BY MEDGAR MARCEAU

CRITICAL MASS

THERE ARE NO EASY ANSWERS FOR THERMAL MASS

Interest in how thermal mass can be used to save energy in buildings has been growing. This is caused in part by rising energy costs, the urgent need to reduce greenhouse-gas emissions and the number of points available within the Washington, D.C.-based U.S. Green Building Council's LEED rating system for reducing energy use. Traditional forms of architecture have shown that thermal mass integrated with natural ventilation, small window openings and deep eaves can keep buildings cool in hot climates. But the modern use of buildings with very large windows and high internal loads often makes applying these forms impractical. New thermal-modeling tools show there are significant benefits to thermal mass in all climates, provided it is properly integrated into a building project.

Early research into thermal mass addressed the question, "Does thermal mass save energy?" Researchers have moved away from measuring thermal-mass effects in full-scale environmental chambers and now are simulating energy use in buildings using sophisticated thermal modeling. Recent research attempts to answer the question, "How much energy can you save with thermal mass?" Ongoing research is trying to determine how much thermal mass is enough. The answers, however, are not simple.

PROPERTIES

The thermal behavior of a material is a function of its density, thermal conductivity and specific heat capacity. Thermal mass is an attribute that represents the best combination of these three properties for absorbing, storing and slowly releasing heat. Materials with thermal mass readily absorb excess heat without getting hot. This heat may be from the sun or from internal loads,

◂ Opus Hall at Catholic University of America, Washington, D.C. **PHOTOS COURTESY OF GATE PRECAST**

such as lights and computers. Once ambient temperatures drop, the thermal mass will slowly release stored heat to the surrounding space without getting cold.

Suitable building materials for thermal mass are those that have high specific heat, high density and low conductivity. Insulation materials, such as fiber-glass batts and polystyrene foam, have low conductivity, but their density and specific heat are too low to provide thermal mass. Metals have high specific heat and density, but their levels of conductivity are too high. Materials like brick, stone, adobe and concrete have suitable properties for thermal mass.

Optimal use of thermal mass can reduce a building's energy use, environmental footprint and peak-energy loads, as well as increase occupant thermal comfort. Smaller peak loads mean HVAC systems can be downsized and expensive energy-demand charges can be minimized. Properly integrated into a building project, there even are synergies between thermal mass and other green-building practices. For example, concrete ceilings or interior masonry walls can be painted or sealed and left bare. Not only is less material used, but the exposed thermal-mass elements now can more readily absorb excess internal heat.

LIGHTEN THE LOAD

A study titled "Modeling Energy Performance of Concrete Buildings for LEED-NC v. 2.2, Energy and Atmosphere Credit 1," by Medgar Marceau, Martha VanGeem and Iyad Alsamsam, looks at typical office buildings for a given building envelope U-value. All the buildings in this study are 55,000-square-foot (5110-m^2), 5-story commercial buildings with plan dimensions of 105 by 105 feet (32 by 32 m). They are square in plan with the same amount of glazing equally distributed on each wall to minimize the influence of solar effects caused by orientation. Because thermal-mass effects vary with climate, the buildings were modeled in six cities representing the range of climates in the U.S. The baseline buildings were insulated to meet the minimum requirements of the International Energy Conservation Code.

The study shows that more thermal mass in the interior frame—floors, columns and shear walls—lowers energy use and cost. Whole-building energy savings range from 3 to 11 percent, and the energy cost savings range from 2 to 9 percent. In commercial buildings, thermal mass in the interior has more impact because commercial buildings are internal-load dominant as a result of lights, equipment and people within.

The results of this study represent potential savings in typical buildings. If the buildings were designed to make optimal use of thermal mass—for example, if they had less glazing on the north façade and more on the south façade instead of equal amounts on all sides—the results would show much greater energy savings.

The same study also showed that combining thermal mass with modest improvements to the building envelope, such as increasing the wall and roof R-value by 5, would create significant energy savings. Of the six climates where buildings were modeled for the study, energy savings were most significant in Chicago; Denver; Memphis, Tenn.; and Salem, Ore. In Chicago and Denver, buildings with concrete frames and concrete exterior walls could demonstrate energy-cost savings of 17.5 percent. In Memphis, these buildings could save at least 14 percent on energy costs and in Salem at least 21 percent. Furthermore, the study showed that steel-frame buildings with exterior concrete walls and windows modestly exceeding code could save at least 14 percent in energy costs in Denver and Salem. To exceed code, window

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Centralia High School, Centralia, Ill. **PHOTO COURTESY OF GATE PRECAST**

The University of Michigan Cardiovascular Center, Ann Arbor, Mich.
PHOTO COURTESY OF THERMOMASS BUILDING INSULATION SYSTEMS

U-factors were reduced by 40 percent and the solar-heat-gain coefficients were reduced by an average of 30 percent.

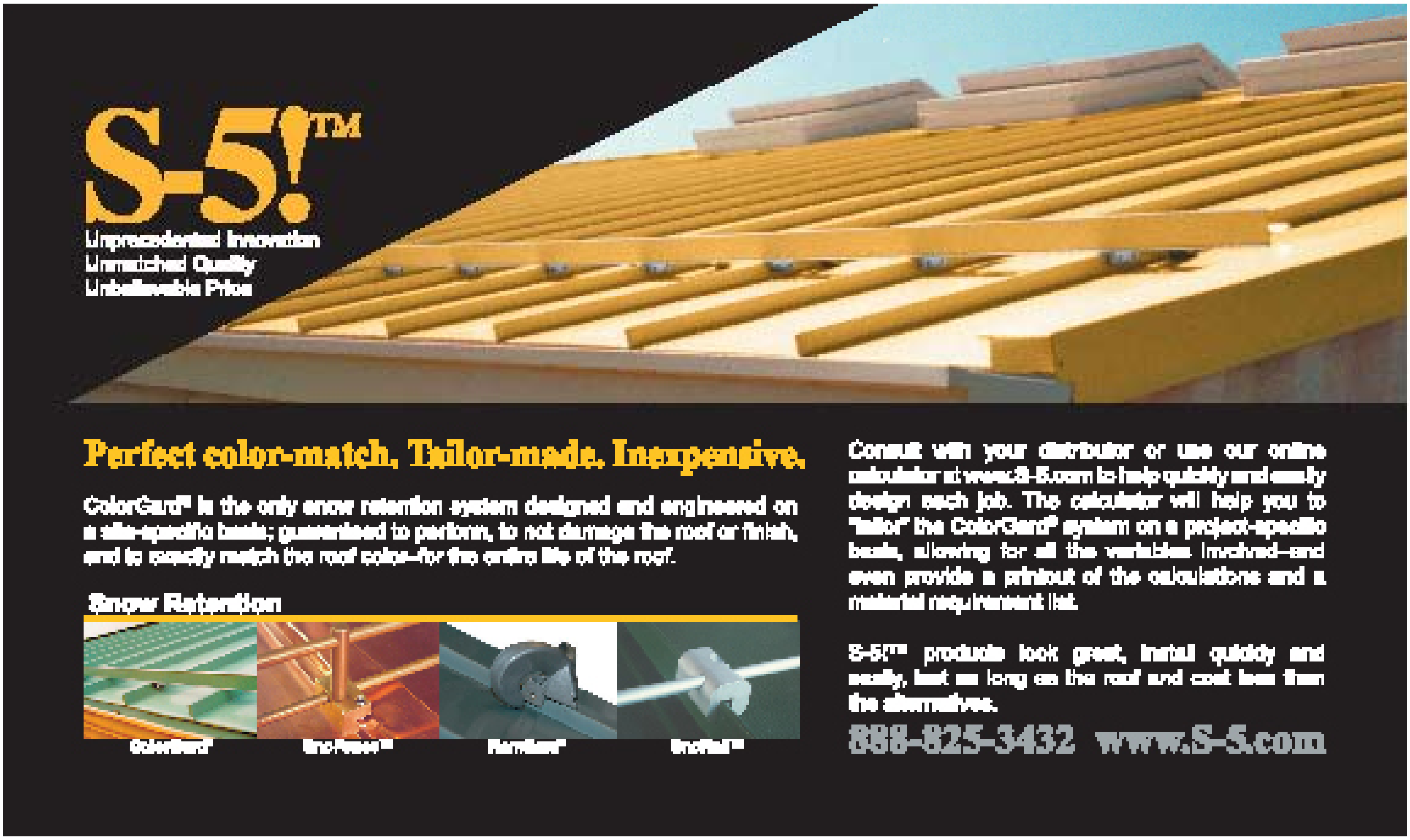
Energy codes and standards recognize thermal-mass effects by requiring less insulation in thermal-mass walls than in lightweight walls in the same climate. For example, according to the Atlanta-based American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.'s Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings," commercial buildings in Chicago need to have a total wall R-value of 11 for mass walls, but this is increased to R-15 for steel-framed walls.

In a study conducted by Edmonton, Alberta, Canada-based Stantec Consulting, "Building Energy Requirements for Thermally Light, Medium

Dynamic R-value equivalents for two generic insulated concrete forms compared to wood-framed walls with R-13 batt insulation and insulated sheathing.

CITY	STEADY-STATE R-VALUE	DYNAMIC R-VALUE EQUIVALENT*
Lake Charles, La.	16 (4-inch ICF)	22
	20 (8-inch ICF)	26
Tucson, Ariz.	16 (4-inch ICF)	36
	20 (8-inch ICF)	43
Seattle	16 (4-inch ICF)	19
	20 (8-inch ICF)	22
Minneapolis	16 (4-inch ICF)	18
	20 (8-inch ICF)	20

*The analysis assumes single-family homes with equal rates of air infiltration.



> THE ENERGY-SAVING POTENTIAL OF THERMAL MASS SHOULD BE DESIGNED AND OPTIMIZED ON A CASE-BY-CASE BASIS USING WHOLE-BUILDING ENERGY SIMULATION FOR THE SPECIFIC CLIMATE IN WHICH THE BUILDING IS LOCATED.

PHOTO COURTESY OF GATE PRECAST

and Heavy Construction in 6 U.S. Locations," similar results were demonstrated for mixed-use buildings with commercial on the ground floor and residential units on the upper floors. For a given U-value, more thermal mass lowered heating and cooling energy use and peak heating and cooling loads. Overall cooling loads were reduced 0 to 4 percent and overall heating loads were reduced 2 to 70 percent. Peak cooling loads were reduced 1 to 4 percent, and peak heating loads were reduced 2 to 22 percent. The range in results is caused by the range of climates in which the buildings were modeled, minimum insulation required by code and levels of thermal mass in the exterior envelope—low, medium and high.

MAXIMIZING POTENTIAL

A way to demonstrate the thermal-mass effect is to consider how much additional insulation would have to be added to a lightweight wall, such as a wood-frame wall, to achieve the same energy use as a mass wall. Using whole-building energy simulation, one can calculate the dynamic R-value equivalent, which is defined as the R-value of a lightweight wall that results in the same space heating and cooling energy use as a similar building with mass walls. For example, wood-frame walls in a typical single-family house in Tucson, Ariz., would have to have an R-value of at least 43 to match the same heating and cooling loads of a house with 8-inch (203-mm) insulated concrete forms consisting of 4 inches (102 mm) of expanded polystyrene. The steady-state R-value of this system is R-20, but the dynamic R-value equivalent is R-43. The difference is less dramatic in colder climates. The table on page 64 shows steady-state R-values and dynamic R-values converge as the climate gets colder.

Researchers in Canada now are looking into the threshold amount of thermal mass in the building envelope to achieve energy savings. The initial modeling shown by Mark Gorgolewski's study, "Framing Systems and Thermal Mass," suggests the existence of a critical R-value of the exterior walls, defined as the "threshold R-value," above which additional thermal mass is beneficial and below which additional thermal mass leads to additional energy use and poor thermal comfort. The work to date shows the final results will be heavily dependent on climate and ratio of window-to-wall area.

There is no doubt thermal mass in buildings can reduce energy use compared to buildings with less thermal mass. In general, the energy savings will be greatest in commercial buildings where a large area of thermal mass is exposed to the interior. The energy-saving potential of thermal mass should be designed and optimized on a case-by-case basis using whole-building energy simulation for the specific climate in which the building is located.

Although determining how much depends on many variables, there is credible evidence that maximizing the exposure of existing thermal-mass elements can pay dividends from an energy-conservation perspective. There are no easy answers to determining the optimal use of thermal-mass elements, but designers should maximize the thermal advantage of the thermal-mass element in buildings by considering basic exposure, orientation and placement in relation to the thermal insulation.

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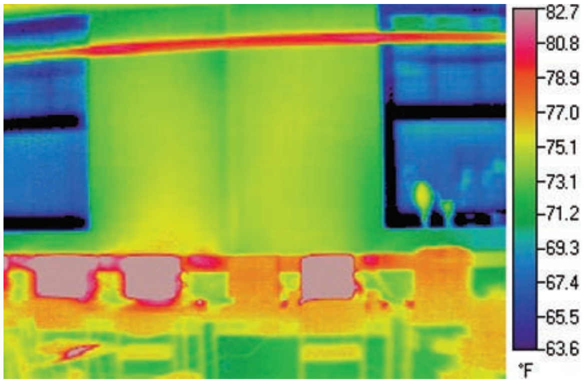

The inside face of this insulated mass wall has an even, warm temperature.

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