TECHNICAL NOTE #16

Thermal Mass, Resistance and heat flows in walls

The concepts of Thermal Resistance and Thermal Capacity are explained in layman's terms

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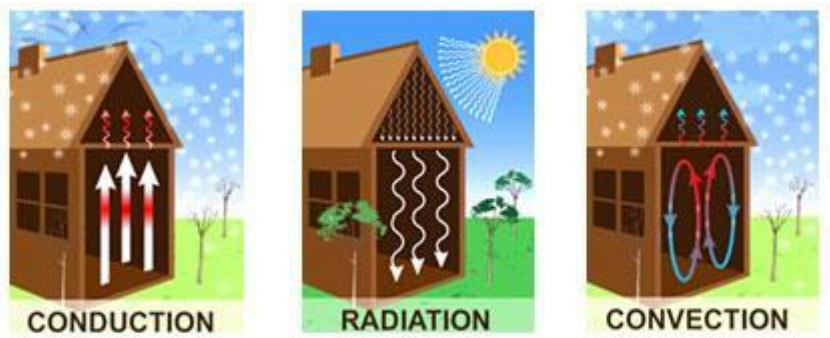
THERMAL MASS, RESISTANCE AND HEAT FLOWS IN WALLS

Heat flows by three mechanisms: conduction, convection, and radiation.



CONDUCTION is the molecule-to-molecule transfer of kinetic energy (one molecule becomes energized and, in turn, energizes adjacent molecules). A cast-iron skillet handle heats up because of conduction through the metal.

RADIATION is the transfer of heat through space via electromagnetic waves (radiant energy). A campfire can warm you even if there is wind between you and the fire, because radiation is not affected by air

CONVECTION is the transfer of heat by physically moving the molecules from one place to another. Hot air rises and heated less dense water rises.

With buildings, we refer to heat flow in a number of different ways.

R-VALUE or resistance to heat flow. The higher the R-value of a material, the better it is at resisting heat loss (or heat gain).

U-FACTOR (or U-value) is a measure of the flow of heat—thermal transmittance—through a material, given a difference in temperature on either side. The units are Watts of energy passing through a square meter of the material for every degree difference (W/m2°C). This is measured in a 'hot box ' test (ASTMC1363) at that time when a steady state of heat flow has developed.

R-value and U-value are mathematically the inverse of one another: $U = 1/R$. See Technical Note 6 for the calculation of these properties. Materials that are very good at resisting the flow of heat (high R-value, low U-value) can serve as insulation materials.

Thermal Mass or heat capacity

Materials have another property that can affect their energy performance in certain situations: i.e. heat capacity. Heat capacity is a measure of how much heat a material can hold. The property is most significant with heavy, high-thermal-mass materials.

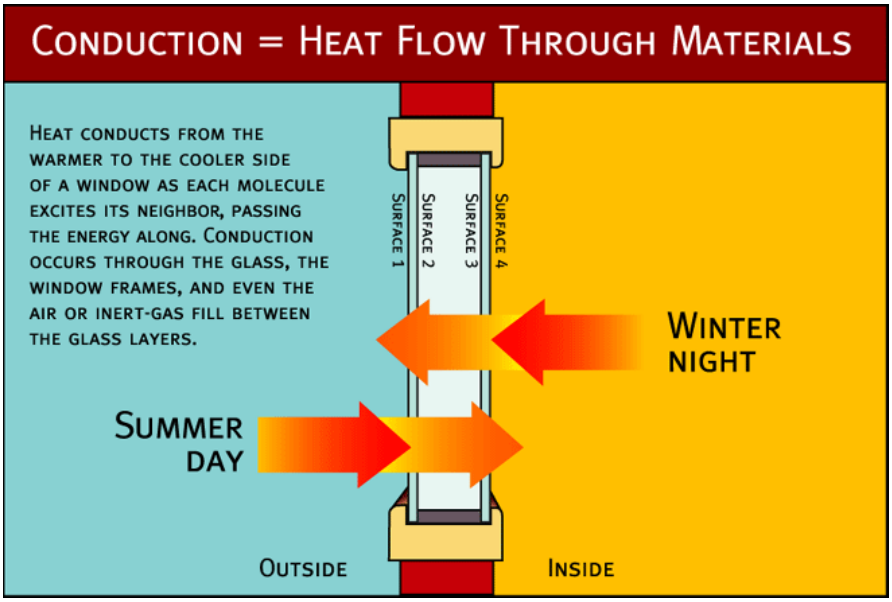
Heat capacity is determined per unit area of wall. For each layer in a wall system, the heat capacity is found by multiplying the density of that material, by its thickness, by its specific heat (specific heat is the amount of heat a material can hold per unit of mass).

If there are various layers in the wall, total heat capacity is found by adding up the heat capacities for each layer (masonry block, and plaster, for example).

Heat flows in walls

In real-life situations the inside and outside temperatures of walls are not constant. In fact, in many parts of the country, the driving force for conductive heat flow (heat always moves from warmer to colder) can change dramatically or even reverse during the course of a day. On a summer afternoon in Pretoria the air might be 32°C outside, but the wall surface might feel even hotter. It's cooler inside, so heat conducts from the outside surface of the wall inward.

As night falls the outer wall surface cools down. The air temperature may drop to 10°C. The driving force for the heat flow then 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. This dynamic process is what some people call the "mass effect."



Another common scenario is when the outside temperature fluctuates but the bricks of the wall take time to heat up so the direction of heat flow never changes.

For example, if the outdoor temperature in Kimberley peaks at 35°C at 14:00 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 when the ourdoor temperature is 10°C. This can result in significant savings in electricity as there is not need for air-conditioning during the day or heating at night can result. The walls act as a "thermal battery" storing the day's heat for when it is needed later.

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. – and this is why R-values can be misleading.

When is thermal mass most effective

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 daily temperature swings outdoors. Most of South Africa has this.

Other factors that influence heat transfer

Thermal Bridging:

A building's structural elements (e.g., wood or steel beams in light-frame construction and concrete and steel columns/walls in commercial construction) can act as a thermal bridge causing heat flow to short-circuit through these materials. The use of insulation to break thermal bridges will effectively reduce this type of heat transfer.

Air Leakage:

Air leakage through the building enclosure can be a major source of energy loss. Airtight buildings use far less energy. Again, the simple, commonly used, analysis techniques cannot assess the influence of air leakage on the thermal performance of a building system. The loss of energy by air leakage (convection) must be calculated in addition to the loss by conduction through the enclosure.

For further information:
The Clay Brick Association of South Africa
Website: www.claybrick.org