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Thermal Mass—The Energy Saver In Concrete and Masonry Buildings

The concept that massive walls absorb and retain heat, and that this heat is later released, has been understood since the time of the world's earliest structures when both mud hut and stone temple were built to benefit from the delaying effect of mass on the transfer of heat. In modern times concrete and masonry have provided this thermal function with great effect, except during the brief era of cheap energy that ended in the 1970's. And now enlightened thinking is once again steering a prudent course in building design, calling for "sustainable development," which provides for meeting the needs of today without sacrificing the needs of the future. As a consequence of this revised outlook, builders and designers are once again turning to materials like concrete and masonry for their inherent energy saving advantages, particularly their thermal mass benefits.

R-VALUE AS STOP-GAP MEASURE

Despite vast empirical evidence, modern understanding about thermal mass has taken some time to evolve. For one thing, few scientific studies had focused on this phenomenon in building design before the US oil crisis of the early '70s. For another, the energy policies resulting from the oil crisis were developed to meet an immediate emergency and were by necessity tied in with the most widely used and easily analyzed construction methods. The mandate, to stop as quickly as possible the prodigal waste of energy, was addressed with a readily available corrective measure. Insulation with minimum R-values was prescribed for all structures. Tables of R-values were issued, with guidelines on the required minimum values for walls and roofs. Required R-values were the same for all materials.

As a method that cut down on overall energy use for low-mass building materials, minimum insulation requirements have been successful. For concrete and masonry, however, this path of prescriptive compliance was less appropriate. It failed, in part, because R-value is a measure of resistance to heat flow during constant temperature, a condition that in real world climates rarely occurs. This kind of R-value measurement neglects thermal mass characteristics.

RESEARCH AND EXPERIENCE CONVERGE

Thermal mass regained its proper place in building design when scientific investigations, by both government and private industry, demonstrated its true value through field and laboratory testing. The first significant study that led to this new appreciation was sponsored by the US Department of Energy (DOE), which showed that mass in exterior walls reduces annual energy costs in buildings. Thermal mass research has also been done by the U.S. Department of Housing and Urban Development (HUD), and the National Institute of Standards and Technology (NIST).

Data assembled by the DOE study addressed several factors that were understood to influence the effect of thermal mass in a building: weather conditions,

individual building operating parameters for heating and cooling, and overall energy consumption. The data were collected from specially erected residential houses made with different types of walls including adobe, concrete masonry, wood frame, and log. These wall types were incorporated in model predictions for heating and cooling loads, and eventually used by the Council of American Building Officials (CABO) 1987 Model Energy Code (MEC), in the form of a thermal mass credit table.

Conventional concrete and masonry have low R-values but high thermal mass. Insulated frame walls have high R-values but very little thermal mass. However, the combination of insulation with thermal mass forms a superior wall system exhibiting the benefits of both. Modeling and testing has shown that thermal mass effects can be enhanced by judicious placement of the insulation in the wall assembly. For example: Integral insulation is typically located between wythes of concrete sandwich panels, in the core of concrete masonry units, or in the space between wythes of cavity walls where it provides greater thermal mass benefits than interior placement. These systems perform best when the mass on the inside of the insulation is in direct contact with the conditioned space.

Exterior insulation placed on the outside of either concrete or masonry provides the highest degree of thermal mass benefits. As with the integrally insulated walls, mass should be in intimate contact with the interior for optimum effectiveness.

Interior insulation usually consists of placing batt or rigid board insulation on the interior of single-wythe or multi-wythe walls. Such systems isolate the concrete or masonry from direct contact with the interior, reducing the benefits of thermal mass.

Figure 1 illustrates interior, integral,

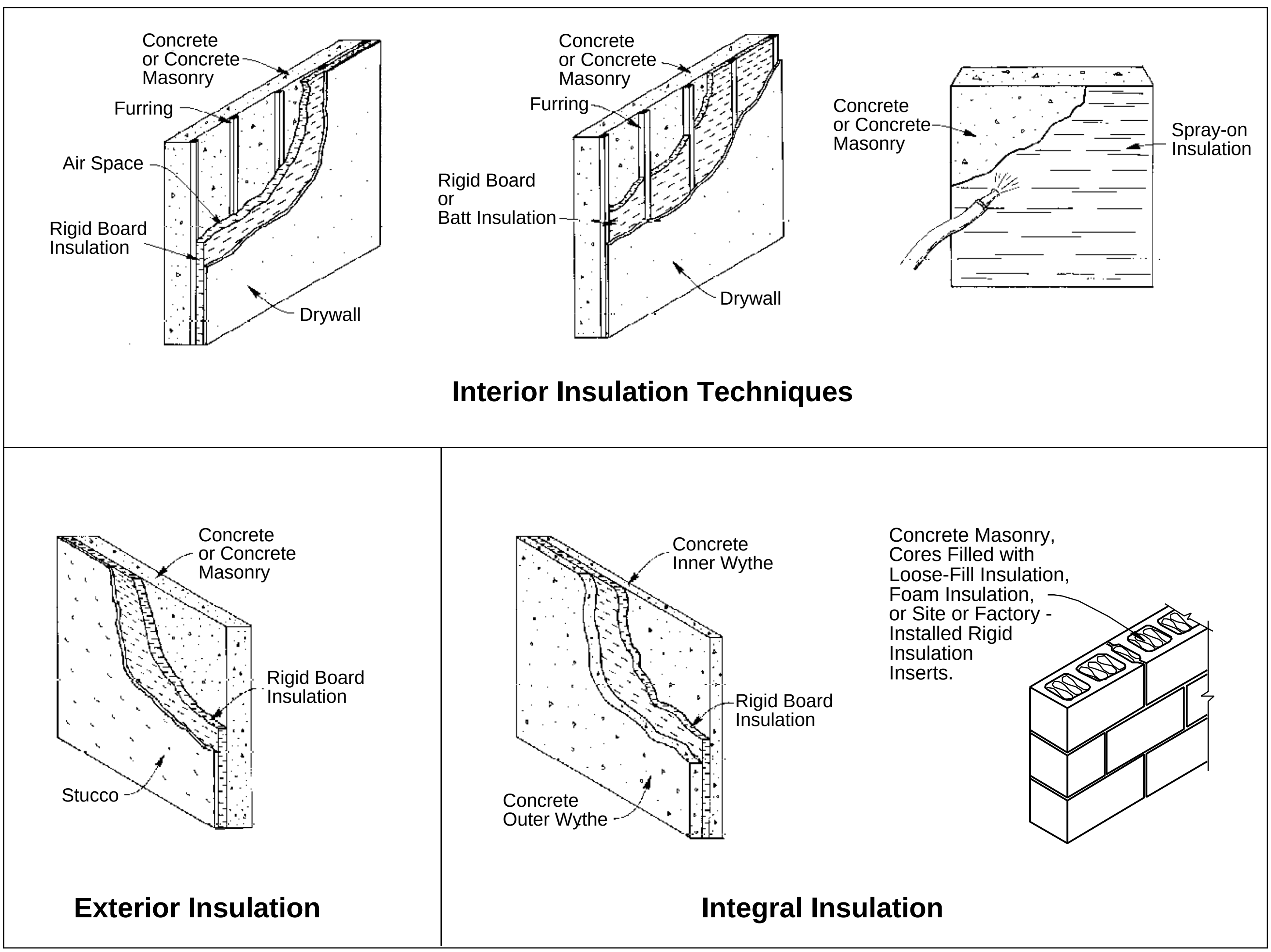


Fig. 1. Interior, exterior, and integral insulation methods.

and exterior insulation strategies for concrete and masonry walls.

THERMAL MASS AS PRACTICAL QUANTITY

The significance of thermal mass also came to light in the laboratory where the phenomenon could be isolated for analysis. There, the process of heat transfer is simulated by what is known as a hot box. The prototype for the hot box, (American Society for Testing and Materials, Designation: C976), consists of three basic parts: an outdoor chamber, an insulating frame that surrounds the test wall, and an indoor chamber. Temperatures in the outdoor chamber can be maintained at a constant (steady-state) level or they can be varied to follow a predetermined time-temperature (dynamic) cycle.

Decisive thermal mass research using hot box technology was performed by Construction Technology Laboratories (CTL), and it included both steady-state and dynamic tests. Both types of tests measured the amount of energy required to maintain a constant interior temperature. Under steady-state conditions, in which a constant rate of heat flow was maintained through the test wall, the measurements revealed traditional overall thermal resistance (R) and transmittance (U). Thermal mass characteristics including heat absorption, thermal lag, and lower energy consumption were demonstrated in the dynamic portion of the test.

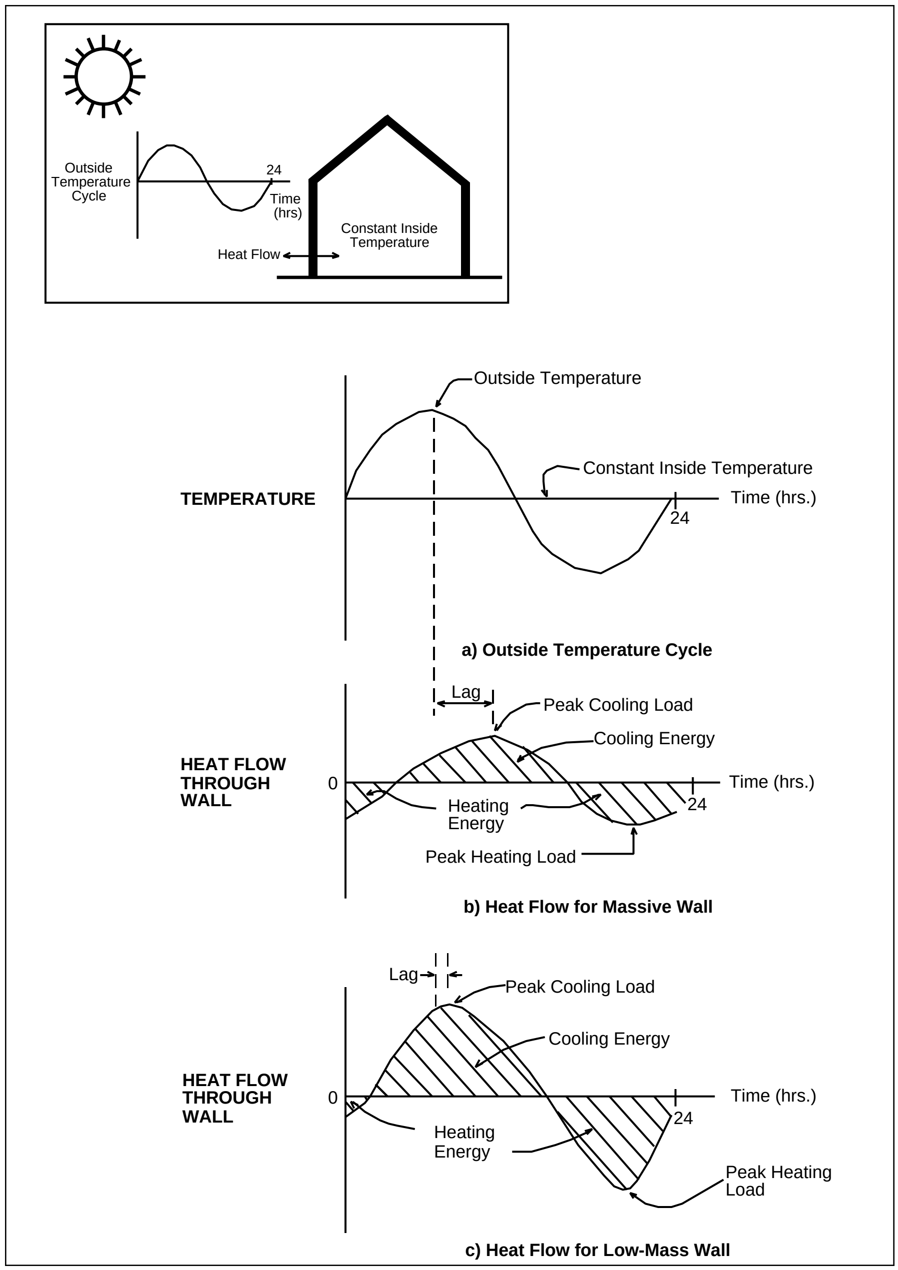
CTL's dynamic tests provided data on thermal resistance and heat storage capacity of mass walls. Masonry walls showed a marked difference in their heat absorption capability compared to wood frame walls. Fig. 2a shows a dynamic temperature cycle representing hypothetical outdoor conditions over a 24 hour period. Figs. 2b and 2c demonstrate heat flow over the same period through massive (i.e. concrete or masonry) and low mass (i.e. wood frame or metal) exterior walls, respectively.

Note that three characteristics of thermal mass are evident. First, the time lag between peak heating and cooling loads and outside temperature peaks is greater for the massive wall. This feature can be used in buildings by delaying needed heating or cooling energy to take advantage of off-peak energy pricing now available in some areas.

Second, the massive wall demonstrates lower peak heating and cooling loads. This allows the use of smaller heating and cooling equipment which reduces costs. Third, the massive wall requires less overall heating and cooling energy to maintain the same interior temperature. This is demonstrated by the shaded area under the curves. Less heating and cooling energy translate to lower utility bills.

In certain climates and during specific seasons, thermal mass is particularly beneficial. Both empirical data and laboratory experiments on dynamic heat flow have

Fig 2. The effects of thermal mass on heating and cooling loads



The Environmental Council
of Concrete Organizations
is a coalition dedicated to
promoting the environmental
benefits of concrete
and its role in safe and
sustainable construction.

ECCO members are
companies, organizations,
and individuals affiliated
with the concrete industry.
Together, they are
committed to developing
and disseminating
information on the
environmental benefits
of concrete
and concrete products.

identified climates where thermal mass has the greatest benefits: climates with fluctuating outdoor temperature that swings above and below the indoor temperature. This causes the mass wall to release its stored energy, a process called heat flow reversal. Such temperature conditions occur mostly in the spring and fall in moderate climates, most of the year in southern and western U.S. climates, and year-round in the desert regions (Southwest U.S.). The greater the outdoor temperature swings in a twenty-four hour cycle, the greater the thermal mass benefits, and the greater the energy savings.

Practical applications of thermal mass take the form of distinctive insulation strategies in different climatic regions. In all climates, integral or exterior insulation is used to achieve maximum thermal mass benefits. In hot, humid climates, one effective strategy involves circulating cooled air through spaces in the walls. In moderate and cold climates, concrete slabs used in conjunction with passive solar designs are suitable thermal mass solutions. Walls with exterior or integral insulation can also be used as thermal storage for passive solar buildings in moderate climates.

ENERGY STANDARDS EVOLVE

As thermal mass history demonstrates, the phenomenon has been slow to gain its proper place as a building energy conservation strategy. Much of this stall stems from its complex nature, and the fact that thermal mass measurements involve many factors. This presents both conceptual and practical difficulties for the construction industry. But this complication has been eased now that building codes reflect the actual contributions of thermal mass in energy conservation.

The course of standards development for thermal mass has reflected the course of the technology itself. Discussed earlier in the article, the CABO Model Energy Code adopted the thermal mass energy credits suggested by DOE research findings. This code, which applies to residential structures only, recognizes the benefits of thermal mass by granting R-value credits to thermal mass walls. The R-value credits for concrete and masonry wall systems are based on their heat capacity, which is a function of wall density and specific heat.

A broader set of guidelines for thermal mass has been issued by the American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), and apply to both residential and commercial structures. Like CABO, ASHRAE standards incorporate thermal mass credits, but they also expand them. ASHRAE Standard 90.1, Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings, gives designers three options for taking advantage of thermal mass benefits.

The simplest is the so-called prescriptive compliance path, which relies on tables of R-values based on the heat capacity of the wall. The second method, focusing on overall performance of the building envelope, provides an alternative performance path specifying only the amount of energy a building is allowed to consume, but otherwise leaves the path for the designer to choose. The third method, using cost budget techniques, compares the proposed building with a standard building as a way of determining its allowable energy use or energy budget.

ASHRAE Standard 90.2, Energy Efficient Design of New Low-Rise Residential Buildings, utilizes the same three compliance options for recognizing thermal mass as ASHRAE Standard 90.1. Separate R-value graphs are provided for concrete and masonry walls with interior, exterior, or integral insulation. To use the tables the user only needs to know the heating and cooling degree days at the location where the building is to be located. The required R-values are read directly from the graphs without the need for any calculations. It is anticipated that ASHRAE Standard 90.2 will eventually become recognized as the national residential energy standard.

The guiding principle for all thermal mass standards has been performance, whether of the individual components or the overall building envelope. These standards have successfully translated the behavior of thermal mass into understandable and easy to use terms. The result is that thermal mass has become a feasible element of building design.