there was no simple way of calculating this response. We now understand that the transmission of heat through building walls is a dynamic process and that any method of calculating heat loss or heat gain that assumes it is static or steady state is not an accurate measure of performance.

Heat flows from hot to cold. As the temperature rises on one side of a wall, heat begins to migrate toward the cooler side. Before heat transfer from one space to another can be achieved, the wall itself must undergo a temperature increase. The amount of thermal energy necessary to produce this increase is directly proportional to the weight of the wall. Masonry is heavy, so it can absorb and store heat and substantially retard its migration. This characteristic is called *thermal storage capacity* or *capacity insulation*. One measure of this storage capacity is the elapsed time required to achieve equilibrium between inside and outside wall surface temperatures. The midday solar radiation load on the south face of a building will not completely penetrate a 12-in. solid masonry wall for approximately 8 hours.

The effects of wall mass on heat transmission are dependent on the magnitude and duration of temperature differentials during the daily cycle. Warm climates with cool nights benefit most. Seasonal and climatic conditions with only small daily temperature differentials tend to diminish the benefits.

Thermal lag and capacity insulation are of considerable importance in calculating heat gain when outside temperature variations are great. During a daily cycle, walls with equal *U* values but unequal mass will produce significantly different peak loads. The greater the storage capacity, the lower will be the total heat gain. Increased mass reduces actual peak loads in a building, thus requiring smaller cooling equipment. Building envelopes with more thermal storage capacity will also delay the peak load until after the hottest part of the day, when solar radiation through glass areas is diminished and, in commercial buildings, after lighting, equipment, and occupant loads are reduced. This lag time decreases the total demand on cooling equipment by staggering the loads.

Steady-state heat-gain calculations do not recognize the significant benefits of thermal inertia when they employ constant indoor and outdoor design temperatures. Computer studies completed by Francisco Arumi for the Energy Research and Development Administration and the National Concrete Masonry Association (NCMA) made close comparisons between static calculations and dynamic calculations. *Figure 8-26* shows the time–temperature curves derived from each method in calculating inside room temperature.

The attenuation of temperature amplitudes found with the dynamic response calculation graphically illustrates the actual effect that the thermal inertia of massive walls has on indoor comfort. Another study conducted by Mario Catani and Stanley E. Goodwin for the Portland Cement Association (PCA) and reported in the *Journal of the American Concrete Institute* shows heat-gain comparisons for several wall types (*see Fig. 8-27*). Computer analysis using dynamic response methods showed that, when *U* values were equal, the peak heat gains of the lighter-weight walls were 38 to 65% higher than for the heavy walls. In comparisons of a model building with four alternative wall types, the same results were evident. Using dynamic analysis methods, two heavy concrete walls, a concrete tilt-up wall, and a metal building wall were studied to determine peak cooling loads. Results showed that the heavier walls were far superior in performance to the lightweight sections and that, despite a *U* value that was 33% higher than the others, the peak loads for one thick concrete wall were 60 to 65% less than those for the lightweight construction.

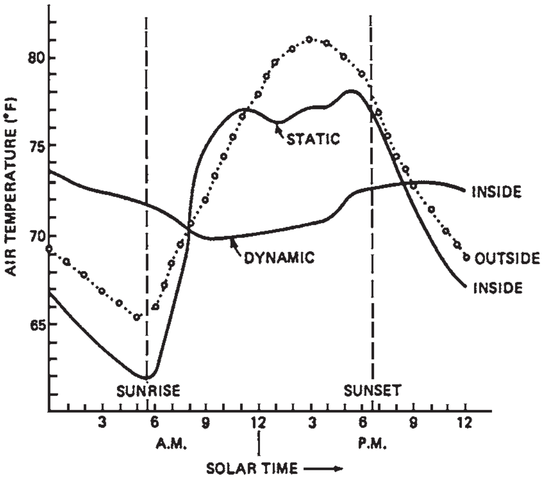

Figure 8-26 Example of static and dynamic thermal calculations for a masonry wall. (*From Francisco N. Arumi,* Thermal Inertia in Architectural Walls, *National Concrete Masonry Association, Herndon, VA, 1977.*)

NCMA reports other cooling load tests made using NIST computer programs. *U* values of the walls, roof, and floor were held constant while the wall weight was varied from 10 to 70 lb/sq ft in 5-lb increments. The size of the required air-conditioning equipment varied inversely with the weight of the structure. The lightest-weight walls (10 lb/sq ft) required over 35,000 Btu/hour in air conditioning. The heaviest walls (70 lb/sq ft) required less than 25,000 Btu/hour. When the data is grouped in weight categories matching those of the equivalent temperature difference graph, the relationships are easily compared (*see Fig. 8-28*).

Heat gain is known to be affected not only by mass and density, but also by surface color and emissivity of the wall, orientation, intensity of direct and diffused solar radiation, and surface reflectivity. Because of these many factors, heat-gain calculations are more complex than simple heat-loss calculations. In any climate where there are large fluctuations in the daily temperature cycle, the thermal inertia of masonry walls can contribute substantially to increased comfort and energy efficiency. The time lag created by delayed heat flow through the walls reduces peak cooling demands to a much greater extent than *U* values alone indicate.

In northern climates, where heat loss is usually more critical than heat gain, winter temperature cycles more nearly approximate static design conditions because daily temperature fluctuations are smaller. There is still, however, significant advantage to be gained by using masonry walls with thermal inertia. The methods developed by ASHRAE for measuring the dynamic thermal response of heavy construction are more complicated for heat-loss calculations than for heat gain, and require sophisticated computer programs.

The Catani and Goodwin study compared steady-state heat-loss calculations with dynamic analysis. They found that the predicted heat loss based on static conditions was 22% higher than the actual recorded loss for heavy walls, and 8% lower than the actual loss for lightweight walls. Using three different wall types with the same *U* value, they made a direct comparison of