"Mass-Enhanced R-Value"

Last Post 14 Jun 2009 02:32 PM by markever. 1 Replies.

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"Mass-Enhanced R-Value"

When people refer to the "mass effect" or "effective R-value," they are generally referring to the ability of high-mass materials, when used in certain ways, to achieve better energy performance than would be expected if only the commonly accepted (steady-state) R-value or U-factor of that material were considered. Let's take a look at a typical use of one of these high-mass materials in a wall system. When one side of the wall is warmer than the other side, heat will conduct from the warm side into the material and gradually move through it to the colder side. If both sides are at constant temperatures--say the inside surface at 75°F (42°C) and the outside surface at 32°F (18°C)--conductivity will carry heat out of the building at an easily predicted rate. As described above, this steady-state heat flow is what most test procedures for determining R-value measure.

In real-life situations, however, the inside and outside temperatures are not constant. In fact, in many parts of the country, the driving force for conductive heat flow (remember, heat always moves from warmer to colder) can change dramatically or even reverse during the course of a day. On a summer afternoon in Albuquerque, New Mexico, for example, it might be 90°F (32°C) outside, and the outside wall surface--because it has a dark stucco--might be even hotter. It's cooler inside, so heat conducts from the outside surface of the wall inward. As night falls, however, it cools down outside. The air temperature may drop to 50°F (10°C). The driving force for heat flow changes. As the temperature difference across the wall is reversed, the heat flow is also reversed--drawing heat back towards the outside of the building. As a result of this modulating heat flow through a high-heat-capacity material, less heat from outside the building makes its way inside. Under these conditions, the wall has an ***effective thermal performance*** that is higher than the steady-state R-value listed in books (such as ASHRAE's *Handbook of Fundamentals*). This dynamic process is what some people call the "mass effect."

Another common scenario is when the outside temperature fluctuates but never crosses the indoor set point temperature. In this case, the direction of heat flow never changes, but the ***thermal lag*** or ***time delay*** in heat flow can still be beneficial by delaying the peak heating or cooling load. For example, if the outdoor temperature in Miami peaks at 95°F (35°C) at 5:00 on a summer afternoon, but it takes eight hours for the heat to travel through the wall, the effect of that peak temperature won't be felt inside the building until the middle of the night. Because most cooling equipment operates at higher efficiency if the outdoor air temperature is lower and because night time thermostat settings may be higher (at least in commercial buildings), potentially significant savings can result. Not only can total cooling energy be reduced, but peak loads can also be reduced. This can lead to smaller (and less costly) mechanical systems and lower demand charges for electricity. This time lag effect can save energy and money, but note that it does not affect the total amount of heat flowing through the wall.

As noted above, the amount of heat flow through a wall is reduced by the use of thermal mass when the temperatures fluctuate above and below the desired indoor temperature, so under these conditions a material might have a "mass-enhanced" R-value that is greater than its steady-state R-value. To estimate this mass-enhanced R-value for a given high-mass material in a particular climate, researchers at Oak Ridge National Laboratory measure the thermal performance of a high-mass wall under *dynamic* conditions, in which the temperature on one side of the wall is kept constant and the temperature on the other side is made to fluctuate up or down. With this measured heat flow under dynamic conditions as a basis, they then use computer modeling to arrive at steady-state wall R-values that would be required to achieve comparable overall energy performance under various climate conditions. Those results are what we are calling the "mass-enhanced R-values" for the high-mass material under the modeled conditions.

When is Mass-Enhanced R-Value Significant?

The mass effect is real. High-mass walls really can significantly outperform low-mass walls of comparable steady-state R-value--i.e., they can achieve a higher "mass-enhanced R-value." BUT (and this is an important "but"), this mass-enhanced R-value is only significant when the outdoor temperatures cycle above and below indoor temperatures within a 24-hour period. Thus, high-mass walls are most beneficial in moderate climates that have high diurnal (daily) temperature swings around the desired indoor setpoint.

Nearly all areas with significant cooling loads can benefit from thermal mass in exterior walls. The sunny Southwest, particularly high-elevation areas of Arizona, New Mexico and Colorado, benefit the most from the mass effect for heating. In northern climates, when the temperature during a 24-hour period in winter is always well below the indoor temperature, the mass effect offers almost no benefit, and the mass-enhanced R-value is nearly identical to the steady-state R-value. The ASHRAE *Handbook of Fundamentals* lists "mean daily temperature range" data for hundreds of U.S. climates in the chapter on climate data. These values can be helpful in figuring out how significant mass-enhanced R-value might be for a particular climate, but they do not tell the whole story; also significant is the percentage of days during the heating and cooling seasons when the outdoor temperature cycles *above and below* the indoor temperature.

Do We Need Mass-Enhanced R-Value Ratings?

Clearly, high-mass materials used in exterior walls perform better than would be expected based solely on their steady-state R-values. But the actual thermal performance is highly dependent on where the building is located. Manufacturers of these materials rightly want to take credit for this improved performance, but how can that be done in a way that doesn't exaggerate performance for parts of the country where the mass effect benefit just isn't there? "Right now, we don't have a system that forces people to deal with calculations in a constant way," says Bruce Wilcox, P.E., of the Berkeley Solar Group, who has done extensive modeling of mass effects for the Portland Cement Association and others.

All sorts of claims are being made about mass-enhanced R-value (usually called "effective R-value") with little standardization. The first step needs to be consensus on how the mass effect should be accounted for in testing and modeling. Jeffrey Christian at Oak Ridge National Laboratory has been developing and refining the method of dynamic thermal analysis and simulation described above. This is the most extensive effort to date to quantify the mass effect. Christian's group, with the help of Bruce Wilcox and others, also developed thermal mass tables for the Model Energy Code in the late 1980s that can be used to account for the thermal mass benefits of high-mass building materials in wall systems.

The next step, suggests Christian, might be to formalize the testing and simulation procedures through development of ASTM standards. Establishment of an ASHRAE committee to address the mass effect may also be in the works. To ensure that such standards would be applied in a consistent manner, Wilcox suggests that applicable industries might have to set up some sort of council, perhaps modeled after the National Fenestration Rating Council (NFRC), which enforces consistent reporting of window energy performance. Such a "Thermal Mass Rating Council" might oversee standards relating to how mass effect and mass-enhanced R-value are reported. Wilcox remains leery of the whole concept of mass-enhanced R-value--not that the effect exists, but whether it can be used clearly with building materials. "I don't know if there's any way to make it a property of the material," he told *EBN*, "It's a property of the system." There are a lot of questions to sort out, such as how many climates need to be modeled: are six enough, as Oak Ridge researchers have used, or do we need 20? Would such a system take credit for time delays in heat transfer, or just actual reductions in the amount of heat that moves through? Who will pay for all the research to make this happen? Are the industries that sell high-mass materials large enough to support a Thermal Mass Rating Council and the additional research needed on these issues?

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thanks so much for taking the time to share this information!

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