Thermal mass of concrete

Latest information on how this important property gives concrete an advantage over other materials in saving energy

BY GEORGE B. BARNEY
DIRECTOR
BUILDING DESIGN AND CONSTRUCTION DEPARTMENT
PORTLAND CEMENT ASSOCIATION

Thermal mass relates to the ability of a material to store and release heat. All materials have thermal mass. However, because concrete is used in large amounts in buildings, these buildings have greater total thermal mass than most buildings made with competitive materials.

The effect of thermal mass on heating and cooling requirements in buildings has been the subject of intense debate for several years. On one side the concrete and masonry industries, based on research they have done, have claimed that thermal mass reduces annual heating and cooling requirements. Because of this, these industries contend that insulation requirements specified in energy codes and standards should be less for concrete and masonry buildings than for buildings constructed of lighter weight materials. On the other hand competing industry groups, including the forest products and insulation industries, have contested the effect of thermal mass on building energy performance and the ability of modern day computer programs to predict this effect.

Because of this controversy, national energy codes and standards have been slow to adopt separate thermal requirements for concrete and masonry buildings.

This article will explain some of the benefits of thermal mass and present an update of thermal mass research and codes and standards activities.

How does thermal mass work?

A complete explanation of how thermal mass works is very complex. This is because the behavior of thermal mass depends on how it interacts with other elements of the building, the operation of the building, and the environment. However, a simplified explanation of thermal mass can be made by looking at one part of a building, such as a wall. Assume that this wall separates a conditioned space held at a constant temperature, such as the inside of a building, from the outside air. If the outside temperature fluctuates above and below the inside temperature over a 24-hour period, the flow of heat through a non-massive wall during that period might be as shown in Figure 1. When the outside temperature is below the inside temperature, heat flows from inside to outside and heating is required to maintain the inside temperature. The amount of heat required can be represented by the shaded area below the line in Figure 1. When it is warmer outside than inside, heat flows from

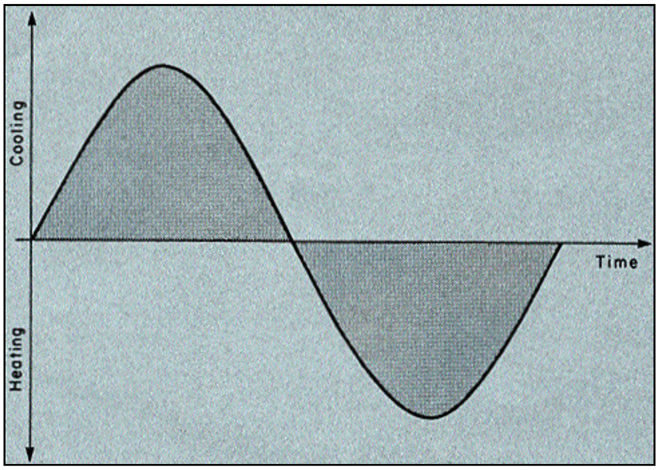

Figure 1. Schematic view of heating and cooling requirements for a non-massive wall subjected to fluctuating temperature over a 24 hour period. The shaded area indicates relative amounts of heating and cooling needed.

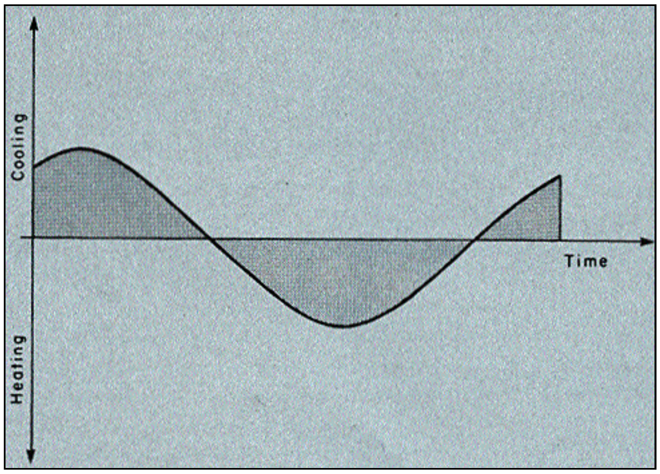

Figure 2. Schematic view of heating and cooling requirements for a massive wall subjected to the same 24-hour temperatures as the non-massive wall in Figure 1. Shaded area indicates a significant reduction in heating and cooling energy, compared to the non-massive wall.

outside to inside and cooling energy is required to keep the inside temperature from rising. The amount of cooling required is indicated by the shaded area above the line.

Now assume the non-massive wall is replaced by a normal weight concrete wall with the same level of insulation. If the concrete wall is subjected to the same temperature cycle, the heating and cooling energy required to maintain the inside temperature might be as shown by the shaded area in Figure 2. Because the concrete wall can absorb more heat than the lightweight wall, less energy flows through the concrete wall, and thus less heating and cooling are required. Also, the times at which peak heating and cooling occur are delayed by the concrete wall.

Thermal mass research has shown that this energy reduction benefit only occurs when alternate heating and cooling are required in a 24-hour period. If the outside temperature remains so low that only heating is required, then the curves in Figures 1 and 2 would fall completely below the horizontal line, and the area between the curve and the line would be equal for both the non-massive and concrete wall. Similarly, if the outside temperature remains so high that only cooling is required, the same amount of cooling would be required for both the non-massive and concrete wall. However, all locations in the continental United States and most of the populated areas of Canada have days during the year when the temperature fluctuates in a range that benefits massive buildings.

How big is the thermal mass benefit?

The effectiveness of thermal mass varies significantly, depending on the climate and on building function. Generally speaking, the benefits of thermal mass are greatest for commercial and industrial type buildings and for buildings in temperate climates such as the sunbelt regions of the United States.

An example of energy savings resulting from thermal mass can be seen in the results of a recent computer study by the Portland Cement Association. This study analyzed a single-story commercial building typical of those frequently found in shopping malls. Both nonmassive and massive walls were analyzed. Non-massive walls were represented by insulated metal building panels, and the massive walls were normal weight 8-inch concrete tilt-up walls. For insulation levels specified in ANSI/ASHRAE/IES Standard 90A-1980 for six cities in the United States, the combined annual heating and cooling loads for the metal and tilt-up walls are shown in Table 1. The savings for the tilt-up buildings were determined for insulation placed on either the inside face or the outside face of the concrete walls. Greater savings are shown with insulation on the outside.

Comparing energy savings for concrete versus metal buildings for identical levels of insulation is only one way to look at the thermal mass benefit. Another way to take advantage of thermal mass would be to reduce the level of insulation in the building with concrete walls until it uses the same amount of energy as the building with metal walls. This is the approach being pursued by the concrete and masonry industries in their attempt to get energy codes and standards to recognize the benefits of thermal mass. Reducing the level of insulation required for concrete walls can result in significant first-cost savings.

Applying this approach for the six cities in the shopping mall study, we find that no insulation would be required for 8-inch-thick concrete walls in Washington, D.C. and points south to match the performance of metal building walls insulated according to the ANSI/ASHRAE/IES standard. In Chicago and Minneapolis reduced amounts of insulation would meet the performance of the ASHRAE-specified R-value, if proper allowance were made for thermal mass effects (Table 2). The greatest

TABLE 1. COMPARISON OF ANNUAL ENERGY USE FOR METAL WALL AND CONCRETE WALL BUILDINGS INSULATED TO SATISFY REQUIREMENTS OF ANSI / ASHRAE / IES STANDARD 90A-1980

City	Annual heating and cooling (Million Btu)				Savings for concrete			
	Heating degree days	Insulated metal wall panels	Concrete walls insulated on inside	Concrete walls insulated on outside	Insulated on inside		Insulated on outside	
					Million Btu	Percent	Million Btu	Percent
Tampa	683	800	720	710	80	10	90	11
Phoenix	1765	840	725	710	115	14	130	16
Atlanta	2961	560	495	480	65	12	80	14
Washington D.C.	4224	585	535	505	50	9	80	14
Chicago	6639	640	590	565	50	80	75	12
Minneapolis	8382	845	805	775	40	50	70	8

TABLE 2. INSULATION SAVING FOR CONCRETE WALLS, COMPARED WITH NON-MASSIVE WALLS, BASED ON COMPUTER ANALYSIS INCLUDING THERMAL MASS EFFECTS

City	Heating degree days	R-value of wall to meet ASHRAE standard	Actual R-value of concrete wall which will perform as well as non-massive wall meeting ASHRAE standards*		R-value of insulation, savings
			Inside insulation	Outside insulation	
Tampa Phoenix Atlanta Washington D.C.	683 1765 2961 4224	2.8 3.0 3.2 3.4	8-inch concrete walls require no insulation to match performance of non-massive walls meeting ASHRAE standard		
Chicago Minneapolis	6639 8382	4.0 4.8	2.8 4.0	2.4 3.6	1.2-1.6 0.8-1.2

*Insulation of concrete wall reduced to level at which concrete building uses same amount of energy as non-massive building meeting ASHRAE standard. Thermal mass efffects allowed for in calculations.

saving is possible when insulation is placed on the outside of the concrete walls.

Thermal mass research

The Portland Cement Association has been conducting thermal mass research for several years. We do studies such as the shopping mall investigation using a sophisticated computer program which performs an hour-by-hour energy analysis for an entire year. The program takes into account the shape and construction of the building; the way the building is operated; and various climatic factors including humidity, temperature, solar radiation, wind speed, and cloud cover.

In addition to the computer studies, we experiment with full-scale wall assemblies in the calibrated hot-box test facility operated by the Construction Technology Laboratories, research arm of the Portland Cement Association. Tests of wall assemblies subject to fluctuating temperatures in the calibrated hot box have confirmed the thermal mass effect and shown that massive walls do in fact perform better than non-massive walls.

The controversy between competing industry groups over thermal mass has led to the involvement of the U.S. Department of Energy (DOE). To help resolve the issue, DOE is supporting two experimental investigations on outdoor test structures. One investigation by the National Bureau of Standards (NBS) is measuring the difference in energy consumption for six test structures in Gaithersburg, Maryland. The test houses are identical except for wall construction. The walls being investigated are: insulated and uninsulated wood frame; insulated and uninsulated masonry; brick and block cavity; and a log wall. This program has been in progress for more than a year. Preliminary results confirm that thermal mass reduces energy consumption during spring, summer, and fall. In the winter when the outside temperature remains so low that the test homes must be heated continuously, NBS has reported that there is no apparent thermal mass benefit. These observations confirm research by the concrete and masonry industries during the past several years.

A second experiment supported by DOE is taking place in Santa Fe, New Mexico at the New Mexico Energy Research and Development Institute (NMERDI). Eight test homes are being monitored in this project to determine the performance of wood frame, masonry, and adobe walls. This research is about a year behind the work being done at NBS, and no firm conclusions have yet been reported.

Results from the NBS and NMERDI research program will be used to validate existing computer programs. Once it is demonstrated that computer programs can accurately predict the energy performance of massive structures, competing industry groups will no longer be able to question code change proposals based on these computer programs.

THERMAL MASS HELPS IN PASSIVE SOLAR INSTALLATIONS

This article on thermal mass stresses the value of the massiveness of concrete in building walls to help cut conventional heating and cooling energy requirements or to reduce insulation needed for a certain level of temperature control. Another important way to use the thermal mass of concrete is as a storage reservoir for solar energy collected through south-facing glass. Concrete passive solar collectors may be either floors or trombe walls which later re-radiate the heat when surrounding temperatures have dropped. Both cast in place concrete and concrete masonry are important. (See CONCRETE CONSTRUCTION article on residential solar collection, November 1982, page 841.)

Codes and standards update

These favorable research results are good news, but full benefits will not be realized by the concrete industry until they are introduced into building codes and standards. Despite opposition from competing industries, thermal mass benefits are currently included in seven state energy codes (California, Florida, New Mexico, North Carolina, Oregon, Utah, and Washington) and one model building code (Standard Building Code) .

Thermal mass is included in the cooling requirements of ANSI/ASHRAE/IES Standard 90A-1980 but not in the heating requirements. Since cooling rarely governs the building envelope requirements of buildings designed by this standard, the fact that thermal mass is accounted for is of little benefit. However, two task groups are currently studying ANSI/ASHRAE/IES Standard 90A-1980 with the objective of recommending changes. One change being considered is to include thermal mass. It is still too early to predict the findings of these task groups. But if the results of available research are any indication, provisions for thermal mass have a good chance of being included in the next revision of this standard.

Conclusions

In summary, the outlook for thermal mass is improving, but the battle is far from over. Based on research findings, it appears that the potential benefits are worth the fight. However, a concerted and coordinated effort by the concrete and allied industries will be required at the national, state, and local levels to successfully introduce provisions for thermal mass into building codes and standards.

Reference: Energy Conservation in New Building Design, ANSI/ASHRAE/IES Standard 90A-1980, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle NE, Atlanta, Georgia 30329.

PUBLICATION #C830525