

Green Building and Low Energy Building

Engineering



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WORLD TECHNOLOGIES

Table of Contents

- Chapter 1 - Green Building
- Chapter 2 - Sustainable Design
- Chapter 3 - Sustainable Architecture
- Chapter 4 - Examples of Sustainable Architecture
- Chapter 5 - Indoor Air Quality in Green Building Architecture
- Chapter 6 - Building Material
- Chapter 7- Low-Energy House
- Chapter 8 - Zero-Energy Building
- Chapter 9 - Passive House
- Chapter 10 - Heat Recovery Ventilation
- Chapter 11 - Building Automation
- Chapter 12 - Over-Illumination
- Chapter 13 - Compact Fluorescent Lamp
- Chapter 14 - Cool Roof
- Chapter 15 - Green Roof

Green Building



US EPA Kansas City Science & Technology Center. This facility features the following green attributes:

- *LEED 2.0 Gold certified
- *Green Power
- *Native Landscaping

Green building (also known as **green construction** or **sustainable building**) is the practice of creating structures and using processes that are 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.

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

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. 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 use, energy and water consumption, and air and atmosphere alteration. Considering the statistics, reducing the amount of natural resources buildings consume and the amount of pollution given off is seen as crucial for future sustainability, according to EPA. The building sector alone accounts for 30-40 percent of global energy use. Over 80 percent of the environmentally harmful emissions from buildings are due to energy consumption during the times when the buildings are in use. Green building does not typically include the concept of renovations although many of the 2050 homes are already built and UK homes account for 30% of UK Carbon Emissions. Domestic energy improvement targets of 20% between now and 2010, and again by a further 20% between 2010 and 2020 have been suggested by the UK government. The environmental impact of buildings is often underestimated, while the perceived costs of green buildings are overestimated. A recent survey by the World Business Council for Sustainable Development finds that green costs are overestimated by 300 percent, as key players in real estate and construction estimate the additional cost at 17 percent above conventional construction, more than triple the true average cost difference of about 5 percent. According to the UK Green Building Council, existing buildings account for 17% of the UK's total carbon emissions.

Goals of green building



the Blu Homes mkSolaire, a green building designed by Michelle Kaufmann.

The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s. 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 rapidly renewable plant materials like bamboo (because bamboo grows quickly) and straw, lumber from forests certified to be sustainably managed, ecology blocks, 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) , etc.) The EPA (Environmental Protection Agency) also suggests using recycled industrial goods, such as coal combustion products, foundry sand, and demolition debris in construction projects. 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.

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 VOC's 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.

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. 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. 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.

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. The stigma is between the knowledge of up-front cost 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. 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. 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.

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 / Green Star
-  Brazil: AQUA / LEED Brasil
-  Canada: LEED Canada / Green Globes
-  China: GBAS
-  Finland: PromisE
-  France: HQE
-  Germany: DGNB / CEPHEUS
-  Hong Kong: HKBEAM
-  India: Indian Green Building Council (IGBC) / GRIHA

-  Italy: Protocollo Itaca / Green Building Council Italia
-  Japan: CASBEE
-  Malaysia: GBI Malaysia
-  Mexico: LEED Mexico
-  Netherlands: BREEAM Netherlands
-  New Zealand: Green Star NZ
-  Philippines: BERDE / Philippine Green Building Council
-  Portugal: Lider A
-  Singapore: Green Mark
-  South Africa: Green Star SA
-  Spain: VERDE
-  Switzerland: Minergie
-  United States: LEED / Living Building Challenge / Green Globes / Build it Green / NAHB NGBS / International Green Construction Code International Green Construction Code (IGCC)
-  United Kingdom: BREEAM
-  United Arab Emirates: Estidama
-  IAPGSA Pakistan Institute of Architecture Pakistan Green Sustainable Architecture

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.

UNEP and Climate change

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

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

Agenda 21

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

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.

Sustainable Design

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

Intentions

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

Applications

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

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

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

old ones; that physical impacts of delivering goods and services are not localized, but are distributed throughout the economies; and that the scale of resource use is growing and not stabilizing.

Sustainable Design Principles

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

- Low-impact materials: choose non-toxic, sustainably produced or recycled materials which require little energy to process
- Energy efficiency: use manufacturing processes and produce products which require less energy
- Quality and durability: longer-lasting and better-functioning products will have to be replaced less frequently, reducing the impacts of producing replacements
- Design for reuse and recycling: "Products, processes, and systems should be designed for performance in a commercial 'afterlife'."
- Design Impact Measures for total carbon footprint and life-cycle assessment for any resource used are increasingly required and available. Many are complex, but some give quick and accurate whole-earth estimates of impacts. One measure estimates any spending as consuming an average economic share of global energy use of 8,000btu per dollar and producing CO₂ at the average rate of 0.57 kg of CO₂ per dollar (1995 dollars US) from DOE figures.
- Sustainable Design Standards and project design guides are also increasingly available and are vigorously being developed by a wide array of private organizations and individuals. There is also a large body of new methods emerging from the rapid development of what has become known as 'sustainability science' promoted by a wide variety of educational and governmental institutions.
- Biomimicry: "redesigning industrial systems on biological lines ... enabling the constant reuse of materials in continuous closed cycles..."
- Service substitution: shifting the mode of consumption from personal ownership of products to provision of services which provide similar functions, e.g., from a private automobile to a carsharing service. Such a system promotes minimal resource use per unit of consumption (e.g., per trip driven).
- Renewability: materials should come from nearby (local or bioregional), sustainably managed renewable sources that can be composted when their usefulness has been exhausted.
- Healthy Buildings: sustainable building design aims to create buildings that are not harmful to their occupants nor to the larger environment. An important emphasis is on indoor environmental quality, especially indoor air quality.
- Robust eco-design: robust design principles are applied to the design of a pollution sources).

Bill of Rights for the Planet

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

The Bill of Rights:

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

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

- Placing environmental and social sustainability at the core of practices and professional responsibilities
- Developing and continually improving practices, procedures, products, services, and standards for sustainable design

- Educating the building industry, clients, and the general public about the importance of sustainable design
- Working to change policies, regulations, and standards in government and business so that sustainable design will become the fully supported standard practice
- Bringing the existing built environment up to sustainable design standards

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

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

Conceptual Problems to Solve

- **Diminishing Returns:** The principle that all directions of progress run out, ending with diminishing returns, is evident in the typical 'S' curve of The Technology Life Cycle and in the useful life of any system as discussed in Industrial Ecology and Life Cycle Assessment. It's as reliable an expectation as any principle of science that diminishing returns signal natural limits. Common office and business management practice is to read diminishing returns in any direction of effort as an indication of diminishing opportunity, a potential for accelerating their decline and signal to turn elsewhere.
- **Unsustainable Investment:** A problem arises when the limits of a resource are hard to see, so increasing investment in response to diminishing returns may seem profitable as in the Tragedy of the Commons, but may lead to a collapse. This problem of increasing investment in diminishing resources has also been studied in relation to the causes of civilization collapse by Joseph Tainter among others. This natural error in investment policy contributed to the collapse of both the Roman and Mayan, among others. Relieving over-stressed resources requires reducing pressure on them, not continually increasing it whether more efficiently or not

Waste Prevention

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

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

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

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

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

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

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

Examples of sustainable design

Sustainable planning



Cohousing community illustrating greenspace preservation, tightly clustered housing, and parking on periphery, Ann Arbor, Michigan, 2003.

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

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

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

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

Sustainable architecture

Sustainable architecture is the design of sustainable buildings. Sustainable architecture attempts to reduce the collective environmental impacts during the production of building components, during the construction process, as well as during the lifecycle of the building (heating, electricity use, carpet cleaning etc.) This design practice emphasizes efficiency of heating and cooling systems; alternative energy sources such as solar hot water, appropriate building siting, reused or recycled building materials; on-site power generation - solar technology, ground source heat pumps, wind power; rainwater harvesting for gardening, washing and aquifer recharge; and on-site waste management such as green roofs that filter and control stormwater runoff. This requires close cooperation of the design team, the architects, the engineers, and the client at all project stages, from site selection, scheme formation, material selection and procurement, to project implementation.

Sustainable architects design with sustainable living in mind. Sustainable vs green design is the challenge that designs not only reflect healthy processes and uses but are powered by renewable energies and site specific resources. A test for sustainable design is — can the design function for its intended use without fossil fuel — unplugged. This challenge suggests architects and planners design solutions that can function without pollution rather than just reducing pollution. As technology progresses in architecture and design theories and as examples are built and tested, architects will soon be able to create not only passive, null-emission buildings, but rather be able to integrate the entire power system into the building design. In 2004 the 59 home housing community, the Solar Settlement, and a 60,000 sq ft (5,600 m²) integrated retail, commercial and residential building, the Sun Ship, were completed by architect Rolf Disch in Freiburg, Germany. The Solar Settlement is the first housing community world wide in which every home, all 59, produce a positive energy balance.

Sustainable landscape and garden design

Sustainable landscape architecture is a category of sustainable design and energy-efficient landscaping concerned with the planning and design of outdoor space. Design techniques include planting trees to shade buildings from the sun or protect them from wind, using local materials, on-site composting and chipping to reduce green waste hauling, and also may involve using drought-resistant plantings in arid areas (xeriscaping) and buying stock from local growers to avoid energy use in transportation.

Sustainable graphic design

Sustainable graphic design considers the environmental impacts of graphic design products (such as packaging, printed materials, publications, etc.) throughout a life cycle that includes: raw material; transformation; manufacturing; transportation; use; and disposal. Techniques for sustainable graphic design include: reducing the amount of materials required for production; using paper and materials made with recycled, post-consumer waste; printing with low-VOC inks; and using production and distribution methods that require the least amount of transport.

Sustainable Agriculture

Sustainable agriculture adheres to three main goals:

- environmental health,
- economic profitability,
- social and economic equity.

A variety of philosophies, policies and practices have contributed to these goals. People in many different capacities, from farmers to consumers, have shared this vision and contributed to it. Despite the diversity of people and perspectives, the following themes commonly weave through definitions of sustainable agriculture.

There are strenuous discussions — among others by the agricultural sector and authorities — if existing pesticide protocols and methods of soil conservation adequately protect topsoil and wildlife. Doubt has risen if these are sustainable, and if agrarian reforms would permit an efficient agriculture with fewer pesticides, therefore reducing the damage to the ecosystem.

Domestic machinery and furniture



Stainless Steel Table with FSC Teca Wood - Brazil sustainable design. Stainless is 100% recyclable and teca wood comes environmental friendly reforestation

Automobiles, home appliances and furnitures can be designed for repair and disassembly (for recycling), and constructed from recyclable materials such as steel, aluminum and glass, and renewable materials, such as Zelfo, wood and plastics from natural feedstocks. Careful selection of materials and manufacturing processes can often create products comparable in price and performance to non-sustainable products. Even mild design efforts can greatly increase the sustainable content of manufactured items.

Improvements to heating, cooling, ventilation and water heating

- Absorption refrigerator
- Annualized geothermal solar
- Earth cooling tubes
- Geothermal heat pump
- Heat recovery ventilation
- Hot water heat recycling
- Passive cooling
- Renewable heat
- Seasonal thermal storage
- Solar air conditioning

- Solar hot water

Disposable products

Detergents, newspapers and other disposable items can be designed to decompose, in the presence of air, water and common soil organisms. The current challenge in this area is to design such items in attractive colors, at costs as low as competing items. Since most such items end up in landfills, protected from air and water, the utility of such disposable products is debated.

Eco fashion and home accessories

Creative designers and artists are perhaps the most inventive when it comes to upcycling or creating new products from old waste. A growing number of designers upcycle waste materials such as car window glass and recycled ceramics, textile offcuts from upholstery companies, and even decommissioned fire hose to make belts and bags. Whilst accessories may seem trivial when pitted against green scientific breakthroughs; the ability of fashion and retail to influence and inspire consumer behaviour should not be underestimated. Eco design may also use bi-products of industry, reducing the amount of waste being dumped in landfill, or may harness new sustainable materials or production techniques e.g. fabric made from recycled PET plastic bottles or bamboo textiles.

Energy Sector

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

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

Water Sector

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

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

Sustainable technologies

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

Encouraging sustainability



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

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

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

Terminology

In some countries the term *sustainable design* is known as Ecodesign, green design or environmental design. Ecodesign as meant by Victor Papanek, did include social design and social aspects. Over the past years the terms *sustainable design* and *design for sustainability* — besides other new terms — became more accepted globally, including the triple bottom line (people, planet and profit).

WWT

Sustainable Architecture



Sustainable portable classroom design proposal

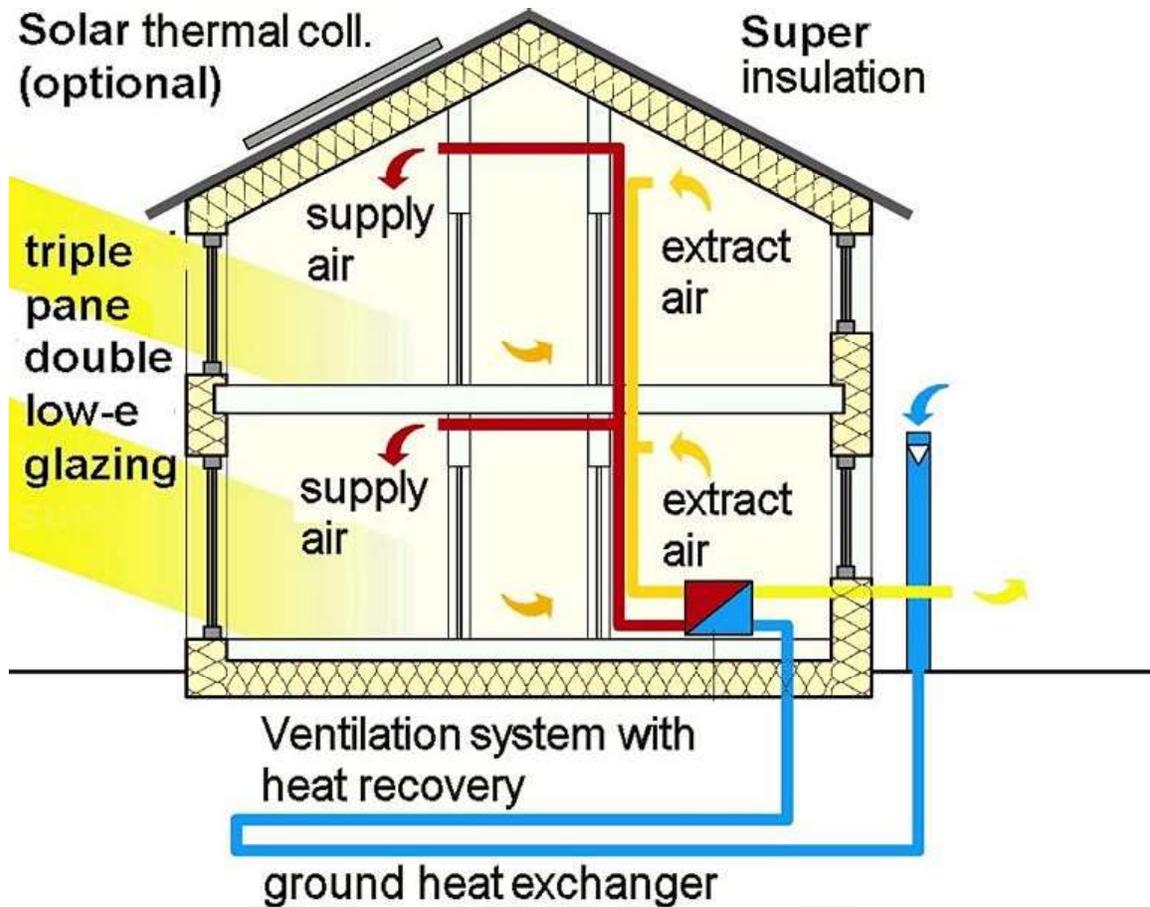
Sustainable architecture is a general term that describes environmentally conscious design techniques in the field of architecture. Sustainable architecture is framed by the larger discussion of sustainability and the pressing economic and political issues of our world. In the broad context, sustainable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

opportunities of future generations. This term can be used to describe an energy and ecologically conscious approach to the design of the built environment.

Sustainable energy use



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



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



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

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

Heating, Ventilation and Cooling System Efficiency

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

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

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

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

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

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

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

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

Renewable energy generation

Solar Panels

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

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

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

Wind Turbines

Undersized wind turbines (normal turbines are often over 250 feet) may have been oversold and do not always provide the returns promised, particularly for North American households. The use of undersized wind turbines in energy production in

sustainable structures requires the consideration of many factors. In considering costs, small wind systems are generally more expensive than larger wind turbines relative to the amount of energy they produce. For small wind turbines, maintenance costs can be a deciding factor at sites with marginal wind-harnessing capabilities. At low-wind sites, maintenance can consume much of a small wind turbine's revenue. Wind turbines begin operating when winds reach 8 mph, achieve energy production capacity at speeds of 32-37 mph, and shut off to avoid damage at speeds exceeding 55 mph. The energy potential of a wind turbine is proportional to the square of the length of its blades and to the cube of the speed at which its blades spin. Though wind turbines are available that can supplement power for a single building, because of these factors, the efficiency of the wind turbine depends much upon the wind conditions at the building site. For these reasons, for wind turbines to be at all efficient, they must be installed at locations that are known to receive a constant amount of wind (with average wind speeds of more than 15 mph), rather than locations that receive wind sporadically. A small wind turbine can be installed on a roof. Installation issues then include the strength of the roof, vibration, and the turbulence caused by the roof ledge. Small-scale rooftop wind turbines have been known to be able to generate power from 10% to up to 25% of the electricity required of a regular domestic household dwelling. Turbines for residential scale use are available. They are usually approximately 7 feet (2 m) to 25 feet (8 m) in diameter and produce electricity at a rate of 900 watts to 10,000 watts at their tested wind speed. In the United States, residential wind turbines with outputs of 2-10 kW, typically cost between \$12,000 and \$55,000 installed (\$6 per watt), although there are incentives and rebates available in 19 states that can reduce the purchase price for homeowners by up to 50 percent, to (\$3 per watt).

Solar Water Heating

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

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

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

The two most common types of collector panels are Flat-Plate and Evacuated-tube. The two work similarly except that evacuated tubes do not convectively lose heat, which greatly improves their efficiency (5%-25% more efficient). With these higher

efficiencies, Evacuated-tube solar collectors can also produce higher-temperature space heating, and even higher temperatures for absorption cooling systems.

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

Heat Pumps

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

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

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

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

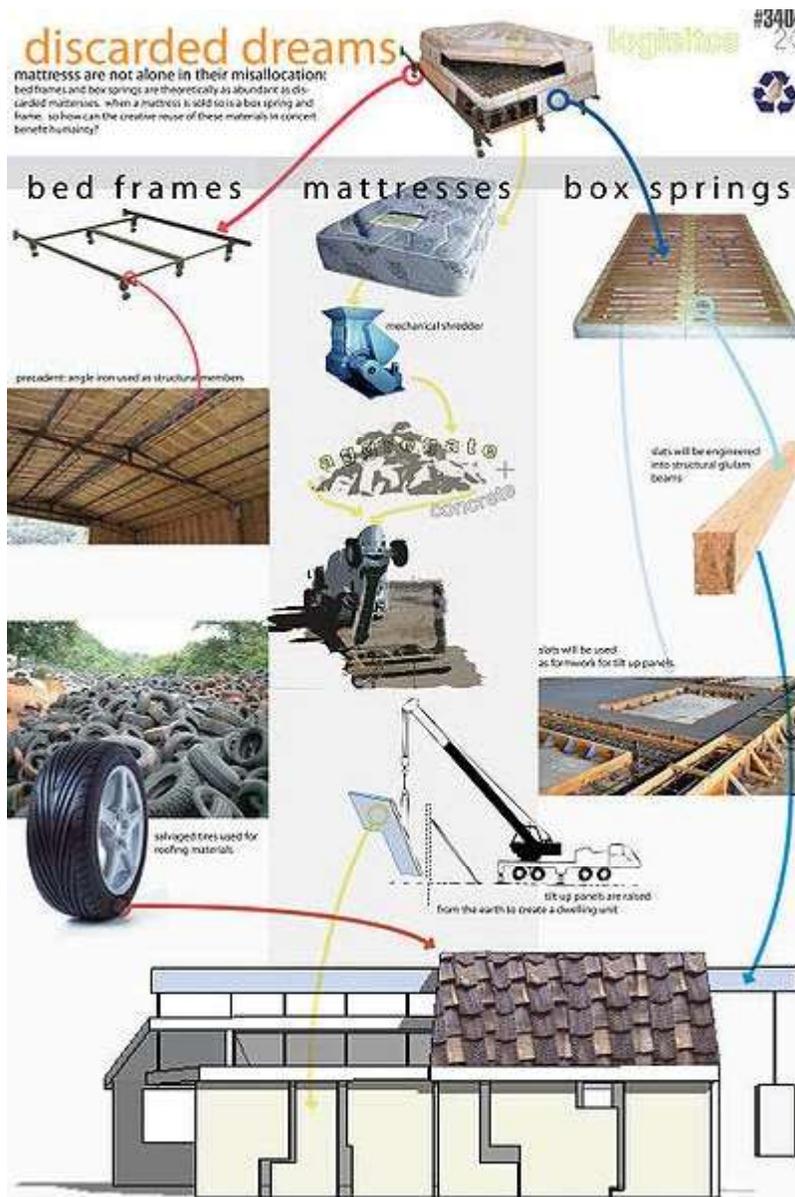
In terms of initial cost, the ground-source heat pump system costs about twice as much as a standard air-source heat pump to be installed. However, the up-front costs can be more than offset by the decrease in energy costs. The reduction in energy costs is especially apparent in areas with typically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

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

Sustainable building materials

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

Recycled Materials



Recycling items for building

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

Lower Volatile Organic Compounds

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

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

Green products are usually considered to contain fewer VOCs and be better for human and environmental health. A case study conducted by the Department of Civil,

Architectural, and Environmental Engineering at the University of Miami that compared three green products and their non-green counterparts found that even though both the green products and the non-green counterparts both emitted levels of VOCs, the amount and intensity of the VOCs emitted from the green products were much safer and comfortable for human exposure.

Waste management

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

Water management

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

Building placement

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

Social sustainability in architecture

Public housing is cost effective. This approach lets everyone have their own sleeping/recreation space, yet incorporate communal spaces (e.g. mess halls, Latrines, public showers).

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

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

Art can be a powerfully positive social force. It can help to reduce stress in many situations, lowering the risk of stress-related health problems, both physical and mental.

The cohousing movement with a high degree of social sustainability and participation where the majority of participants are non-architects invariably uses traditional architecture that resonates with the general public.

Criticism

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

Chapter- 4

Examples of Sustainable Architecture

30 St Mary Axe

Coordinates: $51^{\circ}30'52''\text{N } 00^{\circ}04'49''\text{W}$ / $51.51444^{\circ}\text{N } 0.08028^{\circ}\text{W}$



30 St Mary Axe, also known as the **Gherkin** and the **Swiss Re Building**, is a skyscraper in London's main financial district, the City of London, completed in December 2003 and opened at the end of May 2004. With 40 floors, the tower is 190 metres (623 ft) tall, and stands on the former site of the Baltic Exchange building, which was severely damaged on 10 April 1992 by the explosion of a bomb placed by the Provisional IRA.

After the plans to build the Millennium Tower were dropped, the current building was designed by Norman Foster, his then business partner Ken Shuttleworth and Arup engineers, and was erected by Skanska in 2001–2003.

History

The building is on the former site of the Baltic Exchange building, the headquarters of a global marketplace for ship sales and shipping information. On 10 April 1992 the Provisional IRA detonated a bomb close to the Exchange, severely damaging the historic Exchange building and neighbouring structures.

The UK government's statutory adviser on the historic environment, English Heritage, and the City of London governing body, the City of London Corporation, were keen that any redevelopment must restore the building's old façade onto St Mary Axe. The Exchange Hall was a celebrated fixture of the ship trading company.

After English Heritage later discovered the damage was far more severe than previously thought, they stopped insisting on full restoration, albeit over the objections of the architectural conservationists who favoured reconstruction. Baltic Exchange sold the land to Trafalgar House in 1995. Most of the remaining structures on the site were then carefully dismantled, the interior of Exchange Hall and the façade were preserved, hoping for a reconstruction of the building in the future.

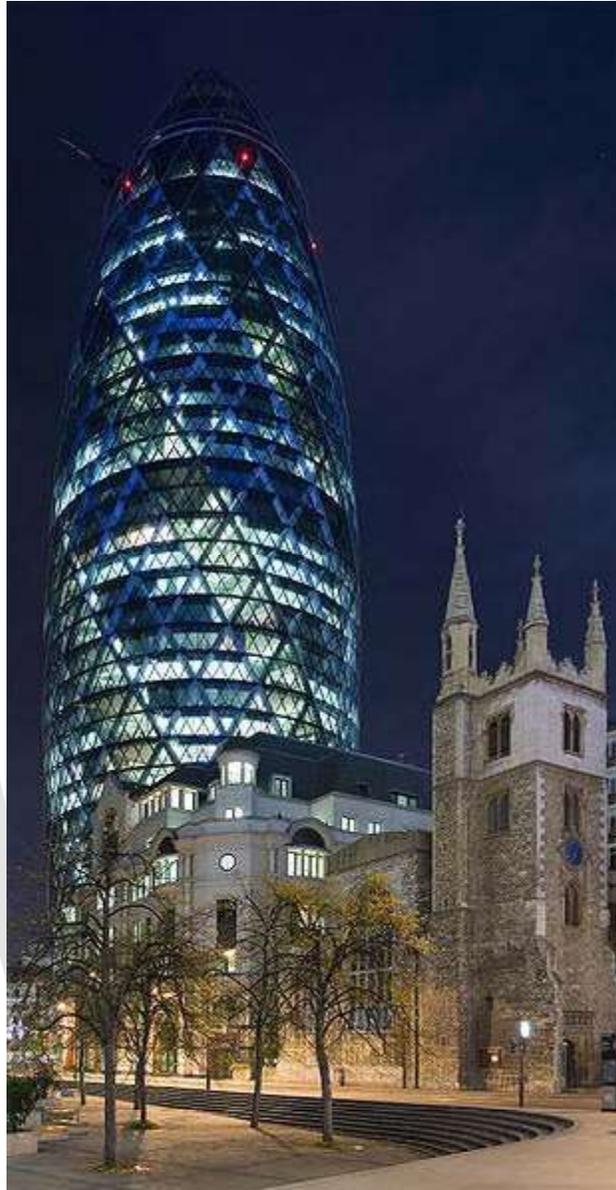
In 1996 Trafalgar House submitted plans for the Millennium Tower, a 386 metres (1,266 ft) building with more than 140,000 m² (1,500,000 sq ft) office space, apartments, shops, restaurants and gardens. This plan was dropped after objections for being totally out-of-scale with the City of London and anticipated disruption to flight paths for both City and Heathrow airports; the revised plan for a lower tower was accepted.

The *gherkin* name dates back to at least 1999, referring to that plan's highly unorthodox layout and appearance.

Planning process



Looking south down Bishopsgate, one of the main roads leading through London's financial district



The tower contrasted with other buildings, seen from the southern end of St Mary Axe

23 August 2000, Deputy Prime Minister John Prescott granted planning permission to construct a building much larger than the old Exchange on the site. The site was special because it needed development, was not on any of the "sight lines" (planning guidance requires that new buildings do not obstruct or detract from the view of St Paul's dome when viewed from a number of locations around London), and it had housed the Baltic Exchange.

The plan for the site was to reconstruct the Baltic Ex. GMW Architects proposed building a new rectangular building surrounding a restored exchange — the square shape would have the type of large floor plan that banks liked. Eventually, the planners realised that the exchange was not recoverable, forcing them to relax their building constraints; they hinted that an "architecturally significant" building might pass favourably with city

authorities. This move opened up the architect to design freely; it eliminated the restrictive demands for a large, capital-efficient, money-making building that favoured the client.

Swiss Re's low level plan met the planning authority's desire to maintain London's traditional streetscape with its relatively narrow streets. The mass of the Swiss Re tower was not too imposing. Like Barclays Bank's former City headquarters, the passerby is nearly oblivious to the tower's existence in neighbouring streets until directly underneath it.

Design and construction

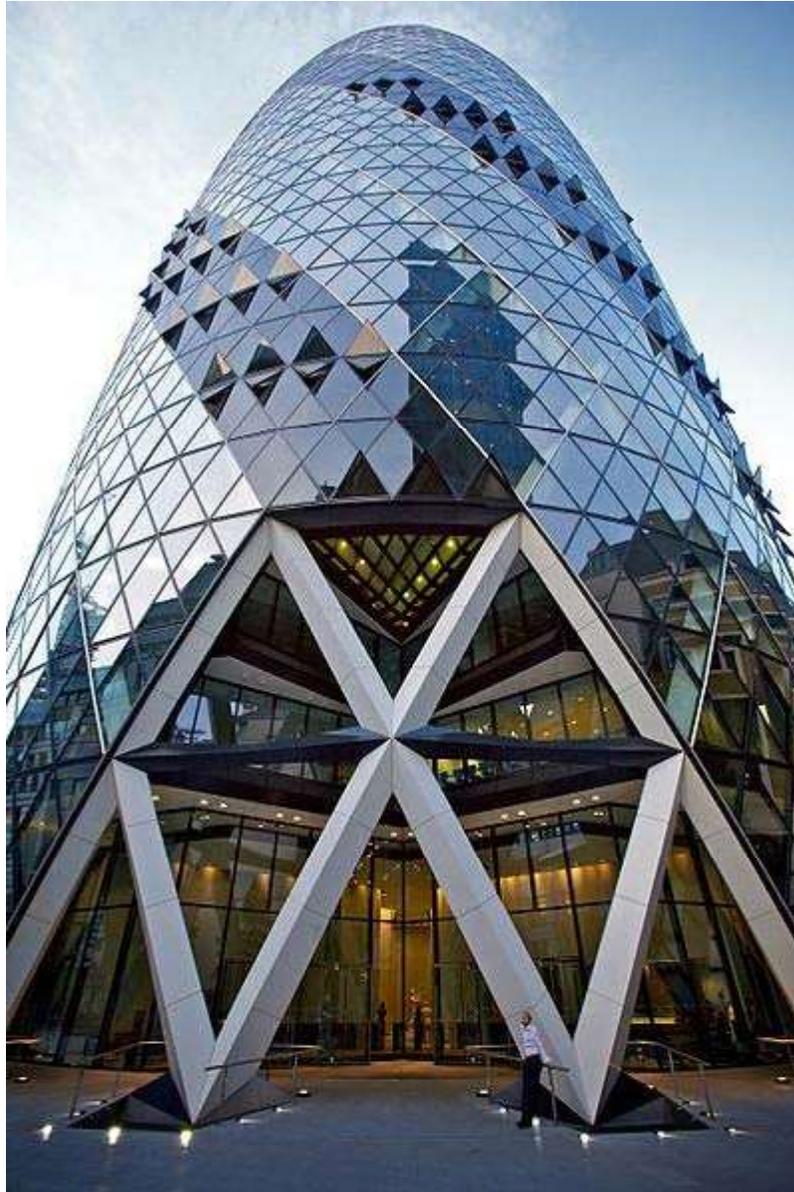


The top floor of the Gherkin.

The building was constructed by Skanska, completed in December 2003 and opened on 28 April 2004. The primary occupant of the building is Swiss Re, a global reinsurance company, who had the building commissioned as the head office for their UK operation. The tower is sometimes known as "Swiss Re Tower", although this name is not official.

The building uses energy-saving methods which allow it to use half the power a similar tower would typically consume. Gaps in each floor create six shafts that serve as a natural ventilation system for the entire building even though required firebreaks on every sixth floor interrupt the "chimney." The shafts create a giant double glazing effect; air is sandwiched between two layers of glazing and insulates the office space inside.

Architects limit double glazing in residential houses to avoid the inefficient convection of heat, but the tower exploits this effect. The shafts pull warm air out of the building during the summer and warm the building in the winter using passive solar heating. The shafts also allow sunlight to pass through the building, making the work environment more pleasing, and keeping the lighting costs down. The primary methods for controlling wind-excited sways are to increase the stiffness, or increase damping with tuned/active mass dampers. To a design by Arup, its fully triangulated perimeter structure makes the building sufficiently stiff without any extra reinforcements. Despite its overall curved glass shape, there is only one piece of curved glass on the building — the lens-shaped cap at the very top.



The base of the tower

On the building's top level (the 40th floor), there is a bar for tenants and their guests featuring a 360° view of London. A restaurant operates on the 39th floor, and private dining rooms on the 38th. Whereas most buildings have extensive lift equipment on the roof of the building, this was not possible for the Gherkin, since a bar had been planned for the 40th floor. The architects dealt with this by having the main lift only reach the 34th floor, and then having a push-from-below lift to the 39th floor. There is a marble stairwell and a disabled persons' lift which leads the visitor up to the bar in the dome.

The building is visible over long distances: from the north, for instance, it can be seen from the M11 motorway some 32 kilometres (20 mi) away, while to the west it can be seen from the statue of George III in Windsor Great Park.

After completion

On 25 April 2005, the press reported that a glass panel two thirds up the 590 ft (180 m) tower had fallen to the plaza beneath on 18 April. The plaza was sealed off, but the building remained open. A temporary covered walkway, extending across the plaza to the building's reception, was erected to protect visitors. Engineers examined the other 744 glass panels on the building. The cost of repair was covered by main contractor Skanska and curtainwall supplier Schmidlin.

Since its completion, the building has won a number of prestigious awards for architecture. In October 2004, the building was awarded the 2004 RIBA Stirling Prize. For the first time in the prize's history, the judges reached a unanimous decision . In December 2005, a survey of the world's largest firms of architects published in *2006 BD World Architecture 200* voted the tower as the most admired new building in the world. The building also featured in recent movies such as *Harry Potter and the Half Blood Prince*, Sharon Stone's *Basic Instinct 2* and Woody Allen's *Match Point* and, rechristened the *Spirit of London*, became the spaceship centrepiece of Keith Mansfield's 2008 novel *Johnny Mackintosh and the Spirit of London*.

Since February 2010, Sky News has broadcast its flagship business programme, Jeff Randall Live, from a studio in the building.

In September 2006, the building was put up for sale with a price tag of GB£600 million. Potential buyers included British Land, Land Securities, Prudential, ING and the Abu Dhabi royal family. On 21 February 2007, IVG Immobilien AG and UK investment firm Evans Randall completed their joint purchase of the building for GB£630 million, making it Britain's most expensive office building.



Skyline view with Tower 42, the Willis Building, **30 St Mary Axe** and the Broadgate Tower.

WWT

Bank of America Tower (New York City)



Bank of America Tower seen from the New York Public Library.

The **Bank of America Tower at One Bryant Park** is a 1,200 ft (366 m) skyscraper in the Midtown district of Manhattan in New York City, in the United States. It is located on Sixth Avenue, between 42nd and 43rd Street, opposite Bryant Park.

The US\$1 billion project has been designed by Cook+Fox Architects to be one of the most efficient and ecologically friendly buildings in the world. It is the second tallest building in New York City, after the Empire State Building, and the fourth tallest building in the United States. Construction was completed in 2009.

In June 2010, the Bank of America Tower was the recipient of the 2010 Best Tall Building Americas award by the Council on Tall Buildings and Urban Habitat.

Details

The tower's architectural spire is 255.5 ft (77.9 m) tall. The building is 55 stories high and has 2,100,000 square feet (195,096 m²) of office space. Its final height was reached upon the placement of its spire on 15 December 2007. The building has three escalators and a total of 51 elevators – 50 to serve the offices and one leading to the transit mezzanine below ground.

Several buildings were demolished to make way for the tower.

Environmental features

The design of the building makes it environmentally friendly, using technologies such as floor-to-ceiling insulating glass to contain heat and maximize natural light, and an automatic daylight dimming system. The tower also features a greywater system, which captures rainwater and reuses it. Bank of America states that the building is made largely of recycled and recyclable materials. Air entering the building is filtered, as is common, but the air exhausted is cleaned as well. Bank of America Tower is the first skyscraper designed to attain a Platinum LEED Certification.



The Bank of America Tower under construction in October 2007.

The Bank of America tower is constructed using a concrete manufactured with slag, a byproduct of blast furnaces. The mixture used in the tower concrete is 55% cement and 45% slag. The use of slag cement reduces damage to the environment by decreasing the amount of cement needed for the building, which in turn lowers the amount of carbon dioxide greenhouse gas produced through normal cement manufacturing. One ton of cement produced emits about one ton of carbon dioxide into the atmosphere.

Control of the temperature of Bank of America's tower and the production of some of its energy are executed in an environmentally-friendly manner. Insulating glass reduces thermal loss somewhat, which lowers energy consumption and increases transparency. Carbon dioxide sensors signal increased fresh air ventilation when elevated levels of carbon dioxide are detected in the building.



The Bank of America Tower Exterior Lobby/Subway View

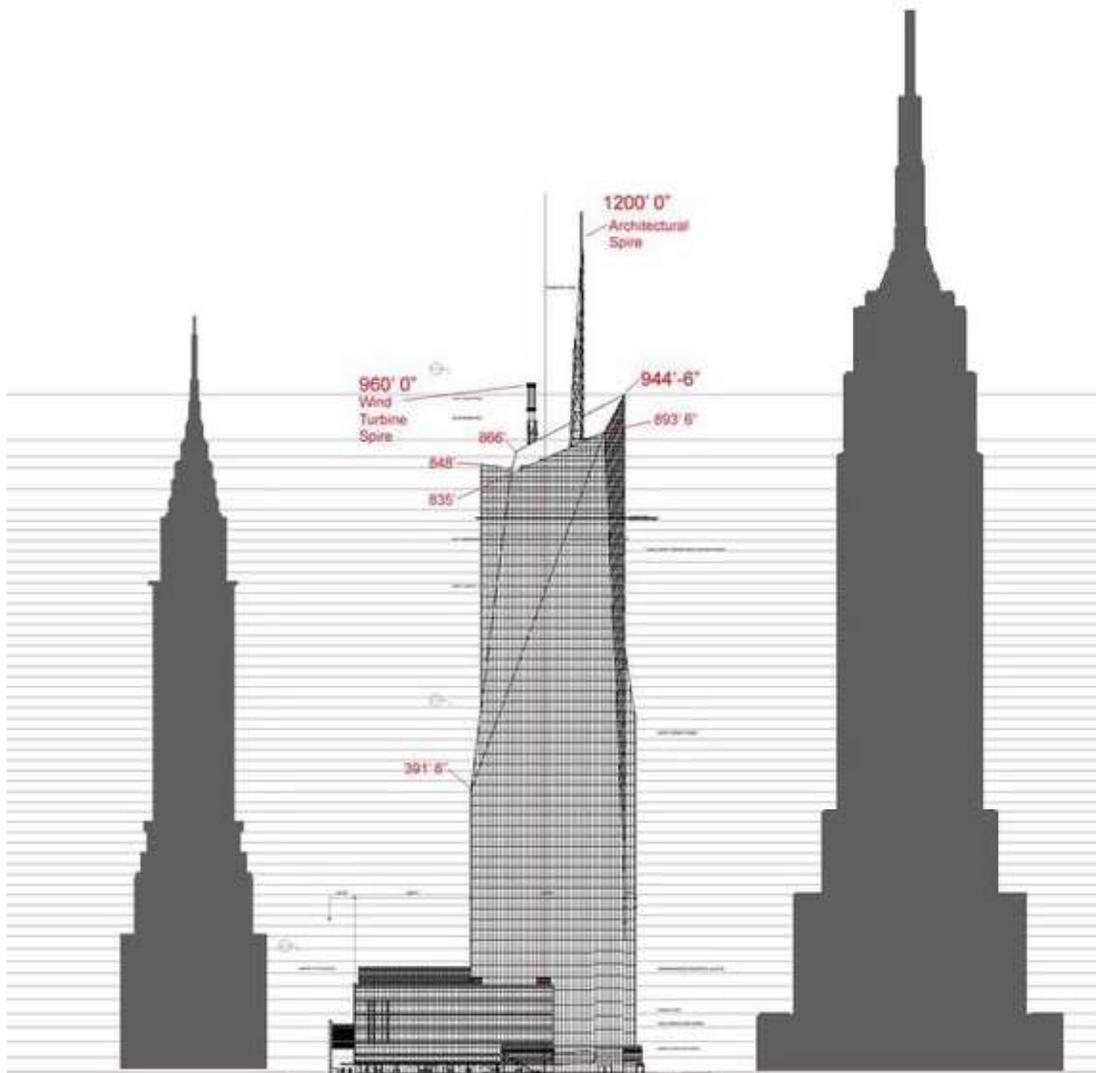
Conditioned air for the occupants is provided by multiple air column units located in the tenant space that deliver 62 degree air into a raised access floor plenum. This underfloor air system provides users with the ability to control their own space temperature as well as improving the ventilation effectiveness. When building churn occurs, workstation moves can be performed easier with lower cost and less product waste.

The cooling system produces and stores ice during off-peak hours, and allows the ice to melt to help cool the building during peak load, similar to the ice batteries in the 1995 Hotel New Otani in Tokyo, Japan. Ice batteries have been used since absorption chillers first made ice commercially 150 years ago, before the electric light bulb was invented.

Water conservation features in the tower include waterless urinals, which are estimated to save 8 million gallons of water per year and reduce CO₂ emissions by 144,000 pounds per year (as calculated with the Pacific Institute water-to-air model). The tower has a 4.6-megawatt cogeneration plant, which provides part of the base-load energy requirements. Onsite power generation reduces the significant electrical transmission losses that are typical of central power production plants.

In June 2008, the New York Academy of Sciences launched a podcast which highlights these green features.

Height



Height comparison of the Empire State Building (right), Bank of America Tower (center), and the Chrysler Building (left).

When comparing building height, only the structural height is used, according to rules and regulations of the World Council on Tall Buildings. It is debatable as to whether what is being called an architectural spire will count toward the structural height. Currently, the New York Times Building and the Chrysler Building are tied for the position of the third tallest buildings in New York City. Comparing the Bank of America Tower to the Chrysler Building, the Bank of America Tower is taller when considering two factors:

	Tip Height	Roof Height
Empire State Building	1,472 ft (449 m)	1,250 ft (380 m)
Bank of America Tower	1,200 ft (366 m)	953.5 ft (290.6 m)
Chrysler Building	1,046 ft (319 m)	925 ft (282 m)
New York Times Building	1,046 ft (319 m)	748 ft (228 m)

A formal ruling by the World Council on Tall Buildings has yet to be released.

Construction Incidents



Bank of America Tower construction site, seen from across 42nd Street and 6th Avenue, 2006

Since 2006, material has fallen from the building at least six times.

October 17, 2007 - A construction container fell from a crane around 1 p.m., causing damage to the tower and injuring eight people on the sidewalk. The container broke windows on several floors of the building, spraying debris that rained down on the streets below. Eight people suffered cuts and bruises. The Buildings Department temporarily stopped construction at the site.

August 12, 2008 - A 1,500-pound (680 kg) glass panel fell onto a sidewalk. Two people suffered minor injuries.

September 17, 2008 - A debris container fell, shattered a panel of glass facade, and caused several pieces of glass to fall from the 50th floor to the sidewalk/street (West 42nd and Sixth Avenue) around 3PM. No one was injured.

Nano House

The **Nano House** was named to be the world's smallest sustainable house.

The Nano Living System is a Swiss-made "green" pre-engineered concept for residential use that presents an innovative and sustainable architectural proposition. The design is based on the combination of using pre-engineered SIPs (made from cement fiberboard, recycled light gauge steel and polyurethane foam), creation of flexible spaces (through Nano Living Systems' "Suspending Technology") and use of renewable energy systems. This suggests an optimistic and environmental solution for the global housing issue of very small living spaces at extremely high prices.

The "Nano House" can be used by a family of four in an area consisting of just 25 m² or 250 sq ft. This is made possible by the incorporation of the "suspending technology," which nearly doubles the living area within this space by transforming what is common living space by day into two separate bedrooms by night. The "suspending technology" can be used in new construction and can also be adapted to be used in existing structures, for example hotels, studios, dormitories and very small housing.

Indoor Air Quality in Green Building Architecture

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

IAQ can be affected by microbial contaminants (mold, bacteria), gases (including carbon monoxide, radon, volatile organic compounds), particulates, or any mass or energy stressor that can induce adverse health conditions. Indoor air is becoming an increasingly more concerning health hazard than outdoor air. Using ventilation to dilute contaminants, filtration, and source control are the primary methods for improving indoor air quality in most buildings.

Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modelling of air flow inside buildings.

Common pollutants

Radon

Radon is an invisible, radioactive atomic gas that results from the radioactive decay of radium, which may be found in rock formations beneath buildings or in certain building materials themselves. Radon is probably the most pervasive serious hazard for indoor air in the United States and Europe, probably responsible for tens of thousands of deaths from lung cancer each year. There are relatively simple tests for radon gas, but these tests are not commonly done, even in areas of known systematic hazards. Radon is a heavy gas and thus will tend to accumulate at the floor level. Building materials can actually be a significant source of radon, but little testing is done for stone, rock or tile products brought into building sites; radon accumulation is greatest for well insulated homes. The half life for radon is 3.8 days, indicating that once the source is removed, the hazard will

be greatly reduced within a few weeks. However annually thousands of people go to radon contaminated mines for purposeful exposure to help with the symptoms of arthritis without any serious known health effects, though lung cancer can take many years to develop. Radon mitigation methods include sealing concrete slab floors, basement foundations, water drainage systems, or by increasing ventilation.. They are usually cost effective and can greatly reduce or even eliminate the contamination and the associated health risks.

Molds and other allergens

These biological chemicals can arise from a host of means, but there are two common classes: (a) moisture induced growth of mold colonies and (b) natural substances released into the air such as animal dander and plant pollen. Moisture buildup inside buildings may arise from water penetrating compromised areas of the building envelope or skin, from plumbing leaks, from condensation due to improper ventilation, or from ground moisture penetrating a building part. In areas where cellulosic materials (paper and wood, including drywall) become moist and fail to dry within 48 hours, mold mildew can propagate and release allergenic spores into the air.

In many cases, if materials have failed to dry out several days after the suspected water event, mold growth is suspected within wall cavities even if it is not immediately visible. Through a mold investigation, which may include destructive inspection, one should be able to determine the presence or absence of mold. In a situation where there is visible mold and the indoor air quality may have been compromised, mold remediation may be needed. Mold testing and inspections should be done by an independent investigator to avoid any conflict of interest and to insure accurate results; free mold testing offered by remediation companies is not recommended.

There are some varieties of mold that contain toxic compounds (mycotoxins). However, exposure to hazardous levels of mycotoxin via inhalation is not possible in most cases, as toxins are produced by the fungal body and are not at significant levels in the released spores. The primary hazard of mold growth, as it relates to indoor air quality, comes from the allergenic properties of the spore cell wall. More serious than most allergenic properties is the ability of mold to trigger episodes in persons that already have asthma, a serious respiratory disease.

Mold is always associated with moisture, and its growth can be inhibited by keeping humidity levels below 50%. Moisture problems causing mold growth can be direct such as a water leaks and/or indirect such as condensation due to humidity levels.

Carbon monoxide

One of the most acutely toxic indoor air contaminants is carbon monoxide (CO), a colorless, odorless gas that is a byproduct of incomplete combustion of fossil fuels. Common sources of carbon monoxide are tobacco smoke, space heaters using fossil fuels, defective central heating furnaces and automobile exhaust. Improvements in indoor

levels of CO are systematically improving from increasing numbers of smoke-free restaurants and other legislated non-smoking buildings. By depriving the brain of oxygen, high levels of carbon monoxide can lead to nausea, unconsciousness and death.

According to the American Conference of Governmental Industrial Hygienists (ACGIH), the time-weighted average (TWA) limit for carbon monoxide (630-08-0) is 25 ppm.

Volatile organic compounds

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions.

Organic chemicals are widely used as ingredients in household products. Paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. Fuels are made up of organic chemicals. All of these products can release organic compounds during usage, and, to some degree, when they are stored. Testing emissions from building materials used indoors has become increasingly common for floor coverings, paints, and many other important indoor building materials and finishes.

Legionella

Legionellosis or Legionnaire's Disease is caused by a waterborne bacterium *Legionella* that grows best in slow-moving or still, warm water. The primary route of exposure is aerosolization, most commonly from evaporative cooling towers or showerheads. A common source of *Legionella* in commercial buildings is from poorly placed or maintained evaporative cooling towers, which often release aerosolized water that may enter nearby ventilation intakes. Outbreaks in medical facilities and nursing homes, where patients are immuno-suppressed and immuno-weak, are the most commonly reported cases of Legionellosis. More than one case has involved outdoor fountains in public attractions. The presence of *Legionella* in commercial building water supplies is highly under-reported, as healthy people require heavy exposure to acquire infection.

Legionella testing typically involves collecting water samples and surface swabs from evaporative cooling basins, shower heads, faucets, and other locations where warm water collects. The samples are then cultured and colony forming units (cfu) of *Legionella* are quantified as cfu/Liter.

Legionella is a parasite of protozoans such as amoeba, and thus requires conditions suitable for both organisms. The bacterium forms a biofilm which is resistant to chemical and antimicrobial treatments, including chlorine. Remediation for *Legionella* outbreaks in

commercial buildings vary, but often include very hot water flushes (160 °F; 70 °C), sterilization of standing water in evaporative cooling basins, replacement of shower heads, and in some cases flushes of heavy metal salts. Preventative measures include adjusting normal hot water levels to allow for 120°F at the tap, evaluating facility design layout, removing faucet aerators, and periodic testing in suspect areas.

Asbestos fibers

The U.S. Federal Government and some States have set standards for acceptable levels of asbestos fibers in indoor air. Many common building materials used before 1975 contain asbestos, such as some floor tiles, ceiling tiles, taping muds, pipe wrap, mastics and other insulation materials. Normally significant releases of asbestos fiber do not occur unless the building materials are disturbed, such as by cutting, sanding, drilling or building remodelling. There are particularly stringent regulations applicable to schools.

Inhalation of asbestos fibers over long exposure times is associated with increased incidence of lung cancer.

Asbestos is found in older homes and buildings, but it is most dangerous in schools and industrial settings. It was once widely used in shingles, fireproofing, heating systems and floor and ceiling, tiles in older buildings. When asbestos-containing material is damaged or disintegrates, microscopic fibers are dispersed into the air. The risk of lung cancer from inhaling asbestos fibers is also greater to smokers. The symptoms of the disease do not usually appear until about 20 to 30 years after the first exposure to asbestos. Removal of asbestos-containing materials is not always optimal because the fibers can be spread into the air during the removal process. A management program for intact asbestos-containing materials is often recommended instead.

Carbon dioxide

Carbon dioxide (CO₂) is a surrogate for indoor pollutants emitted by humans and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. To eliminate most Indoor Air Quality complaints, total indoor carbon dioxide should be reduced a difference of less than 600 ppm above outdoor levels. NIOSH considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. ASHRAE recommends that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels. The UK standards for schools say that carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day should not exceed 1,500 ppm. The whole day refers to normal school hours (i.e. 9.00am to 3.30pm) and includes unoccupied periods such as lunch breaks. European standards limit carbon dioxide to 3500 ppm. OSHA limits carbon dioxide concentration in the workplace to 5,000 ppm for prolonged periods, and 35,000 ppm for 15 minutes. Exhaust gas leakages can occur from furnace

metal exhaust pipes that lead to the chimney when there are leaks in the pipe and the pipe gas flow area diameter has been reduced.

Ozone

Ozone is produced by ultraviolet light from the Sun hitting the Earth's atmosphere (especially in the ozone layer), lightning, certain electric devices (such as air ionisers), and as a byproduct of other types of pollution.

Ozone exists in greater concentrations at altitudes commonly flown by passenger jets. Reactions between ozone and onboard substances, including skin oils and cosmetics, can produce toxic chemicals as byproducts. Ozone itself is also irritating to lung tissue and harmful to human health. Larger jets have ozone filters to reduce the cabin concentration to safer and more comfortable levels.

Outdoor air used for ventilation may have sufficient ozone to react with common indoor pollutants as well as skin oils and other common indoor air chemicals or surfaces. Particular concern is warranted when using "green" cleaning products based on citrus or terpene extracts as these chemicals react very quickly with ozone to form toxic and irritating chemicals as well as fine and ultrafine particles. Ventilation with outdoor air containing elevated ozone concentrations may complicate remediation attempts.

Developing countries

A major source of indoor air pollution in developing countries is the burning of biomass (e.g. wood, charcoal, dung, or crop residue) for heating and cooking. The resulting exposure to high levels of particulate matter resulted in between 1.5 million and 2 million deaths in 2000.

Effect of indoor plants

Houseplants together with the medium in which they are grown can reduce components of indoor air pollution, particularly volatile organic compounds (VOC) such as benzene, toluene, and xylene. Plants can also remove CO₂, which is correlated with lower work performance, from indoor areas. The effect has been investigated by NASA for use in spacecrafts. Plants also appear to reduce airborne microbes, molds, and increase humidity.

A study published by the American Chemical Society on October 6, 2009 considered uptake rates of ketones and aldehydes by the peace lily (*Spathiphyllum clevelandii*) and golden pothos (*Epipremnum aureum*.) Akira Tani and C. Nicholas Hewitt found "Longer-term fumigation results revealed that the total uptake amounts were 30–100 times as much as the amounts dissolved in the leaf, suggesting that volatile organic carbons are metabolized in the leaf and/or translocated through the petiole." It is worth noting the researchers sealed the plants in Teflon bags. "No VOC loss was detected from the bag when the plants were absent. However, when the plants were in the bag, the levels of

aldehydes and ketones both decreased slowly but continuously, indicating removal by the plants"

While results do indicate house plants may be effective at removing some VOCs from air supplies, many studies neglect to consider ventilation, reductions when faced with continuous emission rather than burst, and other real world factors. A review of studies between 1989 and 2006 on the performance of houseplants as air cleaners, presented at the Healthy Buildings 2009 conference in Syracuse, NY, concluded "...indoor plants have little, if any, benefit for removing indoor air of VOC in residential and commercial buildings."

Since high humidity is associated with increased mold growth, allergic responses, and respiratory responses, the presence of additional moisture from houseplants may not be desirable in all indoor settings.

HVAC design

The "green design" movement in the commercial and residential heating, ventilation and air-conditioning (HVAC) industry emphasizes paying attention to the issue of indoor air quality throughout the design and construction stages of a building's life.

One technique to reduce energy consumption while maintaining adequate air quality, is *demand controlled ventilation*. Instead of setting throughput at a fixed air replacement rate, carbon dioxide sensors are used to control the rate dynamically, based on the emissions of actual building occupants.

For the past several years, there have been many debates among indoor air quality specialists about the proper definition of indoor air quality and specifically what constitutes "acceptable" indoor air quality.

One way of quantitatively ensuring the health of indoor air is by the frequency of effective turnover of interior air by replacement with outside air. In the UK, for example, classrooms are required to have 2.5 outdoor air changes per hour. In halls, gym, dining, and physiotherapy spaces, the ventilation should be sufficient to limit carbon dioxide to 1,500 ppm. In the USA, and according to ASHRAE Standards, ventilation in classrooms is based on the amount of outdoor air per occupant plus the amount of outdoor air per unit of floor area, not air changes per hour. Since carbon dioxide indoors comes from occupants and outdoor air, the adequacy of ventilation per occupant is indicated by the concentration indoors minus the concentration outdoors. The value of 615 ppm above the outdoor concentration indicates approximately 15 cubic feet per minute of outdoor air per adult occupant doing sedentary office work where outdoor air contains 385 ppm, the current global average atmospheric CO₂ concentration. In classrooms, the requirements in the ASHRAE standard 62.1, Ventilation for Acceptable Indoor Air Quality, would typically result in about 3 air changes per hour, depending on the occupant density. Of course the occupants aren't the only source of pollutants, so outdoor air ventilation may need to be higher when unusual or strong sources of pollution exist indoors. When

outdoor air is polluted, then bringing in more outdoor air can actually worsen the overall quality of the indoor air and exacerbate some occupant symptoms related to outdoor air pollution. Generally, outdoor country air is better than indoor city air. Exhaust gas leakages can occur from furnace metal exhaust pipes that lead to the chimney when there are leaks in the pipe and the pipe gas flow area diameter has been reduced.

The use of air filters can trap some of the air pollutants. The Department of Energy's Energy Efficiency and Renewable Energy section wrote "[Air] Filtration should have a Minimum Efficiency Reporting Value (MERV) of 13 as determined by ASHRAE 52.2-1999." Air filters are used to reduce the amount of dust that reaches the wet coils. Dust can serve as food to grow molds on the wet coils and ducts and can reduce the efficiency of the coils.

Moisture management and humidity control requires operating HVAC systems as designed. Moisture management and humidity control may conflict with efforts to try to optimize the operation to conserve energy. For example, Moisture management and humidity control requires systems to be set to supply Make Up Air at lower temperatures (design levels), instead of the higher temperatures sometimes used to conserve energy in cooling-dominated climate conditions. However, for most of the US and many parts of Europe and Japan, during the majority of hours of the year, outdoor air temperatures are cool enough that the air does not need further cooling to provide thermal comfort indoors. However, high humidity outdoors creates the need for careful attention to humidity levels indoors. High humidities give rise to mold growth and moisture indoors is associated with a higher prevalence of occupant respiratory problems.

The "dew point temperature" is an absolute measure of the moisture in air. Some facilities are being designed with the design dew points in the lower 50's °F, and some in the upper and lower 40's °F. Some facilities are being designed using desiccant wheels with gas fired heater to dry out the wheel enough to get the required dew points. On those systems, after the moisture is removed from the make up air, a cooling coil is used to lower the temperature to the desired level.

Commercial buildings, and sometimes residential, are often kept under slightly-positive air pressure relative to the outdoors to reduce infiltration. Limiting infiltration helps with moisture management and humidity control.

Dilution of indoor pollutants with outdoor air is effective to the extent that outdoor air is free of harmful pollutants. Ozone in outdoor air occurs indoors at reduced concentrations because ozone is highly reactive with many chemicals found indoors. The products of the reactions between ozone and many common indoor pollutants include organic compounds that may be more odorous, irritating, or toxic than those from which they are formed. These products of ozone chemistry include formaldehyde, higher molecular weight aldehydes, acidic aerosols, and fine and ultrafine particles, among others. The higher the outdoor ventilation rate, the higher the indoor ozone concentration and the more likely the reactions will occur, but even at low levels, the reactions will take place.

This suggests that ozone should be removed from ventilation air, especially in areas where outdoor ozone levels are frequently high. Recent research has shown that mortality and morbidity increase in the general population during periods of higher outdoor ozone and that the threshold for this effect is around 20 parts per billion (ppb).

Institutional programs

The topic of IAQ has become popular due to the greater awareness of health problems caused by mold and triggers to asthma and allergies. Awareness has also been increased by the involvement of the United States Environmental Protection Agency. They have developed an "IAQ Tools for Schools" program to help improve the indoor environmental conditions in educational institutions.

The National Institute for Occupational Safety and Health conducts Health Hazard Evaluations (HHEs) in workplaces at the request of employees, authorized representative of employees, or employers, to determine whether any substance normally found in the place of employment has potentially toxic effects, including indoor air quality.

A variety of scientists work in the field of indoor air quality including chemists, physicists, mechanical engineers, biologists, bacteriologists and computer scientists. Some of these professionals are certified by organizations such as the American Industrial Hygiene Association and the American Indoor Air Quality Council.

On the international level, the International Society of Indoor Air Quality and Climate (ISIAQ), formed in 1991, organizes two major conferences, the Indoor Air and the Healthy Buildings series. ISIAQ's journal *Indoor Air* is published 6 times a year and contains peer-reviewed scientific papers with an emphasis on interdisciplinary studies including exposure measurements, modeling, and health outcomes.

Building Material



Concrete and metal rebar used to build a floor

Building material is any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. The manufacture of building materials is an established industry in many countries and the use of these materials is typically segmented into specific specialty trades, such as carpentry, plumbing, roofing and insulation work. They provide the make-up of habitats and structures including homes.

Natural materials

Building materials can be generally categorized into two sources, natural and synthetic. Natural building materials are those that are unprocessed or minimally processed by industry, such as lumber or glass. Synthetic materials are made in industrial settings after much human manipulations, such as plastics and petroleum based paints. Both have their uses.

Mud, stone, and fibrous plants are the most basic building materials, aside from tents made of flexible materials such as cloth or skins. People all over the world have used these three materials together to create homes to suit their local weather conditions. In general stone and/or brush are used as basic structural components in these buildings, while mud is used to fill in the space between, acting as a type of concrete and insulation.

A basic example is wattle and daub mostly used as permanent housing in tropical countries or as summer structures by ancient northern people.

Fabric

The tent used to be the home of choice among nomadic groups the world over. Two well known types include the conical teepee and the circular yurt. It has been revived as a major construction technique with the development of tensile architecture and synthetic fabrics. Modern buildings can be made of flexible material such as fabric membranes, and supported by a system of steel cables, rigid framework or internal (air pressure.)

Mud and clay



Sod buildings in Iceland

The amount of each material used leads to different styles of buildings. The deciding factor is usually connected with the quality of the soil being used. Larger amounts of clay usually mean using the *cob/adobe* style, while low clay soil is usually associated with *sod* building. The other main ingredients include more or less sand/gravel and straw/grasses. *Rammed earth* is both an old and newer take on creating walls, once made by compacting clay soils between planks by hand, now forms and mechanical pneumatic compressors are used.

Soil and especially clay is good thermal mass; it is very good at keeping temperatures at a constant level. Homes built with earth tend to be naturally cool in the summer heat and warm in cold weather. Clay holds heat or cold, releasing it over a period of time like stone. Earthen walls change temperature slowly, so artificially raising or lowering the temperature can use more resources than in say a wood built house, but the heat/coolness stays longer.

Peoples building with mostly dirt and clay, such as cob, sod, and adobe, resulted in homes that have been built for centuries in western and northern Europe as well as the rest of the world, and continue to be built, though on a smaller scale. Some of these buildings have remained habitable for hundreds of years.

Rock



Mont Saint Michel

Rock structures have existed for as long as history can recall. It is the longest lasting building material available, and is usually readily available. There are many types of rock through out the world all with differing attributes that make them better or worse for particular uses. Rock is a very dense material so it gives a lot of protection too, its main draw-back as a material is its weight and awkwardness. Its energy density is also considered a big draw-back, as stone is hard to keep warm without using large amounts of heating resources.

Dry-stone walls have been built for as long as humans have put one stone on top of another. Eventually different forms of mortar were used to hold the stones together, cement being the most commonplace now.

The granite-strewn uplands of Dartmoor National Park, United Kingdom, for example, provided ample resources for early settlers. Circular huts were constructed from loose granite rocks throughout the Neolithic and early Bronze Age, and the remains of an estimated 5,000 can still be seen today. Granite continued to be used throughout the Medieval period and into modern times. Slate is another stone type, commonly used as roofing material in the United Kingdom and other parts of the world where it is found.

Mostly stone buildings can be seen in most major cities, some civilizations built entirely with stone such as the Pyramids in Egypt, the Aztec pyramids and the remains of the Inca civilization.

Thatch

Thatch is one of the oldest of building materials known; grass is a good insulator and easily harvested. Many African tribes have lived in homes made completely of grasses year round. In Europe, thatch roofs on homes were once prevalent but the material fell out of favor as industrialization and improved transport increased the availability of other materials. Today, though, the practice is undergoing a revival. In the Netherlands, for instance, many new buildings have thatched roofs with special ridge tiles on top.

Brush



Toda tribe hut

Brush structures are built entirely from plant parts and are generally found in tropical and sub-tropical areas, such as rainforests, where very large leaves can be used in the building. Native Americans often built brush structures for resting and living in, too. These are built mostly with branches, twigs and leaves, and bark, similar to a beaver's lodge.

Ice

Ice was used by the Inuit for igloos, but has also been used for ice hotels as a tourist attraction in northern areas that might not otherwise see many winter tourists.

Wood

Wood is a product of trees, and sometimes other fibrous plants, used for construction purposes when cut or pressed into lumber and timber, such as boards, planks and similar materials. It is a generic building material and is used in building just about any type of structure in most climates. Wood can be very flexible under loads, keeping strength while

bending, and is incredibly strong when compressed vertically. There are many differing qualities to the different types of wood, even among same tree species. This means specific species are better for various uses than others. And growing conditions are important for deciding quality.

Historically, wood for building large structures was used in its unprocessed form as logs. The trees were just cut to the needed length, sometimes stripped of bark, and then notched or lashed into place.

In earlier times, and in some parts of the world, many country homes or communities had a personal wood-lot from which the family or community would grow and harvest trees to build with. These lots would be tended to like a garden.

With the invention of mechanizing saws came the mass production of dimensional lumber. This made buildings quicker to put up and more uniform. Thus the modern western style home was made.

Concrete



Falkirk Wheel

The Falkirk Wheel is not made of concrete, almost all metal

Concrete is a composite building material made from the combination of aggregate and a binder such as cement. The most common form of concrete is Portland cement concrete, which consists of mineral aggregate (generally gravel and sand), portland cement and water. After mixing, the cement hydrates and eventually hardens into a stone-like material. When used in the generic sense, this is the material referred to by the term **concrete**.

For a concrete construction of any size, as concrete has a rather low tensile strength, it is generally strengthened using steel rods or bars (known as rebars). This strengthened concrete is then referred to as reinforced concrete. In order to minimise any air bubbles, that would weaken the structure, a vibrator is used to eliminate any air that has been entrained when the liquid concrete mix is poured around the ironwork. Concrete has been the predominant building material in this modern age due to its longevity, formability, and ease of transport. Recent advancements, such as Insulating concrete forms, combine the concrete forming and other construction steps (installation of insulation).

Metal



MIT Stata Center

Metal is used as structural framework for larger buildings such as skyscrapers, or as an external surface covering. There are many types of metals used for building. Steel is a metal alloy whose major component is iron, and is the usual choice for metal structural building materials. It is strong, flexible, and if refined well and/or treated lasts a long time. Corrosion is metal's prime enemy when it comes to longevity.

The low density and better corrosion resistance of aluminium alloys and tin sometimes overcome their greater cost. Brass was more common in the past, but is usually restricted to specific uses or specialty items today.

Metal figures quite prominently in prefabricated structures such as the Quonset hut, and can be seen used in most cosmopolitan cities. It requires a great deal of human labor to produce metal, especially in the large amounts needed for the building industries.

Other metals used include titanium, chrome, gold, silver. Titanium can be used for structural purposes, but it is much more expensive than steel. Chrome, gold, and silver are used as decoration, because these materials are expensive and lack structural qualities such as tensile strength or hardness.



Glass



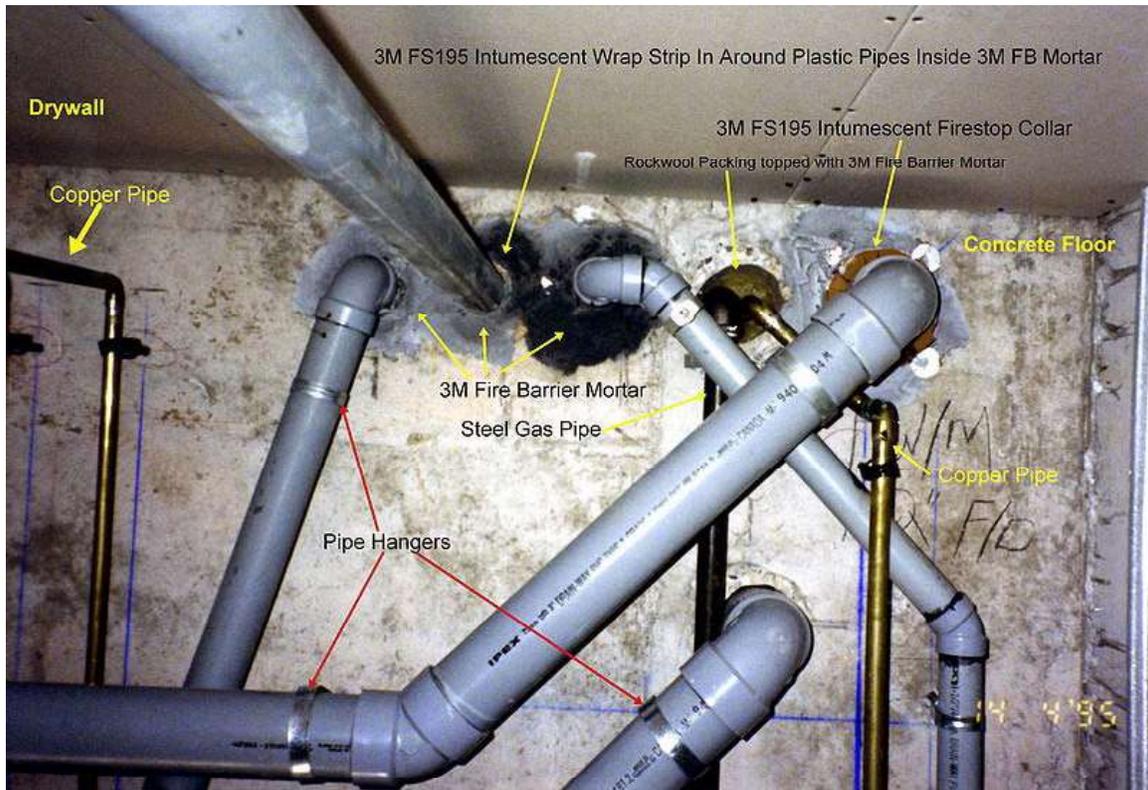
British Museum Great Court

Glassmaking is considered an art form as well as an industrial process or material.

Clear windows have been used since the invention of glass to cover small openings in a building. They provided humans with the ability to both let light into rooms while at the same time keeping inclement weather outside. Glass is generally made from mixtures of sand and silicates, in a very hot fire stove called a *kiln* and is very brittle. Very often additives are added to the mixture when making to produce glass with shades of colors or various characteristics (such as bullet proof glass, or light emittance).

The use of glass in architectural buildings has become very popular in the modern culture. Glass "curtain walls" can be used to cover the entire facade of a building, or it can be used to span over a wide roof structure in a "space frame". These uses though require some sort of frame to hold sections of glass together, as glass by its self is too brittle and would require an overly large kiln to be used to span such large areas by itself.

Plastic



Plastic pipes penetrating a concrete floor in a Canadian highrise apartment building

The term plastics covers a range of synthetic or semi-synthetic organic condensation or polymerization products that can be molded or extruded into objects or films or fibers. Their name is derived from the fact that in their semi-liquid state they are malleable, or have the property of plasticity. Plastics vary immensely in heat tolerance, hardness, and resiliency. Combined with this adaptability, the general uniformity of composition and lightness of plastics ensures their use in almost all industrial applications today.

Foam



Foamed plastic sheet to be used as backing for firestop mortar at CIBC bank in Toronto.

More recently synthetic polystyrene or polyurethane foam has been used in combination with structural materials, such as concrete. It is light weight, easily shaped and an excellent insulator. It is usually used as part of a structural insulated panel where the foam is sandwiched between wood or cement or insulated concrete forms where concrete is sandwiched between two layers of foam.

Cement composites

Cement bonded composites are made of hydrated cement paste that binds wood or alike particles or fibers to make pre-cast building components. Various fibrous materials including paper and fiberglass have been used as binders.

Wood and natural fibres are composed of various soluble organic compounds like carbohydrates, glycosides and phenolics. These compounds are known to retard cement setting. Therefore, before using a wood in making cement bonded composites, its compatibility with cement is assessed.

Wood-cement compatibility is the ratio of a parameter related to the property of a wood-cement composite to that of a neat cement paste. The compatibility is often expressed as a percentage value. To determine wood-cement compatibility, methods based on different properties are used, such as, hydration characteristics, strength, interfacial bond and morphology. Various methods are used by researchers such as the measurement of hydration characteristics of a cement-aggregate mix; the comparison of the mechanical properties of cement-aggregate mixes and the visual assessment of microstructural properties of the wood-cement mixes. It has been found that the hydration test by measuring the change in hydration temperature with time is the most convenient method. Recently, Karade et al. have reviewed these methods of compatibility assessment and suggested a method based on the 'maturity concept' i.e. taking in consideration both time and temperature of cement hydration reaction.

Modern industry

Modern building is a multibillion dollar industry, and the production and harvesting of raw materials for building purposes is on a world wide scale. Often being a primary governmental and trade keypoint between nations. Environmental concerns are also becoming a major world topic concerning the availability and sustainability of certain materials, and the extraction of such large quantities needed for the human habitat.

Building products

In the market place the term *building products* often refers to the ready-made particles/sections, made from various materials, that are fitted in architectural hardware and decorative hardware parts of a building. The list of building products exclusively exclude the building materials, which are used to construct the building architecture and supporting fixtures like windows, doors, cabinets, etc. Building products do not make any part of a building rather they support and make them working in a modular fashion.

It also can refer to items used to put such hardware together such as glues, caulking, paint, and anything else bought for the purpose of constructing a building.

Alternative natural materials

Alternative natural materials is a general term that describes natural materials like rock or adobe that are not as commonly in use as materials such as wood or iron. Alternative natural materials have many practical uses in areas such as sustainable architecture and engineering. The main purpose of using such materials is to minimize the negative effects that our built environment can have on the planet while increasing the efficiency and adaptability of the structures.

History

Alternative natural materials have existed for quite some time but often in very basic forms or only as ingredients to a particular material in the past. For example, earth used as a building material for walls of houses has existed for thousands of years. Much more recently, in the 1920's, the United States government promoted rammed earth as a fireproof construction method for building farmhouses. Another more common example is adobe. Adobe homes are prominent in the southwestern U.S. and several Spanish-speaking countries.

Straw bale construction is a more modern concept, but there even exists evidence that straw was used to make homes in African prairies as far back as the Paleolithic times. Alternative natural materials, specifically their applications, have only recently made their way into more common use. The ideas of being both green and sustainable in response to global warming and climate change shifted more of a focus onto the materials and methods used to build our cityscape and homes. As environmentally conscious decisions became commonplace, the use of alternative natural materials instead of typical natural materials or man-made materials that rely heavily on natural resources became prominent.

Materials

Rock

Rock is a great way to get away from traditional materials that are harmful to the environment. Rocks have two great characteristics: good thermal mass and thermal insulation. These characteristics make stone a great idea because the temperature in the house stays rather constant thus requiring less air conditioning and other cooling systems. Types of rocks that can be employed are reject stone (pieces of stone that are not able to be used for another task), limestone, and flagstone.



Straw bale wall under construction.

Straw

Straw bales can be used as a basis for walls instead of drywall. Straw provides excellent insulation and fire resistance in a traditional post-and-beam structure, where a wood frame supports the house. These straw walls are about 75% more energy efficient than standard drywalls and because no oxygen can get through the walls, fire cannot spread and there is no chance of combustion.



This picture depicts a cyclone- and earthquake-resistant home made completely of bamboo.

Bamboo

In Asian countries, bamboo is being used for structures like bridges and homes. Bamboo is surprisingly strong and rather flexible and grows incredibly fast, making it a rather abundant material. Although it can be difficult to join corners together, bamboo is

immensely strong and makes up for the hardships that can be encountered while building it.

Cordwood

Cordwood is a combination of small remnants of firewood and other lumber that usually go to waste. These small blocks of wood can easily be put together to make a structure that, like stone, has great insulation as well as thermal mass. Cordwood provides the rustic look of log cabins without the use of tons of lumber. You can build an entire building with just cordwood or use stones to fill in the walls.

Rammed Earth

Rammed Earth is a very abundant material that can be used in place of concrete and brick. Soil is packed tightly into wall molds where it is rammed together and hardened to form a durable wall packing made of nothing more than dirt, stones, and sticks. Rammed Earth also provides great thermal mass, which means great energy savings. In addition, it is very weatherproof and durable enough that it was used in the Great Wall of China.

Earth-Sheltered

Earth sheltering is a unique building technique in which buildings are completely constructed on at least one side by some form of Earth whether it be a grass roof, clay walls, or both. This unique system usually includes plenty of windows because of the difficulty involved with using too much electricity in such a house. This adds to the energy efficiency of the house by reducing lighting costs.

Papercrete

Papercrete is an interesting and very new material that is a good substitute for concrete. Papercrete is shredded paper, sand, and cement mixed together that forms a very durable brick-like material. Buildings utilizing papercrete are very well-insulated as well as being termite- and fire-resistant. Papercrete is very cheap as it usually only costs about \$0.35 per square foot.

Adobe

Adobe is an age-old technique that is cheap, easy to obtain, and ideal for hot environments. A mixture of sand, clay, and water is poured into a mold and left in the sun to dry. When dried, it is exceptionally strong and heat-resistant. Adobe doesn't let much

heat through to the inside of the structure, thus providing excellent insulation during the summer to reduce energy costs. Although this clay mixture provides excellent insulation from heat, it is not very waterproof and can be dangerous in earth-quake prone areas due to its tendency to crack easily.

Sawdust

Sawdust is a good material to combine with clay or cement mixtures and use for walls. These walls turn out surprisingly sturdy and effectively recycle any trees that may need to be excavated from the building area. Depending what type of sawdust used (hardwood is best) the wood chips in the walls absorb moisture and help prevent cracking during freeze/thaw cycles. Sawdust may be combined with water and frozen to produce a material commonly known as pykrete, which is strong, and less prone to melting than regular ice.

WWT

Examples



The Dubiotech headquarters, soon to be completed in the United Arab Emirates.

Although this a newer technology there are some buildings that have already employed these materials, as well as other tactics, to make themselves green.

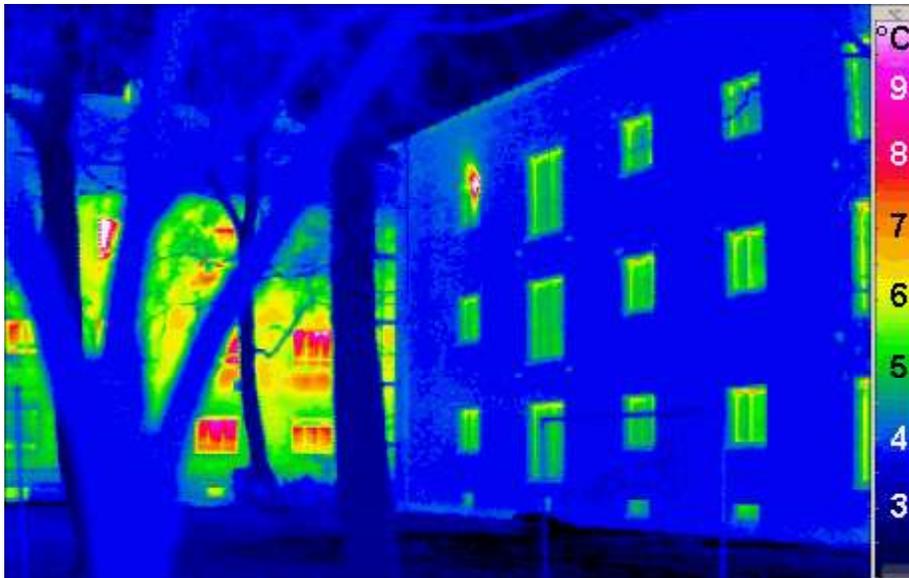
- One such building is the Dubiotech headquarters in Dubai in the United Arab Emirates. This building is covered in solar panels and windows, which lets plenty of natural light in while also getting maximum use out of the sunlight. This building (planned for completion this year) will also be built with an alternative

kind of steel that is not made by a process that releases tons of harsh chemicals into the atmosphere.

- Another example is the School of Art, Media, and Design located in Singapore. This school has a roof made completely of grass (an example of Earth-sheltering). This allows the use of less concrete and other materials for the roof, and the building also includes lots of window to utilize natural lighting.

WWT

Low-Energy House



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

A **Low-energy house** is any type of house that from design, technologies, and building products and uses less energy, from any source, than a traditional or average contemporary house. They are the practice of Sustainable design, Sustainable architecture, Low energy building, Energy-efficient landscaping. They often use Active solar and Passive solar building design techniques and components to reduce their energy expenditure.

General usage

The meaning of the term 'low-energy house' has changed over time, but in Europe it generally refers to a house that uses around half of the German & Swiss low-energy standards referred to below for space heating, typically in the range from 30 kWh/m²a to

20 kWh/m²a (9,500 Btu/ft²/yr to 6,300 Btu/ft²/yr). Below this the term 'Ultra-low energy building' is often used.

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

National standards

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

Europe

In Germany a "Low Energy House" (*Niedrigenergiehaus*) has a limit equivalent to 7 litres of heating oil for each square meter of room *for space heating* annually (50 kWh/m²a or 15,850 Btu/ft²/yr). In Switzerland the term is used in connection with the *MINERGIE* standard (42 kWh/m²a or 13,300 Btu/ft²/yr).

In comparison, the German *Passivhaus* ultra-low energy standard, currently undergoing adoption in some other European countries, has a maximum space heating requirement of 15 kWh/m²a or 4,755 Btu/ft²/yr.

A "Sub-10 Passive House" is under construction in Ireland which has an independently evaluated PHPP (Passive House) rating of 9.5 KW/m²/yr. It's form of construction also tackles the issue of embodied energy, which can significantly distort the lifecycle CO₂ emissions associated with even low energy use houses.

North America

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

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

Zero energy and energy plus buildings

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

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

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

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

- Superinsulation
- PlusEnergy

Low energy technology

Introduction

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

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

A significant feature of ultra low energy buildings is the increasing importance of heat loss through linear thermal bridging within the construction. Failure to eliminate thermal pathways from warm to cold surfaces ("bridges") creates the conditions for interstitial condensation forming deep within the construction and lead to potentially serious issues of mould growth and rot. With near zero filtration losses through the fabric of the

dwelling, air movement cannot be relied upon to dry out the construction and a comprehensive condensation risk analysis of every abutment detail is recommended.

Improvements to heating, cooling, ventilation and water heating

- Absorption refrigerator
- Annualized geothermal solar
- Earth cooling tubes
- Geothermal heat pump
- Heat recovery ventilation
- Hot water heat recycling
- Passive cooling
- Renewable heat
- Seasonal thermal storage
- Solar air conditioning
- Solar hot water
- Solar devices

Passive solar design and landscape

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

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

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

Lighting and electrical appliances

To minimize the total primary energy consumption, the many passive and active daylighting techniques are the first daytime solution to employ. For low light level days, non-daylighted spaces, and nighttime; the use of creative-sustainable lighting design

using low-energy sources such as 'standard voltage' compact fluorescent lamps and solid-state lighting with Light-emitting diode-LED lamps, organic light-emitting diodes, and PLED - polymer light-emitting diodes; and 'low voltage' electrical filament-Incandescent light bulbs, and compact Metal halide, Xenon and Halogen lamps, can be used.

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

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

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



Zero-Energy Building



BedZED zero energy housing in the UK

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

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

Modern evolution

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

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

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

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

Definitions

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

Net zero site energy use

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

Net zero source energy use

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

Net zero energy emissions

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

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

Net zero cost

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

Net off-site zero energy use

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

Off-the-grid

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

Design and construction

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

Zero-Energy Buildings are built with significant energy-saving features. The heating and cooling loads are lowered by using high-efficiency equipment, added insulation, high-

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

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

Energy harvest

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

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

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

The "energy harvest" versus "energy conservation" debate

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

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

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

Occupant behavior

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

Development efforts

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

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

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

Influential zero- and low-energy buildings

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

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

Advantages and disadvantages

Advantages

- isolation for building owners from future energy price increases
- increased comfort due to more-uniform interior temperatures (this can be demonstrated with comparative isotherm maps)
- reduced requirement for energy austerity

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

Disadvantages

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

Zero energy building versus green building

The goal of green building and sustainable architecture is to use resources more efficiently and reduce a building's negative impact on the environment. Zero energy buildings achieve one key green-building goal of completely or very significantly

reducing energy use and greenhouse gas emissions for the life of the building. Zero energy buildings may or may not be considered "green" in all areas, such as reducing waste, using recycled building materials, etc. However, zero energy, or net-zero buildings do tend to have a much lower ecological impact over the life of the building compared with other 'green' buildings that require imported energy and/or fossil fuel to be habitable and meet the needs of occupants.

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

Certification

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

Worldwide

Canada

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

China

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

Germany

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

Ireland

In 2005 *Scandinavian Homes* launched the worlds first standardised passive house in Ireland, this concept makes the design and construction of passive house a standardised process. Conventional low energy construction techniques have been refined and modelled on the PHPP (Passive House Design Package) to create the standardised passive house. Building offsite allows high precision techniques to be utilised and reduces the possibility of errors in construction.

In 2009 the same company started a project to use 23,000 liters of water in a *seasonal storage tank*, heated up by evacuated solar tubes throughout the year, with the aim to provide the house with enough heat throughout the winter months thus eliminating the need for any electrical heat to keep the house comfortably warm. The system is monitored and documented by a research team from The University of Ulster and the results will be included in part of a PhD thesis.

Malaysia

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

Norway

In February 2009, the Research Council of Norway assigned The Faculty of Architecture and Fine Art at the Norwegian University of Science and Technology to host the Research Centre on Zero Emission Buildings (ZEB), which is one of eight new national Centres for Environment-friendly Energy Research (FME). The main objective of the FME-centres is to contribute to the development of good technologies for environmentally friendly energy and to raise the level of Norwegian expertise in this area. In addition, they should help to generate new industrial activity and new jobs. Over the next eight years, the FME-Centre ZEB will develop competitive products and solutions for existing and new buildings that will lead to market penetration of zero emission buildings related to their production, operation and demolition.

Singapore

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

United Arab Emirates

- Masdar City in Abu Dhabi

United Kingdom

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

- BedZED development

United States

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

DOE is also awarding \$4.1 million to two regional building technology application centers that will accelerate the adoption of new and developing energy-efficient

technologies. The two centers, located at the University of Central Florida and Washington State University, will serve 17 states, providing information and training on commercially available energy-efficient technologies.

The U.S. Energy Independence and Security Act of 2007 created 2008 through 2012 funding for a new solar air conditioning research and development program, which should soon demonstrate multiple new technology innovations and mass production economies of scale.

Arizona

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

California

- The IDeAs Z2 Design Facility is a net zero energy, zero carbon retrofit project occupied since 2007. It uses less than one fourth the energy of a typical U.S. office by applying strategies such as daylighting, radiant heating/cooling with a ground-source heat pump and high energy performance lighting and computing. The remaining energy demand is met with renewable energy from its building-integrated photovoltaic array. In 2009, building owner and occupant Integrated Design Associates (IDeAs) recorded actual measured energy use intensity of 21.17 kbtu/sf-year, with 21.72 kbtu/sf-year produced, for a net of -0.55 kbtu/sf-yr. The building is also carbon neutral, with no gas connection, and with carbon offsets purchased to cover the embodied carbon of the building materials used in the renovation.
- Googleplex, Google's headquarters in Mountain View, California, completed a 1.6 megawatt photovoltaic campus-wide renewable power generation system. Google (and others) have developed advanced technology for major reductions in computer-server energy consumption (which is becoming a major portion of modern zero-energy commercial building design, along with daylighting and efficient electrical lighting systems).

Florida

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

Michigan

- The Mission Zero House is the 110-year-old Ann Arbor home of Greenovation.TV host and Environment Report contributor Matthew Grocoff . As of 2011, the home is the oldest home in America to achieve net-zero energy.. The owners are chronicling their project on Greenovation.TV and the Environment Report on public radio.
- The Vineyard Project is a Zero Energy Home (ZEH) thanks to the Passive Solar Design, 3.3 Kws of Photovoltaics,Solar Hot Water and Geothermal Heating and Cooling. The home is pre-wired for a future wind turbine and only uses 600kwh of energy per month while a minimum of 20 kWh of electricity per day with many days net-metering backwards. The project also used ICF insulation throughout the entire house and is certified as Platinum under the LEED for Homes certification. This Project was awarded Green Builder Magazine Home of the Year 2009

New Jersey

- The 31 Tannery Project, located in Branchburg, New Jersey, serves as the corporate headquarters for Ferreira Construction, the Ferreira Group, and Noveda Technologies. The 42,000-square-foot (3,900 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 5,000-square-foot Zero Energy Design® home was built in 1979 with support from President Carter's new United States Department of Energy. It relied heavily on passive solar building design for space heat, water heat and space cooling. It heated and cooled itself effectively in a climate where the summer peak temperature was 110 degrees Fahrenheit, and the winter low temperature was -10 F. It did not use active solar systems. It is a double envelope house that uses a gravity-fed natural convection air flow design to circulate passive solar heat from 1,000 square feet of south-facing glass on its greenhouse through a thermal buffer zone in the winter. A swimming pool in the greenhouse provided thermal mass for winter heat storage. In the summer, air from two 24-inch 100-foot-long underground earth tubes is used to cool the thermal buffer zone and exhaust heat through 7200 cfm of outer-envelope roof vents.

Vermont

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

Passive House



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

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

the architectural design. Although it is mostly applied to new buildings, it has also been used for refurbishments.

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

History



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



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

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

First examples

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

Further implementation and councils

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

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

The products developed for the Passivhaus standard were further commercialised during and following the European Union sponsored CEPHEUS project, which proved the concept in five European countries over the winter of 2000-2001. In North America the first Passivhaus was built in Urbana, Illinois in 2003, and the first to be certified was built in 2006 near Bemidji, Minnesota in Camp Waldsee of the German Concordia Language Villages.

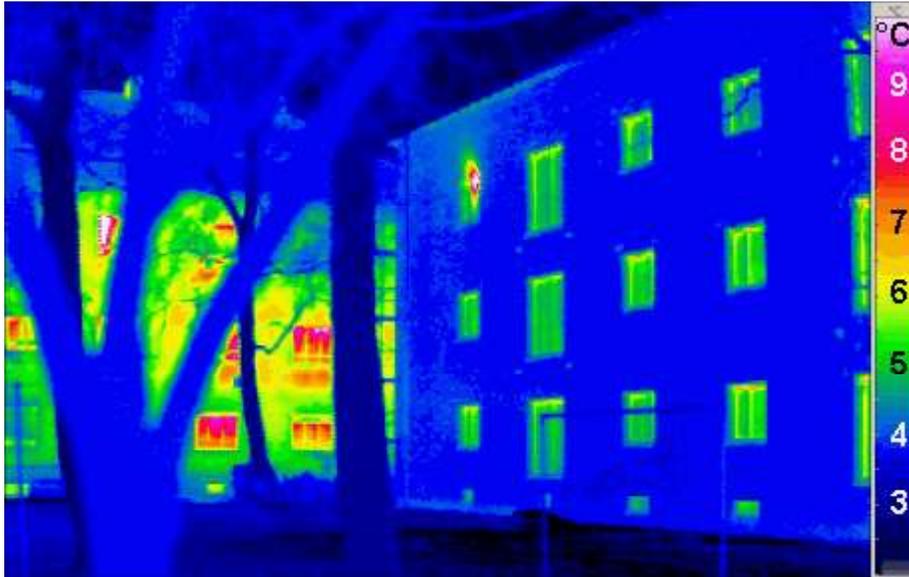
The first US *retrofit* project was certified in July of 2010, the remodeled 2,400 sf craftsman O'Neill house in the town of Sonoma, California.

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

Present day

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

Standards



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

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

Requirements

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

- The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/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 (3.79×10^4 btu/ft² per year)
- The building must not leak more air than 0.6 times the house volume per hour ($n_{50} \leq 0.6$ / hour) at 50 Pa (N/m²) 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 btu/ft² per hour).

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

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

Space heating requirement

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

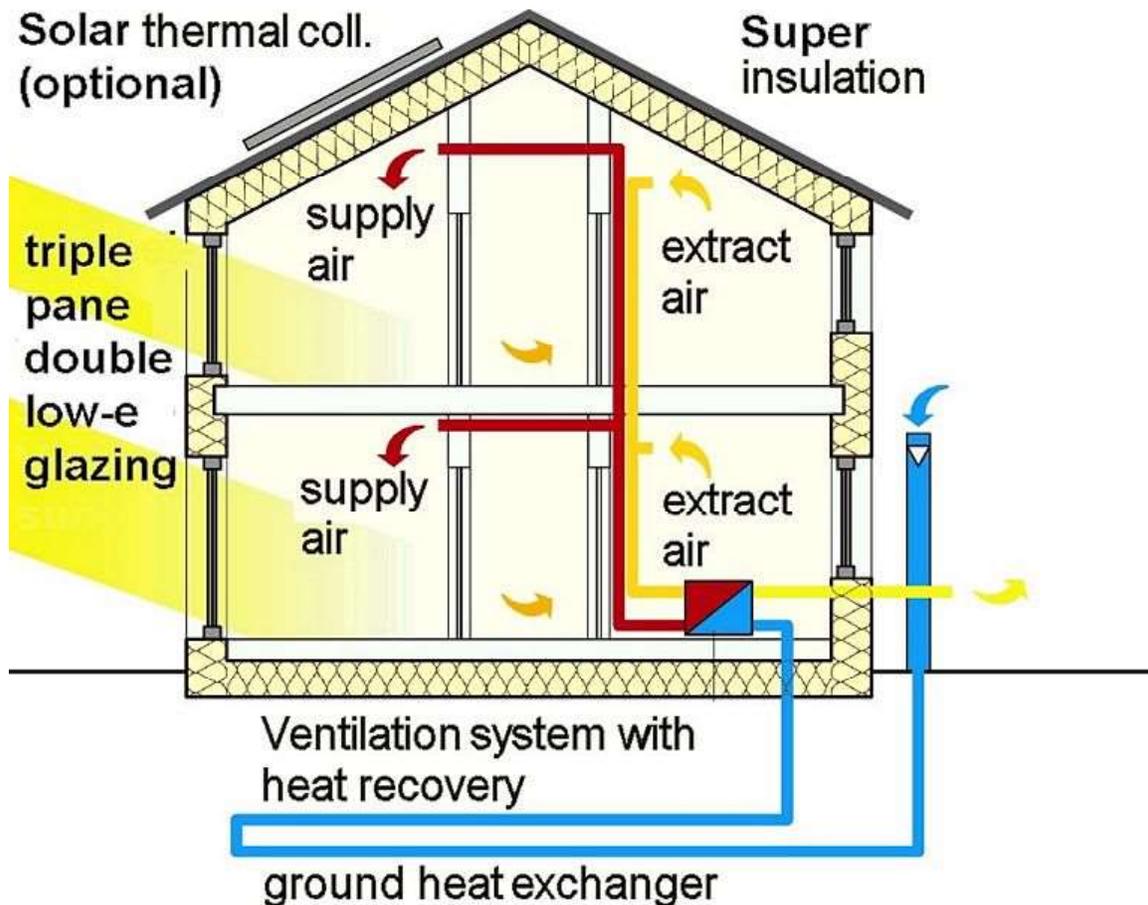
Construction costs

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

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

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

Design and construction



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

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

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

Passive solar design and landscape

Passive solar building design and energy-efficient landscaping support the Passive house energy conservation and can integrate them into a neighborhood and environment. Following passive solar building techniques, where possible buildings are compact in shape to reduce their surface area, with principle windows oriented towards the equator - south in the northern hemisphere and north in the southern hemisphere - to maximize passive solar gain. However, the use of solar gain, especially in temperate climate

regions, is secondary to minimizing the overall house energy requirements. In climates and regions needing to reduce excessive summer passive solar heat gain, whether from the direct or reflected sources, can be done with a Brise soleil, trees, attached pergolas with vines, vertical gardens, green roofs, and other techniques.

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

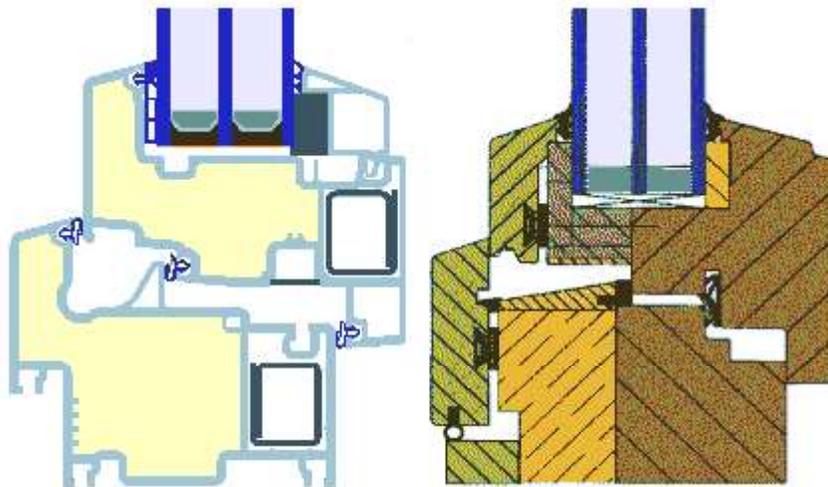
Superinsulation

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

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

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

Advanced window technology



Typical **Passive House** windows

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

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

Airtightness

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

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

Ventilation

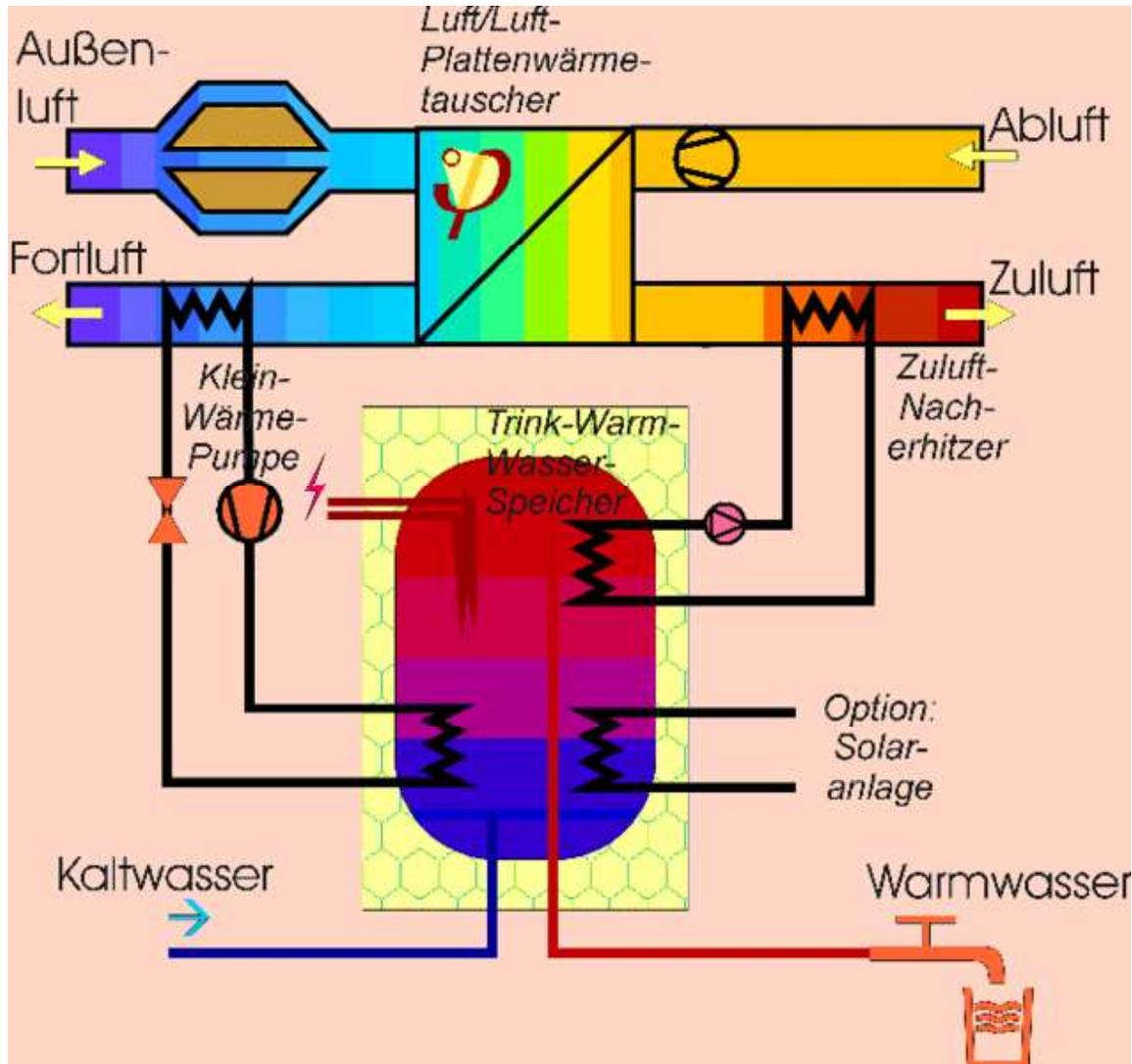
Passive methods of natural ventilation by singular or cross ventilation; by a simple opening or enhanced by the stack effect from smaller ingress - larger egress windows and/or clerestory-openable skylight use; is obvious when the exterior temperature is acceptable.

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

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

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

Space heating



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

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

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

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

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

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

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

Lighting and electrical appliances

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

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

Appliance consumer products meeting independent energy efficiency testing and receiving Ecolabel certification marks for reduced electrical-'natural-gas' consumption

and product manufacturing carbon emission labels are preferred for use in Passive houses. The ecolabel certification marks of Energy Star and EKOenergy are examples.

Traits of passive houses

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

- The air is fresh, and very clean. Note that for the parameters tested, and provided the filters (minimum F6) are maintained, HEPA quality air is provided. 0.3 air changes per hour (ACH) are recommended, otherwise the air can become "stale" (excess 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.
- In the United Kingdom, an average new house built to the Passive House standard would use 77% less energy for space heating, compared to the Building Regulations.

- In Ireland, it is calculated that a typical house built to the Passive House standard instead of the 2002 Building Regulations would consume 85% less energy for space heating and cut space-heating related carbon emissions by 94%.

Comparison with zero energy buildings

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

Tropical climate needs

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

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

Heat Recovery Ventilation

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

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

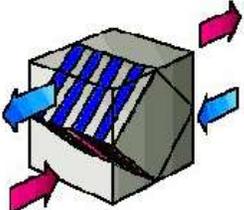
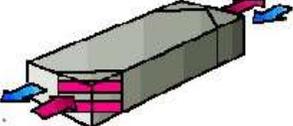
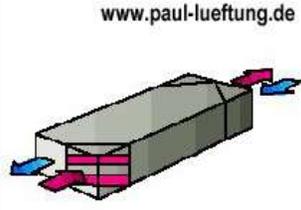
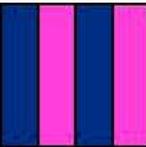
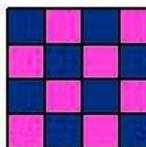
Benefits

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

Technology

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

Air to air heat exchanger

Principle			
Profile			
Counter current Heat exchanger	Vertical flat plate	Horizontal flat plate	Cellular
Efficiency	50 - 70 %	70 - 80 %	85 - 99 %

A Heat exchanger.

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

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

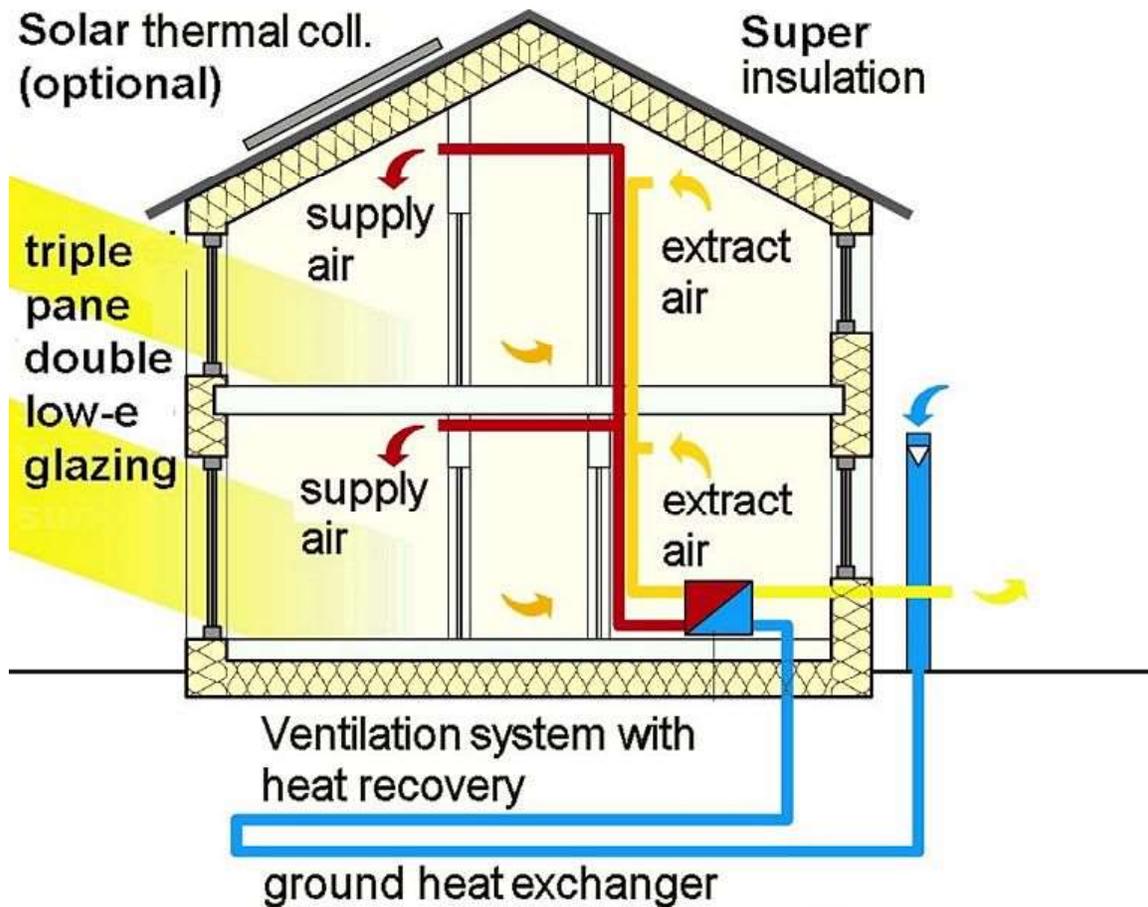
Incoming air

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

A high enough incoming air temperature can also be achieved by

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

Earth-to-air heat exchanger



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

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

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

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

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

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

Air quality

This is highly site dependent.

Radon

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

Bacteria and fungi

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

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

Earth-to-Water heat exchanger

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

In temperate climates in an energy efficient building, such as a passivhaus, this is more than sufficient for comfort cooling during summer without resorting to an airconditioning

system. In more extreme hot climates a very small air to air micro-heat pump in reverse (an air conditioner) with the evaporator (giving heat) on the air inlet after the HRV heat exchanger and the condenser (taking heat) from the air outlet after the heat exchanger will suffice.

Seasonal bypassing

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

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

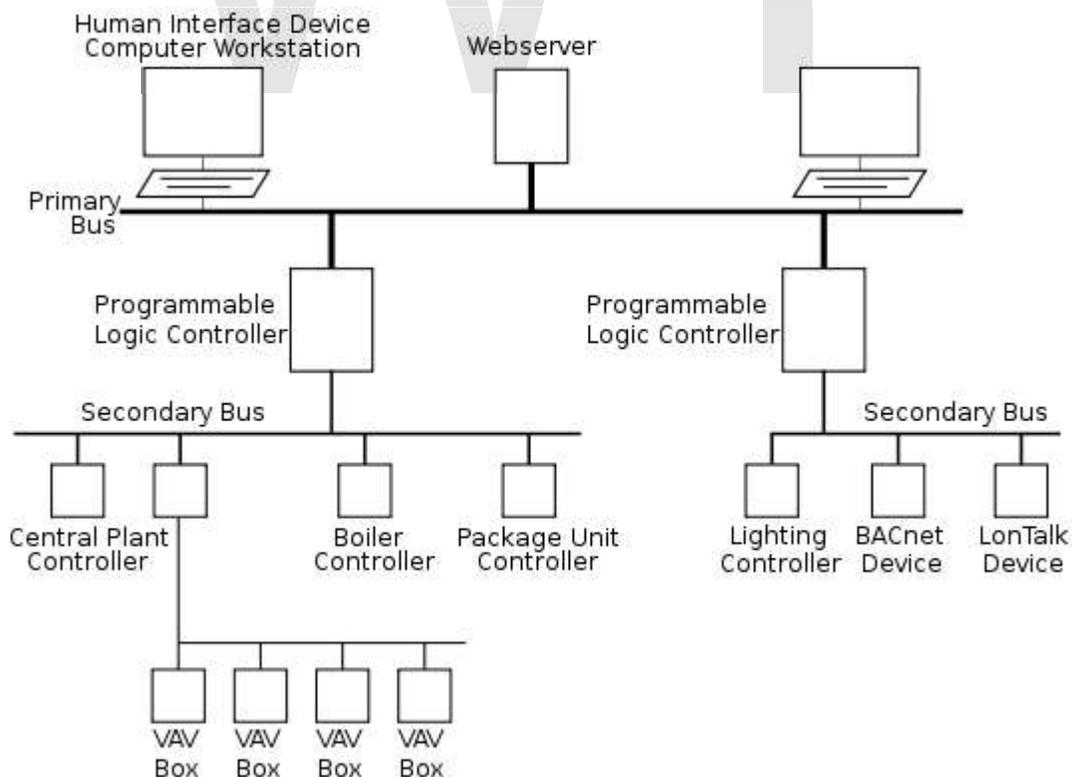
In the summer, the opposite is true. The air becomes cooled in the earth to air exchanger. But after passing through the EAHX, the air is warmed by the heat recovery ventilator using the warmth of the outgoing air. In this case, the HRV can have an internal bypass such that the inflowing air bypasses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

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

Building Automation

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

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



Topology

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

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

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

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

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

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

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

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

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

Infrastructure

Controller

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

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

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

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

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

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

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

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

Occupancy

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

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

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

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

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

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

Lighting

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

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

Air handlers

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

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

Constant volume air-handling units

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

Variable volume air-handling units

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

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

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

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

VAV hybrid systems

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

Central plant

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

Chilled water system

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

Condenser water system

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

Hot water system

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

Alarms and security

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

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

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

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

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

Room automation

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

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



Over-Illumination

Over-illumination



This cosmetics store has lighting levels over twice recommended levels

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

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

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

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

Numerical definition



Some big-box retail stores are over-illuminated.

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

Related phenomena

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

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

Causes

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

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

Forsaking use of sunlight



A fitness club that is illuminated mostly by natural light

Forsaking use of sunlight is often a design decision made by the architect or their subcontractor. Overlooking opportunities for skylights is a major defect of many building designs, but lack of coordination of interior light banks with indirect sunlight is an even more common error. At a minimum, the building design should offer sufficient independent light banks so that building occupants may select the most suitable combination of natural to augmented light. Very frequently entire floors of office buildings are designed with only one switch, so that perimeter areas near natural light are illuminated with the same level of artificial light as the dimmest interior zones. This lack of independent controls also would require an entire office floor of say 10,000 square feet (1,000 m²) to be fully illuminated if one office worker stays late for evening work. This can occur with even the most eminent of architects. Frank Lloyd Wright designed Marin County Civic Center in 1957 with only one or two switches serving very large office pools. This cost Marin County several thousand of dollars per year in unneeded electricity costs.

Failure to use occupancy sensors

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

Failure to delamp or use available lighting controls

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

Health effects

Headaches, fatigue, stress and performance effects



Common T8 fluorescent lighting fixture frequently used in office environments

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

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

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

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

Circulatory and circadian rhythm effects

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

Circadian rhythm disruption is primarily caused by the wrong timing of light in reference to the circadian phase. It can also be affected by too much light, too little light, or incorrect spectral composition of light. This effect is driven by stimulus (or lack of stimulus) to photosensitive ganglion cells in the retina. The "time of day", the circadian phase, is signalled to the pineal gland, the body's photometer, by the suprachiasmatic

nucleus. Bright light in the evening or in the early morning shifts the phase of the production of melatonin. An out-of-sync melatonin rhythm can worsen cardiac arrhythmias and increase oxidized lipids in the ischemic heart. Melatonin also reduces superoxide production and myeloperoxidase (an enzyme in neutrophils which produces hypochlorous acid) during ischemia-reperfusion.

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

Energy and economic considerations

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

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

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

Building and lighting control systems

Building automation and lighting control solutions are now available to help reduce energy usage and cost by eliminating over-illumination. These solutions provide centralized control of all lighting within a home or commercial building, allowing easy implementation of scheduling, occupancy control, daylight harvesting and more. Many

systems also support Demand response and will automatically dim or turn off lights to take advantage of DR incentives and cost savings.

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

WWT

Chapter- 13

Compact Fluorescent Lamp



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



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

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

Compared to general service incandescent lamps giving the same amount of visible light, CFLs use less power and have a longer rated life. In the United States, a CFL has a higher purchase price than an incandescent lamp, but can save over US\$40 in electricity costs

over the lamp's lifetime. Like all fluorescent lamps, CFLs contain mercury, which complicates their disposal.

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

History



An early compact fluorescent lamp

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

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

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

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

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

Construction



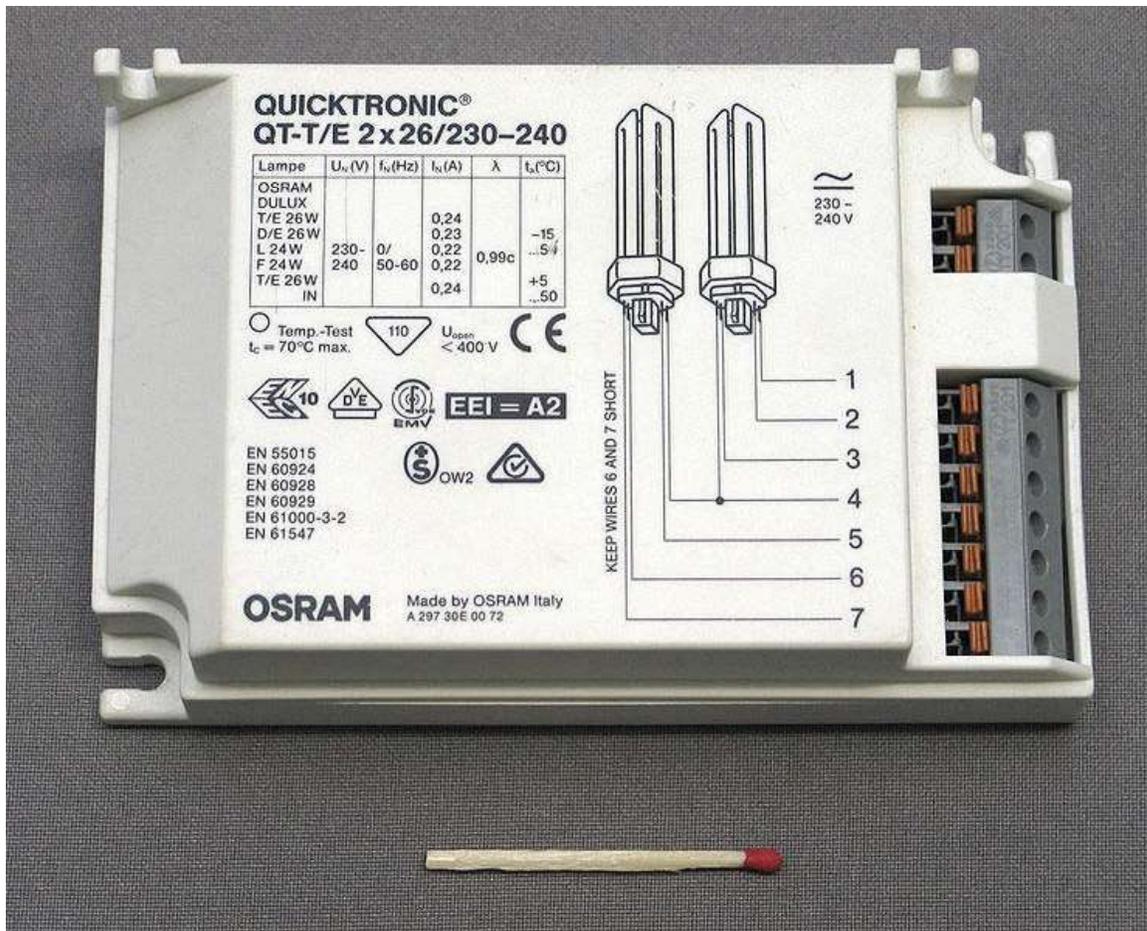
A compact fluorescent lamp used outside of a building.

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

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



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

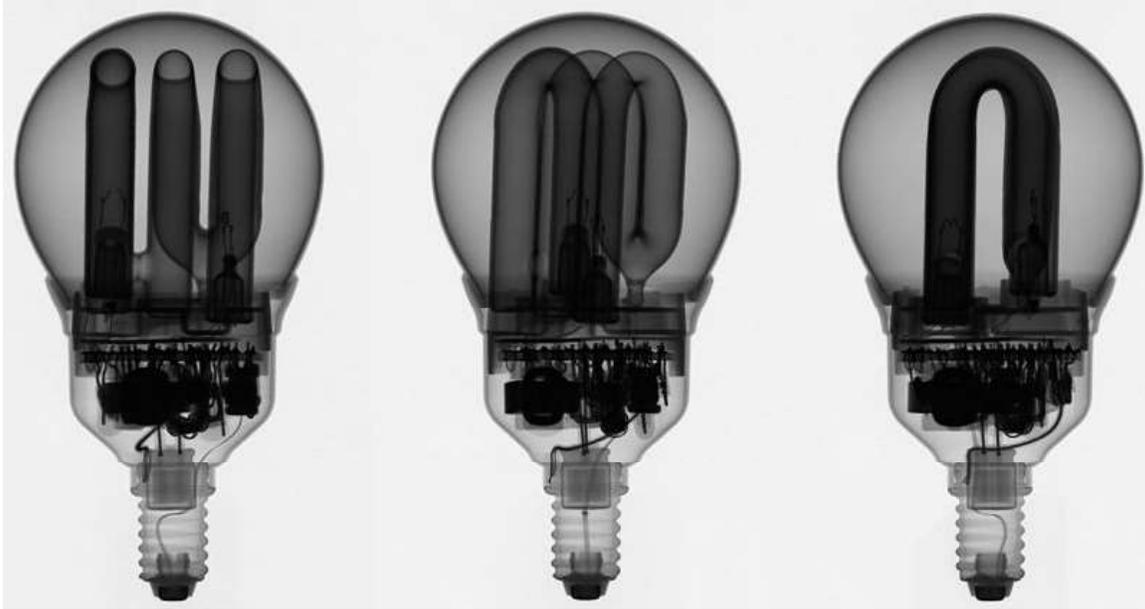


Non-integrated electronic ballast for compact fluorescent lamps

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

Components

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



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

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

CFL power sources

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

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

Comparison with incandescent lamps

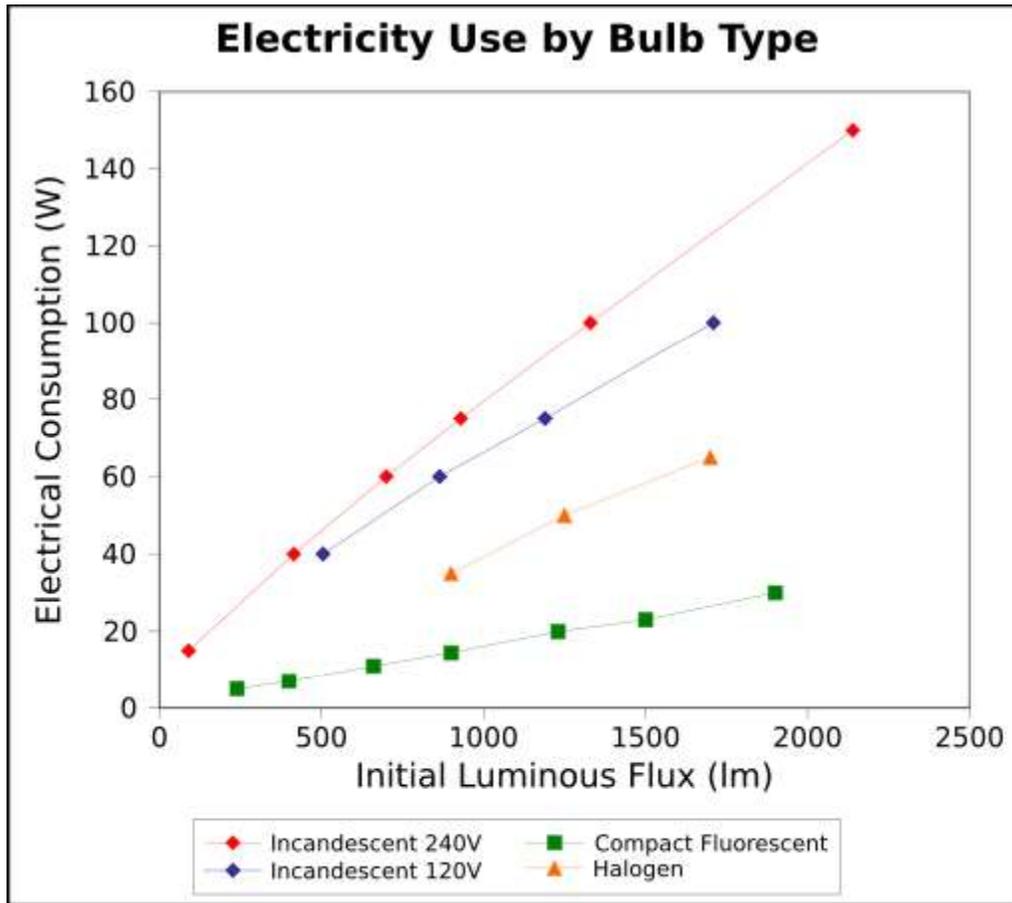
Lifespan

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

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

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

Energy efficiency



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

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

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

Electrical power equivalents for differing lamps

	Electrical power consumption Watts (W)	Minimum light output lumens (lm)
Compact fluorescent	8–9	450
Incandescent	9–15	800

15–20	75	1,100
20–25	100	1,600
25–45	150	2,600

Heating and cooling

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

Efficacy and efficiency

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

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

Embodied energy

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

Cost

While the purchase price of an integrated CFL is typically 3 to 10 times greater than that of an equivalent incandescent lamp, the extended lifetime and lower energy use will more than compensate for the higher initial cost. A US article stated "A household that invested

\$90 in changing 30 fixtures to CFLs would save \$440 to \$1,500 over the five-year life of the bulbs, depending on your cost of electricity. Look at your utility bill and imagine a 12% discount to estimate the savings."

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

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

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

Comparison with alternative technologies

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

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

Other CFL technologies

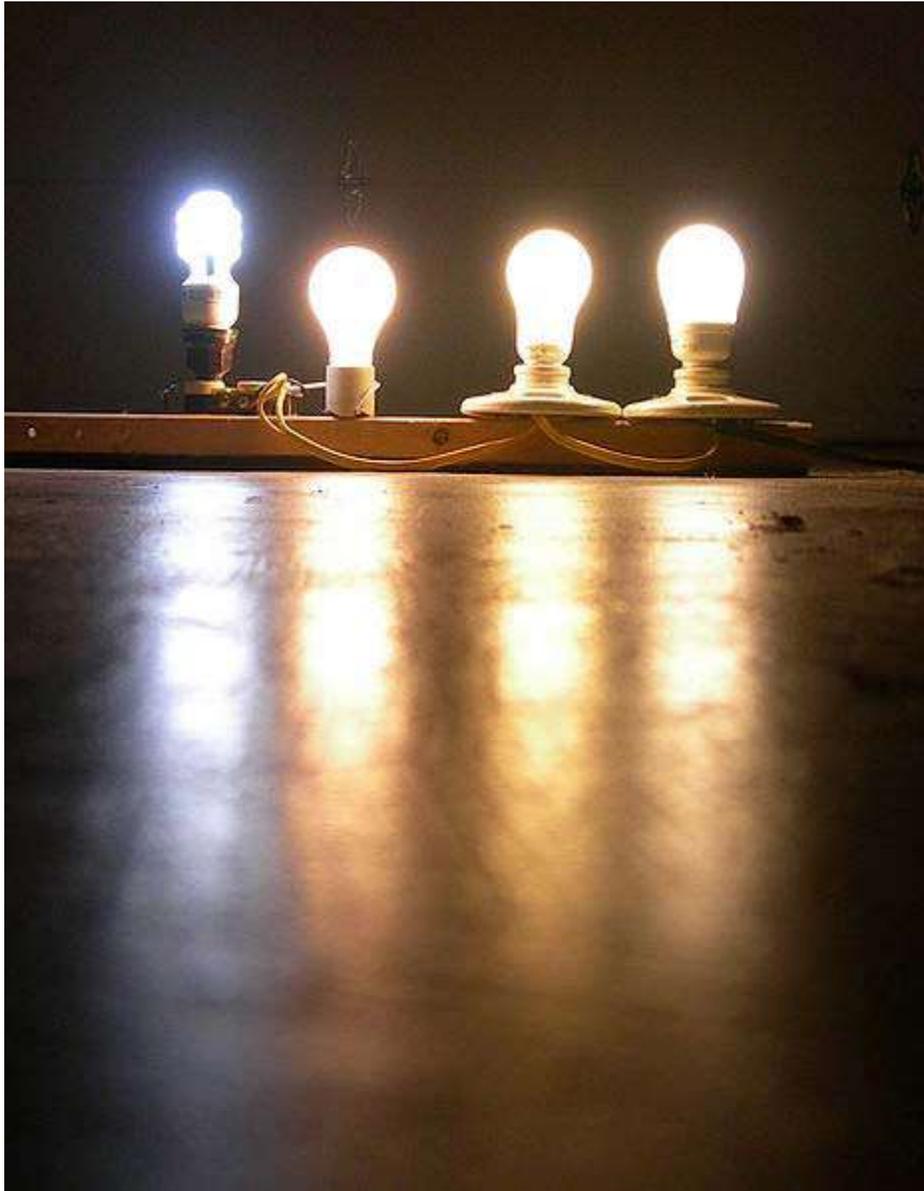
Another type of fluorescent lamp is the electrodeless lamp, known as magnetic induction lamp, radiofluorescent lamp or fluorescent induction lamp. These lamps have no wire

conductors penetrating their envelopes, and instead excite mercury vapor using a radio-frequency oscillator. Currently, this type of light source is struggling with a high cost of production, stability of the products produced by domestic manufacturers in China, establishing an internationally recognized standard and problems with EMC and RFI. Furthermore, induction lighting is excluded from Energy Star standard for 2007 by the EPA.

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

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

Spectrum of light

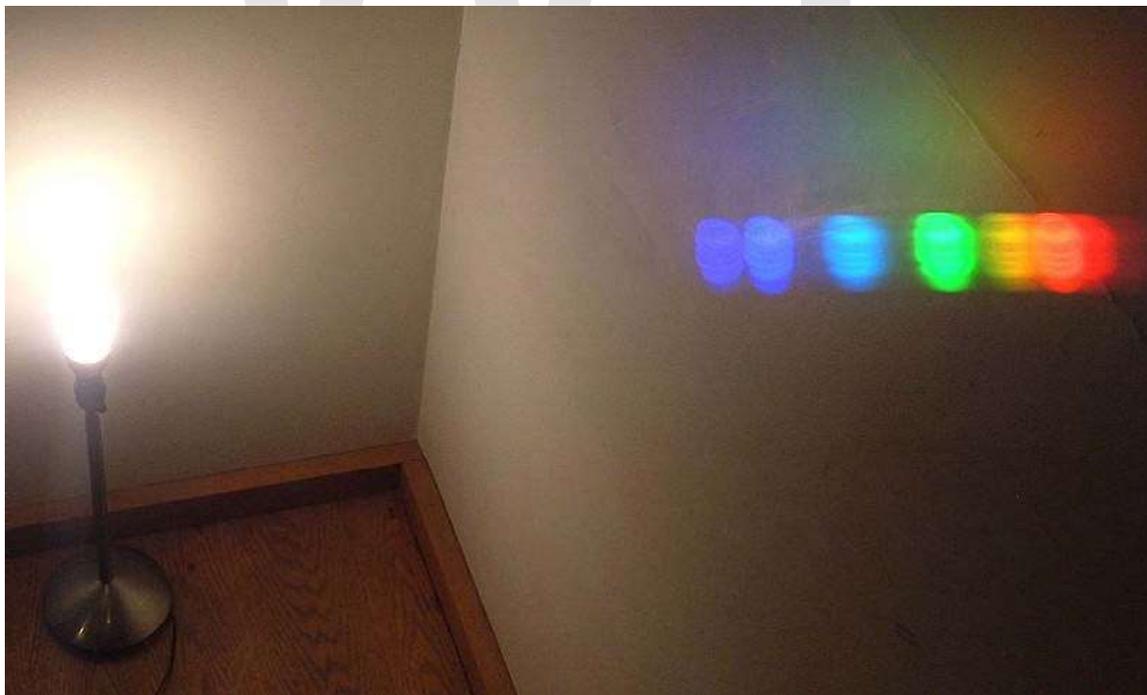


A photograph of various lamps illustrates the effect of color temperature differences (left to right):

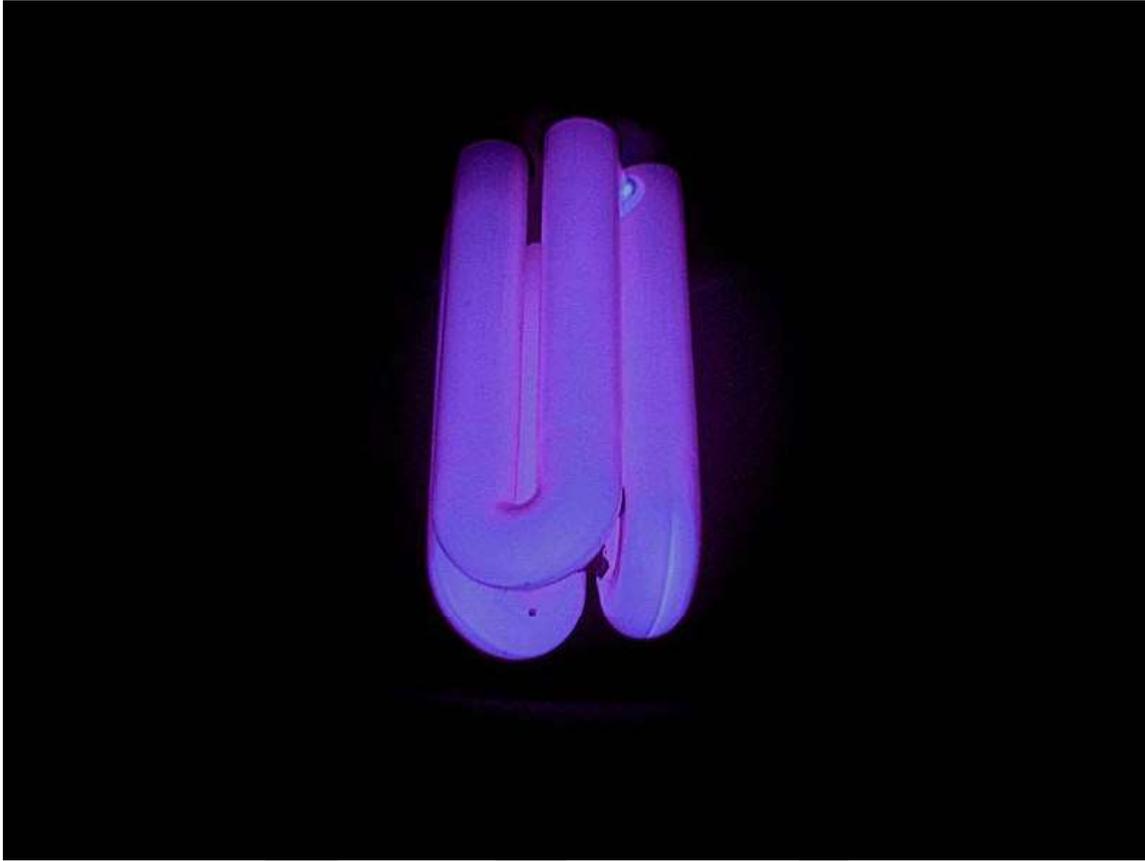
1. Compact Fluorescent: General Electric, 13 W, 6,500 K
2. Incandescent: Sylvania 60 W Extra Soft White
3. Compact Fluorescent: Bright Effects, 15 W, 2,644 K
4. Compact Fluorescent: Sylvania, 14 W, 3,000 K



Color Temperature compared against a white ceiling.



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



A blacklight CFL.

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

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

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

Daylight $\geq 5,000 \leq 200$

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

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

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

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

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

Disadvantages

Starting time

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

Hybrid CFL

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

Health issues

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

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

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

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

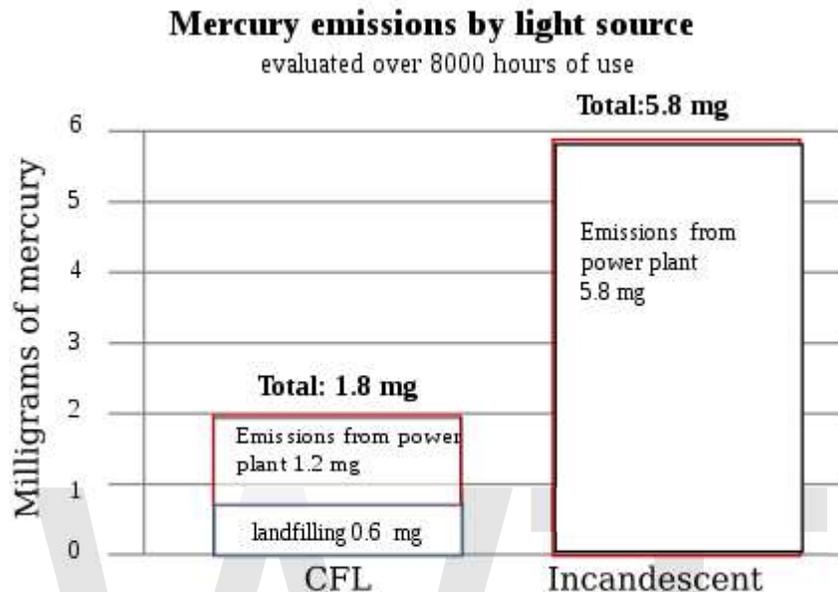
Environmental issues

Mercury emissions

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

In areas with coal-fired power stations, the use of CFLs saves on mercury emissions when compared to the use of incandescent bulbs. This is due to the reduced electrical power demand, reducing in turn the amount of mercury released by coal as it is burned. In July 2008 the US EPA published a data sheet stating that the net system emission of mercury for CFL lighting was lower than for incandescent lighting of comparable lumen

output. This was based on the average rate of mercury emission for US electricity production and average estimated escape of mercury from a CFL put into a landfill. Coal-fired plants also emit other heavy metals, sulfur, and carbon dioxide.



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

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

Broken and discarded lamps

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

Special handling instructions for breakage are currently not printed on the packaging of household CFL bulbs in many countries. The amount of mercury released by one bulb can temporarily exceed U.S. federal guidelines for chronic exposure. *Chronic* however, implies that the exposure continues constantly over a long period of time and the Maine

DEP study noted that it remains unclear what the health risks are from short-term exposure to low levels of elemental mercury. The Maine DEP study also confirmed that, despite following EPA best-practice cleanup guidelines on broken CFLs, researchers were unable to remove mercury from carpet, and agitation of the carpet—such as by young children playing—created spikes as high as 25,000 ng/m³ in air close to the carpet, even weeks after the initial breakage. Conventional tubular fluorescent lamps have been in commercial and domestic use since the 1930s with little public concern about their handling; these and other domestic products such as thermometers contain far more mercury than modern CFLs.

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

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

Mercury poisoning of Chinese factory workers

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

Recycling

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

Design and application issues



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

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

Size

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

End of life

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

Incandescent replacement wattage inflation

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

Dimming

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

Perceived coldness of low intensity CFL

When a CFL is dimmed the colour temperature (warmth) stays the same. This is counter to most other light sources (such as the sun or incandescents) where colour gets warmer as the light source gets dimmer. Emotional response testing suggests that people find dim, bluish light sources to be cold or even sinister. This

may explain the persistent lack of popularity for CFL's in bedrooms and other settings where a subdued light source is preferred.

Heat

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

Power quality

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

Infrared signals

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

Iridescence

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

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

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

Fire hazard

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

Outdoor use

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

Differences among manufacturers

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

Lifetime brightness

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

UV emissions

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

Efforts to encourage adoption

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

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

In 2008, the European Union approved regulations progressively phasing out incandescent bulbs starting in 2009 and finishing at the end of 2012. By switching to energy saving bulbs, EU citizens will save almost 40 TW·h (almost the electricity consumption of 11 million European households), leading to a reduction of about 15 million metric tons of CO₂ emissions per year.

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

Venezuela and Cuba have launched massive incandescent light bulbs replacement programs in order to save energy. In the case of Venezuela, the government was able to save 2000 MW of electricity in the first six months of the 2006 program called Mission

Energy Revolution, which by 2007 replaced 20 million incandescent light bulbs with CFL from a total of an estimated 55 million light bulbs in the country. Cuba replaced all the 11 million light bulbs used in the island. Also, Venezuela signed an agreement with Vietnam, one of the large producers of CFLs in the world, to establish a factory to supply the future demand and hand-outs of government light bulbs.

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

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

Labeling programs

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

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

Cool Roof

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

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

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

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

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

Cool roof can also be used as a geoengineering technique to tackle global warming based on the principle of solar radiation management, provided that the materials used not only reflect solar energy, but also emit infra-red radiation to cool the planet. This technique can give between 0.01-0.19 W/m² of globally-averaged negative forcing, depending on whether cities or all settlements are so treated. This is generally small when compared to the 3.7 W/m² of positive forcing from a doubling of CO₂. 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 CO₂ emissions which worsen global warming. For this reason alone it is still demonstrably worth pursuing as a geoengineering technique.

Benefits of cool roofs

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

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

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

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

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

Energy calculators

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

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

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

ENERGY STAR Roofing Comparison Calculator

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

Cool roofs in cool climates

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

Additionally, higher R values for insulating materials can lessen the impact of roof surface color. Snow on roofs also provides insulation, but it also adds considerable weight to the roofing assembly, which may not have been accounted for in the initial design. For a medium density of snow the resistance per 25 mm is about 0.110 (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 differential in membrane temperature between areas having 300 mm of snow cover compared to areas having no snow.

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

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

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

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

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

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

with a reflective roof is multiplied by the adjacent building that picked it up via the windows.

Types of cool roofs

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

Inherently cool roofs

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

Coated roofs

One of the way to make an existing or new roof reflective is by applying a solar reflective coating on its surface. These coatings are specially engineered to reflect heat, regular white paint is not enough.

Ceramic coatings are the most well known in this domain, they provide an average reflectance of 75% to 85%. They have several limitations such as color (usually white only), which is why they are used by industrial applications mainly (warehouses, factories, ...). Their application is done by trained professionals only and may require specialized equipment and appropriate safety precautions.

High performance *nanotechnology heat reflective paints* are the most innovative in this field. They can reflect up to almost 95% of solar radiations, reducing a roof's heat load by an average of 30% in hot weather with as little as 200 micrometres (0.2 mm) in thickness . Working at nanotechnology levels allows thermal barrier paints like Planet Supra, for example, to offer an unlimited choice of colors in matte or glossy finish (the lighter the color, the higher the performance), easy application like any regular water-based paint and additional benefits such as self-cleaning properties thanks to Titanium Dioxide in the formulation.

Reflectivity and emissivity ratings for some reflective roof products can be found in the CRRC (Cool Roofs Rating Council) website.

Green roofs

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

intensive or extensive; some green roof designs incorporate both intensive and extensive elements.

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

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

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

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

A cool roof case study

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

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

Programs promoting the use of cool roofs

Across the U.S. Federal Government

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

Energy Star

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

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

Cool Roof Rating Council (CRRC)

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

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

Green Globes

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

Green Globes uses performance benchmark criteria to evaluate a building's likely energy consumption, comparing the building design against data generated by the EPA's Target Finder, which reflects real building performance. Buildings may earn a rating of between one and four globes. This is an online system; a building's information is verified by a Green Globes-approved and trained licensed engineer or architect. To qualify for a rating,

roofing materials must have a solar reflectance of at least .65 and thermal emittance of at least .90. As many as 10 points may be awarded for 1-100 percent roof coverage with either vegetation or highly reflective materials or both.

LEED

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

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

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

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

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

COOL ROOFS EUROPE

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

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

The urban heat island effect

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

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

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

Chapter- 15

Green Roof



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



Green roof of City Hall in Chicago, Illinois.

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

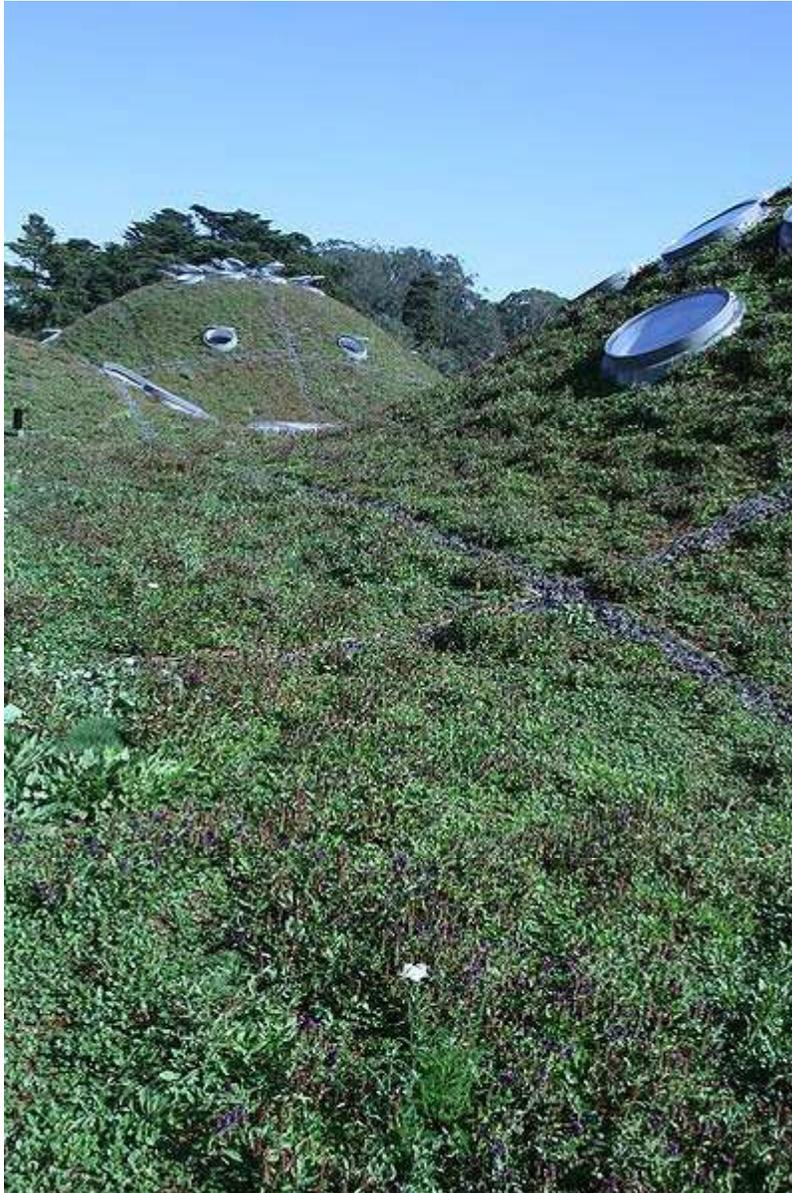
Container gardens on roofs, where plants are maintained in pots, are not generally considered to be true green roofs, although this is an area of debate. Rooftop ponds are another form of green roofs which are used to treat greywater.

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

The term *green roof* may also be used to indicate roofs that use some form of "green" technology, such as a cool roof, a roof with solar thermal collectors or photovoltaic

modules. Green roofs are also referred to as *eco-roofs*, *oikosteges*, *vegetated roofs*, *living roofs*, and *greenroofs*.

Environmental benefits



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

Green roofs are used to:

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

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

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

Financial benefits

- Increase roof life span dramatically
- Increase real estate value

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

Several studies have been carried out in Germany since the 1970s. Berlin is one of the most important centers of green roof research in Germany. Particularly in the last 10 years, much more research has begun. About ten green roof research centers 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.”

Types



An intensive roof garden in Manhattan

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

Another important distinction is between pitched green roofs and flat green roofs. Pitched sod roofs, a traditional feature of many Scandinavian buildings, tend to be of a simpler design than flat green roofs. This is because the pitch of the roof reduces the risk of water

penetrating through the roof structure, allowing the use of fewer waterproofing and drainage layers.

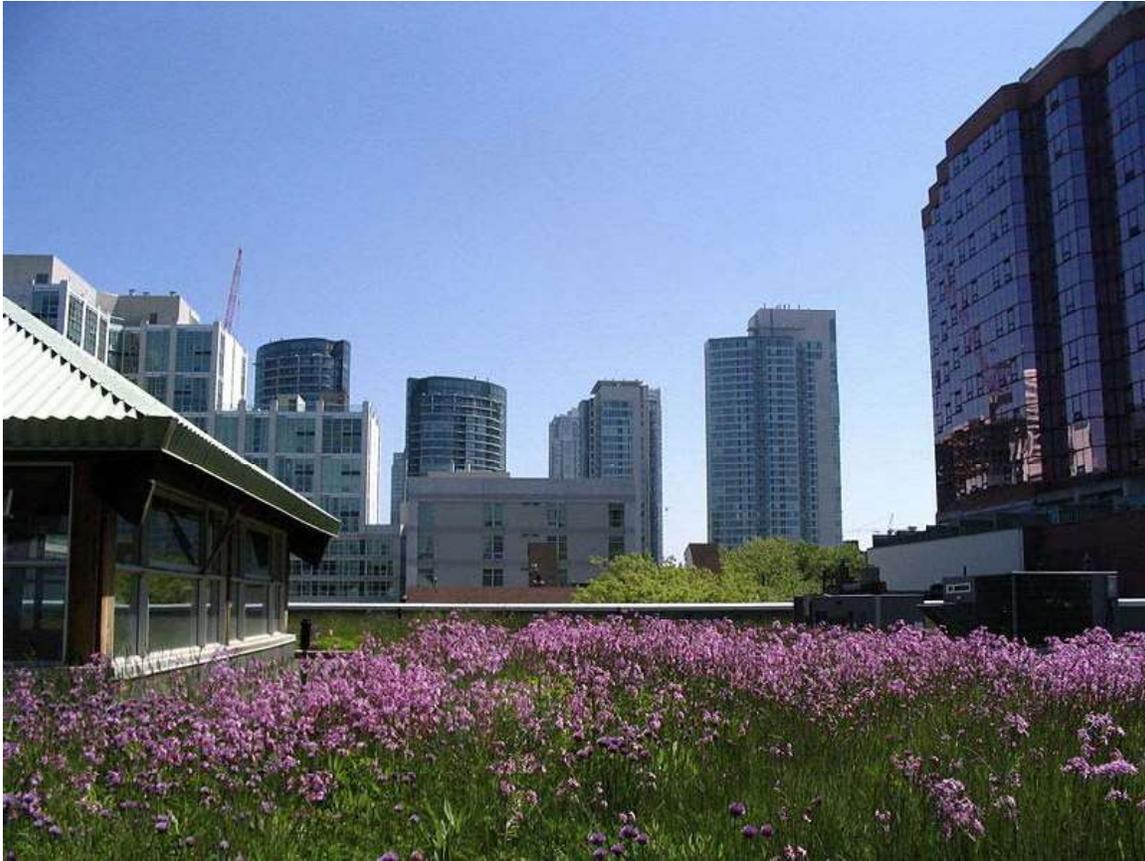
History



Re-creation of Viking houses in Newfoundland



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



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

Green Roofs have a centuries-long history.

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

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

Many green roofs are installed to comply with local regulations and government fees, often regarding stormwater runoff management. In areas with combined sewer-stormwater systems, heavy storms can overload the wastewater system and cause it to

flood, dumping raw sewage into the local waterways. Green roofs decrease the total amount of runoff and slow the rate of runoff from the roof. It has been found that they can retain up to 75% of rainwater, gradually releasing it back into the atmosphere via condensation and transpiration, while retaining pollutants in their soil. Elevation 314, a new development in Washington D.C., uses green roofs to filter and store some of its stormwater on site, avoiding the need for expensive underground sand filters to meet D.C. Department of Health stormwater regulations.

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

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

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

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

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

Brown roofs

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

Examples by country



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

Switzerland

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

Sweden

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

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

Germany

Long-held green roof traditions since the early industrialization about 100 years ago exist in Germany. Since the 1970s, a vibrant green roof industry also exists. Building codes developed by the *Fachvereinigung Bauwerksbegrünung*, have existed since the 1980s. The current issue was published in 2008. Since the 1980s, environmental mitigation regulations have helped to push green roofs to reduce the ecological footprint of buildings. Now, about 10,000,000 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, Geisenheim and Neubrandenburg.

Iceland



Sod roof Church at Hof, Iceland

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

United Kingdom

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

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

Canada

The city of Toronto approved a by-law in May 2009, mandating green roofs on residential and industrial buildings. There is criticism from Green Roofs for Healthy Cities that the new laws are not stringent enough, since they will only apply to residential

building that are a minimum of six storeys high. By 31 January 2011, industrial buildings will be required to render 10% or 2,000m² of their roofs green. In 2008, the Vancouver Convention Center installed a six-acre living roof of indigenous plants and grasses on its West building, making it the largest green roof in Canada.

France

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

Greece



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

The Greek Ministry of Finance has now installed a green roof on the Treasury in Constitution Square in Athens. The so called "oikostegi" (Greek - *oiko*, pronounced *eeke*, meaning building-ecological, and *stegi*, pronounced *staygee*, meaning roof-abode-shelter) was inaugurated in September, 2008. Studies of the thermodynamics of the roof in September 2008 concluded that the thermal performance of the building was significantly affected by the installation. In further studies, in August 2009, energy savings of 50% were observed for air conditioning in the floor directly below the installation. The ten-

floor building has a total floor space of 1.4 hectares. The oikostegi covers 650m², equalling 52% of the roof space and 8% of the total floor space. Despite this, energy savings totalling €5,630 per annum were recorded, which translates to a 9% saving in air conditioning and a 4% saving in heating bills for the whole building. An additional observation and conclusion of the study was that the thermodynamic performance of the oikostegi had improved as biomass was added over the 12 months between the first and second study. This suggests that further improvements will be observed as the biomass increases still further. The study also stated that while measurements were being made by thermal cameras, a plethora of beneficial insects were observed on the roof, such as butterflies, honey bees and ladybirds. Obviously this was not the case before installation. Finally, the study suggested that both the micro-climate and biodiversity of Constitution Square, in Athens, Greece had been improved by the oikostegi.

Spain

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

Egypt

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

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

United States of America



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

One of the largest expanses of extensive green roof is to be found in the US, at Ford Motor Company's River Rouge Plant, Dearborn, Michigan, where 42,000 square metres (450,000 sq ft) of assembly plant roofs are covered with sedum and other plants, designed by William McDonough. Built over Millennium Park Garage, Chicago's 24.5-acre (99,000 m²) Millennium Park is considered one of the largest intensive green roofs. Other well-known American examples include Chicago's City Hall and the Gap headquarters in San Bruno, CA. Recently, the American Society of Landscape Architects retrofitted their existing headquarters building in Washington, D.C. with a green roof designed by landscape architect Michael Van Valkenburgh.

Another example of a green roof in the United States is the Ballard Library in Seattle. The landscape architect was Swift & Co. and the building architect was Bohlin Cywinski Jackson. This green roof has over 18,000 plants to help with insulation and reduce runoff. The plants used on the roof include *Achillea tomentosa* (woolly yarrow), *Armeria maritima* (sea pink, sea thrift), *Carex inops pensylvanica* (long-stolonated 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 (10,000 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, the building consumes 30-35% less energy than required by code.

An early green roofed building (completed in 1971) is the 358,000 sq ft (33,300 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.

Australia

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

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

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

Costs

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

Some cost can also be attributed to maintenance. Extensive green roofs have low maintenance requirements but they are generally not maintenance free. German research has quantified the need to remove unwanted seedlings to approximately 0,1

min/(m²*year). Maintenance of green roofs often includes fertilization to increase flowering and succulent plant cover. If aesthetics is not an issue, fertilization and maintenance is generally not needed. Extensive green roofs should only be fertilized with controlled release fertilizers in order to avoid pollution of the storm-water. Conventional fertilizers should never be used on extensive vegetated roofs. German studies have approximated the nutrient requirement of vegetated roofs to 5gN/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.

Disadvantages

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