Building Envelope

Quick Facts

- Residential and commercial buildings account for almost 39 percent of total U.S. energy consumption and 38 percent of U.S. carbon dioxide (CO_2) emissions.[1]
- Space heating, cooling, and air conditioning (HVAC) account for the largest amount of end-use energy consumption in both residential and commercial buildings. They are responsible for 35 and 32 percent of energy end use in these sectors, respectively.[2]
- The building envelope – the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation – serves as a thermal barrier and plays an important role in determining the amount of energy necessary to maintain a comfortable indoor environment relative to the outside environment.

Background

Nearly all of greenhouse gas (GHG) emissions from the residential and commercial sectors can be attributed to energy use in buildings (see *CLIMATE TECHBOOK: Residential and Commercial Sectors Overview*). Even so, existing technology and practices can be used to construct "zero net energy" buildings - buildings that use design and efficiency measures to reduce energy needs dramatically and rely on renewable energy sources to meet remaining energy demand. The Energy Independence and Security Act of 2007 (EISA 2007) calls for all new commercial buildings to be net zero energy by 2030. An integrated approach provides the best opportunity to achieve significant GHG reductions from the buildings sector, because many different building elements interact with one another to influence overall energy consumption (see *CLIMATE TECHBOOK: Buildings Overview*). However, certain key building elements can play a significant role in determining a building's energy use and associated GHG emissions and merit a more in-depth consideration.

The building envelope is the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating interior temperatures and helps determine the amount of energy required to maintain thermal comfort. Minimizing heat transfer through the building envelope is crucial for reducing the need for space heating and cooling. In cold climates, the building envelope can reduce the amount of energy required for heating; in hot climates, the building envelope can reduce the amount of energy required for cooling. A substantial part of "weatherization" includes improvements to the building envelope, and government weatherization programs often cite energy and energy bill savings as a primary rationale for these initiatives.

Description

The building envelope can affect energy use and, consequently, GHG emissions in a variety of ways:

- **Design of the building envelope**
  The overall design can help determine the amount of lighting, heating, and cooling a building will require. Architects and engineers have developed innovative new ways to improve overall building design in order to maximize light and heat efficiency, for example through passive solar heating, which uses the sun's heat to warm the building when it is cold without relying on any mechanical or electrical equipment. [3] Local climate is an important determinant for identifying the design features

that will result in the greatest reductions of energy needs. These may include such things as south-facing windows in cool climates and shading to avoid summer sun in hot climates.[4]

- **Building envelope materials and product selection**
  - *Embodied energy*
    Embodied energy refers to the energy required to extract, manufacture, transport, install, and dispose of building materials, including those used in the building envelope. Efforts to reduce this energy use and associated emissions, for example through the substitution of bio-based products, can be made as part of a larger effort to reduce emissions from buildings.

  - *Insulation and air sealing*
    Heat naturally flows from a warmer to a cooler space; insulation provides resistance to heat flow, thereby reducing the amount of energy needed to keep a building warm in the winter and cool in the summer. Insulation is frequently discussed in terms of its ability to resist heat flow, its R-value. A variety of insulation options exist, including blanket, concrete block, insulating concrete forms, spray foam, rigid foam, and natural fiber insulation.

    Adding insulation strategically will improve the efficiency of the building; however, it is only effective if the building is properly sealed. Sealing cracks and leaks prevents air flow and is crucial for effective building envelope insulation. Leaks can generally be sealed with caulk, spray foam, or weather stripping.[5]

  - *Roofs*
    Roof design and materials can reduce the amount of air conditioning required in hot climates by increasing the amount of solar heat that is reflected, rather than absorbed, by the roof. For example, roofs that qualify for ENERGY STAR®[6] are estimated to reduce the demand for peak cooling by 10 to 15 percent.[7] Proper insulation is also important in attics and building cavities adjacent to the roof.

    In addition, roofs also offer several opportunities for installing on-site generation systems. Solar photovoltaic (PV) systems can either be installed as a rooftop array on top of the building or a building-integrated photovoltaic system can be integrated into the building as roofing tiles or shingles (see also *CLIMATE TECHBOOK: Solar Power*).

  - *Walls*
    Like roofs, the amount of energy lost or retained through walls is influenced by both design and materials. Design considerations affect the placement of windows and doors, the size and location of which can be optimized to reduce energy losses. Decisions regarding the appropriate material can be more complicated because the energy properties of the entire wall are affected by the design. Importantly, material selection and wall insulation can both affect the building's thermal properties.

    A building's thermal mass – i.e., its ability to store heat – is determined in part by the building materials used. Thermal mass buildings absorb energy more slowly and then hold it longer, effectively reducing indoor temperature fluctuations and reducing overall heating and cooling requirements. Thermal mass materials include traditional materials, such as stone and adobe, and cutting edge products, such as those that incorporate phase change materials (PCMs). PCMs are solid at room temperature and liquefy as they absorb heat; the absorption and release of energy through PCMs helps to moderate building temperature throughout the day.

- o *Windows, doors, and skylights*
  Collectively known as *fenestration*, windows, exterior doors, and skylights influence both the lighting and the HVAC requirements of a building. In addition to design considerations (the placement of windows and skylights affects the amount of available natural light), materials and installation can affect the amount of energy transmitted through the window, door, or skylight, as well as the amount of air leakage around the window components. New materials, coatings, and designs all have contributed to the improved energy efficiency of high-performing windows, doors, and buildings. For example, higher-quality windows on the market today can be six times more energy efficient than lower-quality windows.[8] Some of the advances in windows include: multiple glazing, the use of two or more panes of glass or other films for insulation, which can be further improved by filling the space between the panes with a low-conductivity gas, such as argon, and low-emissivity (low-e) coatings, which reduce the flow of infrared energy from the building to the environment.

  In residential buildings, using optimum window design and glazing specification is estimated to reduce energy consumption from 10 to 50 percent in most climates; in commercial buildings, an estimated 10 to 40 percent reduction in lighting and HVAC costs is attainable through improved fenestration.[9]

- **Interactions with other building elements**
  The building envelope can affect both the lighting and heating and cooling needs of the building. These interactions are important to consider when retrofitting or weatherizing buildings to reduce their energy use in the most cost-effective manner. For example, with a new building it may be more cost-effective to choose a design with a more costly, high-performance building envelope that significantly reduces the need for heating and cooling with a smaller, less-costly HVAC system. For existing buildings, it may be more cost-effective to add insulation to a building than to install a more efficient heating system.

Environmental Benefit / Emission Reduction Potential

Improvements to the building envelope have the potential to reduce GHG emissions from new and existing buildings in the residential, commercial, and industrial sectors. The building envelope can significantly affect the amount of required lighting and HVAC, the two largest end uses of energy in both the residential and commercial sectors. Local climate influences the appropriateness and cost-effectiveness of many decisions pertaining to building envelope design and product selection.

Greater GHG emission reductions can be achieved through integrated approaches that consider the entire building as a whole. Significant improvements in energy efficiency are attainable and can reduce building-related emissions to very low levels or, when coupled with renewable energy sources, to zero (see *Climate TechBook: Buildings Overview*).

In addition to the climate benefits, many building envelope improvements also result in a variety of benefits for consumers, including lower energy bills, as well as improved thermal comfort, moisture control, and noise control.

Cost

Improvements to the building envelope have the potential to be cost-effective for both new and existing buildings. From a climate perspective, improvements to the building envelope should be pursued because they reduce GHG emissions; from a consumer perspective, improvements to the building envelope should be pursued because they can result in both a more comfortable indoor environment and reduced energy costs. The ENERGY STAR® program provides estimates of cost savings associated with several building envelope elements, for example:

- **Windows**
  For a typical home, an ENERGY STAR® window will save $126 to $465 per year when replacing single-pane windows and $27 to $111 per year when replacing double-pane windows.[10]

- **Insulation and air sealing**
  By sealing air leaks and adding insulation from average values to recommended values, the average home in the North can save 12 percent on its total utility bill (19 percent of heating and cooling costs) and the average home in the South can save 11 percent on its total utility bill (20 percent of total costs).[11]

  Energy audits can be conducted to identify the most cost-effective ways to improve energy efficiency in existing buildings. New buildings can be cost-effectively built to have lower energy needs, and the Net-Zero Energy Commercial Building Initiative, a public-private collaboration, has a goal of having all new commercial buildings built beginning in 2030 to be net-zero energy buildings (see *CLIMATE TECHBOOK: Buildings Overview*). Importantly, these whole building efforts include, but are not limited to, improvements to the building envelope.

Obstacles to Further Development or Deployment

In broad terms, the obstacles to improved building envelopes are the same as the obstacles faced by buildings broadly. These barriers include cost concerns, market barriers, public policy and planning barriers, and customer barriers (see *CLIMATE TECHBOOK: Buildings Overview*). More narrowly, these obstacles pose different barriers to new and existing buildings, as well as to each of the different building envelope elements. The cost-effectiveness of certain building envelope improvements, such as improved insulation and sealing of air leaks, has not led to widespread implementation. For example, 46 million U.S. homes, just over 60 percent of all single-family homes, are estimated to be under-insulated. Insulation retrofits would not only reduce GHG emissions, but they would also reduce energy consumption and consumer energy bills, improve air quality, and reap a variety of public health benefits.[12] These kinds of energy efficiency projects are part of the low-hanging fruit for reducing GHG emissions.

Policy Options to Help Promote Building Envelope Improvements

Like the obstacles to building envelope improvements, the available policy options fall into the same general categorization as buildings overall (see *CLIMATE TECHBOOK: Buildings Overview*). Some policy and program interventions focus on improvements to a single building-envelope element, such as insulation. Tax incentives and other programs can change annually. A number of organizations track buildings-related policies; see below for a sample of useful references:

- **Standards and codes**
  Regulatory policies include mandatory and voluntary building codes passed by states and localities.

  Department of Energy (DOE) Building Energy Codes Program – provides state-by-state information on residential and commercial building codes. http://www.energycodes.gov/implement/state_codes/index.stm

- **Financial incentives**
  Financial incentives include tax credits, rebates, low-interest loans, energy-efficient mortgages, and innovative financing, all of which address the barrier of first costs. Many utilities also offer individual incentive programs, because reducing demand, especially peak demand, can enhance the utility's system-wide performance.

  Weatherization Assistance Program – provides low-income families with weatherization services, including insulation, air sealing, and windows. http://apps1.eere.energy.gov/weatherization/about.cfm

  Database of State Incentives for Renewables and Efficiency (DSIRE) – tracks federal and state incentives for renewable and energy efficiency programs, including summary maps and tables, as well as a searchable database. http://www.dsireusa.org/

- **Information and education**
  While many businesses and homeowners express interest in making energy-efficiency improvements for their own buildings and homes, they often do not know which products or services to ask for, who supplies them in their areas, or whether the actual energy savings will live up to claims. A variety of programs provide useful information on building envelope improvements and other energy efficiency measures.

  ENERGY STAR® – a joint program of the U.S. Environmental Protection Agency (EPA) and DOE provides information on and standards for energy efficient products and practices. http://www.energystar.gov

  Energy Savers – a government program that provides information on ways to save energy at home, while driving, and at work. http://www.energysavers.gov

- **Lead-by-example programs**
  A variety of mechanisms are available to ensure that government agencies lead by example in the effort to build and manage more energy-efficient buildings and reduce GHG emissions.

  EPA Clean Energy Policy Maps – track a variety of state programs, including lead-by-example energy efficiency programs in public facilities. http://www.epa.gov/cleanenergy/energy-programs/state-and-local/policy-maps.html

- **Research and development (R&D)**
  R&D programs provide funding and support for advanced building materials and practices. Government funding is important because the fragmented and highly competitive market structure of the building sector and the small size of most building companies discourage private R&D, on both individual components and the interactive performance of components in whole buildings.

  DOE Building Technologies Program – sponsors building envelope R&D to improve materials and systems. http://www1.eere.energy.gov/buildings/envelope_rd.html

Related Business Environmental Leadership Council (BELC) Company Activities

- Alcoa
- BASF
- Dow Chemical Company

- DuPont
- Johnson Controls

Related Pew Center Resources

CLIMATE TECHBOOK: Buildings Overview, 2009 http://www.pewclimate.org/technology/overview/buildings

CLIMATE TECHBOOK: Residential and Commercial Sectors Overview, 2009
http://www.pewclimate.org/technology/overview/res-comm

Building Solutions to Climate Change, 2006
http://www.pewclimate.org/policy_center/policy_reports_and_analysis/buildings/

MAP: *Commercial Building Energy Codes*
http://www.pewclimate.org/what_s_being_done/in_the_states/comm__energy_codes.cfm

MAP*: Green Building Standards for State Buildings*
http://www.pewclimate.org/what_s_being_done/in_the_states/leed_state_buildings.cfm

MAP*: Residential Building Energy Codes*
http://www.pewclimate.org/what_s_being_done/in_the_states/res__energy_codes.cfm

Towards a Climate-Friendly Built Environment, 2005 http://www.pewclimate.org/global-warming-in-depth/all_reports/buildings

Additional Resources

U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE), ENERGY STAR®
http://www.energystar.gov

DOE, Office of Energy Efficiency and Renewable Energy

- *2008 Buildings Energy Data Book*, 2008 http://buildingsdatabook.eren.doe.gov/
- Energy Savers http://www.energysavers.gov/

Whole Building Design Guide http://www.wbdg.org/index.php

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[1] U.S. Department of Energy (DOE). *2008 Buildings Energy Data Book*. Prepared for U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by D&R International, Ltd. Silver Spring, MD. September 2008. http://buildingsdatabook.eren.doe.gov/

[2] Ibid.

[3] For more information on passive solar design, see the DOE's site on Passive Solar Home Design, http://www.energysavers.gov/your_home/designing_remodeling/index.cfm/mytopic=10250. The National Renewable Energy Laboratory also provides case studies of passive solar homes in a variety of climates, http://www.nrel.gov/buildings/passive_solar.html.

[4] The DOE has developed the *Building America Best Practices Series* that includes five climate-specific sets of building best practices that focus on reducing energy use and improving housing durability and comfort. Learn more at

http://www1.eere.energy.gov/buildings/building_america/publications.html; also see the Whole Building Design Guide on Passive Solar Heating http://www.wbdg.org/resources/psheating.php.

5 For more information Insulation and Air Sealing, see http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11220.

6 ENERGY STAR® is joint program of the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) that provides information on and standards for energy efficient products and practices. For more information, see http://www.energystar.gov.

7 For more information on ENERGY STAR® qualified roof products, visit http://www.energystar.gov/index.cfm?c=roof_prods.pr_roof_products.

8 The National Fenestration Window Council has developed a standardized rating system. See http://www.nfrc.org/label.aspx.

9 Ander, G. D. "Windows and Glazing." *Whole Building Design Guide,* updated 26 May 2008. http://www.wbdg.org/resources/windows.php?r=minimize_consumption

10 For more information on ENERGY STAR® windows, see http://www.energystar.gov/index.cfm?c=windows_doors.pr_savemoney.

11 See ENERGY STAR® *Methodology for Estimating Energy Savings from Cost-Effective Air Sealing and Insulating.* http://www.energystar.gov/index.cfm?c=home_sealing.hm_improvement_methodology.

12 Levy, J. I., Y. Nishioka, J. D. Spengler. "The Public Health Benefits of Insulation Retrofits in Existing Housing in the United States." *Environmental Health: A Global Access Science Source* 2: 4 (2003).