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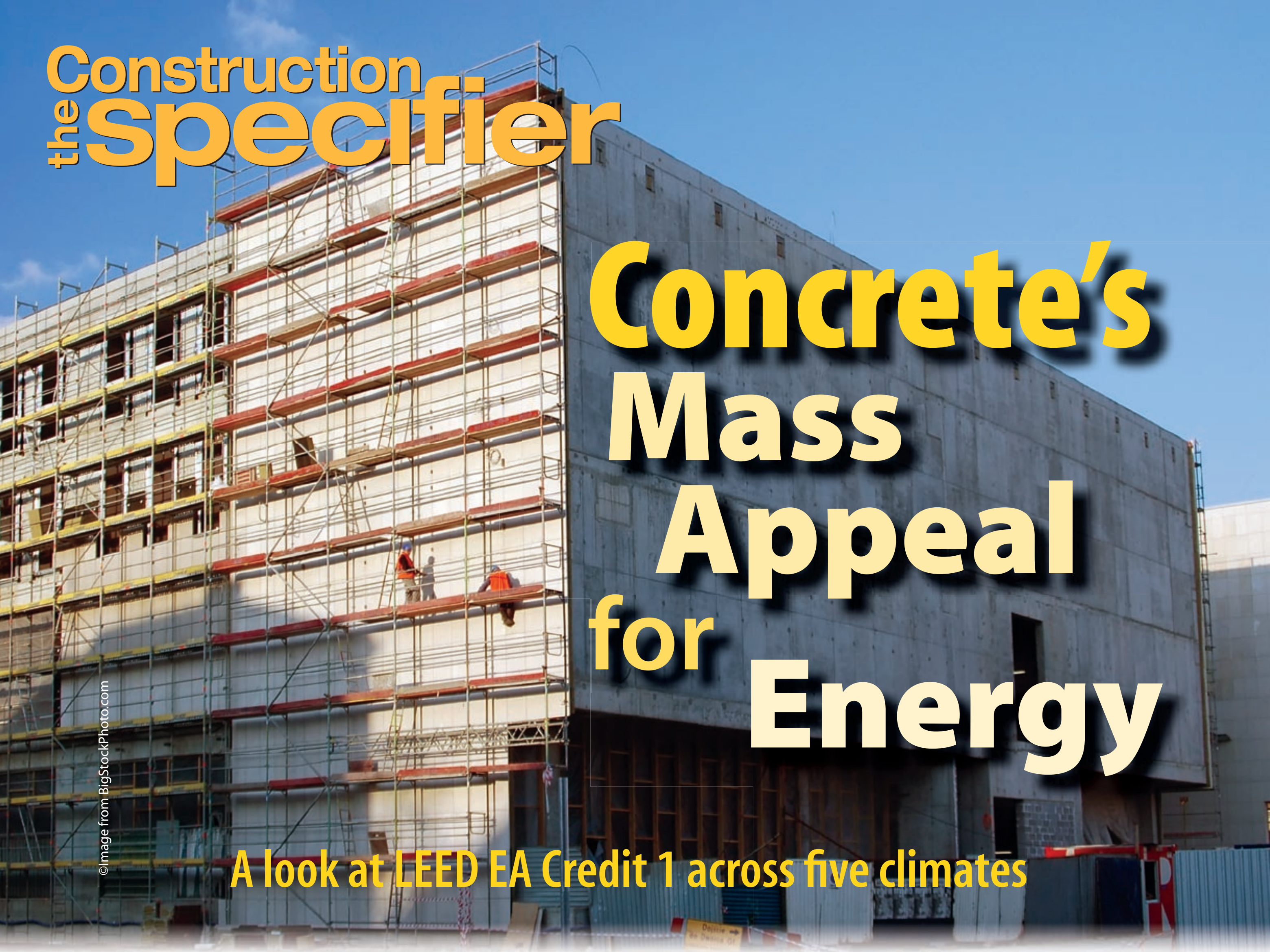

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Concrete's Mass Appeal for Energy

A look at LEED EA Credit 1 across five climates

by Martha G. VanGeem, PE, ASHRAE, LEED AP and Medgar L. Marceau, PE, CSI, ASHRAE, LEED AP

Renowned for its durability, concrete is often considered solely as a structural element. However, the material also provides insulating benefits and acts as a continuous air barrier to reduce infiltration and temperature differential between the exterior and interior. Consequently, concrete buildings generally allow installation of smaller heating and cooling equipment because peak loads are often less than those of a similar building of wood or steel frame construction.

The concept of 'thermal mass' applies to concrete, stone, or masonry—building materials that can absorb heat, store it for a period, and then gradually release it. For example, during the winter, a heavy mass floor absorbs solar radiation and warms up throughout the day; when the sun sets and the space begins to cool, the floor's heat is released to the area.

Interacting with both internal and external environments to delay the effect of thermal changes, such 'massive' materials can be specified to help reduce the mechanical heating and cooling energy needed to meet occupant comfort requirements. Concrete's thermal mass can help achieve points under Energy and Atmosphere (EA) Credit 1, *Optimize Energy Performance,* in the U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED-NC 2.2) program.

Up to 10 points can be obtained under EA Credit 1 using the 'Performance' path, which means modeling with whole-building energy simulation software. Modeling the effect of thermal mass requires software that analyses annual energy use on an hourly basis. To accurately simulate buildings with materials that have time-dependent properties (*e.g.* concrete's heat capacity) in a dynamic temperature environment (*e.g.* fluctuating outdoor air temperatures), one needs software with time-dependent capabilities.

Figure 1 Climate Zones for Major World Cities (ASHRAE 2004)

Climate Zone 1 (very hot), Simulated City: Miami, Florida	
Nassau, Bahamas	Singapore
Guadalajara, Mexico	Djakarta, Indonesia
Rio de Janeiro, Brazil	Bangkok, Thailand
Karachi, Pakistan	Kingston, Jamaica
Mumbai, India	Caracas, Venezuela
Riyadh, Saudi Arabia	Kuala Lumpur, Malaysia
Delhi, India	Saigon, Vietnam
Climate Zone 2 (hot), Simulated City: Phoenix, Arizona	
Hong Kong, China	Cairo, Egypt
Lima, Peru	Taipei, Taiwan
Climate Zone 3 (warm), Simulated City: Memphis, Tennessee	
Buenos Aires, Argentina	Shanghai, China
Tokyo, Japan	Mexico City, Mexico
Sydney, Australia	Jerusalem, Israel
Nairobi, Kenya	Damascus, Syria
Climate Zone 4 (mixed), Simulated City: Salem, Oregon	
Santiago, Chile	Paris, France
Seoul, South Korea	Istanbul, Turkey
China, Beijing	Rome, Italy
Cape Town, South Africa	London, United Kingdom
Climate Zone 5 (cold), Simulated Cities: Chicago, Illinois, and Denver, Colorado	
Brussels, Belgium	Amsterdam, Netherlands
Budapest, Hungary	Prague, Czech Republic
Vancouver Island, Canada	Zurich, Switzerland
Dublin, Ireland	Berlin, Germany
Dalian, China	Lhasa, Tibet
Climate Zone 6 (colder), Simulated City: None	
Halifax, Canada	Moscow, Russia
Oslo, Norway	Montreal, Canada
Toronto, Canada	Stockholm, Sweden
Climate Zone 7 (very cold), Simulated City: None	
Calgary, Canada	Haerbin, China
Helsinki, Finland	Reykjavik, Iceland
Climate Zone 8 (subarctic), Simulated City: None	
Yellowknife, Canada	

This article examines recent research on the actual energy savings—and LEED points—obtainable in mid-rise commercial buildings due to thermal mass of materials like concrete.

Understanding EA Credit 1

EA Credit 1 awards up to 10 points to buildings with increasing levels of energy performance above the baseline in EA Prerequisite 2, *Minimum Energy Performance*—the energy model must comply with Appendix G in American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) 90.1-2004, *Energy Standard for Buildings Except Low-rise Residential Buildings.*

While 10 points are possible under the credit, earning at least two is mandatory for all LEED projects registered after June 26, 2007. Determining how many points are actually earned depends partially on which compliance path is followed—performance or prescriptive.[2] The former is the focus of this article.

Whole building simulation (up to 10 points)
The performance path requires using whole-building energy simulation to demonstrate an improvement in the proposed building performance rating compared to the baseline building defined in ASHRAE 90.1-2004 Appendix G, "Performance Rating Method."

For EA Credit 1, process loads must be identical in both the baseline and the proposed building.[3] However, project teams may follow the Exceptional Calculation Methods (*i.e.* ASHRAE 90.1-2004 G2.5) to document measures that reduce process loads. Documentation of process load energy savings shall include a list of the assumptions made for both the base and proposed design, and theoretical or empirical information supporting these assumptions.

For new buildings, the minimum energy cost savings to obtain points is as follows:

• 14 percent–two points;
• 17.5 percent–three points;
• 21 percent–four points;
• 24.5 percent–five points;
• 28 percent–six points
• 31.5 percent–seven points;
• 35 percent–eight points;
• 38.5 percent–nine points; and
• 42 percent–10 points.

While achieving these goals obviously involves a holistic view of the project and the specification of various energy-efficient building assemblies and systems, the impact of the chosen structural material is still significant.

Methodology

To determine the actual impact of thermal mass on energy efficiency, five-story prototype buildings (with the same plan dimensions and window-to-wall ratios) were modeled using the software program, VisualDOE 4.0.

Climates

Since effects of thermal mass vary with climate, the buildings were modeled in six cities, compensating for the range of conditions found across the United States. Five of these were representative cities for the U.S. Department of Energy (DOE) climate zones in ASHRAE 90.1-2004. The cities and the climate zone numbers are:

• Miami, Florida—very hot and humid (Zone 1);
• Phoenix, Arizona—hot and dry with large daily temperature swings (Zone 2);
• Memphis, Tennessee—warm (Zone 3);
• Salem, Oregon—mixed (Zone 4);
• Denver, Colorado—cold with large daily temperature swings (Zone 5); and
• Chicago, Illinois—cold (Zone 5).

Figure 1 presents climates zones for other major cities worldwide. No cities were simulated for Zones 6, 7, and 8 (the coldest climates), but most of the world's population resides in Zones 1 through 5. For the study, energy costs were based on the costs in the specific city; actual energy costs vary depending on location.

Simulation tool

The results are based on modeling (conforming to the aforementioned Appendix G) of a typical five-story commercial building using VisualDOE. Two buildings were modeled using energy simulation software—a baseline building meeting ASHRAE 90.1 and the proposed above-standard building. The energy costs were then compared to determine the percent improvement of the proposed building.

Concrete's ability to provide thermal mass can help reduce reliance on mechanical systems for conditioning the interior space. The material absorbs, stores, and gradually releases heat.

Appendix G prescribes the baseline building be lightweight steel. The baseline as-modeled consisted of an exterior insulation and finish system (EIFS) with steel stud walls, structural steel frame, and metal deck floors with concrete topping slab.

Building description

All subjects in this study were five-story commercial buildings with square plan dimensions of 32 x 32 m (105 x 105 ft). They had the same amount of glazing equally distributed on each wall to minimize the effect of building orientation (*i.e.* whether the building faces north, south, east, or west).

The building height—19.2 m (63 ft)—was based on 4.6 m (15 ft) for the first story and 3.7 m (12 ft) for the remaining four stories. The ground-level floor consisted of a 150-mm (6-in.) cast-in-place (CIP) concrete slab-on-ground. Each floor was modeled with five zones: four perimeter (10.7-m [35-ft] depth) and one central (10.7 x 10.7 m [35 x 35 ft]).

The façade of each story had a band of 10 windows, measuring approximately 1.5 m high by 3.2 m wide (5 x 10.5 ft) apiece. Windows were flush-mounted (non-recessed), equally spaced, non-operable, and had no blinds or shading devices. The overall window-to-wall ratio was 0.40. As is typical for new construction in rural and suburban locations, no exterior shading was assumed around the buildings.

Figure 2 — **Buildings Modeled**

Designation	Exterior walls	Structural frame	Floors	Interior walls
EL (baseline)	EIFS & metal stud	structural steel	concrete/metal deck	metal stud
CL	curtain wall	structural steel	concrete/metal deck	metal stud
ML	precast concrete	structural steel	concrete/metal deck	metal stud
EM	EIFS & metal stud	concrete	concrete	concrete
CM	curtain wall	concrete	concrete	concrete
MM	precast concrete	concrete	concrete	concrete
MLX	precast concrete (exceeding standard)	structural steel	concrete/metal deck	metal stud
MMX	precast concrete (exceeding standard)	concrete	concrete	concrete
MMI	precast concrete	concrete	concrete	concrete
MMXI	precast concrete (exceeding standard)	concrete	concrete	concrete

Walls

The buildings were the same except for the wall construction, structural frame, location of internal loads, and insulation and fenestration required to meet the standard. Figure 2 summarizes the structural variations.

A system of abbreviated names is used to simplify discussion of the modeled scenarios. The first letter refers to the exterior wall system:

- 'E' for EIFS;
- 'C' for curtain wall; and
- 'M' for precast concrete (the letter 'M' signifying 'mass').

The second letter refers to the structural framing system and interior walls and floors:

- 'L' for light (*i.e.* structural steel framing and metal deck floors with concrete topping slab); and
- 'M' for mass (*i.e.* reinforced concrete framing and concrete floors).

An 'X' indicates the building envelope exceeds the energy standard requirements and an 'I' means the internal loads are clustered near the central core.

Buildings EM, CM, and MM are respectively like EL, CL, and ML, except they have more concrete in interior floors and walls. Buildings MLX and MMX are respectively like ML and MM, except the former pair's building envelopes exceed the standard. Buildings MMI and MMXI are like MM and MMX, except internal loads are clustered near the central core of the building, where most of the interior concrete is located.

The amount of insulation in the exterior walls was varied to achieve the demands of ASHRAE 90.1-2004. Figure 3 shows

Figure 3 — **Requirements in ASHRAE 90.1-2004 for EIFS and Curtain Walls**

Location	Maximum required U-factor*	Insulation** and resulting wall U-factor* to meet standard	
Miami (CZ 1)	0.704	RSI-2.3 batts	0.704
Phoenix (CZ 2)	0.704	RSI-2.3 batts	0.704
Memphis (CZ 3)	0.704	RSI-2.3 batts	0.704
Salem (CZ 4)	0.704	RSI-2.3 batts	0.704
Denver (CZ 5)	0.477	RSI-2.3 batts + RSI-0.7 boards	0.477
Chicago (CZ 5)	0.477	RSI-2.3 batts + RSI-0.7 boards	0.477

*These U-factors, in units of $W/m^2 \cdot K$, include the thermal bridging effects of steel stud framing and the thermal resistance of inside and outside air films.

**Batt insulation is installed between steel studs, which are 400 mm on-center. Board insulation is continuous over the steel studs.

Figure 4

Requirements in ASHRAE 90.1-2004 for Concrete Walls

Location	Maximum required U-factor*	Insulation** and resulting wall U-factor* to meet standard	
Miami (CZ 1)	3.293	None	2.300
Phoenix (CZ 2)	3.293	None	2.300
Memphis (CZ 3)	0.857	RSI-2.3 batts	0.738
Salem (CZ 4)	0.857	RSI-2.3 batts	0.738
Denver (CZ 5)	0.698	RSI-2.6 batts w/ 13-mm air space	0.642
Chicago (CZ 5)	0.698	RSI-2.6 batts w/ 13-mm air space	0.642
All exceeding code	Not applicable	RSI-2.3 batts + RSI-0.7 boards	0.486

*These U-factors, in units of $W/m^2 \cdot K$, include the thermal bridging effects of steel stud framing and the thermal resistance of inside and outside air films.
**Batt insulation is installed between steel studs, which are 400 mm on-center. Board insulation is continuous over the steel studs.

minimum requirements for EIFS and curtain walls, along with construction of the walls selected to meet the standard. Figure 4 depicts the requirements for concrete walls, insulation selected to meet the standard, and insulation chosen to exceed it. Thermal performance requirements for fenestration are shown in Figure 5, along with the properties of the windows selected to meet the standard. Figure 6 illustrates the properties of the windows used to exceed the requirements.

Roofs

Roofs on all buildings in this study consist of 16-mm (5/8-in.) gypsum wallboard, open-web steel joists, ribbed steel deck, board insulation, and built-up waterproofing membrane. The standard demands a U-factor no more than 0.358 $W/m^2 \cdot K$, including air films. Thermal performance requirements for roofs are met using RSI-2.6 board insulation in all locations.

The resulting roof U-factor is 0.352 $W/m^2 \cdot K$, including air films. For Miami (Zone 1) and Phoenix (Zone 2), the roofs exceeding requirements have RSI-2.6 board insulation. For Memphis (Zone 3), Salem (Zone 4), Denver (Zone 5), and Chicago (Zone 5), roofs exceeding requirements have RSI-3.5 board insulation. The built-up roof (BUR) is medium-colored and has a coefficient of solar absorptance of 0.70 (default value required in Appendix G).

Results and discussion

The VisualDOE modeling shows thermal mass in concrete buildings lowers both energy use and cost relative to the baseline steel-framed EIFS building (Figure 7). For each location, the figure shows values for yearly energy consumption and cost. Energy use includes heating, cooling, pumps, fans, domestic hot water, lighting, and receptacle loads.

Figure 5

Fenestration Requirements in ASHRAE 90.1-2004

Location	Required Max. U-factor*	Selected windows Max. SHGC**	U-factor*	SHGC†	VLT††	VisualDOE identifier
Miami (CZ 1) Phoenix (CZ 2)	6.93	0.25	5.00	0.25	0.13	1411 Single clear LR13
Memphis (CZ 3)	3.24	0.25	2.95	0.23	0.18	2420 Double Ref-B Clear-L Air
Salem (CZ 4) Denver (CZ 5) Chicago (CZ 5)	3.24	0.39	2.95	0.30	0.27	2426 Double Ref-B Clear-H Air

*U-factor in units of $W/m^2 \cdot K$.
**Solar heat gain coefficient (SHGC) requirement in a non-north orientation.
†Solar heat gain coefficient at a 60-degree angle of incidence.
††Visible light transmittance (VLT) is not a requirement.

Image courtesy Dukane Precast

At North Central College (Naperville, Illinois), the use of precast concrete not only offers the potential for some energy savings, but also structural strength and long-term durability.

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For multi-family dwellings in various climates, use of thermal mass materials can allow residents to reduce their energy bills.

Energy cost savings

In most scenarios, the effect of a concrete frame with or without precast concrete walls is to lower energy use and cost relative to the baseline building (steel-framed EIFS, EL). In Memphis (Zone 3), Salem (Zone 4), Denver (Zone 5), and Chicago (Zone 5), energy cost savings of six to 11 percent are indicated for the three concrete frame buildings meeting the standard compared to the baseline building (compare EM, CM, and MM to EL in Figure 7).

In Miami (Zone 1) and Phoenix (Zone 2), variations in energy cost scenarios are small. The additional thermal mass in the frame saves less than five percent in energy costs (compare CL to CM, EL to EM, and ML to MM), but the buildings with concrete walls have one to seven percent greater energy costs than the baseline building (compare ML and MM to EL).

Energy cost savings due to walls

Due to thermal mass effects, ASHRAE 90.1-2004 does not require mass walls to have as high an R-value as their low-mass counterparts. Comparing buildings with the same structural frame but different walls shows small differences in energy costs savings (compare EL to CL to ML and/or EM to CM to MM). Energy cost savings range from −6 to +3 percent, with the average as +1 percent. These results justify reduced R-values for mass walls allowed in energy codes and standards.

For a given structural frame, the EIFS and curtain wall buildings in Miami and Phoenix use three to six percent less energy than the buildings with uninsulated concrete walls (compare EL and CL to ML, and compare EM and CM to MM). According to the minimum standard requirements, concrete walls in these hotter climates do not require added insulation, but EIFS and curtain walls in these same cities need at least R-13 batt insulation. Therefore, the mass walls in these climates are over three times more conductive than the lightweight walls—yet they use about the same amount of energy due to their thermal mass.

Walls exceeding energy standard requirements

Results of this research show significant energy cost savings for building envelopes (including walls and windows) exceeding the ASHRAE standard. The amount of added insulation chosen to make the concrete walls exceed the standard is not unusual; it is about the same as the insulation in EIFS and curtains walls meeting the standard in colder climates like Denver and Chicago.

Even more insulation could have been included, but using a low value shows how even modest improvements can result in significant energy savings. This shows the amount of added insulation is realistic, and that concrete with insulation saves energy. Energy cost savings are in the range of nine to 23 percent for all cities except Miami, where the energy cost savings are about five percent (compare MMX to EL).

Figure 6

Selected Windows that Exceed Requirements in ASHRAE 90.1-2004

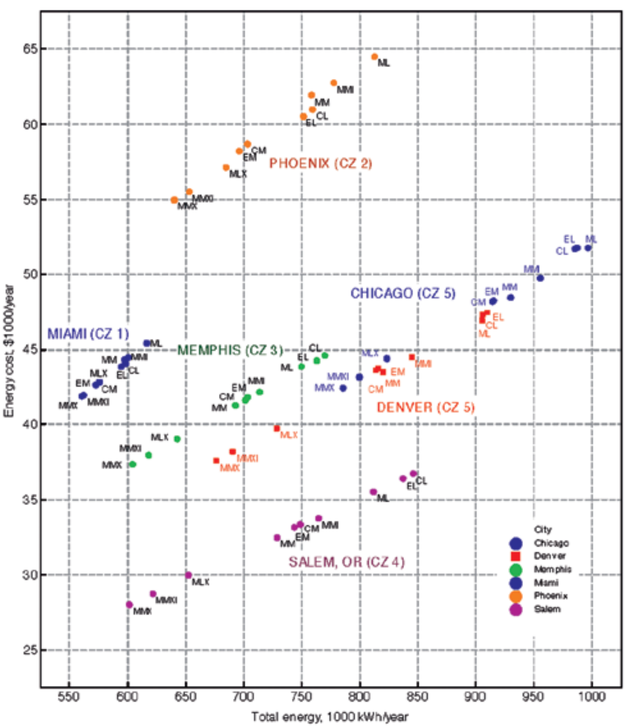
Location	U-factor*	SHGC	VLT	VisualDOE identifier
Miami (CZ 1) Phoenix (CZ 2)	2.95	0.23	0.18	2406 Double ref A clear-H IG
Memphis (CZ 3) Salem (CZ 4) Denver (CZ 5) Chicago (CZ 5)	1.76	0.15	0.14	2823 Double Electrochromic Ref Bleached/Colored, 12.7-mm Gap

*U-factor in units of W/m²·K.

Conclusion

In the four cities representing warm, mixed, and cold climates, reinforced concrete frame buildings with building envelopes exceeding the standard will most likely qualify for points under LEED's EA Credit 1. In the cold climate category, buildings will likely qualify for three points—at least 17.5 percent energy cost savings (actual in Denver is 21 percent; in Chicago, 18 percent). In the mixed climate category, buildings should qualify for four points—at least 21 percent energy cost savings (actual is 23 percent). In warm climates, buildings will likely qualify for two points—at least 14 percent energy cost savings (actual is 16 percent).

Figure 7



Relationship between annual energy use and cost varies by city.

It is important to note adding insulation to uninsulated concrete walls in hot and very hot climates does not save enough energy to gain points (energy savings must be 10.5 percent or greater). Additionally, steel-framed buildings with concrete walls and windows exceeding the standard will likely qualify for two points thanks to at least 14 percent energy savings. (In Zone 4, the actual is 17 percent; in Zone 5, the actual is 16 percent.) These results are particularly significant because the buildings have a relatively large

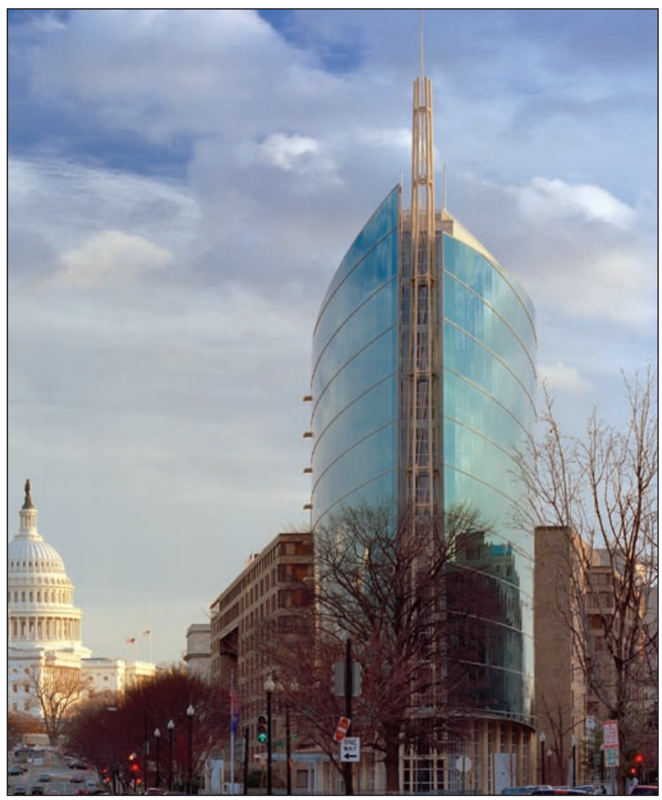


Photo courtesy Portland Cement Association

The Washington, D.C., headquarters of the Portland Cement Association (PCA), fittingly makes use of concrete throughout its design. Recent energy modeling research sponsored by the association quantifies the thermal protection benefits of this material.

window area (*i.e.* 0.40 window-to-wall ratio) and very large associated energy loads.

As previously stated, these results are for the buildings modeled in the cited cities. Actual energy use and cost vary depending on climate, building type and occupancy, orientation, actual building materials, and fenestration amount and type.

While the VisualDOE 4.0 energy modeling shows the positive effect of thermal mass in concrete-framed buildings, it is important to remember selecting concrete is not enough to earn the LEED credit. Specifying thermal improvements to the building envelopes (including walls, roofs, and windows) is also crucial in achieving the energy savings needed.

Notes

[1] This article is adapted from a paper the authors delivered at The First International Conference on Building Energy and Environment (COBEE) 2008 in Dalian, China, in July. The research discussed was conducted with the sponsorship of the Portland Cement Association (PCA) under Project Index No. 04-08 (Iyad Alsamsam, program manager). A complete report, titled "Modeling Energy Performance of Concrete Buildings for LEED-NC Version 2.2: Energy and Atmosphere Credit 1," is available as a free download through the PCA site. Visit www.cement.org/bookstore and search for 'SN2880a.'

[2] Using the prescriptive compliance path, two to four LEED points can be earned. Intended only for certain building types, this involves complying with ASHRAE's 2004 *Advanced Energy Design Guide (AEDG) for Small Office Buildings,* 2006 *AEDG for Small Retail Buildings*, or 2008 *AEDG for Small Warehouse and Self-storage Buildings* from ASHRAE or the New Buildings Institute's (NBI's) *Advanced Buildings Core Performance Guide.*

[3] For the analysis, 'process energy' includes office and general miscellaneous equipment, computers, elevators, and kitchen/laundry equipment. Regulated ('non-process') energy includes lighting (*e.g.* interior, parking garage, surface parking, façade, or building grounds), HVAC (*e.g.* space heating, space cooling, fans, pumps, toilet exhaust, parking garage ventilation, and kitchen hood exhaust), and service water heating for domestic or space heating purposes.

Additional Information

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Abstract

Concrete's thermal mass can help regulate a building's interior temperature, reducing reliance on mechanical systems. This article provides information on energy modeling in mid-rise commercial buildings in six different U.S. climates, examining the implications for ASHRAE 90.1-2004 and LEED's Energy and Atmosphere category.