solar thermal power plant to utilize molten salt for heat storage and nighttime generation. It came online March 2009.\[71\]
Graphite heat storage

Direct
The proposed power plant in Cloncurry Australia will store heat in purified graphite. The plant has a power tower design. The graphite is located on top of the tower. Heat from the heliostats goes directly to the storage. Heat for energy production is drawn from the graphite. This simplifies the design.[72]

Indirect
Molten salt coolants are used to transfer heat from the reflectors to heat storage vaults. The heat from the salts are transferred to a secondary heat transfer fluid via a heat exchanger and then to the storage media, or alternatively, the salts can be used to directly heat graphite. Graphite is used as it has relatively low costs and compatibility with liquid fluoride salts. The high mass and volumetric heat capacity of graphite provide an efficient storage medium.[73]

Phase-change materials for storage
Phase Change Material (PCMs) offer an alternate solution in energy storage. Using a similar heat transfer infrastructure, PCMs have the potential of providing a more efficient means of storage. PCMs can be either organic or inorganic materials. Advantages of organic PCMs include no corrosives, low or no undercooling, and chemical and thermal stability. Disadvantages include low phase-change enthalpy, low thermal conductivity, and flammability. Inorganics are advantageous with greater phase-change enthalpy, but exhibit disadvantages with undercooling, corrosion, phase separation, and lack of thermal stability. The greater phase-change enthalpy in inorganic PCMs make hydrate salts a strong candidate in the solar energy storage field.[74]

Use of water
A design which requires water for condensation or cooling may conflict with location of solar thermal plants in desert areas with good solar radiation but limited water resources. The conflict is illustrated by plans of Solar Millennium, a German company, to build a plant in the Amargosa Valley of Nevada which would require 20% of the water available in the area. Some other projected plants by the same and other companies in the Mojave Desert of California may also be affected by difficulty in obtaining adequate and appropriate water rights. California water law currently prohibits use of potable water for cooling.[75]

Other designs require less water. The proposed Ivanpah Solar Power Facility in south-eastern California will conserve scarce desert water by using air-cooling to convert the steam back into water. Compared to conventional wet-cooling, this results in a 90 percent reduction in water usage. The water is then returned to the boiler in a closed process which is environmentally friendly.[76]

Conversion rates from solar energy to electrical energy
Of all of these technologies the solar dish/stirling engine has the highest energy efficiency. A single solar dish-Stirling engine installed at Sandia National Laboratories National Solar Thermal Test Facility produces as much as 25 kWh of electricity, with a conversion efficiency of 31.25%.[77]

Solar parabolic trough plants have been built with efficiencies of about 20%. Fresnel reflectors have an efficiency that is slightly lower (but this is compensated by the denser packing).

The gross conversion efficiencies (taking into account that the solar dishes or troughs occupy only a fraction of the total area of the power plant) are determined by net generating capacity over the solar energy that falls on the total area of the solar plant. The 500-megawatt (MW) SCE/SES plant would extract about 2.75% of the radiation (1 kW/m²; see Solar power for a discussion) that falls on its 4,500 acres (18.2 km²).[78] For the 50 MW AndaSol Power Plant[79] that is being built in Spain (total area of 1,300×1,500 m = 1.95 km²) gross conversion efficiency comes out at 2.6%
Furthermore, efficiency does not directly relate to cost: on calculating total cost, both efficiency and the cost of construction and maintenance should be taken into account.

**Levelised cost**

Since a solar power plant does not use any fuel, the cost consists mostly of capital cost with minor operational and maintenance cost. If the lifetime of the plant and the interest rate is known, then the cost per kWh can be calculated. This is called the levelised energy cost.

The first step in the calculation is to determine the investment for the production of 1 kWh in a year. Example, the fact sheet of the Andasol 1 project shows a total investment of 310 million euros for a production of 179 GWh a year. Since 179 GWh is 179 million kWh, the investment per kWh a year production is 310 / 179 = 1.73 euro.

Another example is Cloncurry solar power station in Australia. It is planned to produce 30 million kWh a year for an investment of 31 million Australian dollars. So, if this is achieved in reality, the cost would be 1.03 Australian dollar for the production of 1 kWh in a year. This would be significantly cheaper than Andasol 1, which can partially be explained by the higher radiation in Cloncurry over Spain. The investment per kWh cost for one year should not be confused with the cost per kWh over the complete lifetime of such a plant.

In most cases the capacity is specified for a power plant (for instance Andasol 1 has a capacity of 50MW). This number is not suitable for comparison, because the capacity factor can differ. If a solar power plant has heat storage, then it can also produce output after sunset, but that will not change the capacity factor, it simply displaces the output. The average capacity factor for a solar power plant, which is a function of tracking, shading and location, is about 20%, meaning that a 50MW capacity power plant will typically provide a yearly output of 50 MW × 24 hrs × 365 days × 20% = 87,600 MWh/year, or 87.6 GWh/yr.

Although the investment for one kWh year production is suitable for comparing the price of different solar power plants, it does not give the price per kWh yet. The way of financing has a great influence on the final price. If the technology is proven, an interest rate of 7%[80] should be possible. However, for a new technology investors want a much higher rate to compensate for the higher risk. This has a significant negative effect on the price per kWh. Independent of the way of financing, there is always a linear relation between the investment per kWh production in a year and the price for 1 kWh (before adding operational and maintenance cost). In other words, if by enhancements of the technology the investments drop by 20%, then the price per kWh also drops by 20%.

If a way of financing is assumed where the money is borrowed and repaid every year, in such way that the debt and interest decreases, then the following formula can be used to calculate the division factor: \((1 - (1 + interest / 100) ^ {-lifetime}) / (interest / 100)\). For a lifetime of 25 years and an interest rate of 7%, the division factor is 11.65. For example, the investment of Andasol 1 was 1.73 euro per kWh, divided by 11.65 results in a price of 0.15 euro per kWh. If one cent operation and maintenance cost is added, then the levelized cost is 0.16 euro per kWh. Other ways of financing, different way of debt repayment, different lifetime expectation, different interest rate, may lead to a significantly different number.

If the cost per kWh may follow the inflation, then the inflation rate can be added to the interest rate. If an investor puts his money on the bank for 7%, then he is not compensated for inflation. However, if the cost per kWh is raised with inflation, then he is compensated and he can add 2% (a normal inflation rate) to his return. The Andasol 1 plant has a guaranteed feed-in tariff of 0.21 euro for 25 years. If this number is fixed, after 25 years with 2% inflation, 0.21 euro will have a value comparable with 0.13 euro now.

Finally, there is some gap between the first investment and the first production of electricity. This increases the investment with the interest over the period that the plant is not active yet. The modular solar dish (but also solar photovoltaic and wind power) have the advantage that electricity production starts after first construction.

Given the fact that solar thermal power is reliable, can deliver peak load and does not cause pollution, a price of US$0.10 per kWh[81] starts to become competitive. Although a price of US$0.06 has been claimed[82] With some
operational cost a simple target is 1 dollar (or lower) investment for 1 kWh production in a year.

### Standards
- EN 12975 (efficiency test)

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External links

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- Concentrating Solar Power (http://europe.theoildrum.com/node/2583) An overview of the technology by Gerry Wolff, coordinator of TREC-UK
- NREL Concentrating Solar Power Program Site (http://www.nrel.gov/csp)
- Comprehensive review of parabolic trough technology and markets (http://www.nrel.gov/csp/troughnet)
Tools

Architectural light shelf

A light shelf is an architectural element that allows daylight to penetrate deep into a building. This horizontal light-reflecting overhang is placed above eye-level and has a high-reflectance upper surface. This surface is then used to reflect daylight onto the ceiling and deeper into a space. Light shelves are generally made of an extruded aluminium chassis system and aluminium composite panel surfaces. Extruded components can be painted or anodized and they are all field fabricated and assembled from stock lengths.

Light shelves are typically used in high-rise and low-rise office buildings, as well as institutional buildings. This design is generally used on the equator-facing side of the building, which is where maximum sunlight is found, and as a result is most effective. Not only do light shelves allow light to penetrate through the building, they are also designed to shade near the windows, due to the overhang of the shelf, and help reduce window glare. Exterior shelves are generally more effective shading devices than interior shelves. A combination of exterior and interior shelves will work best in providing an even illumination gradient. For maximum benefit, perimeter lighting should be controlled by photo-sensors, with lighting zones appropriate to the particular installation.

Benefits

Architectural light shelves have been proven to reduce the amount of artificial lighting in a building. Since they can reflect light deeper into a space, the use of incandescent and fluorescent lighting can be reduced or completely eliminated, depending on the space. Light shelves make it possible for daylight to penetrate the space up to 2.5 times the distance between the floor and the top of the window. Today, advanced light shelf technology makes it possible to increase the distance up to 4 times. In spaces such as classrooms and offices, light shelves have been proven to increase occupant comfort and productivity. Furthermore, incorporating light shelves in a building design is admissible for the Leadership in Energy and Environmental Design point system, falling under the "Indoor Environment Quality: Daylight & Views" category.

Aesthetics

Light shelves integrate themselves with window designs or curtain wall systems which make them aesthetically pleasing. They are made of very light materials which make them visible but not distracting. The aluminium composite panel surfaces can be painted or anodized, and can be ordered in various colours. Two options are available, the fascia cap and the continuous panel.

Limitations

Light shelves may not be suitable for all climates. They are generally used in mild climates and not in tropical or desert climates due to the intense solar heat gain. These hot climates, compared to mild climates, require very small window openings to reduce the amount of heat infiltration.

The fact that light shelves extend a fair distance into a room may result in interference with sprinkler systems. In Canada, they cannot exceed 1200 mm (4 ft.) in width if sprinklers are present or the design will require integration with sprinkler system to cover the floor area under the light shelf. They also require a higher than average floor-to-ceiling heights in order for them to be effective, or daylight may be inadvertently redirected into occupants' eyes.
The distance into a space that light is cast is variable depending on both the time of day and the time of year.

Light Shelves also increase maintenance requirements and window coverings must be coordinated with light shelf design.

Alternatives

Alternatives to light shelves for window daylighting include blinds and louver systems, both of which can be interior or exterior.

Blinds reduce solar gain, but do little to redirect light into the interior space.

Exterior louver systems often rely on adjustments from either complex servo motors or building occupants throughout the day to operate well. Both of these systems can be unreliable at times, reducing the overall benefit of having a daylighting system.

Some newer products have found solutions to many of these problems. Products like LightLouver [1], which are hung on the inside of overhead windows, use fixed louvers with a complex geometry to redirect incoming daylight above 5° onto an interior ceiling. The effect is much like that of a light shelf, only with much more consistent illumination.

References


Roof lantern

The term roof lantern in its most common use today describes a multi-paned glass structure that sits atop a typically flat roof in order to provide natural light into the room below. A roof lantern is in effect a skylight. The term has also been used (Roof Top Lantern) to describe the decorative lighted lanterns atop Japanese taxi cabs designed to mimic the cultural heritage of Japanese lanterns.

Roof lanterns derived from structures first built in 16th century France and Italy called Orangeries. Orangeries were brick or frame structures with tall glass side windows and a central glass area in the flat roof for added sunlight. Orangeries were built to grow fruit in non-temperate climates. Orangeries today are considered a form or style of conservatory. Roof lanterns today serve as an architectural feature beyond the common version of commercial and plain skylights used on countless homes and commercial structures. They allow for unique views of the outdoors, and provide considerably more internal and external architectural appeal than common skylights, without the high cost of a full scale orangery or conservatory. Traditional architectural styles characterize most roof lanterns and the term is used interchangeably in the UK where roof lanterns are a common product in the building vernacular.

The first roof lanterns were made of timber and glass and were often prone to leaking.

“Initially wood-framed in the 18th and 19th centuries, skylights became even more popular in metal construction with the advent of sheet-metal shops during the Victorian era. Virtually every urban row
Roof lantern

house of the late-19th and early-20th centuries relied upon a metal-framed skylight to illuminate its enclosed stairwell. More elaborate dwellings of the era showed a fondness for the Roof Lantern, in which the humble ceiling-window design of the skylight is elaborated into a miniature glass-paneled conservatory-style roof cupola or tower"[1]

With advancements in glazing and sealing techniques, modern roof lanterns can have the same traditional look along with the benefits of high performance insulated glass and sealants, which reduce energy loss and provide water-tightness in the same manner as typical skylights. Today roof lanterns are built of both wood and aluminum, depending upon the style of building it is being added to and the owner’s personal preference.

References


Oculus

This page is about the architectural term. See also: eye.

An Oculus or circular window is a feature of Classical architecture since the 16th century. They are often denoted by their French name, oeil de boeuf, or "bull's-eye". Such circular or oval windows express the presence of a mezzanine on a building's façade without competing for attention with the major fenestration. Circular windows set in dormers have been a feature of French Classical architecture since the beginning of the seventeenth century. For structural reasons, they are also found as the portholes of ships.

Oculus (plural oculi) is the Latin word for eye,[1] and the word remains in use in certain contexts, as the name of the round opening in the top of the dome of the Pantheon in Rome,[2] and in reference to other round windows, openings, and skylights.

The Oculus in the Pantheon has always been open to the weather, allowing rain to enter and fall to the floor, where it is carried away through drains. In the picture, right, sunlight streams through the opening and strikes the lower part of the dome. The bright opening and the surrounding smooth concrete above the coffering resembles an eye, giving the opening its name.

In archaeology, oculus is the name given to a motif found in western European prehistoric art. It consists of a pair of circular or spiral marks, often interpreted as eyes, and appears on pottery, statues and megaliths. The oculus motif may represent the watchful gaze of a god or goddess and was especially common during the Neolithic period.
Notes

[1] While *oculus* is not in common use in English, words derived from it such as ocular (relating to the eye) are, primarily in medical and optical fields. Also, the terms *Oculus Dexter* (right eye), *Oculus Sinister* (left eye), and *Oculus Uterque* (both eyes) are used in medicine, usually abbreviated **OD**, **OS**, and **OU**, respectively.

[2] Since the revival of dome construction beginning in the Italian Renaissance, open oculi have been replaced by light-transmitting cupolas.
**Light tube**

*Light tubes* or *light pipes* are used for transporting or distributing natural or artificial light. In their application to daylighting, they are also often called *sun pipes*, *sun scopes*, *solar light pipes*, or *daylight pipes*.

Generally speaking, a *light pipe* or *light tube* may refer to:
- a tube or pipe for *transport* of light to another location, minimizing the loss of light;
- a transparent tube or pipe for *distribution* of light over its length, either for equidistribution along the entire length (see also sulfur lamp) or for controlled light leakage.

Both have the purpose of lighting, for example in Architecture.

**Materials and set-up**

**Light tube with reflective material**

Also known as a "tubular skylight", "SunScope" or "Tubular Daylighting Device", this is the oldest and most widespread type of light tube used for daylighting. The concept was originally developed by the ancient Egyptians. The first commercial reflector systems were patented and marketed in the 1850s by Paul Emile Chappuis in London, utilising various forms of angled mirror designs. Chappuis Ltd's reflectors were in continuous production until the factory was destroyed in 1943. The concept was rediscovered and patented in 1986 by Solatube International of Australia. This system has been marketed for widespread residential and commercial use. Other daylighting products are on the market under various generic names, such as "SunScope", "solar pipe", "light pipe", "light tube" and "tubular skylight".

A tube lined with highly reflective material leads the light rays through a building, starting from an entrance-point located on its roof or one of its outer walls. A light tube is not intended for imaging (in contrast to a periscope, for example), thus image distortions pose no problem and are in many ways encouraged due to the reduction of "directional" light.
The entrance point usually comprises a dome (cupola), which has the function of collecting and reflecting as much sunlight as possible into the tube. Many units also have directional "collectors", "reflectors" or even Fresnel lens devices that assist in collecting additional directional light down the tube.

A set-up in which a laser cut acrylic panel is arranged to redirect sunlight into a horizontally or vertically orientated mirrored pipe, combined with a light spreading system with a triangular arrangement of laser cut panels that spread the light into the room, was developed at the Queensland University of Technology in Brisbane.\textsuperscript{[3]} In 2003, Veronica Garcia Hansen, Ken Yeang, and Ian Edmonds were awarded the Far East Economic Review Innovation Award in bronze for this development.\textsuperscript{[4]} \textsuperscript{[5]}

Light transmission efficiency is greatest if the tube is short and straight. In longer, angled, or flexible tubes, part of the light intensity is lost. To minimize losses, a high reflectivity of the tube lining is crucial; manufacturers claim reflectivities of their materials, in the visible range, of up to 98 to almost 99.5 percent.\textsuperscript{[6]} \textsuperscript{[7]}

At the end point (the point of use), a diffuser spreads the light into the room.

To further optimize the use of solar light, a heliostat can be installed which tracks the movement of the sun, thereby directing sunlight into the light tube at all times of the day as far as the surroundings´ limitations allow, possibly with additional mirrors or other reflective elements that influence the light path. The heliostat can be set to capture moonlight at night.

**Optical fiber**

Optical fibers are well known as fibrescopes for imaging applications and as light guides for a wide range of non-imaging applications. In the latter context, they can also be used for daylighting: a solar lighting system based on plastic optical fibers was in development at Oak Ridge National Laboratory in 2004;\textsuperscript{[8]} \textsuperscript{[9]} the system was installed at the American Museum of Science and Energy, Tennessee, USA, in 2005;\textsuperscript{[10]} and brought to market the same year by the company Sunlight Direct.\textsuperscript{[11]} \textsuperscript{[12]}

A similar system, but using optical fibers of glass, had earlier been under study in Japan.\textsuperscript{[13]}

In view of the usually small diameter of the fibers, an efficient daylighting set-up requires a parabolic collector to track the sun and concentrate its light.

Optical fibers intended for *light transport* need to propagate as much light as possible within the core; in contrast, optical fibers intended for *light distribution* are designed to let part of the light leak through their cladding.\textsuperscript{[14]}
Transparent hollow light guides

A prism light guide was developed in 1981 and has been used in solar lighting for both transport and distribution of light. A large solar pipe based on the same principle has been set up in a narrow courtyard of a 14-floor building of a Washington D.C. law firm in 2001, and a similar proposal has been made for London. A further system has been installed in Berlin.

The 3M company developed a system based on optical lighting film and developed the 3M light pipe, which is a light guide designed to distribute light uniformly over its length, with a thin film incorporating microscopic prisms, which has been marketed in connection with artificial light sources, e.g. sulfur lamps.

In contrast to an optical fiber which has a solid core, a prism light guide leads the light through air and is therefore referred to as hollow light guide.

The project ARTELIO, partially funded by the European Commission, was an investigation in years 1998 to 2000 into a system for adaptive mixing of solar and artificial light, and which includes a sulfur lamp, a heliostat, and hollow light guides for light transport and distribution.

Fluorescence based system

In a system developed by Fluorosolar and the University of Technology, Sydney, two fluorescent polymer layers in a flat panel capture short wave sunlight, particularly ultraviolet light, generating red and green light, respectively, which is guided into the interior of a building. There, the red and green light is mixed with artificial blue light to yield white light, without infrared or ultraviolet. This system, which collects light without requiring mobile parts such as a heliostat or a parabolic collector, is intended to transfer light to any place within a building. By capturing ultraviolet the system can be especially effective on bright but overcast days; this since ultraviolet is diminished less by cloud cover than are the visible components of sunlight.

Properties and applications

Solar and hybrid lighting systems

Solar light pipes, compared to conventional skylights and other windows, offer better heat insulation properties and more flexibility for use in inner rooms, but less visual contact with the external environment.

In the context of seasonal affective disorder, it may be worth consideration that an additional installation of light tubes increases the amount of natural daily light exposure. It could thus possibly contribute to residents’ or employees’ well-being while avoiding over-illumination effects.

Compared to artificial lights, light tubes have the advantage of providing natural light and of saving energy. The transmitted light varies over the day; should this not be desired, light tubes can be combined with artificial light in a hybrid set-up.

Some artificial light sources are marketed which have a spectrum similar to that of sunlight, at least in the human visible spectrum range, as well as low flicker. Their spectrum can be made to vary dynamically such as to mimick the changes of natural light over the day. Manufacturers and vendors of such light sources claim that their products can provide the same or similar health effects as natural light. When considered as alternatives to solar light pipes, such products may have lower installation costs but do consume energy during use; therefore they may well be more wasteful in terms of overall energy resources and costs.

On a more practical note, light tubes do not require electric installations or insulation, and are thus especially useful for indoor wet areas such as bathrooms and pools. From a more artistic point of view, recent developments, especially those pertaining to transparent light tubes, open new and interesting possibilities for architectural design.
Light tube

Security Applications

Due to the relatively small size and high light output of sun pipes, they have an ideal application to security oriented situations, such as prisons, police cells and other locations where restricted access is required. Being of a narrow diameter, and not largely affected by internal security grills, this provides daylight to areas without providing electrical connections or escape access, and without allowing objects to be passed into a secure area.

Light tubes in electronic devices

Molded plastic light tubes are commonly used in the electronics industry to conduct illumination from LEDs on a circuit board to indicator symbols or buttons. These light tubes typically take on a highly complex shape that uses either gentle curving bends as in an optic fiber or have sharp prismatic folds which reflect off the angled corners. Multiple light tubes are often molded from a single piece of plastic, permitting easy device assembly since the long thin light tubes are all part of a single rigid component that snaps into place.

Light tube indicators make electronics cheaper to manufacture since the old way would be to mount a tiny lamp into a small socket directly behind the spot to be illuminated. This often requires extensive hand-labor for installation and wiring. Light tubes permit all lights to be mounted on a single flat circuit board, but the illumination can be directed up and away from the board by several inches, wherever it is required.

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[4] Lighting up your workplace — Queensland student pipes light to your office cubicle (http://www.scienceinpublic.com/freshinnovators/2005/Veronica/veronicagarciahansen.htm), May 9, 2005
[14] Use Of Diffusive Optical Fibers For Plant Lighting (http://ncr101.montana.edu/Light1994Conf/6_8_Kozai/Kozai Fiber text.htm)
[17] research frame (http://www.physics.ubc.ca/ssp/ssp_research.html#lightpipe)
[21] (German) http://www.bomin-solar.de/Acrobat/Press/DETAIL_4-04_SLP-Washington.pdf
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[29] Fluorosolar (http://www.fluorosolar.com)


[31] Video (http://www.abc.net.au/catalyst/stories/s1610451.htm) on fluorescence based system


[34] Sunlight Direct- Lighting Design Information (http://www.sunlight-direct.com/lighting.html)


[37] (German) http://www.e-wenzl.at/lichtliteratur/vollspektrum_001.html

[38] (German) http://www.j-lorber.de/shn/licht/vollspektrum-bedeutg.htm

[39] (German) http://www.villiton.ch/vollspektrumlicht.php

**External links**

**Overview**

- Light Tubes on "Potsdamer Platz" are made by Heliobus AG Switzerland (http://www.heliobus.com)
- "Smart Lighting for a Smart House" (an overview over daylighting, listing also light pipes) - [1], HTML (http://www.google.com/search?q=cache:hfq4UoFXUMJ:www.smarthouse.duke.edu/downloads/smart_lighting_noor.ppt+sunlight+courtyard+heliostat&hl=de&gl=de&ct=clnk&cd=1)
- A series of technical reference (http://www.sunpipe.co.uk/technical/index.php) information pages from the UK, referring to installation and mounting information
- "A Design Tool for Predicting the Performances of Light Pipes" Jenkins et al. link title (http://www.sciencedirect.com/science?_ob=MImg&agekey=B6V2V-4DTVGNF-3-1&cdi=5712&user=273788&_orig=search&_coverDate=05/01/2005&_sk=999629994&view=c&alid=44861134&_rdoc=34&wchp=dGLbVz-zSkzk&md5=580292344c5f66ba4c271817f2ca2&ie=sdarticle.pdf)
- UK based Monodraught SunPipe (http://www.sunpipe.co.uk/sunpipe/index.php) and www.sunpipe.info with extensive technical and reference information
• Monodraught (http://www.monodraught.co.uk) SunPipe - the UK’s largest and most successful vendor of Light Tube products and solutions.
• Case study installing light tubes in an older residential bungalow (http://www.humphrey-house.com/search/label/suntunnel)

Other approaches to sunlight capture and transmission

• the Japanese approach of "depthscraper" (http://blog.modernmechanix.com/2006/06/01/depthscrapers-defy-earthquakes/#more-715) : a rotating mirror planned to throw sunlight deep down into a courtyard.
• Heliostats in New York City, USA (http://www.tribecatrib.com/newsjune05/mirrors.htm)
• Description, among other topics, of the 3M Solar Optical Products Daylighting Panel (http://ncr101.montana.edu/Light1994Conf/6_6_Kneipp/Kneipp text.htm)
  • US patent 6840645 (http://www.freepatentsonline.com/6502950.html)

• LED tube light (http://www.effort-lighting.com/)
Clerestory

Clerestory (pronounced /ˈklɛərəstiːrə/; lit. clear storey, also clearstory, clearstorey, or overstorey) is an architectural term that historically denoted an upper level of a Roman basilica or of the nave of a Romanesque or Gothic church, the walls of which rise above the rooflines of the lower aisles and are pierced with windows. In modern usage, clerestory refers to any high windows above eye level. In either case, the purpose is to bring outside light, fresh air, or both into the inner space.

History

Ancient world

The technology of the clerestory appears to originate in the temples of Egypt. The term "clerestory" is applicable to Egyptian temples, where the lighting of the hall of columns was obtained over the stone roofs of the adjoining aisles, through slits pierced in vertical slabs of stone. Clerestory appeared in Egypt at least as early as the Amarna period.[1]

In the Minoan palaces of Crete such as Knossos, by contrast, lightwells were employed in addition to clerestories.[2]

The clerestory was used in the Hellenistic architecture of the Greeks. The Romans applied clerestories to basilicas of justice and to the
Early Christian and Byzantine basilicas

Early Christian churches and some Byzantine churches, particularly in Italy, are based closely on the Roman Basilica, and maintained the form of a central nave flanked by lower aisles on each side. The nave and aisles are separated by columns or piers, above which rises a wall pierced by clerestory windows.

Romanesque period

During the Romanesque period, many churches of the basilica form were constructed all over Europe. Many of these churches have wooden roofs with clerestories below them. Some Romanesque churches have barrel vaulted ceilings with no clerestory. The development of the groin vault and ribbed vault made possible the insertion of clerestory windows.

Initially the nave of a large aisled and clerestoried church was of two levels, arcade and clerestory. During the Romanesque period a third level was inserted between them, a gallery called the "triforium". The triforium generally opens into space beneath the sloping roof of the aisle. This became a standard feature of later Romanesque and Gothic large abbey and cathedral churches. Sometimes another gallery set into the wall space above the triforium and below the clerestory. This feature is found in some late Romanesque and early Gothic buildings in France.

Gothic period

In smaller churches, clerestory windows may be quatrefoils or spherical triangles. In some Italian churches they are ocular. In most large churches they are an important feature, both for beauty and utility. The ribbed vaulting and flying buttresses of Gothic architecture concentrated the weight and thrust of the roof, freeing wall-space for larger clerestory fenestration. In Gothic churches, the clerestory is generally divided into bays by the vaulting shafts that continue the same tall columns that form the arcade separating the aisles from the nave.
The clerestory of Amiens Cathedral is 12 metres tall, accounting for nearly a third of the height of the interior.

The tendency from the early Romanesque period to the late Gothic period was for the clerestory level to become progressively taller and the size of the windows to get proportionally larger in relation to wall surface.

**Modern usage**

By extension, "clerestory lights" are any rows of windows above eye level that allow light into a space. In modern architecture, clerestories provide light without distractions of a view or compromising privacy. Factory buildings are often built with clerestory windows; modern housing designs sometimes include them as well. Another example is the new Crosby Theatre of the Santa Fe Opera where the front and rear portions of the roof are joined by a clerestory window. Paolo Soleri uses clerestories in his work, calling them light scoops.[3]

**Other uses**

The word "clerestory" is also used to denote a style of railway rolling stock (predominantly passenger), for example the Great Western Railway Clerestory carriage of the Victorian era had the windows in the roof 'cupola' which provided access to, and ventilation for, the vehicle's gas lighting.

**References**

LiTraCon

LiTraCon ("light transmitting concrete") is a translucent concrete building material. Made of fine concrete embedded with 4% by weight of optical glass fibers,[1] [2] it was developed in 2001 by Hungarian architect Áron Losonczi working with scientists at the Technical University of Budapest.[3]

LiTraCon is manufactured by the inventor’s company, LiTraCon Bt, which was founded in spring 2004. The head office and workshop is located 160 km from the Hungarian capital city of Budapest near the town of Csongrád. As of 2006 all LiTraCon products have been produced by LiTraCon Bt. The concrete comes in precast blocks of different sizes.

The most notable installation of it to date is Europe Gate - a 4 m high sculpture made of LiTraCon blocks, erected in 2004 in observance of the entry of Hungary into the European Union. The product won the German "Red Dot 2005 Design Award" for 'highest design qualities'.[4]

Though expensive, Litracon appeals to architects because it is stronger than glass and translucent unlike concrete. It has been considered as possible sheathing for New York’s Freedom Tower.[5]

References


External links

- Official website (http://www.litracon.hu/)
Sunroom

A sunroom is a structure, usually constructed onto the side of a house, to allow enjoyment of the surrounding landscape while being sheltered from adverse weather conditions such as rain and wind. The concept is popular in the United States, Europe, Canada, Northern Ireland, Australia and New Zealand.

In Great Britain, it is normally described as a conservatory, although the room may not contain plants. However a British sunroom has a solid opaque roof whereas a conservatory has a transparent or semi-transparent roof.

Design

The structure is often referred to as a patio room, solarium, conservatory, patio enclosure or Florida Room. It can be constructed of brick, breeze block, wood, glass or PVC. The brick or wood base makes up the main support for the PVC, referred to as the "knee wall", which is attached to the top of it. The glass panels are large and often clear instead of frosted. The roof may be of glass panels but is more usually of a plastic material which lets in sunlight. Some sunrooms are designed for scenic view, while others are designed to collect sunlight for warmth and light. These, usually called solariums, are found in Northern (low sun angle) or cold (high altitude) locations. Solariums have walls made up of glass (or plastic), often curved joining windows, and glass roofs. Sunrooms tend to have conventional roofs.

Newer rooms are typically constructed of aluminum framing with tempered glass as the primary structure. The room system is normally constructed of aluminum insulated panels or glass for the "high end" options. Skylights may be included in the insulated panels. The outside of the roof is normally constructed with a shingled roofing material.

Whereas the majority of florida rooms or sunrooms of the past appeared to be disassociated with the home, newer public taste places a great deal of emphasis in blending the sunroom into the architecture of the home.

With the latest technologies of glass and heat resistant technology, sunrooms are now able to be used as efficiently in the southern states such as Florida, Texas and Arizona as is possible in the colder, northern states.
History

Farmhouses and urban row homes featured a covered porch as a place for the user to sit and relax. With the suburbanization of America, families increasingly used their back patios and gardens for this purpose. However, weather conditions often made patios unusable at times, providing an incentive for families to cover and screen in their patios for privacy and for shelter.

As this trend evolved, so did improvements in glass manufacture, making it possible to attach storm windows together to enclose a patio space.

During the 1960s, professional re-modelling companies developed affordable systems to enclose a patio or deck, offering design, installation, and full service warranties. Patio rooms featured lightweight, engineered roof panels, single pane glass, and aluminium construction. These versatile patio rooms extended the outdoor season, provided protection from rain, wind and insects, and gave homeowners extra space. The interior of a sun room warms quickly in sunlight, even on cold days, and may provide a means of heating the part of the main house into which the sun room or conservatory opens. Furniture and plants located in a sun room/conservatory should be resistant to temperature change.

As customers became more energy conscious and building technology aware, patio and sunrooms became available with insulated glass, vinyl and vinyl-wood composite framework, and more elaborate designs. Many American companies also began to offer greenhouses and conservatories, which were popular in Europe.

Niche markets

European companies discovered a niche market where customers wanted extra privacy. This meant that blinds and curtains were specially developed to be fitted into the sunroom without damaging the stability of the structure. This has proved a profitable industry where blinds can now be controlled from electronic hand-held devices.

Another market is for specialised flooring in sunrooms. In earlier sunrooms, floors were often tiled because of the possibility of roof leaks, and cold air entering resulted in the room becoming chilly. Floors with heated pipe and insulation are now available. Types of flooring are available in a wide variety of materials and forms and customers are no longer restricted to tiles. Older sunrooms which are not structurally sound may be prone to leaks and draughts, so traditional tiled floors are still in demand.

Newer pre-engineered sunroom designs must meet strict criteria to obtain building permits and product approvals through various agencies. Certain features such as thermal breaks and glass that is designed to meet the high demands of a sunroom will greatly aid in the utilization of the sunroom in a manner that will prevent leakage and allow for full year 'round usage.

Solarium

A solarium is similar to a sunroom in that both are glass structures designed for people to enjoy the sun without being directly touched by the rays of the sun. The chief difference is that solariums often have curved glass corners and glass roofs.
Greenhouse

A greenhouse (also called a glasshouse) is a building where plants are grown. These structures range in size from small sheds to very large buildings. A miniature greenhouse is known as a cold frame.

A greenhouse is a structure with different types of covering materials, such as a glass or plastic roof and frequently glass or plastic walls; it heats up because incoming visible solar radiation (for which the glass is transparent) from the sun is absorbed by plants, soil, and other things inside the building. Air warmed by the heat from hot interior surfaces is retained in the building by the roof and wall. In addition, the warmed structures and plants inside the greenhouse re-radiate some of their thermal energy in the infra-red, to which glass is partly opaque, so some of this energy is also trapped inside the glasshouse. However, this latter process is a minor player compared with the former (convective) process. Thus, the primary heating mechanism of a greenhouse is convection. This can be demonstrated by opening a small window near the roof of a greenhouse: the temperature drops considerably. This principle is the basis of the autovent automatic cooling system. Thus, the glass used for a greenhouse works as a barrier to air flow, and its effect is to trap energy within the greenhouse. The air that is warmed near the ground is prevented from rising indefinitely and flowing away.

Although there is some heat loss due to thermal conduction through the glass and other building materials, there is a net increase in energy (and therefore temperature) inside the greenhouse.

Greenhouses can be divided into glass greenhouses and plastic greenhouses. Plastics mostly used are PEfilm and multiwall sheet in PC or PMMA. Commercial glass greenhouses are often high tech production facilities for vegetables or flowers. The glass greenhouses are filled with equipment like screening installations, heating, cooling, lighting and may be automatically controlled by a computer.
Uses

Greenhouses protect crops from too much heat or cold, shield plants from dust storms and blizzards, and help to keep out pests. Light and temperature control allows greenhouses to turn inarable land into arable land, thereby improving food production in marginal environments.

Because greenhouses allow certain crops to be grown throughout the year, greenhouses are increasingly important in the food supply of high latitude countries. One of the largest greenhouse complexes in the world is in Almeria, Spain, where greenhouses cover almost 50000 acres (200 km²). Sometimes called the sea of plastics [1].

Greenhouses are often used for growing flowers, vegetables, fruits, and tobacco plants. Bumblebees are the pollinators of choice for most greenhouse pollination, although other types of bees have been used, as well as artificial pollination. Hydroponics can be used in greenhouses as well to make the most use of the interior space.

Besides tobacco, many vegetables and flowers are grown in greenhouses in late winter and early spring, and then transplanted outside as the weather warms. Started plants are usually available for gardeners in farmers' markets at transplanting time. Special greenhouse varieties of certain crops such as tomatoes are generally used for commercial production.

The closed environment of a greenhouse has its own unique requirements, compared with outdoor production. Pests and diseases, and extremes of heat and humidity, have to be controlled, and irrigation is necessary to provide water. Significant inputs of heat and light may be required, particularly with winter production of warm-weather vegetables. Because the temperature and humidity of greenhouses must be constantly monitored to ensure optimal conditions, a wireless sensor network can be used to gather data remotely. The data is transmitted to a control location and used to control heating, cooling, and irrigation systems. [2]

History

The idea of growing plants in environmentally controlled areas has existed since Roman times. The Roman emperor Tiberius ate a cucumber-like [3] vegetable daily. The Roman gardeners used artificial methods (similar to the greenhouse system) of growing to have it available for his table every day of the year. Cucumbers were planted in wheeled carts which were put in the sun daily, then taken inside to keep them warm at night. [4] The cucumbers were stored under frames or in cucumber houses glazed with either oiled cloth known as "specularia" or with sheets of selenite (a.k.a. lapis specularis), according to the description by Pliny the Elder. [5]
The first modern greenhouses were built in Italy in the 13th century\[6\] to house the exotic plants that explorers brought back from the tropics. They were originally called giardini botanici (botanical gardens). The concept of greenhouses soon spread to the Netherlands and then England, along with the plants. Some of these early attempts required enormous amounts of work to close up at night or to winterize. There were serious problems with providing adequate and balanced heat in these early greenhouses. Today the Netherlands has many of the largest greenhouses in the world, some of them so vast that they are able to produce millions of vegetables every year.

The French botanist Charles Lucien Bonaparte is often credited with building the first practical modern greenhouse in Leiden, Holland to grow medicinal tropical plants.

Originally on the estates of the rich, with the growth of the science of botany, greenhouses spread to the universities. The French called their first greenhouses orangeries, since they were used to protect orange trees from freezing. As pineapples became popular pineries, or pineapple pits, were built. Experimentation with the design of greenhouses continued during the Seventeenth Century in Europe as technology produced better glass and construction techniques improved. The greenhouse at the Palace of Versailles was an example of their size and elaborateness; it was more than 500 feet (150 m) long, 42 feet (13 m) wide, and 45 feet (14 m) high.

In the nineteenth Century the largest greenhouses were built. The conservatory at Kew Gardens in England is a prime example of the Victorian greenhouse. Although intended for both horticultural and non-horticultural exhibition these included London's Crystal Palace, the New York Crystal Palace and Munich's Glaspalast. Joseph Paxton, who had experimented with glass and iron in the creation of large greenhouses as the head gardener at Chatsworth, in Derbyshire, working for the Duke of Devonshire, designed and built the first, London's Crystal Palace. A major architectural achievement in monumental greenhouse building were the Royal Greenhouses of Laeken (1874–1895) for King Leopold II of Belgium.

In Japan, the first greenhouse was built in 1880 by Samuel Cocking, a British merchant who exported herbs.

In the Twentieth Century the geodesic dome was added to the many types of greenhouses. A notable example is the Eden Project, in Cornwall.

Greenhouse structures adapted in the 1960s when wider sheets of polyethylene film became widely available. Hoop houses were made by several companies and were also frequently made by the growers themselves. Constructed of aluminium extrusions, special galvanized steel tubing, or even just lengths of steel or PVC water pipe, construction
costs were greatly reduced. This meant many more greenhouses on smaller farms and garden centers. Polyethylene film durability increased greatly when more effective inhibitors were developed and added in the 1970s. These UV inhibitors extended the usable life of the film from one or two years up to 3 and eventually 4 or more years.

Gutter-connected greenhouses became more prevalent in the 1980s and 1990s. These greenhouses have two or more bays connected by a common wall, or row of support posts. Heating inputs were reduced as the ratio of floor area to roof area was increased substantially. Gutter connected greenhouses are now commonly used both in production and in situations where plants are grown and sold to the public as well. Gutter connected greenhouses are commonly covered with a double layer of polyethylene film with air blown between to provide increased heating efficiencies, or structured polycarbonate materials.

**Netherlands**

The Netherlands has some of the largest greenhouses in the world. Such is the scale of food production in the country that in 2000, greenhouses occupied 10,526 hectares, or 0.25% of the total land area of the Netherlands.\(^7\)

Greenhouses began to be built in the Westland area of the Netherlands in the mid-nineteenth century. The addition of sand to bogs and clay soil created fertile soil for agriculture, and around 1850, grapes were grown in the first greenhouses, simple glass constructions with one of the sides consisting of solid wall. By the early 20th century, greenhouses began to be constructed of nothing but glass, and they began to be heated. This also allowed for the production of fruits and vegetables that did not ordinarily grow in the area. Today, the Westland and the area around Aalsmeer have the highest concentration of greenhouse agriculture in the world. The Westland produces mostly vegetables, besides plants and flowers; Aalsmeer is noted mainly for the production of flowers and potted plants. Since the twentieth century, the area around Venlo (in Limburg) and parts of Drenthe have also become important regions for greenhouse agriculture.

Since 2000, technical innovations include the "closed greenhouse", a completely closed system allowing the grower complete control over the growing process while using less energy. Floating greenhouses are used in watery areas of the country.

The Netherlands has around 9,000 greenhouse enterprises that operate over 10,000 hectares of greenhouses and employ some 150,000 workers, efficiently producing €4.5 billion worth of vegetables, fruit, plants, and flowers, some 80% of which is exported.
Greenhouse

Gallery

- Victorian conservatory, Kew Gardens
- A modern glasshouse in RHS Wisley
- A greenhouse in Saint Paul, Minnesota.
- Greenhouses lit at night near Amsterdam (seen from an airplane)
- Charles Darwin's lean-to greenhouse at Down House on the outskirts of London where the naturalist conducted many experiments
- Large commercial greenhouse with open roof system in Illinois, United States.

References

Notes

[6] Italian Government Tourist Board: Botanical Gardens in Italy (http://www.italiantourism.com/botanic.html) "the first structures of this kind were already founded in the 13th century at the Vatican in Rome and in the 14th century at Salerno, although both are no longer in existence."

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External links

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• North Carolina State University Greenhouse Food Production website (http://www.ces.ncsu.edu/depts/hort/greenhouse_veg)
• Organic Greenhouse Tomato Production (http://attra.ncat.org/attra-pub/ghtomato.html)
• Planning and Building a Greenhouse (http://www.wvu.edu/~agexten/hortcult/greenhou/building.htm)

Green roof

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

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.[2]

• Reduce cooling (by evaporative cooling) loads on a building by fifty to ninety percent[3]

• 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[4] — see water-wise gardening

• Natural Habitat Creation[5] — see urban wilderness

• Filter pollutants and carbon dioxide out of the air which helps lower disease rates such as asthma[6] — see living wall

• 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[7]

• If installed correctly many living roofs can contribute to LEED points

• Increase 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 exist 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.”[8]
Types

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.[9] “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.[9] 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

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".[10] 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.[11] 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.[12] In areas with combined sewer-stormwater systems, heavy storms can...
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.[13] Elevation 314[14], 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[15] 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.[16]

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.[17]

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.[18] 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.[10]

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[19]) or with plant-based ponds (as being done by WaterWorks UK Grow System[20] and Waterzuiveren.be[21]. Plants used include calamus, Menyanthes trifoliata, Mentha aquatica, etc.[22]

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",[23] 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.[24] 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.[25] 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.[26] (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.[27] Designed combining the principles of green and brown roofs, it is already home to a range of rare invertebrates.

**Examples by country**

**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 30000 square metres ( 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[28] 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) [29], 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 m² 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,
Green roof

Geisenheim and Neubrandenburg.

**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.[30]

**Canada**

The city of Toronto approved a by-law in May 2009,[31] 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.[32] 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.[33]

**France**

In France, a huge green roof of roughly 8000 square metres (86000 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 Greek Ministry of Finance has now installed a green roof on the Treasury in Constitution Square in Athens.[34] 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.[35] 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.[36] 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.[37] 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

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 42000 square metres ( 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 (99000 m²) Millennium Park is considered one of the largest intensive green roofs.[38] 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.[39] Another example of a green roof in the United States is the Ballard Library [40] 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), Eriophyllum 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 (10000 m²) 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,[41] the building consumes 30-35% less energy than required by code.
An early green roofed building (completed in 1971) is the 358000 sq ft (33300 m²) 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.

The first green roof in New York City was installed in midtown Manhattan atop the United States Postal Service's Morgan Processing and Distribution Center. Construction on the 109000 sq ft (10100 m²) project began in September 2008, and was finished and dedicated in July 2009. Covered in native vegetation and having an expected lifetime of fifty years, this green roof will not only save the USPS approximately $30,000 a year in heating and cooling costs, but will also significantly reduce the amount of storm water containments entering the municipal water system.[42] [43]

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 [44] 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 [45]

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.[46]

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[47]. In Europe a well-designed and professionally installed fully integrated green roof can cost anywhere between 100 to 200 euros per square meter, depending on the kind of roof, the building structure, and which plants are used.

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/(m²*year).[48] 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.[49] [50] German studies have approximated the nutrient requirement of vegetated roofs to 5gN/m². 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.[51]
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 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.

References

[1] California (magazine of the University of California Alumni Association), Sept/Oct 2008, cover and pp. 52-53
[20] "WWUK rooftop water purification with plants" (http://www.wwuk.co.uk/grow.htm). .
[23] [cite web url=http://livingroofs.org/url=http://www.brownroofs.co.uk/brown-roof-biodiversity.php title=Brown Roofs and Biodiversity ] }
[24] [cite web
These ideas were brought to the UK by people who have now set up one of the UK's url=http://www.greenroofconsultancy.com/leading green roof advisory bodies. url=http://www.safeguardeurope.
Further reading

- Miller-Klein, Jan. *Gardening for Butterflies, Bees and other beneficial insects*. ISBN 978-0-9555288-0-4 has a large section on green and brown roofs and brownfields, including how to make your own, with contributions from several UK practitioners.


Cool roof

In the world of industrial and commercial buildings, a **cool roof** is 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). 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.\(^\text{[1]}\) 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.\(^\text{[2]}\) 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.\(^\text{[3]}\)

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.\(^\text{[3]}\) 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.\(^\text{[4]}\) 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 (122 °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.[5]
- 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.[6]

**U.S. Department of Energy (DOE) Cool Roof Calculator**[7]

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**[8]

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 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 (m²·°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 difference 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. http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/roofs/RCMA-CommentLetter-081606.pdf

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

An existing (or new) roof can be made reflective by applying a solar reflective coating to its surface. The reflectivity and emissivity ratings for over 1000 reflective roof products can be found in the CRRC (Cool Roofs Rating Council) website [14].

Planet Supra [15] claims to offer "nanotechnology thermal barrier paints", which conflicts with their specifying a thermal emittance of 93.6%; their treatment is solar-reflective, not heat reflective. As for nanotechnology, any paint with a particulate pigment can make the same claim.

Their claim to reflect "almost 95% of solar radiation" is difficult to reconcile with the chart from their webpage:

- Near-infrared rays area: 94.6%
- All wavelength band area: 92.3%
- Visible ray area: 90.4%
- Thermal emittance: 93.6%

The other numbers are similar to those from the CRRC (Cool Roofs Rating Council) website [14], revealing it to be an unexceptional Cool-Roof paint.

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,[16] 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.[17]

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[18] 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.
Certification requirements for different cool roof programs

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<th>Emittance</th>
<th>Solar Reflectance Index</th>
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<tr>
<td>Low, initial</td>
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<td></td>
<td></td>
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<tr>
<td>Low, aged</td>
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**ENERGY STAR**

**Green Globes**

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**USGBC LEED**

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</tr>
<tr>
<td>Steep Slope</td>
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</table>

**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,[22] 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:[23]

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Owner</th>
<th>Location</th>
<th>LEED Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Donald Bren School of Environmental Science &amp; Management</td>
<td>University of California, Santa Barbara</td>
<td>Santa Barbara, California</td>
<td>Platinum</td>
</tr>
<tr>
<td>Edifice Multifunction</td>
<td>Travaux Public et Services Gouvernementaux Canada</td>
<td>Montreal, Quebec</td>
<td>Gold</td>
</tr>
<tr>
<td>Seattle Central Library</td>
<td>City of Seattle</td>
<td>Seattle, Wash.</td>
<td>Silver</td>
</tr>
<tr>
<td>National Geography Society Headquarters Complex</td>
<td>National Geographic Society</td>
<td>Washington, D.C.</td>
<td>Silver</td>
</tr>
<tr>
<td>Utah Olympic Oval</td>
<td>Salt Lake City Olympic Winter Games 2002 Organizing Committee</td>
<td>Salt Lake City, Utah</td>
<td>Certified</td>
</tr>
<tr>
<td>Premier Automotive Group North American Headquarters</td>
<td>Ford Motor Company</td>
<td>Irvine, California</td>
<td>Certified</td>
</tr>
</tbody>
</table>

**COOL ROOFS EUROPE**

http://www.coolroofs-eu.eu/.

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[24] 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.[25] 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.[26]

**References**


[23] LEED Buildings Table (http://vinylroofs.org/cools-roofs.green-programs-leed.html)


**External links**

- Comprehensive Cool Roof Guide from the Vinyl Roofing Division of the Chemical Fabrics and Film Association (http://vinylroofs.org/cool-roofs/cool-roofs-explained.html)
- Cool Roofs Cool Roof Rating Council (http://coolroofs.org/codes_and_programs.html)
- Cool Colors Project (http://coolcolors.lbl.gov)
- Cool Roofs Europe (http://www.coolroofs.eu.eu)
- Green Log Awards (http://www.precisioncraft.com/greenlogawards.html)
- SimRoof roof thermal simulator (http://people.csail.mit.edu/jaffert/SimRoof)
Solar water heating

Solar water heating (SWH) systems comprise several innovations and many mature renewable energy (or SHW Solar Hot Water) technologies which have been accepted in most countries for many years. SWH has been widely used in Greece, Turkey, Israel, Australia, Japan, Austria and China.

In a "close-coupled" SWH system the storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermosiphon flow. In a "pump-circulated" system the storage tank is ground or floor mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

SWH systems are designed to deliver the optimum amount of hot water for most of the year. However, in winter there sometimes may not be sufficient solar heat gain to deliver sufficient hot water. In this case a gas or electric booster is normally used to heat the water.

Overview

Hot water heated by the sun is used in many ways. While perhaps best known in a residential setting to provide hot domestic water, solar hot water also has industrial applications, e.g. to generate electricity[1]. Designs suitable for hot climates can be much simpler and cheaper, and can be considered an appropriate technology for these places. The global solar thermal market is dominated by China, Europe, Japan and India.

In order to heat water using solar energy, a collector, often fastened to a roof or a wall facing the sun, heats working fluid that is either pumped (active system) or driven by natural convection (passive system) through it. The collector could be made of a simple glass topped insulated box with a flat solar absorber made of sheet metal attached to copper pipes and painted black, or a set of metal tubes surrounded by an evacuated (near vacuum) glass cylinder. In industrial cases a parabolic mirror can concentrate sunlight on the tube. Heat is stored in a hot water storage tank. The volume of this tank needs to be larger with solar heating systems in order to allow for bad weather, and because the optimum final temperature for the solar collector is lower than a typical immersion or combustion heater. The heat transfer fluid (HTF) for the absorber may be the hot water from the tank, but more commonly (at least in active systems) is a separate loop of fluid containing anti-freeze and a corrosion inhibitor which delivers heat to the tank through a heat exchanger (commonly a coil of copper tubing within the tank). Another lower-maintenance concept is the 'drain-back': no anti-freeze is required; instead all the piping is sloped to cause water to drain back to the tank. The tank is not pressurized and is open to atmospheric pressure. As soon as the pump shuts off, flow reverses and the pipes are empty before freezing could occur.

Residential solar thermal installations fall into two groups: passive (sometimes called "compact") and active (sometimes called "pumped") systems. Both typically include an auxiliary energy source (electric heating element or connection to a gas or fuel oil central heating system) that is activated when the water in the tank falls below a minimum temperature setting such as 55°C. Hence, hot water is always available. The combination of solar water
heating and using the back-up heat from a wood stove chimney to heat water\textsuperscript{[2]} can enable a hot water system to work all year round in cooler climates, without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity.

When a solar water heating and hot-water central heating system are used in conjunction, solar heat will either be concentrated in a pre-heating tank that feeds into the tank heated by the central heating, or the solar heat exchanger will replace the lower heating element and the upper element will remain in place to provide for any heating that solar cannot provide. However, the primary need for central heating is at night and in winter when solar gain is lower. Therefore, solar water heating for washing and bathing is often a better application than central heating because supply and demand are better matched. In many climates, a solar hot water system can provide up to 85\% of domestic hot water energy. This can include domestic non-electric concentrating solar thermal systems. In many northern European countries, combined hot water and space heating systems (solar combisystems) are used to provide 15 to 25\% of home heating energy.

**History**

There are records of solar collectors in the United States dating back to before 1900\textsuperscript{[3]}, comprising a black-painted tank mounted on a roof. In 1896 Clarence Kemp of Baltimore, USA enclosed a tank in a wooden box, thus creating the first ‘batch water heater’ as they are known today. Although flat-plate collectors for solar water heating were used in Florida and Southern California in the 1920s there was a surge of interest in solar heating in North America after 1960, but specially after the 1973 oil crisis.

**Work in Israel**

Flat plate solar systems were perfected and used on a very large scale in Israel. In the 1950s there was a fuel shortage in the new Israeli state, and the government forbade heating water between 10 p.m. and 6 a.m.. Levi Yissar built the first prototype Israeli solar water heater and in 1953 he launched the NerYah Company, Israel's first commercial manufacturer of solar water heating\textsuperscript{[4]} . Despite the abundance of sunlight in Israel, solar water heaters were used by only 20\% of the population by 1967. Following the energy crisis in the 1970s, in 1980 the Israeli Knesset passed a law requiring the installation of solar water heaters in all new homes (except high towers with insufficient roof area)\textsuperscript{[5]} . As a result, Israel is now the world leader in the use of solar energy per capita with 85\% of the households today using solar thermal systems (3\% of the primary national energy consumption)\textsuperscript{[6]} , estimated to save the country two million barrels of oil a year, the highest per capita use of solar energy in the world.\textsuperscript{[7]}.
Other countries

The world saw a rapid growth of the use of solar warm water after 1960, with systems being marketed also in Japan and Australia[3]. Technical innovation has improved performance, life expectancy and ease of use of these systems. Installation of solar water heating has become the norm in countries with an abundance of solar radiation, like the Mediterranean[8], and Japan and Austria, where there Colombia developed a local solar water heating industry thanks to the designs of Las Gaviotas, directed by Paolo Lugari. Driven by a desire to reduce costs in social housing, the team of Gaviotas studied the best systems from Israel, and made adaptations as to meet the specifications set by the Banco Central Hipotecario (BCH) which prescribed that the system must be operational in cities like Bogotá where there are more than 200 days overcast. The ultimate designs were so successful that Las Gaviotas offered in 1984 a 25 year warranty on any of its installations. Over 40,000 were installed, and still function a quarter of a century later.

In 2005, Spain became the first country in the world to require the installation of photovoltaic electricity generation in new buildings, and the second (after Israel) to require the installation of solar heating systems in 2006.[9] Australia has a variety of incentives (national and state) and regulations (state) for solar thermal introduced starting with MRET in 1997 [10] [11] [12].

Solar water heating systems have become popular in China, where basic models start at around 1,500 yuan (US$190), much cheaper than in Western countries (around 80% cheaper for a given size of collector). It is said that at least 30 million Chinese households now have one, and that the popularity is due to the efficient evacuated tubes which allow the heaters to function even under gray skies and at temperatures well below freezing [13]. Israel and Cyprus are the per capita leaders in the use of solar water heating systems with over 30%-40% of homes using them.[14]

See Appendix 1 at the bottom of this article for a number of country-specific statistics on the "Use of solar water heating worldwide". Wikipedia also has country-specific articles about solar energy use (thermal as well as photovoltaic) in Australia, Canada, China, Germany, India, Israel, Japan, Portugal, Romania, Spain, the United Kingdom and the United States.
Types of Solar Water Heating (SWH) systems

The type and complexity of a solar water heating system is mostly determined by:

- The changes in ambient temperature during the day-night cycle.
- Changes in ambient temperature and solar radiation between summer and winter.
- The temperature of the water required from the system.

The minimum efficiency of the system is determined by the amount or temperature of hot water required during winter (when the largest amount of hot water is often required). The maximum efficiency of the system is determined by the need to prevent the water in the system from becoming too hot (to boil, in an extreme case). There are two main categories of solar water heating systems. Passive systems rely on convection or heat pipes to circulate water or heating fluid in the system, while active systems use a pump. In addition, there are a number of other system characteristics that distinguish different designs:

- The type of collector used (see below)
- The location of the collector - roof mount, ground mount, wall mount
- The location of the storage tank in relation to the collector
- The method of heat transfer - open-loop or closed-loop (via heat exchanger)
- Photovoltaic thermal hybrid solar collectors can be designed to produce both hot water and electricity.

Passive systems

A special type of passive system is the Integrated Collector Storage (ICS or Batch Heater) where the tank acts as both storage and solar collector. Batch heaters are basically thin rectilinear tanks with glass in front of it generally in or on house wall or roof. They are seldom pressurised and usually depend on gravity flow to deliver their water. They are simple, efficient and less costly than plate and tube collectors but are only suitable in moderate climates with good sunshine.

A step up from the ICS is the Convection Heat Storage unit (CHS or thermosiphon). These are often plate type or evacuated tube collectors with built-in insulated tanks. The unit uses convection (movement of hot water upward) to move the water from collector to tank. Neither pumps nor electricity are used to enforce circulation. It is more efficient than an ICS as the collector heats a small(er) amount of water that constantly rises back to the tank. It can be used in areas with less sunshine than the ICS. An CHS also known as a compact system or monobloc has a tank for the heated water and a solar collector mounted on the same chassis. Typically these systems will function by natural convection or heat pipes to transfer the heat energy from the collector to the tank.
Direct (‘open loop’) passive systems use water from the main household water supply to circulate between the collector and the storage tank. When the water in the collector becomes warm, convection causes it to rise and flow towards the water storage tank. They are often not suitable for cold climates since, at night, the water in the collector can freeze and damage the panels.

Indirect (‘closed loop’) passive systems use a non-toxic antifreeze heat transfer fluid (HTF) in the collector. When this fluid is heated, convection causes it to flow to the tank where a passive heat exchanger transfers the heat of the HTF to the water in the tank. The attraction of passive solar water heating systems lies in their simplicity. There are no mechanical or electrical parts that can break or that require regular supervision or maintenance. Consequently the maintenance of a passive system is simple and cheap. The efficiency of a passive system is often somewhat lower than that of an active system and overheating is largely avoided by the inherent design of a passive system.

Active systems

Active solar hot water systems employ a pump to circulate water or HTF between the collector and the storage tank. Like their passive counterparts, active solar water heating systems come as two types: direct active systems pump water directly to the collector and back to the storage tank (direct collectors can contain conventional freeze-vulnerable metal pipes or low pressure freeze-tolerant silicone rubber pipes), indirect active systems which are usually made of metals pump heat transfer fluid (HTF), the heat of which is transferred to the water in the storage tank. Because the pump should only operate when the fluid in the collector is hotter than the water in the storage tank, a controller is required to turn the pump on and off. The use of an electronically controlled pump has several advantages:

- The storage tank can be situated lower than the collectors. In passive systems the storage tank must be located above the collector so that the
Solar water heating

The thermosiphon effect can transport water or HTF from collector to tank. The use of a pump allows the storage tank to be located lower than the collector since the circulation of water or HTF is enforced by the pump. A pumped system allows the storage tank to be located out of sight.

- Because of the fact that active systems allow freedom in the location of the storage tank, the tank can be located where heat loss from the tank is reduced, e.g. inside the roof of a house. This increases the efficiency of the solar water heating system.

- New active solar water heating systems can make use of an existing warm water storage tanks ("geysers"), thus avoiding duplication of equipment.

- Reducing the risk of overheating. If no water from the solar hot water system is used (e.g. when water users are away), the water in the storage tank is likely to overheat. Several pump controllers avoid overheating by activating the pump during the day at during times of low sunlight, or at night. This pumps hot water or HTF from the storage tank through the collector (which can be cool in low light levels), thus cooling the water in the storage tank.

- Reducing the risk of freezing. For direct active systems in cold weather, where freeze tolerant collectors or drain down approaches are not used, the pump controller can pump hot water from the water storage tank through the collector in order to prevent the water in the collector from freezing, thus avoiding damage to the metal parts of the system.

Active systems can tolerate higher water temperatures than would be the case in an equivalent passive system. Consequently active systems are often more efficient than passive systems but are more complex, more expensive, more difficult to install and rely on either mains or PV sourced electricity to run the pump and controller.

**Active systems with intelligent controllers**

Modern active solar water systems have electronic controllers that permit a wide range of functionality such as full programmability; interaction with a backup electric or gas-driven water heater; measurement of the energy produced; sophisticated safety functions; thermostatic and time-clock control of auxiliary heat, hot water circulation loops, or others; display of error messages or alarms; remote display panels; and remote or local datalogging.

The most popular pump controller is a *differential controller* that senses temperature differences between water leaving the solar collector and the water in the storage tank near the heat exchanger. In a typical indirect configuration, the controller turns the pump on when the water in the collector is about 8-10°C warmer than the water in the tank and it turns the pump off when the temperature difference approaches 0 °C. This ensures the water always gains heat from the collector when the pump operates and prevents the pump from cycling on and off too often. In direct systems this "on differential" can be reduced to around 4C because there is no heat exchanger impediment. By allowing more "pump on" time, this improves performance at low light levels.

Although the pumps of most active systems are driven by mains electricity, some active solar systems obtain energy to power the pump by a photovoltaic (PV) panel. The PV panel converts sunlight into electricity, which in turn drives the direct current (DC) pump. In this way, water flows through the collector only when the sun is shining. The DC-pump and PV panel must be suitably matched to ensure proper performance. The pump starts when there is sufficient solar radiation available to heat the
solar collector and to start the pump. This "pump starting" irradiation varies from 4% to 10% of full sunlight, depending on the pump and its PV power supply. It shuts off later in the day when the available solar energy diminishes. Several DC-pumps are intelligent and employ maximum power point (MPP) tracking to optimise pump rate, for instance during periods of small amounts of electricity from the PV panel during cloudy weather. A PV powered solar controller is sometimes used to prevent the pump from running when there is sunlight to power the pump but the collector is still cooler than the water in storage. The main environmental advantage of a PV-driven pump is that it eliminates the energy / carbon clawback or "parasitics" associated with using a solar thermal systems. Also the solar hot water can still be collected during a power outage. The pump is operated by the sun and is completely independent from mains electricity. Some differential controllers use power from the PV panel when sunlight is available, but revert to mains electricity when light is not available.

The low /variable flow from PV powered pumps for domestic hot water only (no heating) is typically matched with a temperature maximising solar absorber of the serpentine type. This in conjunction with a stratified hot water tank design maximises a small quantity of hot water that reduces the need for the standby heating system to operate. This strategy has been found to maximise efficiency and is the basis for the Swiss compact systems (low /variable flow) developed by Institut für Solartechnik SPF.

**Active systems with drainback**

A drain-back system is an indirect active system where heat transfer fluid circulates through the collector, being driven by a pump. However the collector piping is not pressurised and includes an open drainback reservoir. If the pump is switched off, all the heat transfer fluid drains into the drainback reservoir and none remains in the collector. Consequently the collector cannot be damaged by freezing or overheating.[15] This makes this type of system well-suited to colder climates.

**Active systems with a bubble pump**

An active solar water heating system can be equipped with a bubble pump (also known as geyser pump) instead of an electric pump. A bubble pump circulates the heat transfer fluid (HTF) between collector and storage tank using solar power and without any external energy source and is suitable for flat panel as well as vacuum tube systems. In a bubble pump system, the closed HTF circuit is under reduced pressure, which causes the liquid to boil at low temperature as it is heated by the sun. The steam bubbles form a geyser pump, causing an upward flow. The system is designed such that the bubbles are separated from the hot fluid and condensed at the highest point in the circuit, after which the fluid flows downward towards the heat exchanger caused by the difference in fluid levels.[16] [17] [18] The HTF typically arrives at the heat exchanger at 70 °C and returns to the circulating pump at 50 °C. In frost prone climates the HTF is water with propylene glycol anti-freeze added, usually in the ratio of 60 to 40. Pumping typically starts at about 50°C and increases as the sun rises until equilibrium is reached depending on the efficiency of the heat exchanger, the temperature of the water being heated and the strength of the sun.
Freeze protection

Freeze protection measures prevent damage to the system due to the expansion of freezing transfer fluid. Some systems drain the transfer fluid from the system when the pump stops. In indirect systems (where the transfer fluid is separated from the heated water), this is called drainback and in direct systems (where the heated water is used as the transfer fluid) it is called draindown. Many indirect systems use anti-freeze (e.g. propylene glycol) in the heat transfer fluid. This approach is simpler and more reliable than drainback and is common in climates where freezing temperatures occur often.

In both direct and indirect systems, automatic recirculation may be used for freeze protection. When the water in the collector reaches a temperature near freezing, the controller turns the pump on for a few minutes to warm the collector with water from the tank.

In some direct systems, the collectors are manually drained when freezing is expected. This approach is common in climates where freezing temperatures do not occur often.

Other direct systems use freeze tolerant solar collectors. Here the water channels of the collector are made of flexible polymers such as silicone rubber. Being non-metal, these can freeze solid without cracking. One European solar collector is being produced to this specification under the Solar Keymark and EN 12975 standards.

Overheat protection

Particularly when no hot water has been used for some time, the water from the collector can reach very high temperatures in good sunshine, or if the pump fails to operate, such as during a power cut. Designs which may boil the hot water store usually allow for relief of pressure and excess heat through a heat dump. Almost all sealed and unvented solar circuits have pressure relief valves through which excessive water pressure or steam can be vented. Vented systems have a simpler safety feature already built in via the open vent, a simple and virtually fail-safe approach. Some active systems deliberately cool the water in the storage tank by heat export: circulating hot water through the collector at times when there is little sunlight or at night (when solar energy does not heat the collector). Heat export operates most effectively in systems which do not use basal heat exchangers to add heat to the water store (because cool water sinks below hot water).

11 possible types of overheat control in solar thermal have been identified in the International Energy Agency’s Task Group 39 on Polymeric materials in solar heating and cooling.

A rough comparison of solar hot water systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ICS (Batch)</th>
<th>Thermosyphon</th>
<th>Active direct</th>
<th>Active indirect</th>
<th>Drainback</th>
<th>Bubble Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low profile-unobtrusive</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lightweight collector</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Survives freezing weather</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Low maintenance</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Simple: no ancillary control</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Retrofit potential to existing store</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Space saving: no extra storage tank</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Collectors used in modern domestic solar water heating systems

Solar thermal collectors capture and retain heat from the sun and transfer this heat to a liquid. Two important physical principles govern the technology of solar thermal collectors:

- Any hot object ultimately returns to thermal equilibrium with its environment, due to heat loss from the hot object. The processes that result in this heat loss are conduction, convection and radiation\[^{20}\]. The efficiency of a solar thermal collector is directly related to heat losses from the collector surface (efficiency being defined as the proportion of heat energy that can be retained for a predefined period of time). Within the context of a solar collector, convection and radiation are the most important sources of heat loss. Thermal insulation is used to slow down heat loss from a hot object to its environment. This is actually a direct manifestation of the Second law of thermodynamics but we may term this the ‘equilibrium effect’.

- Heat is lost more rapidly if the temperature difference between a hot object and its environment is larger. Heat loss is predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Conduction, convection as well as radiation occur more rapidly over large thermal gradients\[^{21}\]. We may term this the ‘delta-\(t\) effect’.

The most simple approach to solar heating of water is to simply mount a metal tank filled with water in a sunny place. The heat from the sun would then heat the metal tank and the water inside. Indeed, this was how the very first SWH systems worked more than a century ago\[^{3}\]. However, this setup would be inefficient due to an oversight of the equilibrium effect, above: once when the tank and water has started to be heated, the heat gained would be lost back into the environment, ultimately until the water in the tank would assume the ambient temperature. The challenge is therefore to limit the heat loss from the tank, thus delaying the time until thermal equilibrium is reached.

ICS or batch collectors overcome the above problem by putting the water tank in a box that limits the loss of heat from the tank back into the environment\[^{22}\]\[^{23}\]. This is achieved by encasing the water tank in a glass-topped box that allows heat from the sun to reach the water tank\[^{24}\]. However, the other walls of the box are thermally insulated, reducing convection as well as radiation to the environment\[^{25}\]. In addition, the box can also have a reflective surface on the inside. This reflects heat lost from the tank back towards the tank. In a simple way one could consider an ICS solar water heater as a water tank that has been enclosed in a type of ‘oven’ that retains heat from the sun as well as heat of the water in the tank. Using a box does not eliminate heat loss from the tank to the environment, but it largely reduces this loss. There are many variations on this basic design, with some ICS collectors comprising several smaller water containers and even including evacuated glass tube technology\[^{22}\]. This is because ICS collectors have a characteristic that strongly limits the efficiency of the collector: a small surface-to-volume ratio\[^{26}\]. Since the amount of heat that a tank can absorb from the sun is largely dependent on the surface of the tank directly exposed to the sun, it follows that a small surface would limit the degree to which the water can be heated by the sun. Cylindrical objects such as the tank in an ICS collector inherently have a small surface-to-volume ratio and most modern collectors attempt to increase this ratio for efficient warming of the water in the tank.

Flat plate collectors are an extension of the basic idea to place a collector in an ‘oven’-like box\[^{22}\]. Here, a pipe is connected to the water tank and the water is circulated through this pipe and back into the tank. The water tank is now outside the collector that only contains the pipes. Since the surface-to-volume ratio increases sharply as the diameter of a pipe decreases, most flat-plate collectors have pipes less than 1 cm in diameter. The efficiency of the heating process is therefore sharply increased. The design of a flat-plate collector therefore typically takes the shape of a flat box with a robust glass top.
oriented towards the sun, enclosing a network of piping. In many flat-plate collectors the metal surface of the pipe is increased with flat metal flanges or even a large, flat metal plate to which the pipes are connected. Since the water in a flat-plate collector usually reaches temperatures much higher than that of an ICS, the problem of radiation of heat back to the environment is very important, even though a box-like 'oven' is used. This is because the 'delta-t effect' is becoming important. **Formed collectors** are a degenerate modification of a flat-plate collector in that the piping of the collector is not enclosed in a box-like 'oven'. Consequently these types of collectors are much less efficient for domestic water heating. However, since water colder than the ambient temperature is heated, these collectors are efficient for that specific purpose.

**Evacuated tube collectors** are a way in which heat loss to the environment, inherent in flat plates, has been reduced. Since heat loss due to convection cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes. Since two flat sheets of glass are normally not strong enough to withstand a vacuum, the vacuum is rather created between two concentric tubes. Typically, the water piping in an evacuated tube collector is therefore surrounded by two concentric tubes of glass with a vacuum in between that admits heat from the sun (to heat the pipe) but which limits heat loss back to the environment. The inner tube is coated with a thermal absorbent.

Flat plate collectors are generally more efficient than evacuated tube collectors in full sunshine conditions. However, the energy output of flat plate collectors drops off rapidly in cloudy or cool conditions compared to the output of evacuated tube collectors that decrease less rapidly. In-depth discussion of different solar collector types and their respective applications and performance, also those used in industrial applications, can be found in the Wikipedia article on Solar thermal collectors.

**Heating of swimming pools**

Both pool covering systems floating atop the water and separate solar thermal collectors may be used for pool heating.

Pool covering systems, whether solid sheets or floating disks, act as solar collectors and provide pool heating benefits which, depending on climate, may either supplement the solar thermal collectors discussed below or make them unnecessary. See Swimming Pool Covers for a detailed discussion.

Solar thermal collectors for nonpotable pool water use are often made of plastic. Pool water, mildly corrosive due to chlorine, is circulated through the panels using the existing pool filter or supplemental pump. In mild environments, unglazed plastic collectors are more efficient as a direct system. In cold or windy environments evacuated tubes or flat plates in an indirect configuration do not have pool water pumped through them, they are used in conjunction with a heat exchanger that transfers the heat to pool water. This causes less corrosion. A fairly simple differential temperature controller is used to direct the water to the panels or heat exchanger either by turning a valve or operating the pump. Once the pool water has reached the required temperature, a diverter valve is used to return pool water directly to the pool without heating. Many systems are configured as drainback systems where the water drains into the pool when the water pump is switched off.

The collector panels are usually mounted on a nearby roof, or ground-mounted on a tilted rack. Due to the low temperature difference between the air and the water, the panels are often formed collectors or unglazed flat plate collectors. A simple rule-of-thumb for the required panel area needed is 50% of the pool's surface area. This is for areas where pools are used in the summer season only, not year 'round. Adding solar collectors to a conventional outdoor pool, in a cold climate, can typically extend the pool's comfortable usage by some months or more if an insulating pool cover is also used. An active solar energy system analysis program may be used to optimize the solar pool heating system before it is built.
Economics, energy, environment, and system costs

Energy production

The amount of heat delivered by a solar water heating system depends primarily on the amount of heat delivered by the sun at a particular place (the insolation). In tropical places the insolation can be relatively high, e.g. 7 kW.h/m² per day, whereas the insolation can be much lower in temperate areas where the days are shorter in winter, e.g. 3.2 kW.h/m² per day. Even at the same latitude the average insolation can vary a great deal from location to location due to differences in local weather patterns and the amount of overcast. Useful calculators for estimating insolation at a site can be found with the Joint Research Laboratory of the European Commission[34] and the American National Renewable Energy Laboratory[35][36].

Below is a table that gives a rough indication of the specifications and energy that could be expected from a solar water heating system involving some 2 m² of absorber area of the collector, demonstrating two evacuated tube and three flat plate solar water heating systems. Certification information or figures calculated from those data are used. The bottom two rows give estimates for daily energy production (kW.h/day) for a tropical and a temperate scenario. These estimates are for heating water to 50 degrees C above ambient temperature.

With most solar water heating systems, the energy output scales linearly with the surface area of the absorbers. Therefore, when comparing figures, take into account the absorber area of the collector because collectors with less absorber area yield less heat, even within the 2 m² range. Specifications for many complete solar water heating systems and separate solar collectors can be found at Internet site of the SRCC[37].

<table>
<thead>
<tr>
<th>Daily energy production (kW.h) of five solar thermal systems. The evac tube systems used below both have 20 tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Configuration</td>
</tr>
<tr>
<td>Overall size (m²)</td>
</tr>
<tr>
<td>Absorber size (m²)</td>
</tr>
<tr>
<td>Maximum efficiency</td>
</tr>
<tr>
<td>Energy production (kW.h/day):</td>
</tr>
<tr>
<td>- Insolation 3.2 kW.h/m²/day (temperate)</td>
</tr>
<tr>
<td>- e.g. Zurich, Switzerland</td>
</tr>
<tr>
<td>- Insolation 6.5 kW.h/m²/day (tropical)</td>
</tr>
<tr>
<td>- e.g. Phoenix, USA</td>
</tr>
</tbody>
</table>

The figures are fairly similar between the above collectors, yielding some 4 kW.h/day in a temperate climate and some 8 kW.h/day in a more tropical climate when using a collector with an absorber area of about 2m² in size. In the temperate scenario this is sufficient to heat 200 litres of water by some 17 degrees C. In the tropical scenario the equivalent heating would be by some 33 degrees C. Many thermosiphon systems are quite efficient and have comparable energy output to equivalent active systems. The efficiency of evacuated tube collectors is somewhat lower than for flat plate collectors because the absorbers are narrower than the tubes and the tubes have space between them, resulting in a significantly larger percentage of inactive overall collector area. Some methods of comparison[43] calculate the efficiency of evacuated tube collectors based on the actual absorber area and not on the...
'roof area' of the system as has been done in the above table. The efficiency of the collectors becomes lower if one demands water with a very high temperature.

**System cost**

In sunny, warm locations, where freeze protection is not necessary, an ICS (batch type) solar water heater can be extremely cost effective. In higher latitudes, there are often additional design requirements for cold weather, which add to system complexity. This has the effect of increasing the initial cost (but not the life-cycle cost) of a solar water heating system, to a level much higher than a comparable hot water heater of the conventional type. The biggest single consideration is therefore the large initial financial outlay of solar water heating systems.

Offsetting this expense can take several years and the payback period is longer in temperate environments where the insolation is less intense. When calculating the total cost to own and operate, a proper analysis will consider that solar energy is free, thus greatly reducing the operating costs, whereas other energy sources, such as gas and electricity, can be quite expensive over time. Thus, when the initial costs of a solar system are properly financed and compared with energy costs, then in many cases the total monthly cost of solar heat can be less than other more conventional types of hot water heaters (also in conjunction with an existing hot water heater). At higher latitudes, solar heaters may be less effective due to lower solar energy, possibly requiring larger and/or dual-heating systems. In addition, federal and local incentives can be significant.

The calculation of long term cost and payback period for a household SWH system depends on a number of factors. Some of these are:

- Price of purchasing solar water heater (more complex systems are more expensive)
- Efficiency of SWH system purchased
- Installation cost
- State or government subsidy for installation of a solar water heater
- Price of electricity per kW.h
- Number of kW.h of electricity used per month by a household
- Annual tax rebates or subsidy for using renewable energy
- Annual maintenance cost of SWH system
- Savings in annual maintenance of conventional (electric/gas/oil) water heating system

The following table gives some idea of the cost and payback period to recover the costs. It does not take into account annual maintenance costs, annual tax rebates and installation costs. However the table does give an indication of the total cost and the order of magnitude of the payback period. The table assumes an energy savings of 140 kW.h per month (about 4.6 kW.h/day) due to SWH. Unfortunately payback times can vary greatly due to regional sun, extra cost due to frost protection needs of collectors, household hot water use etc. so more information may be needed to get accurate estimates for individual households and regions. For instance in central and southern Florida the payback period could easily be 7 years or less rather than the 21 years indicated on the chart for the US.

<table>
<thead>
<tr>
<th>Country</th>
<th>Currency</th>
<th>System cost</th>
<th>Subsidy(%)</th>
<th>Effective cost</th>
<th>Electricity cost/kW.h</th>
<th>Electricity savings/month</th>
<th>Payback period(y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>$Aus</td>
<td>5000</td>
<td>40[51]</td>
<td>3000</td>
<td>0.18[52]</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Belgium</td>
<td>Euro</td>
<td>4000</td>
<td>50[54]</td>
<td>2000</td>
<td>0.1[55]</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>Brazil</td>
<td>Real</td>
<td>2500</td>
<td>0</td>
<td>2500</td>
<td>0.25</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>South Africa</td>
<td>ZA Rand</td>
<td>14000</td>
<td>15[57]</td>
<td>11900</td>
<td>0.9</td>
<td></td>
<td>126</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>UK Pound</td>
<td>4000</td>
<td>10[59]</td>
<td>3600</td>
<td>0.11[60]</td>
<td></td>
<td>15.4</td>
</tr>
</tbody>
</table>
Two points are clear from the above table. Firstly, the payback period is shorter in countries with a large amount of insolation and even in parts of the same country with more insolation. This is evident from the payback period less than 10 years in most southern hemisphere countries, listed above. This is partly because of good sunshine, allowing users in those countries to need smaller systems than in temperate areas. Secondly, even in the northern hemisphere countries where payback periods are often longer than 10 years, solar water heating is financially extremely efficient. This is partly because the SWH technology is efficient in capturing irradiation. The payback period for photovoltaic systems is much longer. In many cases the payback period for a SWH system is shortened if it supplies all or nearly all of the warm water requirements used by a household. Many SWH systems supply only a fraction of warm water needs and are augmented by gas or electric heating on a daily basis, thus extending the payback period of such a system.

Solar leasing is now available in Spain for solar water heating systems from Pretasol with a typical system costing around 59 euros and rising to 99 euros per month for a system that would provide sufficient hot water for a typical family home of six persons. The payback period would be five years.

Australia has instituted a system of Renewable Energy Credits, based on national renewable energy targets. This expands an older system based only on rebates.

Operational Carbon / Energy Footprint and Life Cycle Assessment

Unfortunately this topic can seem a bit jargon-laden, so to clarify, here are some synonyms.

Operational energy footprint (OEF) is also called energy parasitics ratio (EPR) or coefficient of performance (CoP).

Operational carbon footprint (OCF) is also called carbon clawback ratio (CCR).

Life cycle assessment is usually referred to as LCA.

The source of electricity in an active SWH system determines the extent to which a system contributes to atmospheric carbon during operation. Active solar thermal systems that use mains electricity to pump the fluid through the panels are called 'low carbon solar'. In most systems the pumping cancels the energy savings by about 8% and the carbon savings of the solar by about 20%. However, some new low power pumps will start operation with 1W and use a maximum of 20W. Assuming a solar collector panel delivering 4 kW.h/day and a pump running intermittently from mains electricity for a total of 6 hours during a 12-hour sunny day, the potentially negative effect of such a pump can be reduced to about 3% of the total power produced.

The carbon footprint of such household systems varies substantially, depending on whether electricity or other fuels such as natural gas are being displaced by the use of solar. Except where a high proportion of electricity is already generated by non-fossil fuel means, natural gas, a common water heating fuel, in many countries, has typically only about 40% of the carbon intensity of mains electricity per unit of energy delivered. Therefore the 3% or 8% energy clawback in a gas home referred to above could therefore be considered 8% to 20% carbon clawback, a very low figure compared to technologies such as heat pumps.

However, zero-carbon active solar thermal systems typically use a 5-30 W PV panel which faces in the same direction as the main solar heating panel and a small, low power diaphragm pump or centrifugal pump to circulate the water. This represents a zero operational carbon and energy footprint: a growing design goal for solar thermal systems.

Work is also taking place in a number of parts of the world on developing alternative non-electrical zero carbon pumping systems. These are generally based on thermal expansion and phase changes of liquids and gases, a variety of which are under development.

Now looking at a wider picture than just the operational environmental impacts, recognised standards can be used to deliver robust and quantitative life cycle assessment (LCA). LCA takes into account the total environmental cost of
Solar water heating

acquisition of raw materials, manufacturing, transport, using, servicing and disposing of the equipment. There are several aspects to such an assessment, including:

- The financial costs and gains incurred during the life of the equipment.
- The energy used during each of the above stages.
- The CO$_2$ emissions due to each of the above stages.

Each of these aspects may present different trends with respect to a specific SWH device.

Financial assessment. The table in the previous section as well as several other studies suggest that the cost of production is gained during the first 5–12 years of use of the equipment, depending on the insolation, with cost efficiency increasing as the insolation does$^{[68]}$.

In terms of energy, some 60% of the materials of a SWH system goes into the tank, with some 30% towards the collector$^{[69]}$ (thermosiphon flat plate in this case) (Tsiligiridis et al.). In Italy$^{[70]}$, some 11 GJ of electricity are used in producing the equipment, with about 35% of the energy going towards the manufacturing the tank, with another 35% towards the collector and the main energy-related impact being emissions. The energy used in manufacturing is recovered within the first two to three years of use of the SWH system through heat captured by the equipment a this southern European study.

Moving further north into colder, less sunny climates, the energy payback time of a solar water heating system in a UK climate is reported as only 2 years.$^{[71]}$. This figure was derived from the studied solar water heating system being: direct, retrofitted to an existing water store, PV pumped, freeze tolerant and of 2.8 sqm aperture. For comparison, a solar electric (PV) installation took around 5 years to reach energy payback, according to the same comparative study.

In terms of CO$_2$ emissions, a large degree of the emissions-saving traits of a SWH system is dependent on the degree to which water heating by gas or electricity is used to supplement solar heating of water. Using the Eco-indicator 99 points system as a yardstick (i.e. the yearly environmental load of an average European inhabitant) in Greece$^{[69]}$, a purely gas-driven system may be cheaper in terms of emissions than a solar system. This calculation assumes that the solar system produces about half of the hot water requirements of a household. The production of a test SWH system in Italy$^{[70]}$ produced about 700 kg of CO$_2$ with all the components of manufacture, use and disposal contributing small parts towards this. Maintenance was identified as an emissions-costly activity when the heat transfer fluid (Glycol-based) was periodically replaced. However, the emissions cost was recovered within about two years of use of the equipment through the emissions saved by solar water heating. In Australia$^{[72]}$, the life cycle emissions of a SWH system are also recovered fairly rapidly, where a SWH system has about 20% of the impact of an electrical water heater and half of the emissions impact of a gas water heater.

Analysing their lower impact retrofit solar water heating system, Allen et al (qv) report a production CO$_2$ impact of 337 kg, which is around half the environmental impact reported in the Ardente et al (qv) study.

Where information based on established standards are available, the environmental transparency afforded by life cycle analysis allows consumers (of all products) to make increasingly well-informed product selection decisions. As for identifying sectors where this information is likely to appear first, environmental technology suppliers in the microgeneration and renewable energy technology arena are increasingly being pressed by consumers to report typical CoP and LCA figures for their products.

In summary, the energy and emissions cost of a SWH system forms a small part of the life cycle cost and can be recovered fairly rapidly during use of the equipment. Their environmental impacts can be reduced further by sustainable materials sourcing, using non-mains circulation, by reusing existing hot water stores and, in cold climates, by eliminating antifreeze replacement visits.
DIY solar water heating systems (DIY SWH)

With an ever-rising do-it-yourself-community and their increasing environmental awareness, people have begun building their own (small-scale) solar water heating systems from scratch or buying easy to install kits. Plans for solar water heating systems are available on the Internet,[73] [74] [75] [76] [77] [78] and people have set about building them for their own domestic requirements. DIY solar water heating systems are usually much cheaper than commercial ones, and installation costs can sometimes be avoided as well. The DIY solar water heating systems are being used both in the developed world, as in the developing world, to generate hot water.[79]

Rather than build DIY solar water heating systems from scratch, many DIY solar enthusiasts are buying simple off-the-shelf solar DIY kits. In particular the new freeze tolerant, zero-carbon PV active systems, are becoming common in parts of Europe. Their simplicity enables them to be plumbed in quickly and safely without the need of a mains electrician. In such installations a low voltage PV powered controller, switches the variable speed pump. In some PV pumped systems, overnight display of temperatures is enabled by internal energy stores such as large supercapacitors.

Considerations for specifying and installing a solar water heating (SWH) system

- Except in rare instances it will be inefficient to install a SWH system with no electrical or gas or other fuel backup. Many SWH systems (e.g. thermosiphon systems) have an integrated electrical heater in the integrated tank. Conversely, many active solar systems incorporate a conventional "geyser". But even in a tropical environment there are rainy and cloudy days when the insolation is low and the temperature of the water in the tank increases very little on account of solar heating. Electrical or other backup heating ensures a reliable supply of hot water and ensures control of legionella risks when heated to the base.

- The temperature stability of a system is dependent on the ratio of the volume of warm water used per day as a fraction of the size of the water reservoir/tank that stores the hot water. If a large proportion of hot water in the reservoir is used each day, a large fraction of the water in the reservoir needs to be heated. This brings about large fluctuations in water temperature every day, with risks of overheating or underheating. Since the amount of heating that needs to take place every day is proportional to hot water usage and not to the size of the reservoir, it pays to have a fairly large reservoir, larger than three times the hot water daily usage. A larger reservoir decreases the daily fluctuations in hot water temperature.

- Usually a large SWH system is more efficient economically than a small system.[69] This is because the price of a system is not linearly proportional to the size of the collector, so a square meter of collector is cheaper in a larger system. If this is the case, it pays to use a system that covers all or nearly all of the domestic hot water needs, and not only a small fraction of the needs. This facilitates more rapid cost recovery.

- Not all installations require new replacement solar hot water stores. Existing stores may be large enough and in suitable condition. Direct systems can be retrofitted to existing stores while indirect systems can be also sometimes be retrofitted using internal and external heat exchangers.

- The installation of a SWH system needs to be complemented with efficient insulation of all the water pipes connecting the collector and the water storage tank, as well as the storage tank (or "geyser") and the most important warm water outlets. The installation of efficient lagging significantly reduces the heat loss from the hot water system. The installation of lagging on at least two meters of pipe on the cold water inlet of the storage tank reduces heat loss, as does the installation of a "geyser blanket" around the storage tank (if inside a roof). In cold climates the installation of lagging and insulation is often performed even in the absence of a SWH system.

- On the zero or low carbon choice arena, the most efficient PV pumps are designed start to operate very slowly in very low light levels, so if connected uncontrolled, they may cause a small amount of unwanted circulation early in the morning - for example when there is enough light to drive the pump but while the collector is still cold. To eliminate the risk of hot water in the storage tank from being coothata way this is very important. solar controller
may be required.
• The modularity of an evacuated tube collector array allows the adjustment of the collector size by removing some tubes or their heat pipes. Budgeting for a larger than required array of tubes therefore allows for the customisation of collector size to the needs of a particular application, especially in warmer climates.
• Particularly in locations further towards the poles than 45 degrees from the equator, roof mounted sun facing collectors tend to outperform wall mounted collectors in terms of total energy output. However it is total useful energy output which usually matters most to consumers. So arrays of sunny wall mounted steep collectors can sometimes produce more useful energy because there can be a small increase in winter gain at the expense of a large unused summer surplus.

Standards

Europe
• EN 806: Specifications for installations inside buildings conveying water for human consumption. General.
• EN 1717: Protection against pollution of potable water in water installations and general requiremens of devices to prevent pollution by backflow.
• EN 60335: Specification for safety of household and similar electrical appliances. (2-21)

APPENDIX 1. Use of solar water heating worldwide

Top countries worldwide

<table>
<thead>
<tr>
<th>#</th>
<th>Country</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>55.5</td>
<td>67.9</td>
<td>84.0</td>
<td>105.0</td>
<td>134.0</td>
</tr>
<tr>
<td></td>
<td>European Union</td>
<td>11.2</td>
<td>13.5</td>
<td>15.5</td>
<td>20.0</td>
<td>22.8</td>
</tr>
<tr>
<td>2</td>
<td>Turkey</td>
<td>5.7</td>
<td>6.6</td>
<td>7.1</td>
<td>7.8</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>5.0</td>
<td>4.7</td>
<td>4.9</td>
<td>5.0</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Israel</td>
<td>3.3</td>
<td>3.8</td>
<td>3.5</td>
<td>3.6</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>Brazil</td>
<td>1.6</td>
<td>2.2</td>
<td>2.5</td>
<td>2.4</td>
<td>2.9</td>
</tr>
<tr>
<td>6</td>
<td>United States</td>
<td>1.6</td>
<td>1.8</td>
<td>1.7</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>7</td>
<td>Australia</td>
<td>1.2</td>
<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>India</td>
<td>1.1</td>
<td>1.2</td>
<td>1.5</td>
<td>1.7</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>Germany</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>10</td>
<td>Mexico</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>0.7</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>World (GW th)</td>
<td>88</td>
<td>105</td>
<td>126</td>
<td>149</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Solar heating in European Union + CH

#### Solar thermal heating in European Union (MW\text{th})\textsuperscript{[85]}

<table>
<thead>
<tr>
<th>#</th>
<th>Country</th>
<th>New installations</th>
<th>All installations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2006</td>
<td>2007</td>
</tr>
<tr>
<td>1</td>
<td>Germany</td>
<td>1,050</td>
<td>665</td>
</tr>
<tr>
<td>2</td>
<td>Austria</td>
<td>205</td>
<td>197</td>
</tr>
<tr>
<td>3</td>
<td>Greece</td>
<td>168</td>
<td>198</td>
</tr>
<tr>
<td>4</td>
<td>Italy</td>
<td>130</td>
<td>172</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>154</td>
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EU27 (MW\text{th}) | 2,060 | 1,870 | 3,280 | 19,967 | 22,786
Solar water heating

By country

- Australia: Solar hot water in Australia

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Solar water heating

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Solar water heating


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External links

- Using Excel to predict solar water heating, and heating of other objects (http://rack1.ul.cs.cmu.edu/hotcars)
- Parts of a solar heating system (http://www.nrel.gov/docs/fy04osti/34279.pdf)

Trombe wall

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.

![Passive solar design using an unvented trombe wall and summer shading](image-url)
Current basic design

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[1] 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.[2]

The Druk White Lotus School in Ladakh uses Trombe walls[3] and as part of “a model of appropriate design and development”.[4]

**References**


**External links**

• Community Office for Resource Efficiency (http://www.aspencore.org/file/Trombe_Wall_Heating.html) A Primer in Trombe Walls with Photos
• Druk White Lotus School website (http://www.dwls.org) including Trombe wall example (http://www.dwls.org/Sustainable-Design-Examples.html).
• Trombe Walls (http://www.nrel.gov/docs/fy04osti/36277.pdf) -- NREL page extolling Trombe walls, with no reference to heat loss issues.
Windcatcher

A windcatcher (Persian: بادگیر, Arabic: ملقف or لجراب "Barjeel" in Eastern Arabia) 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

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.
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.
Windcatchers in the Persian Gulf

Windtowers in the Arab world date to the Abbasid era, where it had its fame. The mosque of Al-Salih Tala'i has the oldest remaining windcatchers in the world, the usage of Windcatchers in the Gulf area was recorded by the Syrian pilgrim "Murtaḍá ibn 'Alwān" who visited the area around 1722.

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.

In Kuwait there are four remaining buildings using windcatchers, they date to the early 18th century and are part of the "traditional area" in Kuwait city, which is preserved by the Government and considered one of Kuwait tourist attractions.
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 meshes 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 louvers (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.

References
- The Barra system is described on pages 169-171 and 181 of Baruch Givoni's Climate Considerations book (Wiley, 1998.)

External links
- The Barra system[1]

References
Brise soleil

Brise soleil, sometimes brise-soleil (French pronunciation: [bʁiːz soˈleil], plural, "brise-soleil" (invariable), from French, "sun breaker"), 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.

Gallery

I. The movable Burke brise soleil on the Quadracci Pavilion of the Milwaukee Art Museum closes at sunset
II.
III.
Side view of the brise soleil on the Quadracci Pavilion

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.
External links

- Brise soleil at the Milwaukee Art Museum \(^1\)
- British-Yemini Society \(^2\) Influence of climate on window design

References

\(^1\) http://www.mam.org/visit/details/detail_burke.php
\(^2\) http://www.al-bab.com/bys/articles/windows.htm
Earth sheltering

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,[1] 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
Earth sheltering

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 (see more under Materials: Structural). 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, atria 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 built 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 where 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 Zoworks 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." (See Nick Pine's posting on usenet alt.homepower and alt.solar.thermal groups about this type of house.) In the umbrella house, Polystyrene insulation extends around 23 feet radius from underground walls. A plastic film covers the insulation.
Earth sheltering

(for waterproofing), and soil is layered 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.

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 examples like Hvalsøy 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 buildings 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.
Earth sheltering

**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. See Coober Pedy and Lightning Ridge. The Forestiere Underground Gardens in Fresno, California is a North American example.

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.

**Gallery**

- Loir-et-Cher, France
- Kandovan in Iran
- Hôtel Siddriss in Matmata in Tunisia
- Interior of a cave in Matmata (Tunisia)
- Granada, Spain

**Notes**


**References**

- **De Mars, John. *Hydrophobic Concrete Sheds Waterproofing Membrane***. Concrete Products, January 2006. Concrete industry magazine it can be accessed online at (http://www.concreteproducts.com).
- **Edelhart, Mike. *The Handbook of Earth Shelter Design***. Dolphin Books, 1982. This has in depth information about earth shelter construction with many illustrations.
- **Miller, David E. *Toward a New Regionalism***. University of Washington Press, 2005. It includes examples and information of sustainable building including earth shelters.
Earth sheltering


• The Underground Space Center University of Minnesota. *Earth Sheltered Housing Design*. Van Nostrand Reinhold Company, ed. 1978 and ed. 1979. This is an academic look at how to construct an earth shelter building.


**External links**

- British Earth Sheltering Association (http://www.besa-uk.org)
- Earth Shielded Structures: A Pathfinder and Annotated Bibliography (http://www.geotecture.org/)
- Eco-Flex Rubber (http://www.aquasealusa.com) - Eco-Flex is a water based, solvent free, non flammable, liquid waterproofing membrane.
- Formworks Building Inc. (http://www.formworksbuilding.com) - Designer of contemporary earth-sheltered homes.
- Grancrete (http://www.grancrete.net) - Grancrete claims to be a green product that is stronger than concrete, is water and fire resistant and sets up quickly.
- Hockerton Housing Project (http://www.hockertonhousingproject.org.uk) - Community of 5 earth sheltered homes near Nottingham, UK
- Hycrete Technologies (http://www.hycrete.com) - Hycrete admixture has the highest "cradle to cradle" rating for sustainability.
- Home Sweet Earth Home (http://undergroundhomes.com/) - Designers and builders of earth sheltered homes
Superinsulation

**Superinsulation** is an approach to building design, construction, and retrofitting that dramatically reduces heat loss (and gain) by using much higher levels of insulation and airtightness than normal. A superinsulated house is intended to reduce heating needs very significantly and may even be heated predominantly by intrinsic heat sources (waste heat generated by appliances and the body heat of the occupants) with very small amounts of backup heat. This has been demonstrated to work even in very cold climates but requires close attention to construction details in addition to the insulation (see IEA Solar Heating & Cooling Implementing Agreement Task 13).

Superinsulation is one of the ancestors of the passive house approach. A related approach to efficient building design is zero energy building.

There is no set definition of superinsulation, but superinsulated buildings typically include:

- Very high levels of insulation (typically R_{wall} 40 walls and R_{roof} 60 roof)
- Details to ensure insulation continuity where walls meet roofs, foundations, and other walls
- Airtight construction, especially around doors and windows
- a Heat recovery ventilation to provide fresh air
- No large windows facing any particular direction
- Much smaller than conventional heating system, sometimes just a small backup heater

Nisson & Dutt (1985) suggest that a house might be described as "superinsulated" if the cost of space heating is lower than the cost of water heating.

History

The term "superinsulation" was coined by Wayne Schick at the University of Illinois at Urbana-Champaign. In 1976 he was part of a team that developed a design called the "Lo-Cal" house, using computer simulations based on the climate of Madison, Wisconsin. Several houses, duplexes and condos based on Lo-Cal principles were built in Champaign-Urbana, Illinois in the 1970s.[1]

In 1978 the "Saskatchewan House" was built in Regina, Saskatchewan by a group of several Canadian government agencies. It was the first house to publicly demonstrate the value of superinsulation and generated a lot of attention. It originally included some experimental evacuated-tube solar panels, but they were not needed and were later removed.

In 1979 the "Leger House" was built by Eugene Leger, in East Pepperell, Massachusetts. It had a more conventional appearance than the "Saskatchewan House", and also received extensive publicity.

Publicity from the "Saskatchewan House" and the "Leger House" influenced other builders, and many superinsulated houses were built over the next few years, but interest declined as energy prices fell. Many US builders now use more insulation than will fit in a traditional 2x4 stud wall (either using 2x6 studs or by adding rigid foam to the
outside of the wall), but few would qualify as "superinsulated".

Numerous custom homes and demonstration superinsulated homes continue to be built Westford House[2].

Retrofits

It is possible, and increasingly desirable, to retrofit superinsulation to an existing older house or building. The easiest way is often to add layers of continuous rigid exterior insulation[3], and sometimes by building new exterior walls that allow more space for insulation. A vapor barrier can be installed on the outside of the original framing but may not be needed. An improved continuous air barrier is almost always worth adding, as older homes tend to be leaky, and such an air barrier can be important for energy savings and durability. Care should be exercised when adding a vapor barrier as it can reduce drying of incidental moisture, or even cause summer (in climates with humid summers) condensation and consequent mold and mildew. This may cause health problems for the occupants and damage the existing structure. Many builders in northern Canada use a simple 1/3 to 2/3 approach, placing the vapor barrier no further out than 1/3 of the R-value of the insulated portion of the wall. This method is generally valid for interior walls that have little or no vapor resistance (e.g. they use fibrous insulation) and controls air leakage condensation as well as vapor diffusion condensation. This approach will ensure that condensation does not occur on or to the inside of the vapor barrier during cold weather. The 1/3:2/3 rule will ensure that the vapor barrier temperature will not fall below the dew point temperature of the interior air, and will minimize the possibility of cold-weather condensation problems. For example, with an internal room temperature of 20°C (68°F), the vapor barrier will then only reach 7.3°C (45°F) when the outside temperatures is at −18°C (-1°F). Indoor air dewpoint temperatures are more likely to be in the order of around 0 °C (32 °F) when it is that cold outdoors, much lower than the predicted vapor barrier temperature, and hence the 1/3:2/3 rules is quite conservative. For climates that do not often experience -18°C, the 1/3:2/3 rule should be amended to 40:60% or 50:50. As the interior air dewpoint temperature is an important basis for such rules, buildings with high interior humidities during cold weather (e.g., museums, swimming pools, humidified or poorly ventilated airtight homes) may require different rules, as can buildings with drier interior environments (such as highly ventilated buildings, warehouses). The 2009 International Residential Code (IRC) embodies more sophisticated rules to guide the choice of insulation on the exterior of new homes, which can be applied when retrofitting older homes.

A vapor permeable building wrap on the outside of the original wall helps keep the wind out, yet allows the wall assembly to dry to the exterior. Asphalt felt and other products such as permeable polymer based products are available for this purpose, and usually double as the Water Resistant Barrier / drainage plane as well.

Interior retrofits are possible where the owner wants to preserve the old exterior siding, or where setback requirements don't leave space for an exterior retrofit. Sealing the air barrier is more difficult and the thermal insulation continuity compromised (because of the many partition, floor, and service penetrations), the original wall assembly is rendered colder in cold weather (and hence more prone to condensation and slower to dry), occupants are exposed to major disruptions, and the house is left with less interior space. Another approach is to use the 1/3 to 2/3 method mentioned above — that is, to install a vapor retarder on the inside of the existing wall (if there isn't one there already) and add insulation and support structure to the inside. This way, utilities (power, telephone, cable, and plumbing) can be added in this new wall space without penetrating the air barrier. Polyethylene vapor barriers are risky except in very cold climates, because they limit the wall's ability to dry to the interior. This approach also limits the amount of interior insulation that can be added to a rather small amount (e.g., only R6 can be added to a 2x4 R12 wall).
Costs and benefits
In new construction, the cost of the extra insulation and wall framing may be offset by not requiring a dedicated central heating system. In homes with numerous rooms, more than one floor, air conditioning or large sized, a central furnace is often justified or required to ensure sufficiently uniform thermal conditions. Small furnaces are not very expensive and some ductwork to every room is almost always required to provide ventilation air in any case. Because the peak demand and annual energy use is low, sophisticated and expensive central heating systems are not often required. Hence, even electric resistance heaters may be used. Electric heaters are typically only used on the coldest winter nights when overall demand for electricity is low. Other forms of backup heater are widely used, such as wood pellets, wood stoves, natural gas boilers or even furnaces. The cost of a superinsulation retrofit may need to be balanced against the future cost of heating fuel (which can be expected to fluctuate from year to year due to supply problems, natural disasters or geopolitical events), the desire to reduce pollution from heating a building, or the desire to provide exceptional thermal comfort.

A superinsulated house takes longer to cool in the event of an extended power failure during cold weather, for example after a severe ice storm disrupts electric transmission because heat loss is much less than normal buildings, but the thermal storage capacity of the structural materials and contents is the same. Adverse weather may hamper efforts to restore power, leading to outages lasting a week or more. When deprived of their continuous supply of electricity (either for heat directly, or to operate gas-fired furnaces), conventional houses cool more rapidly during cold weather, and may be at greater risk of costly damage due to freezing water pipes. Residents who use supplemental heating methods without proper care during such episodes, or at any other time, may subject themselves to risk of fire or carbon monoxide poisoning.

Notes

References
• Computation and description of an outside insulation house: To build for tomorrow (http://jehhan.ifrance.com/index.html) (translated from French)
External links

- Optimization of the Building Shell with Superinsulation (http://www.quadlock.com/green_building/building_shell_superinsulation.htm)
- Why Superinsulation is so important in building to passive house standard (http://www.scanhome.ie/philosophy.php)
- Drawings and specs of 12 different superinsulated wall assemblies (http://www.buildingscience.com/resources/high-r-value)
- Superinsulation retrofit of a 1915 Sears Roebuck house (http://www.buildingscience.com/documents/digests/bd-139-deep-energy-retrofit-of-a-sears-roebuck-house-a-home-for-the-next-100-years)

Solar air conditioning

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

This can be done through passive solar, solar thermal energy conversion and photovoltaic conversion (sun to electricity). The U.S. Energy Independence and Security Act of 2007[^1] created 2008 through 2012 funding for a new solar air conditioning research and development program, which should develop and demonstrate multiple new technology innovations and mass production economies of scale. Solar air conditioning will play an increasing role in zero energy and energy-plus buildings design.

**Solar A/C using desiccants**

Air can be passed over common, solid desiccants (like silica gel or zeolite) to draw moisture from the air to allow an efficient evaporative cooling cycle. The desiccant is then regenerated by using solar thermal energy to dry it out, in a cost-effective, low-energy-consumption, continuously repeating cycle.[^2] A photovoltaic system can power a low-energy air circulation fan, and a motor to slowly rotate a large disk filled with desiccant.

Energy recovery ventilation systems provide a controlled way of ventilating a home while minimizing energy loss. Air is passed through an "enthalpy wheel" (often using silica gel) to reduce the cost of heating ventilated air in the winter by transferring heat from the warm inside air being exhausted to the fresh (but cold) supply air. In the summer, the inside air cools the warmer incoming supply air to reduce ventilation cooling costs.[^3] This low-energy fan-and-motor ventilation system can be cost-effectively powered by photovoltaics, with enhanced natural convection exhaust up a solar chimney - the downward incoming air flow would be forced convection (advection).

A desiccant like calcium chloride can be mixed with water to create an attractive recirculating waterfall, that dehumidifies a room using solar thermal energy to regenerate the liquid, and a PV-powered low-rate water pump. (See Liquid Desiccant Waterfall for attractive building dehumidification[^4])

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

Active solar cooling wherein solar thermal collectors provide input energy for a desiccant cooling system: A packed column air-liquid contactor has been studied in application to air dehumidification and regeneration in solar air conditioning with liquid desiccants. A theoretical model has been developed to predict the performance of the device under various operating conditions. Computer simulations based on the model are presented which indicate the practical range of air to liquid flux ratios and associated changes in air humidity and desiccant concentration. An experimental apparatus has been constructed and experiments performed with monoethylene glycol (MEG) and lithium bromide as desiccants. MEG experiments have yielded inaccurate results and have pointed out some
practical problems associated with the use of glycols. LiBr experiments show very good agreement with the theoretical model. Preheating of the air is shown to greatly enhance desiccant regeneration. The packed column yields good results as a dehumidifier/regenerator, provided pressure drop can be reduced with the use of suitable packing.\[^{[5]}\]

**Passive solar cooling**

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

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

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

**Solar thermal cooling**

Active solar cooling uses solar thermal collectors to provide thermal energy to drive thermally driven chillers (usually adsorption or absorption chillers).\[^{[6]}\] The Sopogy concentrating solar thermal collector, for example, provides solar thermal heat by concentrating the sun’s energy on a collection tube and heating the recirculated heat transfer fluid within the system.\[^{[7]}\] The generated heat is then used in conjunction with absorption chillers to provide a renewable source of industrial cooling.\[^{[8]}\]

The solar thermal energy system can be also used to produce hot water.

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

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

These projects have shown that flat plate solar collectors specially developed for temperatures over 200 °F (featuring double glazing, increased backside insulation, etc.) can be effective and cost efficient.\[^{[9]}\] Evacuated-tube solar panels can be used as well. Concentrating solar collectors required for absorption chillers are less effective in hot humid, cloudy environments, especially where the overnight low temperature and relative humidity are uncomfortably high. Where water can be heated well above 190 °F (88 °C), it can be stored and used when the sun is not shining.

The Audubon Environmental Center in Los Angeles has an example solar air conditioning installation.\[^{[10]}\] The Southern California Gas Co. (The Gas Company), and its sister utility, San Diego Gas & Electric (SDG&E), are also testing the practicality of solar thermal cooling systems at their Energy Resource Center (ERC) in Downey, California. Solar Collectors from Sopogy and HelioDynamics were installed on the rooftop at the ERC and are producing cooling for the building's air conditioning system.\[^{[8]}\]
In the late 19th century, the most common phase change refrigerant material for absorption cooling was a solution of ammonia and water. Today, the combination of lithium and bromide is also in common use. One end of the system of expansion/condensation pipes is heated, and the other end gets cold enough to make ice. Originally, natural gas was used as a heat source in the late 19th century. Today, propane is used in recreational vehicle absorption chiller refrigerators. Innovative hot water solar thermal energy collectors can also be used as the modern "free energy" heat source.

For 150 years, absorption chillers have been used to make ice (before the electric light bulb was invented).\[11\] This ice can be stored and used as an "ice battery" for cooling when the sun is not shining, as it was in the 1995 Hotel New Otani in Tokyo Japan.\[12\] Mathematical models are available in the public domain for ice-based thermal energy storage performance calculations.\[13\]

The ISAAC Solar Icemaker is an intermittent solar ammonia-water absorption cycle. The ISAAC uses a parabolic trough solar collector and a compact and efficient design to produce ice with no fuel or electric input, and with no moving parts.\[14\]

Makers include SOLID \[15\] and Mirroxx \[16\] for commercial installations and ClimateWell,\[17\] Fagor-Rotartica, Sopogy, SorTech and Daikin mostly for residential systems.

**Photovoltaic (PV) solar cooling**

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

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

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

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

A solar-tracking 7 kW photovoltaic system would probably have an installed price well over $20,000 USD (with PV equipment prices currently falling at roughly 17% per year). (New advances in ingot manufacturing have dropped raw silicon (refined sand) costs... leading to lower crystalline silicon; with the advances places like www.sunelec.com can sell inferior strip amorphous silicon modules for $1.20-1.50/kwh of raw modules; infrastructure, wiring., mounting and NEC code costs may add up to an additional cost; for instance a 3120 watt solar panel grid tie system has a panel cost of $0.99/watt hour peak, but still costs ~$2.2/watt hour peak. Other systems of different capacity cost even more, let alone battery backup systems, which cost even more. Due to the advent of net metering allowed by utility companies, your photovoltaic system can produce enough energy in the course of the year to completely offset the cost of the electricity used to run air conditioning, depending on the amount of your electric costs you wish to offset.
A more efficient air conditioning system would require a smaller, less-expensive photovoltaic system. A high-quality geothermal heat pump installation can have a SEER in the range of 20 (+/-). A 100,000 BTU SEER 20 air conditioner would require less than 5 kW while operating.

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

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

A less-expensive partial-power photovoltaic system can reduce (but not eliminate) the monthly amount of electricity purchased from the power grid for air conditioning (and other uses). With American state government subsidies of $2.50 to $5.00 USD per photovoltaic watt,[18] the amortized cost of PV-generated electricity can be below $0.15 per kWh. This is currently cost effective in some areas where power company electricity is now $0.15 or more. Excess PV power generated when air conditioning is not required can be sold back to the power grid in many locations, which can reduce (or eliminate) annual net electricity purchase requirement. (See Zero energy building)

The key to solar air conditioning cost effectiveness is in lowering the cooling requirement for the building. Superior energy efficiency can be designed into new construction (or retrofitted to existing buildings). Since the U.S. Department of Energy was created in 1977, their Weatherization Assistance Program[19] has reduced heating-and-cooling load on 5.5 million low-income affordable homes an average of 31%. A hundred million American buildings still need improved weatherization. Careless conventional construction practices are still producing inefficient new buildings that need weatherization when they are first occupied.

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

Since U.S. President Carter created the Solar Energy Tax Incentives in 1978, hundreds of thousands of passive solar and zero energy buildings have demonstrated 70% to 90% heating-and-cooling load reductions (and even 100% reduction in some climates). In contrast, well over 25 million new conventional U.S. buildings have ignored well-documented energy efficiency techniques since 1978. As a result, U.S. buildings waste more energy (39%) than transportation or industry.[20] If their architects and builders had listened to the U.S. Department Of Energy presentations at the National Energy Expositions three decades ago, American buildings could be using $200 billion USD less energy per year today.

Geothermal cooling

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

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

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

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

**Zero energy buildings**

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

**References**


[14] [http://www.energy-concepts.com/isaac](http://www.energy-concepts.com/isaac)

[15] [http://www.solid.at/](http://www.solid.at/)

[16] [http://www.mirrox.com/](http://www.mirrox.com/)


[18] Dsire: Dsire Home (http://www.dsireusa.org)


External links

- Liquid Desiccant Waterfall for attractive building dehumidification (http://solarteam.org/page.php?id=641)
- Solar Thermal Absortion Cooling System (http://www.cf.ac.uk/archi/research/stacs/STACS.htm).
- Ultra High Vacuum (UHV) panels from SRB (Segura Roig Benvenuti) (http://www.roig.es/principal/index.php?idioma=eng) and CERN.
- Distributed Energy Resources Customer Adoption Model (DER-CAM) (http://der.lbl.gov)
- Center for Energy and innovative Technologies (http://www.cet.or.at)
- SOLEM Consulting - International consortium of solar cooling engineering consultants (http://www.solem-consulting.com)

Passive cooling

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

Passive cooling

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

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

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

Shading

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

Buildings can be orientated to take advantage of winter sun (longer in the East / West dimension), while shading walls and windows from direct hot summer sun. This can be achieved by designing location-specific wide eaves or overhangs above the Equator-side vertical windows (South side in the Northern hemisphere, North side in the Southern hemisphere).
Passive solar buildings should not allow direct sunlight through, use large glass areas directly into the living space in
the summer. A greenhouse / solarium is usually integrated into the equator side of the building. It captures low
winter sun, and blocks direct sunlight in the summer, when the sun's altitude is 47 degrees higher. The outer glass of
the solarium, plus interior glass between the solarium and the interior living quarters acts like a Thermal Buffer
Zone\textsuperscript{1} . Two smaller temperature differentials produce much lower heat transfer than one large temperature
differential.

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

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

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

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

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

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

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

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

Cross ventilation requires openings on two sides of a room.

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

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

An energy audit uses a calibrated exhaust fan to measure and locate poor-weatherization air-infiltration leaks cause
by careless conventional construction.
In hot humid climates with uncomfortable nights, fresh air ventilation can be controlled, filtered, dehumidified, and cooled (possibly using an air exchanger). A solar air conditioner can be used to cool and dehumidify hot humid air. ASHRAE, an international society of HVAC engineers, recommends a minimum 0.35 air changes / hour AND 15 CFM of fresh air for each person in a room (year round regardless of outside conditions). Carbon dioxide monitors can be used to increase fresh air intake in high-occupancy rooms when the air becomes unhealthy.

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

**Examples**


**References**


**Absorption heat pump**

Absorption heat pump is essentially an air-source heat pump driven not by electricity, but by a heat source such as solar-heated water, or geothermal-heated water. There are also absorption coolers available that work on the same principle, but are not reversible and cannot serve as a heat source.

**Solar thermal**

Single, double or triple iterative absorption cooling cycles are used in different solar-thermal-cooling system designs. The more cycles, the more efficient they are.

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

Efficient absorption chillers require water of at least 190 °F (88 °C). Common, inexpensive flat-plate solar thermal collectors only produce about 160 °F (70 °C) water, but several successful commercial projects in the US, Asia and Europe have shown that flat plate solar collectors specially developed for temperatures over 200 °F (featuring double glazing, increased backside insulation, etc.) can be effective and cost efficient. [1] Evacuated-tube solar panels can be used as well. Concentrating solar collectors required for absorption chillers are less effective in hot humid, cloudy environments, especially where the overnight low temperature and relative humidity are uncomfortably high. Where water can be heated well above 190 °F (88+ °C), it can be stored and used when the sun is not shining.

For 150 years, absorption chillers have been used to make ice (before the electric light bulb was invented). [2] This ice can be stored and used as an "ice battery" for cooling when the sun is not shining, as it was in the 1995 Hotel New
Absorption heat pump

Otani in Tokyo Japan.[3] Mathematical models are available in the public domain for ice-based thermal energy storage performance calculations.[4]

The ISAAC Solar Icemaker is an intermittent solar ammonia-water absorption cycle. The ISAAC uses a parabolic trough solar collector and a compact and efficient design to produce ice with no fuel or electric input, and with no moving parts.[5]

Makers include ClimateWell,[6] Fagor-Rotartica and Daikin.

Other

By using a fuel cell as opposed to a burner to create heat, it would be theoretically possible to create an air-conditioner which converted approximately 55% of the fuel (assuming a methane fuel cell) to electricity and the rest to driving an air-conditioner.

References


External links

• Absorption Heat Pumps (http://apps1.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12680) (EERE)
Radiant cooling

A radiant cooling system refers to a temperature-controlled surface that cools indoor temperatures by removing sensible heat and where more than half of heat transfer occurs through thermal radiation.\(^1\) Heat will flow from objects, occupants, equipment and lights in a space to a cooled surface as long as their temperatures are warmer than that of the cooled surface and they are within the line of sight of the cooled surface. The process of radiant exchange has a negligible effect on air temperature, but through the process of convection, the air temperature will be lowered when air comes in contact with the cooled surface. Radiant cooling systems use the opposite effect of radiant heating systems, which rely on the process of heat flow from a heated surface to objects and occupants.

System design

Radiant cooling systems are usually hydronic, cooling using circulating water running in pipes in thermal contact with the surface. Typically the circulating water only needs to be 2-4°C below the desired indoor air temperature.\(^2\) Once having been absorbed by the actively cooled surface, heat is removed by water flowing through a hydronic circuit, replacing the warmed water with cooler water. Since the majority of the cooling process results from removing sensible heat through radiant exchange with people and objects and not air, occupant thermal comfort can be achieved with warmer interior air temperatures than with air based cooling systems. As a result of the high cooling capacity of water, and the delivery of a cooled surface close to the desired indoor air temperature, radiant cooling systems potentially offer reductions in cooling energy consumption.\(^3\) The latent loads (humidity) from occupants, infiltration and processes generally need to be managed by an independent system. Radiant cooling may also be integrated with other energy-efficient strategies such as night time flushing, indirect evaporative cooling, or ground source heat pumps as it requires a small difference in temperature between desired indoor air temperature and the cooled surface.\(^2\)

System types

While there are a broad range of system technologies, there are two primary types of radiant cooling systems. The first type is systems that deliver cooling through the building structure, usually slabs, this systems are also name thermally activated building systems (TABS).\(^4\) The second type is systems that deliver cooling through specialized panels. Systems using concrete slabs are generally cheaper than panel systems and offer the advantage of thermal mass while panel systems offer faster temperature control and flexibility.

Chilled slabs

Radiant cooling from a slab can be delivered to a space from the floor or ceiling. Since radiant heating systems tend to be in the floor, the obvious choice would be to use the same circulation system for cooled water. While this makes sense in some cases, delivering cooling from the ceiling has several advantages. First, it is easier to leave ceilings exposed to a room than floors, increasing the effectiveness of thermal mass. Floors offer the downside of coverings and furnishings that decrease the effectiveness of the system. Second, greater convective heat exchange occurs through a chilled ceiling as warm air rises, leading to more air coming in contact with the cooled surface. Cooling delivered through the floor makes the most sense when there is a high amount of solar gains from sun penetration, as the cool floor can more easily remove those loads than the ceiling.\(^2\) Chilled slabs, compared to panels, offer more significant thermal mass and therefore can take better advantage of outside diurnal temperatures swings. Chilled slabs cost less per unit of surface area, and are more integrated with structure.
Ceiling panels
Radiant cooling panels are generally attached to ceilings, but can be attached to walls. They are usually suspended from the ceiling, but can also be directly integrated with continuous dropped ceilings. Modular construction offers increased flexibility in terms of placement and integration with lighting or other electrical systems. Lower thermal mass compared to chilled slabs means they can’t easily take advantage of passive cooling from thermal storage, but controls in panels can more quickly adjust to changes in outdoor temperature. Chilled panels are also better suited to buildings with spaces that have a greater variance in cooling loads. Perforated panels also offer better acoustical dampening than chilled slabs. Ceiling panels are also very suitable for retrofits as they can be attached to any ceiling. Chilled ceiling panels can be more easily integrated with ventilation supplied from the ceiling. Panels tend to cost more per unit of surface area than chilled slabs.

Advantages
Radiant cooling systems offer lower energy consumption than conventional cooling systems based on research conducted by the Lawrence Berkeley National Laboratory. Radiant cooling energy savings depend on the climate, but on average across the US savings are in the range of 30% compared to conventional systems. Cool, humid regions might have savings of 17% while hot, arid regions have savings of 42%. Hot, dry climates offer the greatest advantage for radiant cooling as they have the largest proportion of cooling by way of removing sensible heat. While this research is informative, more research needs to be done to account for the limitations of simulation tools and integrated system approaches. Much of the energy savings is also attributed to the lower amount of energy required to pump water as opposed to distribute air with fans. By coupling the system with building mass, radiant cooling can shift some cooling to off-peak night time hours. Radiant cooling appears to have lower first costs and lifecycle costs compared to conventional systems. Lower first costs are largely attributed to integration with structure and design elements, while lower life cycle costs result from decreased maintenance.

Limiting factors
Because of the potential for condensate formation on the cold radiant surface (resulting in water damage, mold and the like), radiant cooling systems have not been widely applied. Condensation caused by Humidity is a limiting factor for the cooling capacity of a radiant cooling system. The surface temperature should not be equal or below the dew point temperature in the space. Some standards suggest a limit for the relative humidity in a space to 60% or 70%. An air temperature of 26°C (79°F) would mean a dew point between 17°C and 20°C (63°F and 68°F). There is, however, evidence that suggests decreasing the surface temperature to below the dew point temperature for a short period of time may not cause condensation. Also, the use of an additional system, such as a dehumidifier, can limit humidity and allow for increased cooling capacity.

References
Radiant cooling

Further reading
Kessling, W., Holst, S., Schuler, M. Innovative Design Concept for the New Bangkok International Airport, NBIA.
Olesen, B.W. Radiant Heating and Cooling by Water-based systems. Technical University of Denmark, International Centre for Indoor Environment and Energy.

Natural ventilation

Natural ventilation is the process of supplying and removing air through an indoor space by natural means. There are two types of natural ventilation occurring in buildings: wind driven ventilation and stack ventilation. The pressures generated by buoyancy, also known as 'the stack effect', are quite low (typical values: 0.3 Pa to 3 Pa) while wind pressures are usually far greater (~1 Pa to 35 Pa). The majority of buildings employing natural ventilation rely primarily on wind driven ventilation, but stack ventilation has several benefits. The most efficient design for a natural ventilation building should implement both types of ventilation.

Process
The static pressure of air is the pressure in a free-flowing air stream and is depicted by isobars in weather maps. Differences in static pressure arise from global and microclimate thermal phenomena and create the air flow we call wind. Dynamic pressure is the pressure exerted when the wind comes into contact with an object such as a hill or a building and it is related to the air density and the square of the wind speed. The impact of wind on a building affects the ventilation and infiltration rates through it and the associated heat losses or heat gains. Wind speed increases with height and is lower towards the ground due to frictional drag.)

The impact of wind on the building form creates areas of positive pressure on the windward side of a building and negative pressure on the leeward and sides of the building. Thus building shape is crucial in creating the wind pressures that will drive air flow through its apertures. In practical terms wind pressure will vary considerably creating complex air flows and turbulence by its interaction with elements of the natural environment (trees, hills) and urban context (buildings, structures). Vernacular and traditional buildings in different climatic regions rely heavily on natural ventilation for maintaining human comfort conditions in the enclosed spaces.)
Design

Typical building design relies on rules of thumb for harnessing the power of wind for the purpose of natural ventilation. Design guidelines are offered in building regulations and other related literature and include a variety of recommendations on many specific areas such as:

- Building location and orientation
- Building form and dimensions
- Window typologies and operation
- Other aperture types (doors, chimneys)
- Construction methods and detailing (infiltration)
- External elements (walls, screens)
- Urban planning conditions

Wind driven ventilation has several significant benefits:

- Greater magnitude and effectiveness
- Readily available (natural occurring force)
- Relatively economic implementation
- User friendly (when provisions for control are provided to occupants)

Some of the important limitations of wind driven ventilation:

- Unpredictableness and difficulties in harnessing due to speed and direction variations
- The quality of air it introduces in buildings may be polluted for example due to proximity to an urban or industrial area
- May create strong draughts, discomfort.

Wind driven ventilation

Wind driven ventilation or roof mounted ventilation design in buildings provides ventilation to occupants using the least amount of resources. Mechanical ventilation drawbacks include the use of equipment that is high in embodied energy and the consumption of energy during operation. By utilising the design of the building, Wind driven ventilation takes advantage of the natural passage of air without the need for high energy consuming equipment. Windcatchers are able to aid wind driven ventilation by directing air in and out of buildings.

Wind driven ventilation depends on wind behavior, on the interactions with the building envelope and on openings or other air exchange devices such as inlets or chimneys. For a simple volume with two openings, the cross wind flow rate was calculated by Aynsley et al.:[1]

\[ Q = U_{\text{wind}} \sqrt{((Cp_1 - Cp_2)/(1/A_1^2 C_1^2) + (1/A_2^2 C_2^2))} \] (1)

The knowledge of the urban climatology i.e. the wind around the buildings is crucial when evaluating the air quality and thermal comfort inside buildings as air and heat exchange depends on the wind pressure on facades. As we can see in the equation (1), the air exchange depends linearly on the wind speed in the urban place where the architectural project will be built. CFD (Computational Fluid Dynamics) tools and zonal modelings are usually used to calculate pressure. One of these CFD tools, called UrbaWind (UrbaWind [2]) makes the link between this pressure and the real urban climatology. It computes with a macroscopic method the mass flow rate incoming the building for each wind characteristic (incidence and velocity magnitude), to finally give cross ventilation statistics according to the wind statistics of the considered urban location. It helps quantifying the natural cross ventilation induced by the wind flow crossing the buildings.
Stack driven ventilation

(For more details, see Stack effect)

Stack effect is temperature induced. When there is a temperature difference between two adjoining volumes of air the warmer air will have lower density and be more buoyant thus will rise above the cold air creating an upward air stream. Forced stack effect in a building takes place in a traditional fire place. Passive stack ventilators are common in most bathrooms and other type of spaces without direct access to the outdoors. In order for a building to be ventilated adequately via stack effect the inside and outside temperatures must be different so that warmer indoor air rises and escapes the building at higher apertures, while colder, denser air from the exterior enters the building through lower level openings. Stack effect increases with greater temperature difference and increased height between the higher and lower apertures. The neutral plane in a building occurs at the location between the high and low openings at which the internal pressure will be the same as the external pressure (in the absence of wind). Above the neutral plane, the air pressure will be positive and air will rise. Below the neutral plane the air pressure will be negative and external air will be drawn into the space. Stack driven ventilation has several significant benefits:

- Does not rely on wind: can take place on still, hot summer days when it is most needed.
- Natural occurring force (hot air rises)
- Stable air flow (compared to wind)
- Greater control in choosing areas of air intake
- Sustainable method

Limitations of stack driven ventilation:

- Lower magnitude compared to wind ventilation
- Relies on temperature differences (inside/outside)
- Design restrictions (height, location of apertures) and may incur extra costs (ventilator stacks, taller spaces)
- The quality of air it introduces in buildings may be polluted for example due to proximity to an urban or industrial area

Natural ventilation in buildings relies mostly in wind pressure differences but stack effect can augment this type of ventilation and partly restore air flow rates during hot, still days. Stack ventilation can be implemented in ways that air inflow in the building does not rely solely on wind direction. In this respect it may provide improved air quality in some types of polluted environments such as cities. For example air can be drawn through the backside or courtyards of buildings avoiding the direct pollution and noise of the street facade. Wind can augment the stack effect but also reduce its effect depending on its speed, direction and the design of air inlets and outlets. Therefore prevailing winds must be taken into account when designing for stack effect ventilation.

Examples of stack effect ventilation can be seen on aluminium smelters, steel mills, and glass plants. Stack effect ventilators have undergone numerous evolutionary steps in recent years to correspond to new safety standards for protection against weather penetration, air hygiene for plant workforce and methodology of construction to reduce total installed costs of greenfield and brownfield projects.
Estimating stack effect ventilation

The natural ventilation flow rate can be estimated with this equation:[3]

\[ Q_s = C_d A \sqrt{2 g H_d \left( \frac{T_I - T_O}{T_I} \right)} \]

**English units:**

where:

- \( Q_s \) = Stack vent airflow rate, ft³/s
- \( A \) = cross-sectional area of opening, ft² (assumes equal area for inlet and outlet)
- \( C_d \) = Discharge coefficient for opening
- \( g \) = gravitational acceleration, around 32.2 ft/s² on Earth
- \( H_d \) = Height from midpoint of lower opening to neutral pressure level (NPL), ft
- \( NPL \) = location/s in the building envelope with no pressure difference between inside and outside (ASHRAE 2001, p.26.11)
- \( T_I \) = Average indoor temperature between the inlet and outlet, °R
- \( T_O \) = Outdoor temperature, °R

**SI units:**

where:

- \( Q_s \) = Stack vent airflow rate, m³/s
- \( A \) = cross-sectional area of opening, m² (assumes equal area for inlet and outlet)
- \( C_d \) = Discharge coefficient for opening
- \( g \) = gravitational acceleration, around 9.8 m/s² on Earth
- \( H_d \) = Height from midpoint of lower opening to neutral pressure level (NPL), m
- \( NPL \) = location/s in the building envelope with no pressure difference between inside and outside (ASHRAE 2001, p.26.11)
- \( T_I \) = Average indoor temperature between the inlet and outlet, K
- \( T_O \) = Outdoor temperature, K

Natural ventilation of boiler rooms and industrial buildings

Due to high internal heat loads, natural ventilation of boiler rooms, warehouses, and other similar spaces is often employed. Often, conventional or overhead doors are manually opened to provide ventilation. When natural ventilation does not suffice alone, large box fans are often employed to enhance air movement.

But to provide security, and cooling-by-ventilation, some buildings have two sets of overhead doors in hot boiler and equipment rooms. The second set of doors are custom-made grilles with bird screens, similar to the security grilles used by some stores at indoor shopping malls. Some of the custom grilles have solid slats in the lowest section to reduce the amount of trash that might blow into the rooms. During hot weather the grilles help secure the opening while the solid doors are fully open. During cool and cold weather the solid doors can be partially or fully closed.
Underfloor air distribution

Underfloor air distribution (UFAD) is an air distribution strategy for providing ventilation and space conditioning in buildings as part of the design of an HVAC system. UFAD systems use the air plenum beneath a raised floor to provide conditioned air through diffusers directly to the occupied zone.

Applications

Underfloor air distribution is frequently used in office buildings, particularly highly-reconfigurable and open plan offices where raised floors are desirable for cable management. UFAD is also common in command centers, IT data centers and computer rooms which have large cooling loads from electronic equipment and requirements for routing power and data cables. The ASHRAE Underfloor Air Distribution Design Guide suggests that any building considering a raised floor for cable distribution should consider UFAD.[1]

System description

Like other HVAC systems, UFAD systems rely on air handling units to filter and condition air to the appropriate supply conditions so it can be delivered to the occupied zone. While overhead systems typically use ducts to distribute the air, UFAD systems use the plenum formed by installation of a raised floor. The plenum generally sits 0.3-0.48 m (12-18 in) above the structural concrete slab, although lower heights are possible. Specially designed floor diffusers are used as the supply outlets[2]. The most common UFAD configuration consists of a central air handling unit delivering air through a pressurized plenum and into the space through floor diffusers. Other approaches may incorporate fan powered thermal units at the outlets, underfloor ducts, desktop vents or connections to Personal Environmental Control Systems.[3]

UFAD air distribution and stratification

UFAD systems rely on the natural stratification that occurs when warm air rises due to thermal buoyancy. In a UFAD design, cold, fresh air stays in the lower, occupied part of the room, while heat sources such as occupants and equipment generate thermal plumes, which carry the warm air and pollutants towards the ceiling where they are exhausted through the return air ducts.[4] The optimal ventilation strategy controls the supply outlets to limit the mixing of supply air with room air to just below the breathing height of the space. Above this height, stratified and more polluted air is allowed to occur. The air that the occupant breathes will have a lower concentration of contaminants compared to conventional uniformly mixed systems.[5]

Many factors, including the ceiling height,[6] diffuser characteristics, number of diffusers, supply air temperature, total flow rate, cooling load and conditioning mode[7] affect the efficacy of the UFAD system. Swirl diffusers and perforated-floor-panel diffusers have been shown to create a low air velocity in the occupied zone, while linear
diffusers created the highest velocity in the occupied zone, disturbing thermal stratification and posing a potential draft risk.\[^8\]

**UFAD and energy**

The energy efficiency of UFAD systems is a not fully solved issue, currently generating numerous research projects within the building science and mechanical engineering community. Proponents of UFAD point to the lower fan pressures required to deliver air in a building via the plenum as compared to through ducts. Typical plenum pressures are 0.1 in. H\(_2\)O (25 Pa) or less.\[^9\] The improvements in cooling-system efficiency inherent in operation at higher temperatures save energy, and relatively higher supply air temperatures allow longer periods of economizer operation. However, an economizer strategy is highly climate-dependent and necessitate careful control of humidity to avoid condensation.\[^10\] Critics, on the other hand, cite the shortage of rigorous research and testing to account for variations in climate, system design, thermal comfort and air quality to question whether UFAD is able to deliver improved energy efficiency in practice. Limited simulation tools, the shortage of design standards and relatively scarcity of exemplar projects compound these problems.\[^11\]\[^12\]

**Thermal decay**

Thermal decay is the temperature increase of the conditioned air due to convective heat gain as it travels through the underfloor supply plenum from the plenum inlet to the floor diffusers.\[^13\] This is caused by cool supply air coming into contact with the concrete slab and raised floor warmed by heat gains, for example from the story below. Modeling studies have shown that for a range of typical operating conditions the total supply plenum heat gain can amount to 30-40% of the total system heat gain.\[^14\]

**UFAD compared to other distribution systems**

**Overhead (mixing)**

Conventional *overhead mixing systems* usually locate both the supply and return air ducts at the ceiling level. Supply air is supplied at velocities higher then typically acceptable for human comfort and the air temperature may be lower, higher or the same as desired room temperature depending on the cooling/heating load. High speed turbulent air jets mix incoming supply air with the room air.

**Displacement ventilation**

*Displacement Ventilation* systems (DV) work on similar principals as UFAD systems. DV systems deliver cool air into the conditioned space at or near the floor level and return air at the ceiling level. This works by utilizing the natural buoyancy of warm air and the thermal plumes generated by heat sources as cooler air is delivered from lower elevations. While similar, UFAD tends to encourage more mixing within the occupied zone. The major practical differences are that in UFAD, air is supplied at a higher velocity through smaller sized supply outlets than in DV, and the supply outlets are usually controlled by the occupants.\[^15\]
References


External links

University-based research centers that currently conduct UFAD research:

1. The Center for the Built Environment (CBE), University of California, Berkeley. http://www.cbe.berkeley.edu/
2. The International Centre for Indoor Environment and Energy (ICIEE), Technical University of Denmark. http://www.ie.dtu.dk/

Professional and Trade groups which provide research funding and publish standards or guides regarding UFAD systems include:

2. Air-Conditioning and Refrigeration Technology Institute (ARTI)
Solar chimney

This article refers to a device for ventilation. For the power generation technology, see Solar updraft tower.

A solar chimney — often referred to as a thermal chimney — is a way of improving the natural ventilation of buildings by using convection of air heated by passive solar energy. A simple description of a solar chimney is that of a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building.

The solar chimney has been in use for centuries, particularly in the Middle east and Near East by the Persians, as well as in Europe by the Romans.

Description

In its simplest form, the solar chimney consists of a black-painted chimney. During the day solar energy heats the chimney and the air within it, creating an updraft of air in the chimney. The suction created at the chimney’s base can be used to ventilate and cool the building below.[1] In most parts of the world it is easier to harness wind power for such ventilation as is done with a Badgir (ریگداب), but on hot windless days a Solar chimney can provide ventilation where otherwise there would be none.

There are however a number of solar chimney variations. The basic design elements of a solar chimney are:

• The solar collector area: This can be located in the top part of the chimney or can include the entire shaft. The orientation, type of glazing, insulation and thermal properties of this element are crucial for harnessing, retaining and utilizing solar gains.

• The main ventilation shaft: The location, height, cross section and the thermal properties of this structure are also very important.

• The inlet and outlet air apertures: The sizes, location as well as aerodynamic aspects of these elements are also significant.

A principle has been proposed for solar power generation, using a large greenhouse at the base rather than relying solely on heating the chimney itself. (For further information on this issue, see Solar updraft tower.)

Solar chimneys are painted black so that they absorb the sun’s heat more easily and efficiently. When the air inside the chimney is heated, it rises and pulls cold air out from under the ground via the heat exchange tubes.

Solar chimney and sustainable architecture

Air conditioning and mechanical ventilation have been for decades the standard method of environmental control in many building types, especially offices, in developed countries. Pollution and reallocating energy supplies have led to a new environmental approach in building design. Innovative technologies along with bioclimatic principles and traditional design strategies are often combined to create new and potentially successful design solutions. The solar chimney is one of these concepts currently explored by scientists as well as designers, mostly through research and experimentation.
A Solar chimney can serve many purposes. Direct gain warms air inside the chimney causing it to rise out the top and drawing air in from the bottom. This drawing of air can be used to ventilate a home or office, to draw air through a geothermal heat exchange, or to ventilate only a specific area such as a composting toilet.

Natural ventilation can be created by providing vents in the upper level of a building to allow warm air to rise by convection and escape to the outside. At the same time cooler air can be drawn in through vents at the lower level. Trees may be planted on that side of the building to provide shade for cooler outside air.

This natural ventilation process can be augmented by a solar chimney. The chimney has to be higher than the roof level, and has to be constructed on the wall facing the direction of the sun. Absorption of heat from the sun can be increased by using a glazed surface on the side facing the sun. Heat absorbing material can be used on the opposing side. The size of the heat-absorbing surface is more important than the diameter of the chimney. A large surface area allows for more effective heat exchange with the air necessary for heating by solar radiation. Heating of the air within the chimney will enhance convection, and hence airflow through the chimney. Openings of the vents in the chimney should face away from the direction of the prevailing wind.

To further maximize the cooling effect, the incoming air may be led through underground ducts before it is allowed to enter the building. The solar chimney can be improved by integrating it with a trombe wall. The added advantage of this design is that the system may be reversed during the cold season, providing solar heating instead.

A variation of the solar chimney concept is the solar attic. In a hot sunny climate the attic space is often blazingly hot in the summer. In a conventional building this presents a problem as it leads to the need for increased air conditioning. By integrating the attic space with a solar chimney, the hot air in the attic can be put to work. It can help the convection in the chimney, improving ventilation.\(^3\)

The use of a solar chimney may benefit natural ventilation and passive cooling strategies of buildings thus help reduce energy use, CO\(_2\) emissions and pollution in general. Potential benefits regarding natural ventilation and use of solar chimneys are:

- Improved ventilation rates on still, hot days
- Reduced reliance on wind and wind driven ventilation
- Improved control of air flow though a building
- Greater choice of air intake (i.e. leeward side of building)
- Improved air quality and reduced noise levels in urban areas
- Increased night time ventilation rates
- Allow ventilation of narrow, small spaces with minimal exposure to external elements

Potential benefits regarding passive cooling may include:

- Improved passive cooling during warm season (mostly on still, hot days)
- Improved night cooling rates
- Enhanced performance of thermal mass (cooling, cool storage)
- Improved thermal comfort (improved air flow control, reduced draughts)
**Precedent Study: The Environmental Building**

The Building Research Establishment (BRE) office building in Garston, incorporates solar assisted passive ventilation stacks as part of its ventilation strategy.

Designed by architects Feilden Clegg Bradley, the BRE offices aim to reduce energy consumption and CO\textsubscript{2} emissions by 30% from current best practice guidelines and sustain comfortable environmental conditions without the use of air conditioning. The passive ventilation stacks, solar shading, and hollow concrete slabs with embedded under floor cooling are key features of this building. Ventilation and heating systems are controlled by the building management system (BMS) while a degree of user override is provided to adjust conditions to occupants’ needs.

The building utilizes five vertical shafts as an integral part of the ventilation and cooling strategy. The main components of these stacks are a south facing glass-block wall, thermal mass walls and stainless steel round exhausts rising a few meters above roof level. The chimneys are connected to the curved hollow concrete floor slabs which are cooled via night ventilation. Pipes embedded in the floor can provide additional cooling utilizing groundwater.

On warm windy days air is drawn in through passages in the curved hollow concrete floor slabs. Stack ventilation naturally rising out through the stainless steel chimneys enhances the air flow through the building. The movement of air across the chimney tops enhances the stack effect. During warm, still days, the building relies mostly on the stack effect while air is taken from the shady north side of the building. Low-energy fans in the tops of the stacks can also be used to improve airflow.

Overnight, control systems enable ventilation paths through the hollow concrete slab removing the heat stored during the day and storing coolth for the following day. The exposed curved ceiling gives more surface area than a flat ceiling would, acting as a cool ‘radiator’, again providing summer cooling. Research based on actual performance measurements of the passive stacks found that they enhanced the cooling ventilation of the space during warm and still days and may also have the potential to assist night-time cooling due to their thermally massive structure.\textsuperscript{[4]}

**Passive down-draft cooltower**

A technology closely related to the solar chimney is the evaporative down-draft coiltower. In areas with a hot, arid climate this approach may contribute to a sustainable way to provide air conditioning for buildings.

Evaporation of moisture from the pads on top of the Toguna buildings built by the Dogon people of Mali, Africa contribute to the coolness felt by the men who rest underneath. The women's buildings on the outskirts of town are functional as more conventional solar chimneys.

The principle is to allow water to evaporate at the top of a tower, either by using evaporative cooling pads or by spraying water. Evaporation cools the incoming air, causing a downdraft of cool air that will bring down the temperature inside the building.\textsuperscript{[5]} Airflow can be increased by using a solar chimney on the opposite side of the building to help in venting hot air to the outside.\textsuperscript{[6]} This concept has been used for the Visitor Center of Zion National Park. The Visitor Center was designed by the High Performance Buildings Research of the National Renewable Energy Laboratory (NREL).

The principle of the downdraft coiltower has been proposed for solar power generation as well. (See Energy tower for more information.)
References


External links

- Sustainability at SCU - Tour Sustainable Features "The Commons on Kennedy Mall" [16]. Santa Clara University. Retrieved 2007-03-10. - includes simple description and graphic of solar chimney used in a "Green Demonstration Building".
- Ventilation Improved Pit (VIP) Latrines at the award winning [17] Druk White Lotus School [18], Ladakh, India

Notes

A garden solar lamp

Outdoor lamps are used for lawn and garden decorations. Indoor solar lamps are also used for general illumination (i.e. for garages and the solar panel is deattached of the LED lamp).

Solar lights are used for decoration, and come in a wide variety of designs. They are sometimes holiday-themed and may come in animal shapes. They are frequently used to mark, for example, footpaths or the areas around swimming pools.

Solar lamps recharge during the day. At dusk, they turn on (usually automatically, although some of them include a switch for on, off and automatic) and remain illuminated overnight, depending on how much sunlight they receive during the day. Discharging time is generally 8 to 10 hours.

Some solar lights do not provide as much light as a line-powered lighting system, but they are easily installed and maintained, and provide a cheaper alternative to wired lamps.
Solar cooker

A solar oven or solar cooker is a device which uses sunlight as its energy source. Because they use no fuel and they cost nothing to run, humanitarian organizations are promoting their use worldwide to help slow deforestation and desertification, caused by using wood as fuel for cooking. Solar cookers are a form of outdoor cooking and are often used in situations where minimal fuel consumption is important, or the danger of accidental fires is high.

Types

There are a variety of types of solar cookers: over 65 major designs and hundreds of variations of them. The basic principles of all solar cookers are:

• Concentrating sunlight: Some device, usually a mirror or some type of reflective metal, is used to concentrate light and heat from the sun into a small cooking area, making the energy more concentrated and therefore more potent.

• Converting light to heat: Any black on the inside of a solar cooker, as well as certain materials for pots, will improve the effectiveness of turning light into heat. A black pan will absorb almost all of the sun's light and turn it into heat, substantially improving the effectiveness of the cooker. Also, the better a pan conducts heat, the faster the oven will work.

• Trapping heat: Isolating the air inside the cooker from the air outside the cooker makes an important difference. Using a clear solid, like a plastic bag or a glass cover, will allow light to enter, but once the light is absorbed and converted to heat, a plastic bag or glass cover will trap the heat inside. This makes it possible to reach similar temperatures on cold and windy days as on hot days.
• Plastic Sheet: Uses plastic sheets to assure that liquids do not seep through into the oven. Also to prevent staining of the underlying sheet in the oven.

The top can usually be removed to allow dark pots containing food to be placed inside. One or more reflectors of shiny metal or foil-lined material may be positioned to bounce extra light into the interior of the oven chamber. Cooking containers and the inside bottom of the cooker should be dark-colored or black. Inside walls should be reflective to reduce radiative heat loss and bounce the light towards the pots and the dark bottom, which is in contact with the pots.

**Box cookers**

Insulator for the solar box cooker has to be able to withstand temperatures up to 150 °C (300 °F) without melting or off-gassing. Crumpled newspapers, wool, rags, dry grass, sheets of cardboard, etc. can be used to insulate the walls of the cooker, but since most of the heat escapes through the top glass or plastic, very little insulation in the walls is necessary. The transparent top is either glass, which is durable but hard to work with, or an oven cooking bag, which is lighter, cheaper, and easier to work with, but less durable. If dark pots and/or bottom trays cannot be located, these can be darkened either with flat-black spray paint (one that is non-toxic when warmed), black tempera paint, or soot from a fire.

The solar box cooker typically reaches a temperature of 150 °C (300 °F). This is not as hot as a standard oven, but still hot enough to cook food over a somewhat longer period of time. Food containing a lot of moisture cannot get much hotter than 100 °C (212 °F) in any case, so it is not always necessary to cook at the high temperatures indicated in standard cookbooks. Because the food does not reach too high a temperature, it can be safely left in the cooker all day without burning. It is best to start cooking before noon, though. Depending on the latitude and weather, food can be cooked either early or later in the day. The cooker can be used to warm food and drinks and can also be used to pasteurize water or milk. If you use an indoor stove for your actual cooking, you can save significant fuel by using the solar cooker to preheat the water to be used for cooking grains, soups, etc., to nearly boiling.

Solar box cookers can be made of locally available materials or be manufactured in a factory for sale. They range from small cardboard devices, suitable for cooking a single meal when the sun is shining, to wood and glass boxes built into the sunny side of a house. Although invented by Horace de Saussure, a Swiss naturalist, as early as 1767, solar box cookers have only gained popularity since the 1970s. These surprisingly simple and useful appliances are seen in growing numbers in almost every country of the world. An index of detailed wiki pages for each country can be found here.
Panel cookers

Panel solar cookers are very inexpensive solar cookers that use shiny panels to direct sunlight to a cooking pot that is enclosed in a clear plastic bag. A common model is the CooKit. Developed in 1994 by Solar Cookers International, it is often produced locally by pasting a reflective material, such as aluminum foil, onto a cut and folded backing, usually corrugated cardboard. It is lightweight and folds for storage. When completely unfolded, it measures about three feet by four feet (1 m by 1.3 m). Using materials purchased in bulk, the typical cost is about US$5. However, CooKits can also be made entirely from reclaimed materials, including used cardboard boxes and foil from the inside of cigarette boxes.\[5\]

The CooKit is considered a low-to-moderate temperature solar cooker, easily reaching temperatures high enough to pasteurize water or cook grains such as rice. On a sunny day, one CooKit can collect enough solar energy to cook rice, meat or vegetables to feed a family with up to three or four children. Larger families use two or more cookers.

To use a panel cooker, it is folded into a bowl shape. Food is placed in a dark-colored pot, covered with a tightly fitted lid. The pot is placed in a clear plastic bag and tied, clipped, or folded shut. The panel cooker is placed in direct sunlight until the food is cooked, which usually requires several hours for a full family-sized meal. For faster cooking, the pot can be raised on sticks or wires to allow the heated air to circulate underneath it.

High-temperature plastic bags (oven roasting bags) can be re-used for more than a month, but any plastic bag will work, if measures (such as sticks or wires) are taken to keep the bag from touching the hot cooking pot and melting to it. The purpose of the plastic bag is to trap heated air next to the pot; it may not be needed on very bright, windless days.

A recent development is the HotPot developed by US NGO Solar Household Energy, Inc. The cooking vessel in this cooker is a large clear pot with a clear lid into which a dark pot is suspended. This design has the advantage of very even heating since the sun is able to shine onto the sides and the bottom of the pot during cooking. An added advantage is that the clear lid allows the food to be observed while it is cooking without removing the lid. The HotPot provides an alternative to using plastic bags in a panel cooker.

Solar kettles

Solar kettles are solar thermal devices that can heat water to boiling point through the reliance on solar energy alone. Some of them use evacuated solar glass tube technology to capture, accumulate and store solar energy needed to power the kettle. Besides heating liquids, since the stagnating temperature of solar vacuum glass tubes is a high 220 °C (425 °F), solar kettles can also deliver dry heat and function as ovens and autoclaves. Moreover, since solar vacuum glass tubes work on accumulated rather than concentrated solar thermal energy, solar kettles only need diffused sunlight to work and needs no sun tracking at all. If solar kettles use solar vacuum tubes technologies, the vacuum insulating properties will keep previously heated water hot throughout the night e.g. the SK-TF [6].
Cookers with parabolic reflectors

Although these types of solar cookers can cook as well as a conventional oven, they are difficult to construct. Parabolic cookers reach high temperatures and cook quickly, but require frequent adjustment and supervision for safe operation. Several hundred thousand exist, mainly in China. They are especially useful for large-scale institutional cooking.

Parabolic reflectors that have their centres of mass coincident with their focal points are useful. They can be easily turned, to follow the sun's motions in the sky, rotating about an axis that passes through the focus. The cooking pot therefore stays stationary. If the paraboloid is axially symmetrical and is made of material of uniform thickness, this condition occurs if the depth of the paraboloid is $1.8478$ times its focal length.

Using two parabolic troughs to simulate a paraboloid

It is possible to use two parabolic troughs, curved in perpendicular directions, to bring sunlight to a point focus as does a paraboloidal reflector. The incoming light strikes one of the troughs, which sends it toward a line focus. The second trough intercepts the converging light and focuses it to a point. A diagram that shows the principle is at:

http://kmr.nada.kth.se/files/pointfocus/PointFocus-cyl-1+2-rays.jpg

Compared with a single paraboloid, using two partial troughs has important advantages. The troughs are "single curves", which can be made by bending a sheet of metal without any need for cutting, crumpling, or stretching. Also, the light that reaches the target - the cooking pot - is directed approximately downward, which reduces the danger of damage to the eyes of anyone nearby. On the other hand, there are disadvantages. More mirror material is needed, increasing the cost, and the light is reflected by two surfaces instead of one, which inevitably increases the amount that is lost.

Experimental arrangements of this kind have been made, and have worked well. The two troughs have been held in a fixed orientation relative to each other by being both fixed to a wooden frame. The whole assembly of frame and troughs has to be moved to track the sun as it moves in the sky. http://kmr.nada.kth.se/files/pointfocus/pics/Mirror-craddle.jpg

However, this idea does not yet seem to have been tried in a practical cooker.
**Cookers with spherical reflectors**

The Solar Bowl is a unique concentrating technology used by the Solar Kitchen in Auroville, India. Unlike nearly all concentrating technologies that use tracking reflector systems, the solar bowl uses a stationary spherical reflector. This reflector focuses light along a line perpendicular to the sphere's surface and a computer control system moves the receiver to intersect this line. Steam is produced in the solar bowl's receiver at temperatures reaching 150 °C and then used for process heat in the kitchen where 2,000 meals are prepared daily.[7]

**Hybrid cookers**

A hybrid solar oven is a solar box cooker equipped with a conventional electrical heating element for cloudy days or nighttime cooking. Hybrid solar ovens are therefore more independent. However, they lack the cost advantages of some other types of solar cookers, and so they have not caught on as much in third world countries where electricity or fuel sources simply do not exist.

A hybrid solar grill consists of an adjustable parabolic reflector suspended in a tripod with a movable grill surface.[8] These outperform solar box cookers in temperature range and cooking times. When solar energy is not available, the design uses any conventional fuel as a heat source, including gas, electricity, or wood.

**Using a solar cooker**

The different kinds of solar cookers have somewhat different methods for use, but most follow the same basic principles.

Food is prepared as it would be for an oven or stove top. Because food cooks faster when it is in smaller pieces, solar cookers usually cut the food into smaller pieces than they might otherwise.[9] For example, potatoes are usually cut into bite-sized pieces rather than being roasted whole.[10] For very simple cooking, such as melting butter or cheese, a lid may not be needed and the food may be placed on an uncovered tray or in a bowl. If several foods are to be cooked separately, then they are placed in different containers.

The container of food is placed inside the solar cooker, perhaps elevated on a brick, rocks, metal trivet, or other heat sink, and the solar cooker is placed in direct sunlight.[9] If the solar cooker is entirely in direct sunlight, then the shadow of the solar cooker will not overlap with the shadow of any nearby object. Foods that cook quickly may be added to the solar cooker later. Rice for a mid-day meal might be started early in the morning, with vegetables, cheese, or meat added to the solar cooker in the middle of the morning. Depending on the size of the solar cooker and the number and quantity of cooked foods, a family may use one or more solar cookers.

The solar cooker is turned towards the sun and left until the food is cooked. Unlike cooking on a stove or over a fire, which may require more than an hour of constant supervision, food in a solar cooker is generally not stirred or turned over, both because it is unnecessary and because opening the solar cooker allows the trapped heat to escape and thereby slows the cooking process. If wanted, the solar cooker may be checked every one to two hours, to turn the cooker to face the sun more precisely and to ensure that shadows from nearby buildings or plants have not blocked the sunlight. If the food will be left untended for many hours during the day, then the solar cooker is often turned to face the point where the sun will be when it is higher in the sky, instead of towards its current position.[11]
The cooking time depends primarily on the equipment being used, the amount of sunlight at the time, and the quantity of food that needs to be cooked. Air temperature, wind, and latitude also affect performance. Food cooks faster in the two hours before and after the local solar noon than it does in either the early morning or the late afternoon. Larger quantities of food, and food in larger pieces, take longer to cook. As a result, only general figures can be given for cooking time. For a small solar panel cooker, it might be possible to melt butter in 15 minutes, to bake cookies in 2 hours, and to cook rice for four people in 4 hours. However, depending on the local conditions and the solar cooker type, these projects could take half as long, or twice as long.

It is difficult to burn food in a solar cooker. Food that has been cooked even an hour longer than necessary is usually indistinguishable from minimally cooked food. The exception to this rule is some green vegetables, which quickly change from a perfectly cooked bright green to olive drab, while still retaining the desirable texture. For most foods, such as rice, the typical person would be unable to tell how it was cooked from looking at the final product. There are some differences, however: Bread and cakes brown on their tops instead of on bottom. Compared to cooking over a fire, the food does not have a smoky flavor.

**Advantages**

Solar ovens can be used to prepare anything that can be made in a conventional oven or stove—from baked bread to steamed vegetables to roasted meat. Since solar ovens are placed outside, they do not contribute unwanted heat inside houses.

Solar cookers use no fuel, which means that their users do not need to fetch or pay for firewood, gas, electricity, or other fuels.

Solar cookers do not produce any smoke. The indoor concentration of health-damaging pollutants from a typical wood-fired cooking stove creates carbon monoxide and other noxious fumes at anywhere between seven and 500 times over the allowable limits. Fire-based cooking also produces ashes and soot, which make the home dirtier.

Unlike cooking over an open fire, children cannot be burned by touching solar cookers, which are made from the cardboard or plastic and do not get hot. Unlike all fuel-based cooking arrangements, solar cookers are not fire hazards.

**Disadvantages**

Solar cooking system provide hot food during or shortly after the hottest part of the day, when people are less inclined to eat a hot meal. However, a thick pan that conducts heat slowly (such as cast iron) will lose heat at a slower rate, and that, combined with the insulation of the oven or an insulated basket, can be used to keep food warm well into the evening.

Solar cookers take longer time to cook food compared to an oven. Using a solar oven therefore requires that food preparation be started several hours before the meal. However, it requires less hands-on time cooking, so this is often considered a reasonable trade-off.

Cooks may need to learn special cooking techniques to cook common foods, such as fried eggs or flatbreads like chapatis and tortillas. It may not be possible to safely or completely cook some thick foods, such as large roasts, loaves of bread, or pots of soup, particularly in small panel cookers; the cook may need to divide these into smaller portions before cooking.

Solar cookers are less usable in cloudy or rainy weather, so some fuel-based backup heat source must still be available to cook food at these times. Some solar cooker designs are affected by strong winds, which can slow the cooking process, cool the food, and disturb the reflector.
Solar cooking projects

Bakeries in Lesotho

Michael Hönes of Germany has established solar cooking in Lesotho, enabling small groups of women to build up community bakeries using solar ovens.[13]

Darfur refugee camps

Cardboard, aluminum foil, and plastic bags for well over 10,000 solar cookers have been donated to the Iridimi refugee camp and Touloum refugee camps in Chad by the combined efforts of the Jewish World Watch, the Dutch foundation KoZon[14], and Solar Cookers International. The refugees construct the cookers themselves, using the donated supplies and locally purchased Arabic gum,[15] and use them for midday and evening meals. The goal of this project was to reduce the Darfuri women's need to leave the relative safety of the camp to gather firewood, which exposed them to a high risk of being beaten, raped, kidnapped, or murdered.[16] [17] [18] It has also significantly reduced the amount of time women spend tending open fires each day, with the results that they are healthier and they have more time to grow vegetables for their families and make handicrafts for export.[15] By 2007, the Jewish World Watch had trained 4,500 women, and had provided 10,000 solar cookers to refugees. The project has also reduced the number of foraging trips by as much as 70 percent, thus reducing the number of attacks.[19]

Indian solar cooker village

Bysanivaripalle, a silk-producing village that is 125 km (80 mi) northwest of Tirupati in the Indian state of in Andhra Pradesh, is the first of its kind: an entire village that uses only solar cooking. Intersol, an Austrian non-governmental organisation, sponsored the provision of powerful "Sk-14" parabolic solar cookers in 2004.[20]

Gaza

Some Gazans have started to make solar cookers in order to cook their meals, due to a lack of cooking fuels. The cooker is made from cement bricks, mud mixed with straw and two sheets of glass. About 40 to 45 Palestinian households are said to have started using these solar cookers.[21]

References

Ground-coupled heat exchanger

A **ground-coupled heat exchanger** is an underground heat exchanger loop that can capture or dissipate heat to or from the ground. They use the Earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial uses. If building air is blown through the heat exchanger for heat recovery ventilation, they are called **earth tubes** (also known as earth cooling tubes or earth warming tubes) in Europe or **earth-air heat exchangers** (EAHE or EAHX) in North America. These systems are known by several other names, including: air-to-soil heat exchanger, earth channels, earth canals, earth-air tunnel systems, ground tube heat exchanger, hypocausts, subsoil heat exchangers, underground air pipes, and others.

Earth tubes are often a viable and economical alternative or supplement to conventional central heating or air conditioning systems since there are no compressors, chemicals or burners and only blowers are required to move the air. These are used for either partial or full cooling and/or heating of facility ventilation air. Their use can help buildings meet the German Passive House standards or the North American LEED's (Leadership in Energy and Environmental Design) Green Building rating system.

Earth-air heat exchangers have been used in agricultural facilities (animal buildings) and horticultural facilities (greenhouses) in the United States over the past several decades and have been used in conjunction with solar chimneys in hot arid areas for thousands of years, probably beginning in the Persian Empire. Implementation of these systems in Austria, Denmark, Germany, and India has become fairly common since the mid-1990s, and is slowly being adopted into North America.

Ground-coupled heat exchanger may also use water or antifreeze as a heat transfer fluid, often in conjunction with a geothermal heat pump. See, for example downhole heat exchangers.[1] The rest of this article deals primarily with earth-air heat exchangers or earth tubes.

**Design**

Earth-air heat exchangers can be analyzed for performance with several software applications using weather gage data. These software applications include GAEA, AWADUKT Thermo, EnergyPlus, L-EWTSim, WKM, and others. However, numerous earth-air heat exchanger systems have been designed and constructed improperly, and failed to meet design expectations. Earth-air heat exchangers appear best suited for air pretreatment rather than for full heating or cooling. Pretreatment of air for an air-source heat pump or ground-source heat pump often provides the best economic return on investment, with simple payback often achieved within one year after installation.

Most systems are usually constructed from 100 to 600 mm (4 to 24 inch) diameter.
Ground-coupled heat exchanger

smooth-walled (so they do not easily trap condensation moisture and mold), rigid or semi-rigid plastic, plastic-coated metal pipes or plastic pipes coated with inner antimicrobial layers, buried 1.5 to 3 m (5 to 10 ft) underground where the ambient earth temperature is typically 10 to 23 °C (50-73 °F) all year round in the temperate latitudes where most humans live. Ground temperature becomes more stable with depth, and between about 3 m and 12 m (10 ft and 40 ft) the soil is steadily at - or close to - the median annual air temperature.

Smaller diameter tubes require more energy to move the air and have less earth contact surface area. Larger tubes permit a slower airflow, which also yields more efficient energy transfer and permits much higher volumes to be transferred, permitting more air exchanges in a shorter time period, when, for example, you want to clear the building of objectionable odors or smoke. It is more efficient to pull air through a long tube than to push it with a fan. A solar chimney can use natural convection (warm air rising) to create a vacuum to draw filtered passive cooling tube air through the largest diameter cooling tubes. Natural convection may be slower than using a solar-powered fan. Sharp 90-degree angles should be avoided in the construction of the tube - two 45-degree bends produce less-turbulent, more efficient air flow. While smooth-wall tubes are more efficient in moving the air, they are less efficient in transferring energy.

There are three configurations, a closed loop design, an open 'fresh air' system or a combination:

- **Closed loop system**: Air from inside the home or structure is blown through a U-shaped loop(s) of typically 30 to 150 m (100 to 500 ft) of tube(s) where it is moderated to near earth temperature before returning to be distributed via ductwork throughout the home or structure. The closed loop system can be more effective (during air temperature extremes) than an open system, since it cools and recools the same air.

- **Open system**: outside air is drawn from a filtered air intake (Minimum Efficiency Reporting Value MERV 8+ air filter is recommended). The cooling tubes are typically 30 m (100 ft) long (or more) of straight tube into the home. An open system combined with energy recovery ventilation can be nearly as efficient (80-95%) as a closed loop, and ensures that entering fresh air is filtered and tempered.

- **Combination system**: This can be constructed with dampers that allow either closed or open operation, depending on fresh air ventilation requirements. Such a design, even in closed loop mode, could draw a quantity of fresh air when an air pressure drop is created by a solar chimney, clothes dryer, fireplace, kitchen or bathroom exhaust vents. It is better to draw in filtered passive cooling tube air than unconditioned outside air.

Single-pass earth air heat exchangers offer the potential for indoor air quality improvement over conventional systems by providing an increased supply of outdoor air. In some configurations of single-pass systems, a continuous supply of outdoor air is provided. This type of system would usually include one or more ventilation heat recovery units.
Safety

If humidity and associated mold colonization is not addressed in system design, occupants may face health risks. At some sites, the humidity in the earth tubes may be controlled simply by passive drainage if the water table is sufficiently deep and the soil has relatively high permeability. In situations where passive drainage is not feasible or needs to be augmented for further moisture reduction, active (dehumidifier) or passive (desiccant) systems may treat the air stream.

Formal research indicates that earth-air heat exchangers reduce building ventilation air pollution. Rabindra (2004) states, "The tunnel [earth-Air heat exchanger] 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".

Whether using earth tubes with or without antimicrobial material, it is extremely important that the underground cooling tubes have an excellent condensation drain and be installed at a 2-3 degree grade to ensure the constant removal of condensed water from the tubes. When implementing in a house without a basement on a flat lot, an external condensation tower can be installed at a depth lower than where the tube enters into the house and at a point close to the wall entry. The condensation tower installation requires the added use of a condensate pump in which to remove the water from the tower. For installations in houses with basements, the pipes are graded so that the condensation drain located within the house is at the lowest point. In either installation, the tube must continually slope towards either the condensation tower or the condensation drain. The inner surface of the tube, including all joints must be smooth to aid in the flow and removal of condensate. Corrugated or ribbed tubes and rough interior joints must not be used. Joints connecting the tubes together must be tight enough to prevent water or gas infiltration. In certain geographic areas, it is important that the joints prevent Radon gas infiltration. Porous materials like uncoated concrete tubes cannot be used. Ideally, Earth Tubes with antimicrobial inner layers should be used in installations to inhibit the potential growth of molds and bacteria within the tubes.

Effectiveness

Implementations of earth-air heat exchangers for either partial or full cooling and/or heating of facility ventilation air have had mixed success. The literature is, unfortunately, well populated with over-generalizations about the applicability of these systems - both supportive and unsupportive. A key aspect of earth-air heat exchangers is the passive nature of operation and consideration of the wide variability of conditions in natural systems.

Earth-air heat exchangers can be very cost effective in both up-front/capital costs as well as long-term operation and maintenance costs. However, this varies widely depending on the location latitude, altitude, ambient Earth temperature, climatic temperature-and-relative-humidity extremes, solar radiation, water table, soil type (thermal conductivity), soil moisture content and the efficiency of the building's exterior envelope design / insulation. Generally, dry-and-low-density soil with little or no ground shade will yield the least benefit, while dense damp soil with considerable shade should perform well. A slow drip watering system may improve thermal performance. Damp soil in contact with the cooling tube conducts heat more efficiently than dry soil.

Earth cooling tubes are much less effective in hot humid climates (like Florida) where the ambient temperature of the earth approaches human comfort temperature. The higher the ambient temperature of the earth, the less effective they
are for cooling and dehumidification. However, they can be used to partially cool and dehumidify the replacement fresh air intake for passive-solar thermal buffer zone areas like the laundry room, or a solarium / greenhouse, especially those with a hot tub, swim spa, or indoor swimming pool, where warm humid air is exhausted in the summer, and a supply of cooler drier replacement air is desired.

Not all regions and sites are suitable for earth-air heat exchangers. Conditions which may hinder or preclude proper implementation include shallow bedrock, high water table, and insufficient space, among others. In some areas, only cooling or heating may be afforded by earth-air heat exchangers. In these areas, provision for thermal recharge of the ground must especially be considered. In dual function systems (both heating and cooling), the warm season provides ground thermal recharge for the cool season and the cool season provides ground thermal recharge for the warm season, though overtaxing the thermal reservoir must be considered even with dual function systems.

Renata Limited, a prominent pharmaceutical company in Bangladesh, tried out a pilot project trying to find out whether they could use the Earth Air Tunnel technology to complement the conventional air conditioning system. Concrete pipes (total length 60 feet, inner diameter 9 inches, outer diameter 11 inches) were placed at a depth of 9 feet underground and a blower of 1.5 kW rated power was employed. The underground temperature at that depth was found to be around 28°C. The mean velocity of air in the tunnel was about 5 m/s. The Coefficient of Performance (COP) of the underground heat exchanger thus designed was poor ranging from 1.5-3. The results convinced the authorities that in hot and humid climates, it is unwise to implement the concept of Earth-Air heat exchanger. The cooling medium (earth itself) being at a temperature approaching that of the ambient environment happens to be the root cause of the failure of such principles in hot, humid areas (parts of Southeast Asia, Florida in the U.S.A. etc.). However, investigators from places like Britain and Turkey have reported very encouraging COPs—well above 20. The underground temperature seems to be of prime importance when planning an Earth-Air heat exchanger.

Environmental impact

In the context of today's diminishing fossil fuel reserves, increasing electrical costs, air pollution and global warming, properly-designed earth cooling tubes offer a sustainable alternative to reduce or eliminate the need for conventional compressor-based air conditioning systems, in non-tropical climates. They also provide the added benefit of controlled, filtered, temperate fresh air intake, which is especially valuable in tight, well-weatherized, efficient building envelopes.

Water to earth

An alternative to the earth-to-air heat exchanger is the "water" to earth heat exchanger. This is typically similar to a geothermal heat pump tubing embedded horizontally in the soil (or could be a vertical sonde) to a similar depth of the earth-air heat exchanger. It uses approximately double the length of pipe of 35 mm diameter, e.g., around 80 m compared to an EAHX of 40 m. A heat exchanger coil is placed before the air inlet of the heat recovery ventilator. Typically a brine liquid (heavily salted water) is used as the heat exchanger fluid.

Many European installations are now using this setup due to the ease of installation. No fall or drainage point is required and it is safe because of the reduced risk from mold.
References


External links

• Small home system using 4” earth air pipes - 7 year retrospective: Vermont, USA (http://sugarmtnfarm.com/blog/2008/09/earth-air-tubes.html)

Seasonal thermal store

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

Types of seasonal thermal storage system

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

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

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

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

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

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

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

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

Two basic techniques can be employed:

- In the Passive Annual Heat Storage (PAHS)\(^1\) and similar direct solar gain systems, solar heat is directly captured by the structure's spaces (through windows and other surfaces) in summer and then passively transferred (by conduction) through its floors, walls (and, sometimes, roof) into adjoining thermally-buffered soil. It is then passively returned (by conduction and radiation) as those spaces cool in winter. These techniques were advocated in Daniel Geery's 1982 book *Solar Greenhouses: Underground* and John Hait's 1983 *Passive Annual Heat Storage - Improving the Design of Earth Shelters*.

- The Annualized Geothermal Solar (AGS) concept\(^2\) involves the capture of heat by isolated solar gain devices (rather than the building structure). From here it is deposited in the earth (or other storage masses or mediums) adjoining the building using active or passive technology. The depth at which the heat is deposited is calculated (according to soil type) to provide a controlled 6-month heat-return time-lag to the building through conduction as the building cools. This alternative was posed by Don Stephens.

These concepts are compared in greater detail at: www.greenshelter.org\(^3\).

Warm-temperature seasonal heat stores

Warm-temperature heat stores are a development of low-temperature stores in that solar collectors are used to capture surplus heat in summer and actively raise the temperature of large thermal banks of soil so that heat can be extracted more easily (and more cheaply) in winter. Interseasonal Heat Transfer\(^4\) uses water circulating in pipes embedded in asphalt solar collectors to transfer heat to Thermal Banks\(^5\) beneath the insulated foundation of buildings. A ground source heat pump is used in winter to extract the warmth from the Thermal Bank to provide space heating via underfloor heating. A high Coefficient of Performance is obtained because the heat pump starts with a warm temperature of 25°C (77°F) from the thermal store, instead of a cold temperature of 10°C (50°F) from the ground\(^6\).

High-temperature seasonal thermal stores

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

Individual structures

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

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

The more recent "Zero Heating Energy House", completed in 1997 in Berlin as part of the IEA Task 13 low energy housing demonstration project, stores water at temperatures up to 90 °C (195 °F) inside a 20m³ (700 cubic feet) tank in the basement\(^7\), and is now one of a growing number of similar properties.
Another similar example was set up in Ireland in 2009. The *solar seasonal store*\(^8\) consists of a 23m\(^3\) (23,000 liters) tank, filled with water\(^9\), which was installed in the ground, heavily insulated all around, to store heat from evacuated solar tubes during the year. The system was installed as an experiment to heat the *world's first standardised pre-fabricated passive house*\(^{10}\) in Galway, Ireland. The aim was to find out if this heat would be sufficient to eliminate the need for any electricity in the already highly efficient home during the winter months. The system is monitored and documented by a research team from The University of Ulster and the results will be included in part of a PhD thesis.

**Neighbourhoods**

At the neighbourhood level, the Wiggenhausen-Süd solar development at Friedrichshafen has received international attention. This features a 12,000 m\(^3\) (424,000 cubic feet) reinforced concrete thermal store linked to 4,300m\(^2\) (46,000 square feet) of solar collectors, which will supply the 570 houses with around 50% of their heating and hot water\(^{11}\).

A different approach is illustrated by the Drake Landing Solar Community development in Okotoks, Alberta. This community consists of 52 houses built to the stringent R-2000 building code. Here the store is created from the ground itself, with solar heated water pumped into a Borehole Thermal Energy Storage (BTES)\(^{12}\) system. It consists of 144 boreholes, each 37 m (121 ft) deep, which heat the ground to a maximum of around 90 °C (195 °F)\(^{13}\). During the winter, the hot water flows from the BTES field to the houses through a distribution network. Once inside the house, it flows through coil units, over which air is blown. The hot air then heats the house. Each house also has an independent solar thermal system installed on its sloped roof to provide domestic hot water. This system has a 90% solar fraction, meaning 90% of the energy required to heat the air and water within the community is provided by the sun. This results in a reduction of over 5 tonnes of CO\(_2\) equivalent, per house.

**Greenhouses**

Thermal storage (sometimes referred to as heat and cold storage) is also used extensively for applications as the heating of greenhouses.\(^{14}\) In summer, the greenhouse is cooled with ground water, pumped from an aquifer, which is the cold source. This heats the water, which is then stored by the system in a warm source. In winter, the warm water is pumped up to supply heat. The now cooled water is returned to the cold source.\(^{14}\)\(^{15}\)\(^{16}\)\(^{17}\)\(^{18}\) The combination of cold and heat storage with heat pumps has an additional benefit for greenhouses, as it may be combined with humidification. In the (closed circuit) system, the hot water is stored in one aquifer, while the cold water is stored in another. The water is used to heat or cool the air, which is moved by fans.\(^{19}\) Such a system can be completely automated.\(^{20}\)
References

[4] Interseasonal Heat Transfer (http://www.icax.co.uk)

External links

• December 2005, Seasonal thermal store being fitted in an ENERGETIKhaus100 (http://www.energetikhaus100.de/tagebuch.html)
• Earth Notes: Milk Tanker Thermal Store with Heat Pump (http://www.earth.org.uk/milk-tanker-thermal-store.html)
• Heliostats used for concentrating solar power (photos) (http://www.practicalsolar.com/photos/photos.html)
• Wofati Eco building with annualized thermal inertia (http://www.richsoil.com/wofati.jsp)
Absorption refrigerator

An **absorption refrigerator** is a refrigerator that uses a heat source (e.g., solar, kerosene-fueled flame) to provide the energy needed to drive the cooling system. Absorption refrigerators are a popular alternative to regular compressor refrigerators where electricity is unreliable, costly, or unavailable, where noise from the compressor is problematic, or where surplus heat is available (e.g., from turbine exhausts or industrial processes). For example, absorption refrigerators powered by heat from the combustion of liquefied petroleum gas are often used for food storage in recreational vehicles.

Both absorption and compressor refrigerators use a refrigerant with a very low boiling point (less than 0 °F/−18 °C). In both types, when this refrigerant evaporates (boils), it takes some heat away with it, providing the cooling effect. The main difference between the two types is the way the refrigerant is changed from a gas back into a liquid so that the cycle can repeat. An absorption refrigerator changes the gas back into a liquid using a different method that needs only heat, and has no moving parts. In comparison, a compressor refrigerator uses an electrically-powered compressor to increase the pressure on the gas, and then condenses the hot high pressure gas back to a liquid by heat exchange with a coolant (usually air). Once the high pressure gas has cooled and condensed into a liquid, it passes through an orifice which creates a pressure drop, which causes the liquid to evaporate. The evaporation process absorbs heat, and the temperature of the refrigerant drops to its boiling point at the (now) low pressure. The other difference between the two types is the refrigerant used. Compressor refrigerators typically use an HCFC or HFC, while absorption refrigerators typically use ammonia.

The standard for the absorption refrigerator is given by the ANSI/AHRI standard 560-2000[^1].

**Principles**

Absorptive refrigeration uses a source of heat to provide the energy needed to drive the cooling process. The most common use is in commercial climate control and cooling of machinery. Absorptive refrigeration is also used to air-condition buildings using the waste heat from a gas turbine or water heater. This use is very efficient, since the gas turbine produces electricity, hot water and air-conditioning (called Trigeneration).

The absorption cooling cycle can be described in three phases:

1. **Evaporation**: A liquid refrigerant evaporates in a low partial pressure environment, thus extracting heat from its surroundings — the refrigerator.

2. **Absorption**: The gaseous refrigerant is absorbed — dissolved into another liquid - reducing its partial pressure in the evaporator and allowing more liquid to evaporate.

3. **Regeneration**: The refrigerant-laden liquid is heated, causing the refrigerant to evaporate out. It is then condensed through a heat exchanger to replenish the supply of liquid refrigerant in the evaporator.
Simple salt and water system

A simple absorption refrigeration system common in large commercial plants uses a solution of lithium bromide salt and water. Water under low pressure is evaporated from the coils that are being chilled. The water is absorbed by a lithium bromide/water solution. The water is driven off the lithium bromide solution using heat.

Water spray absorption refrigeration

Another variant, depicted to the right, uses air, water, and a salt water solution. The intake of warm, moist air is passed through a sprayed solution of salt water. The spray lowers the humidity but does not significantly change the temperature. The less humid, warm air is then passed through an evaporative cooler, consisting of a spray of fresh water, which cools and re-humidifies the air. Humidity is removed from the cooled air with another spray of salt solution, providing the outlet of cool, dry air.

The salt solution is regenerated by heating it under low pressure, causing water to evaporate. The water evaporated from the salt solution is re-condensed, and rerouted back to the evaporative cooler.

Single pressure absorption refrigeration

A single-pressure absorption refrigerator uses three substances: ammonia, hydrogen gas, and water. At standard atmospheric conditions, ammonia is a gas with a boiling point of -33°C, but a single-pressure absorption refrigerator is pressurised to the point where the ammonia is a liquid. The cycle is closed, with all hydrogen, water and ammonia collected and endlessly reused.

The cooling cycle starts with liquefied ammonia entering the evaporator at room temperature. The ammonia is mixed in the evaporator with hydrogen. The partial pressure of the hydrogen is used to regulate the total pressure, which in turn regulates the vapour pressure and thus the boiling point of the ammonia. The ammonia boils in the evaporator, providing the cooling required.

The next three steps exist to separate the gaseous ammonia and the hydrogen. First, in the absorber, the mixture of gasses enters the bottom of an uphill series of tubes, into which water is added at the top. The ammonia dissolves in the water, producing a mixture of ammonia solution and hydrogen. The hydrogen is collected at the top of the absorber, with the ammonia solution collected at the bottom.

The second step is to separate the ammonia and water. In the generator, heat is applied to the solution, to distill the ammonia from the water. Some water remains with the ammonia, in the form of vapour and bubbles. This is dried in the final separation step, called the separator, by passing it through an uphill series of twisted pipes with minor obstacles to pop the bubbles, allowing the collected water to drain back to the generator.

Finally the pure ammonia gas enters the condenser. In this heat exchanger, the hot ammonia gas is cooled to room temperature and hence condenses to a liquid, allowing the cycle to restart.
History

Absorption cooling was invented by the French scientist Ferdinand Carré in 1858. The original design used water and sulfuric acid.

In 1922 Baltzar von Platen and Carl Munters, while they were still students at the Royal Institute of Technology in Stockholm, Sweden, enhanced the principle with a 3 fluids configuration. This "Platen-Munters" design can operate without a pump.

Commercial production began in 1923 by the newly formed company AB Arctic, which was bought by Electrolux in 1925. In the 60s the absorption refrigeration saw a renaissance due to the substantial demand for refrigerators for caravans. AB Electrolux established a subsidiary in the U.S. named Dometic Sales Corporation. The company marketed refrigerators for caravans under the Dometic brand. In 2001 Electrolux sold most of its Leisure Products line to the venture-capital company EQT. The Dometic Group was created.

In 1926 Albert Einstein and his former student Leó Szilárd proposed an alternative design known as Einstein refrigerator.

In 2007, Adam Grosser presented his research of a new, very small, "intermittent absorption" refrigeration system for use in third world countries at the TED Conference. The refrigerator is a small unit placed over a campfire, that can later be used to cool 3 gallons of water to just above freezing for 24 hours in a 30 degree Celsius environment.

References

[2] Eric Granryd & Björn Palm, Refrigerating engineering, Stockholm Royal Institute of Technology, 2005, see chap. 4-3

External links

• Arizona Energy (http://www.arizonaenergy.org/AltEnergyClub/SPECIAL AMMONIA REFRIGERATOR. htm) Explanation with diagrams
• Air Conditioning Thermodynamics (http://www.arb.ca.gov/cc/ccms/documents/august_tsd/ ac_thermo_august.pdf), published by the California EPA, Air Resources Board
• Thermally-Activated Machines Refrigeration Cycle (http://www.northeastchp.org/nac/businesses/ refrigeration.htm): Northeast CHP Application Center at the University of Massachusetts Amherst and Pace University
Annualized geo solar

**Annualized Geo-Solar** enables passive solar heating in even cold, foggy north temperate areas. It uses the ground under or around a building as thermal mass to heat and cool the building. After a designed, conductive thermal lag of 6 months the heat is returned to, or removed from, the inhabited spaces of the building. In hot climates, exposing the collector to the frigid night sky in winter can cool the building in summer.[1]

The six month thermal lag is provided by about three meters (ten feet) of dirt. A six-meter-wide (20ft) buried skirt of insulation around the building keeps rain and snow melt out of the dirt, which is usually under the building. The dirt does radiant heating and cooling through the floor or walls. A thermal siphon moves the heat between the dirt and the solar collector. The solar collector may be a sheet-metal compartment in the roof, or a wide flat box on the side of a building or hill. The siphons may be made from plastic pipe and carry air. Using air prevents water leaks and water-caused corrosion. Plastic pipe doesn't corrode in damp earth, as metal ducts can.

AGS heating systems typically consist of:

- A very well-insulated, energy efficient, eco-friendly living space;
- Heat captured in the summer months from a sun-warmed sub-roof or attic space, a sunspace or greenhouse, a ground-based, flat-plate, thermosyphon collector, or other solar-heat collection device;
- Heat transported from the collection source into (typically) the earth mass under the living space (for storage), this mass surrounded by a sub-surface perimeter "cape" or "umbrella" providing both insulation from easy heat-loss back up to the outdoors air and a barrier against moisture migration through that heat-storage mass;
- A high-density floor whose thermal properties are designed to radiate heat back into the living space, but only after the proper sub-floor-insulation-regulated time-lag;
- A control-scheme or system which activates (often PV-powered) fans and dampers, when the warm-season air is sensed to be hotter in the collection area(s) than in the storage mass, or allows the heat to be moved into the storage-zone by passive convection (often using a solar chimney and thermally-activated dampers.)

Usually it requires several years for the storage earth-mass to fully preheat from the local at-depth soil temperature (which varies widely by region and site-orientation) to an optimum Fall level at which it can provide up to 100% of the heating requirements of the living space through the winter. This technology continues to evolve, with a range of variations (including active-return devices) being explored.[2] The listserve where this innovation is most often discussed is "Organic Architecture" at Yahoo.

This system is almost exclusively deployed in northern Europe. One system has been built at Drake Landing in North America.

**References**


Article Sources and Contributors
