# BUILDING ENVELOPE EFFICIENCY MEASURES

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## Contents





## Summary

A building envelope includes elements, such as walls, windows, doors, roofs, foundations, and chimneys that separate an interior space from an exterior environment. The characteristics of the building envelope dictate how the building will interact with its environment. Careful design and upkeep of the building envelope will minimize energy use by two of the predominant energy-using systems, namely the heating, ventilating, and air conditioning (HVAC) system, and the lighting system. HVAC energy use is optimized by semi-isolation (i.e., minimization of infiltration and unwanted heat loss or heat gain) of the interior conditioned spaces from the exterior environment during periods of heating and cooling; in other words, to maximize efficiency when the building is being heated, cold exterior air should not infiltrate, and

heat from the interior should not transfer across the envelope to the exterior. Similarly, when the building is being cooled, warm exterior air should not infiltrate, and heat from the exterior should not transfer across the envelope to the interior. The exception to this is when natural ventilation (e.g., through an open window, door, or other structural element) is desirable or necessary for ventilation, cooling, or even heating. The term semi-isolation is chosen because in many cases heat gain (or loss) from (or to) the exterior is desirable, and further minimizes HVAC energy use. For example, window designs that allow for solar heat gain and prevent heat loss further reduce heating costs. In regards to the lighting system, a building envelope that is designed to make full use of daylighting will substantially reduce electrical lighting energy use. Daylighting has the additional benefit of reducing the cooling load, as natural light is characterized by less heat than fluorescent or incandescent lamps for a given level of illumination. This article present energy efficiency opportunities associated with the various elements of a building envelope, namely the exterior walls, windows, rooftops and ceilings, foundations, floors, and basements. It also briefly describes ways to control unwanted infiltration, while insuring adequate ventilation.

## 1. Introduction

Buildings account for about 40% of worldwide energy consumption. This large share is indicative of the importance of buildings to humankind. This share also shows the potential for energy efficiency actions, if implemented on a widespread basis, to significantly reduce global energy use, as well as the pollution associated with energy conversion and utilization. Building envelopes are a critical element in determining how efficiently a building responds to environmental conditions. A carefully designed and well-maintained building envelope will incorporate measures to minimize both electrical lighting demand and HVAC energy use.

Buildings or shelters have always been an important part of civilization. Shelters are used not only by humans, but also by many forms of wildlife. For example, bird nests, beehives, and rodent burrows are all forms of shelters, or building envelopes. For humans, structures and buildings have varied greatly over history, and with climate, geography, and economic condition. Building envelope designs have ranged from pyramids to igloos to grass shacks to high rises. Some of the factors that influence building design are aesthetics, religious practices, culture, climate, and functionality. The functions of buildings vary widely as well. For example, buildings are used for shelter from weather, wildlife, or other humans; buildings are used to store and protect belongings, such as food and clothing; buildings are used to house commercial and industrial activities; buildings are used for congregation and prayer; and buildings are even used to entomb Pharaohs.

Some early human designs incorporated good energy management practices. For example, Indian cave dwellers built structures out of materials with large thermal mass, such as sandstone and adobe, to modulate temperature variations between the day and evening in the desert. They also placed their dwellings tucked into hillsides to provide shading in summer and allow low winter sun angles to heat the structures in the winter. Numerous forms of wildlife have also designed energy-efficient structures. For example, insects, such as wasps and termites, have developed ways to control temperature in their structures. In addition, rodents vary the depth of their burrows as a function of season.

Early commercial buildings in the nineteenth century were designed with a high ratio of exterior surface area to interior volume. They also incorporated narrow designs to optimize the penetration of daylight. Early commercial buildings were characterized by smaller internal loads than modern-day commercial buildings, and therefore the external conditions dictated heating and cooling requirements. Presently, external loads heavily influence conditions in residential buildings, while internal loads now dominate in commercial buildings. The shift toward dominant internal loads in commercial buildings is related to an increased number of occupants, more equipment, and the trend of box-like designs that have a smaller external surface area to interior volume ratio.

Since the oil embargoes in the 1970s, more emphasis has been placed on improving the efficiency of building envelopes to save energy and costs. Newer buildings incorporate better insulation and more advanced glazing. There is also an increased awareness about the importance of careful building design on occupant health, productivity, and all around well-being. Commercial buildings that are aesthetically pleasing, comfortable, and healthy attract good employees and increase employee productivity. Similarly, apartment owners with well-designed building envelopes will attract better tenants, and will incur fewer problems and lower energy costs. Homeowners who incorporate energy-efficiency measures will experience increased comfort with reduced operating costs.

The main factors that influence building energy use are the location and climate of the building site, building orientation, building envelope design, building function, and occupancy. This article focuses on the building envelope, and its relationship with lighting and HVAC energy use. For a building to be designed for optimum efficiency, it is important to coordinate the design of interior energy systems (e.g., HVAC, lighting, and miscellaneous equipment) with the building envelope in the initial design stage, rather than during remodeling or retrofit measures. An efficient envelope design will minimize HVAC and lighting use, resulting in the purchase of smaller, less costly equipment at the onset. Without care to integrate the lighting and HVAC designs with the building envelope design, energy may (and most likely will) be wasted.

While the selection of the building site and the orientation play the important role of dictating the climate to which the building is exposed (e.g., temperature, wind velocity, incident solar radiation, shading by vegetation or topography, duration of heating and cooling seasons, humidity, presence of streams and lakes), the building envelope dictates how heat will be transferred to and from its environment. Building envelopes incorporate several main structural elements, including walls, doors, windows, floors, foundations, ceilings, roofs, and chimneys. Heat losses and gains through each of these elements will contribute to the cooling and heating requirements of the space. The level of daylighting through windows and skylights will also affect the electric lighting demand.

Important thermal properties of the building materials include specific heat capacity, conductivity, emissivity, absorptivity, transmissivity, and reflectivity. These properties determine how the building envelope materials will respond to the exterior and interior climates. In addition to energy transfer through the main structural elements of a building, intentional ventilation as well as infiltration through cracks and poorly sealed doors, windows, ducts, vents, pipes, and electrical outlet cracks can affect the heating and cooling loads of the building and occupant comfort.

Materials with a specific high-heat capacity (or large thermal mass) are capable of storing heat or “cool.” This can lead to a thermal lag, which is useful in modulating temperatures in environments with cool nights and hot days. In such environments, the heat of day is stored in the thermal mass, and then dissipated during the evening. Likewise, the cool of the night is stored and used to keep the building cool during the day.

Materials with a high thermal conductivity transfer heat at a high rate. Materials with a low thermal conductivity, or high resistance to heat flow, are good insulators, and transfer heat at a slower rate. In most cases, building materials with a low thermal conductivity are desired to isolate the interior environment from the exterior. The thermal resistivity, or R-value, of a building structure element can be increased with the addition of insulation.

Emissivity, absorptivity, transmissivity, and reflectivity are radiative properties of materials. Emissivity refers to the ability of a surface to radiate heat away. Absorptivity is a quantity that defines how much radiation a surface will absorb. Transmissivity is a measure of the amount of incident radiation that is allowed to pass through (transmit) a material (e.g., glass). Opaque materials have a transmissivity of zero. Reflectivity refers to the quantity of incident radiation that is reflected from a surface. All of these properties are particularly important when considering incident solar radiation on building envelopes.

The primary energy-efficiency opportunities associated with building envelopes are discussed in the following sections. Sections 2–5 each treat a family of building elements: exterior walls; windows; rooftops and ceilings; and foundations, floors, and basements. Section 6 summarizes the main sources of infiltration, and how to minimize infiltration while insuring adequate ventilation.

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**Biographical Sketches**

**Clark W. Gellings's** 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). He coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the US Department of Energy (in US dollars) in the development of energy efficiency technologies. He has demonstrated a unique ability to understand what energy customers want and need, and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among his most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. He has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the US Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

**Kelly E. Parmenter,** Ph.D., is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in the UK. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed-metal contacts, and drag reducing effects of dilute polymer solutions in pipeflow. Dr Parmenter's areas of expertise include: energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.