Modeling the Relative Thermal Stability of Internal and External Wall Insulation

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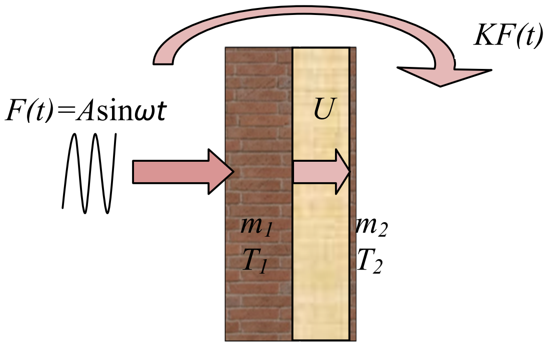
Abstract

The dynamic behavior of Internal Wall Insulation (IWI) and External Wall Insulation (EWI), the two existing techniques for reducing heat loss through building walls is not always well understood. Using EWI results in a high thermal mass on the internal insulated side of the building wall, IWI places the thermal mass on the outside. Given equal thermal masses and equal levels of insulation, it would be reasonable to expect equal heat flow, and hence the same thermal behavior from both. This paper uses some basic analysis from control theory and computer simulations to show that the dynamic behavior is substantially different when allowing for additional heat transfer paths other than through the walls.

Analysis

The heat flow through a unit area of insulated wall can be modeled as an external thermal mass subject to an external heat input, a layer of insulation, and then an internal thermal mass.



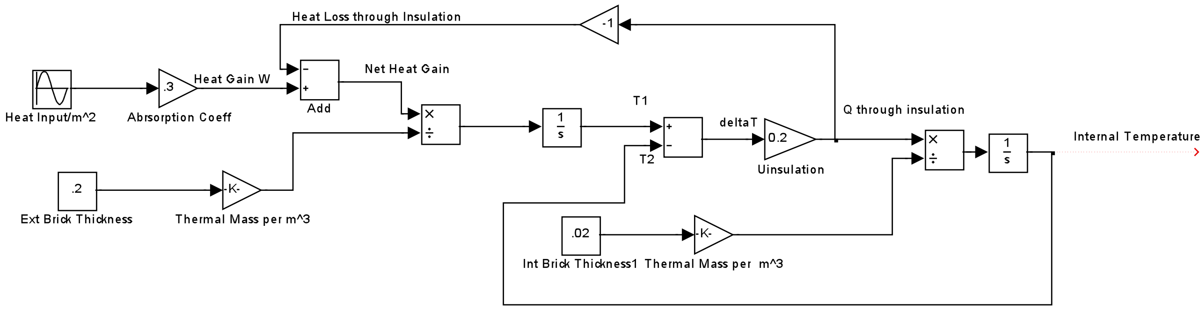
The temperature of the internal mass can be found from the solution to the following simultaneous differential equations.

$$m_2 c \frac{dT_2}{dt} = U(T_1 - T_2) \qquad [1]$$

$$m_1 c \frac{dT_1}{dt} = F(t) - U(T_1 - T_2) \qquad [2]$$

where T_1 is the temperature of the outer layer, m_1 is the mass of the outer layer, T_2 is the temperature of the inner layer, m_2 is the mass of the inner layer, U is the heat transfer coefficient of the insulation, c is the specific heat capacity and $F(t)$ is the external heat energy input. $KF(t)$ is heat flow around the insulation through other thermal transfer paths such as glazing and air exchange. It is initially assumed to be zero.

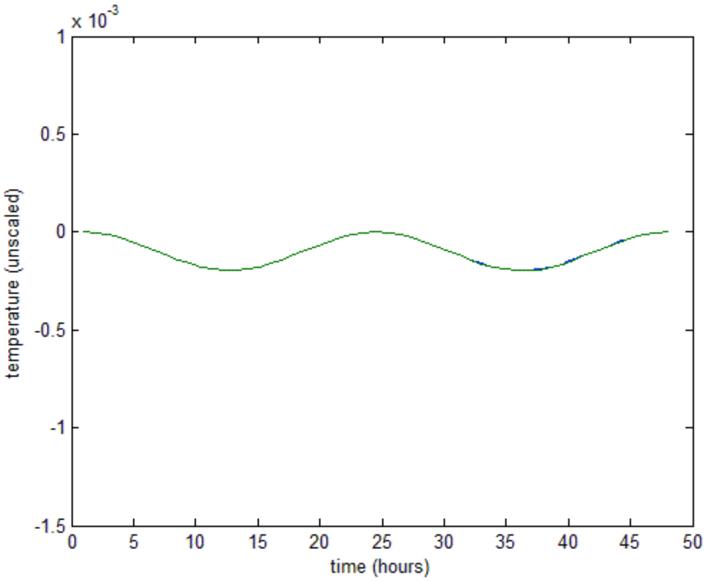
The control system diagram in Laplace space of the heat flow equations is shown below.



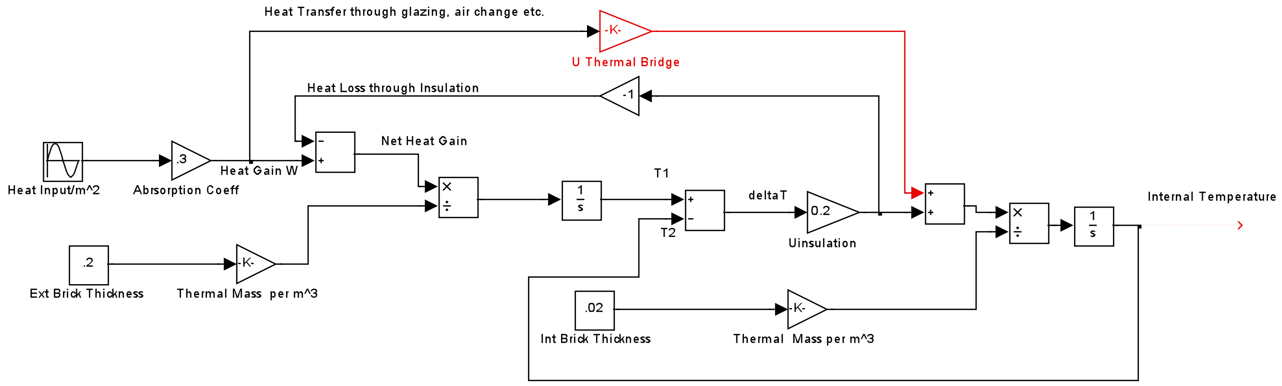
To model IWI, the external brickwork is assumed to be 200mm thick. There is then a layer of insulation with U value 0.2, and an internal layer, modeled as a 20mm thick layer of brick (approximate equivalent thermal mass to a sheet of plasterboard). The model is then subject to a sinusoidal heat input of 1kW/m^2 and an approximated absorption coefficient of 0.3. The only heat transfer path is through the wall insulation. This model was simulated to show the temperature variation of the internal thermal mass over a 48 hour period.

The model was then modified to simulate EWI very simply by setting the external brickwork to 20mm thick (to model either brick slips or render), and the internal brickwork to 200mm, and the simulation rerun.

The internal wall temperature of the two simulation runs are shown below. The traces are identical, as we would expect due to the symmetry of the two equations. Any slight visible difference is due to numerical precision in the simulation. (Note that the temperature is unscaled).



The model was then modified to include the influence of other forms of heat transfer between the exterior and interior of the building, as would be typical of a real building. A thermal bridge function, *KF(t)*, transferring heat directly to the inner thermal mass was added. In a real building typically half the heat transfer is through the walls, so the thermal bridge was calibrated such that it applied an additional heat transfer (due to glazing, ventilation, losses through loft etc.) of equal magnitude to the transmission through the wall. This is shown below (in red).



The modified heat flow equations are now

$$m_2 c \frac{dT_2}{dt} = U(T_1 - T_2) + KF(t) \qquad [3]$$

$$m_1 c \frac{dT_1}{dt} = F(t) - U(T_1 - T_2) \qquad [4]$$

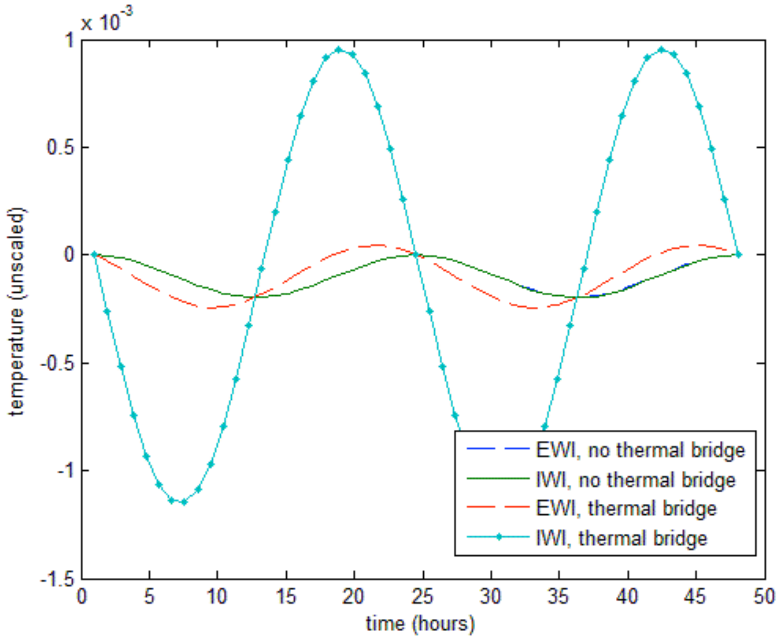
Where K is the coefficient of heat transfer through paths other than through the wall insulation.

Rearranging [3] gives

$$\frac{dT_2}{dt} = \frac{U(T_1 - T_2)}{m_2 c} + \frac{K}{m_2 c} F(t) \qquad [5]$$

Thus it can be seen that the rate of fluctuation of temperature of the inner skin, T_2 as a function of the forcing function $F(t)$ is proportional to the amount of heat that passes around the insulation, K, and inversely proportional to the thermal mass of the inner skin, m_2. Thus with EWI, m_2 is higher and the amplitude of the internal temperature fluctuation is lower.

The same two simulations were then run (EWI and IWI). The results are shown below.



The results from the base model (without thermal bridging) are shown in solid blue and green, and overlap. The effect of adding the thermal bridge to the EWI is shown in red dashes. As can be seen, the thermal bridge increases the amplitude of the temperature fluctuations slightly over the base model, and also phase shifts them forward slightly (the temperature peaks earlier in the day). The results of the simulation of the IWI with thermal bridging (blue, solid line with dots) is dramatically different. The temperature of the inner skin of the IWI fluctuates far more than the EWI.

Conclusions

A simple model of the dynamic thermal behavior of EWI and IWI has been developed. It has shown that under the assumption that the only heat loss from a building is through the walls, the temperature response of the inner wall surface is identical for IWI and EWI, given the same level of insulation. However, when a more realistic allowance for additional heat exchange paths is introduced, the EWI gives a substantially reduced fluctuation in internal temperature than IWI.

This has important implications for thermal comfort of building occupants when choosing between EWI and IWI. If a building can be assumed to have little additional thermal transfer paths, the behavior of the two forms of insulation is similar. However, where additional transfer paths are not negligible, as is often the case in real buildings, then EWI has substantially improved performance.