Energy System Construction Element Modeling

Abstract

This report compares the thermal response of lightweight and heavyweight construction based on a typical diurnal outdoor temperature cycle. This was done using the lumped parameter method and modeling the building wall as a 3R2C circuit. The circuit was constructed using Matlab Simulink's state space block and exciting the input variables (eg. Internal air temperature, radiant flux, and external air temperature. Additional simulations were conducted to study the effect of changing the location of thermal capacitance.

Matthew Kincaid

Introduction

For this study, the lumped parameter method was used to study the effect of thermal mass on the response of a building façade with varying exterior and interior temperatures and solar radiation. To do this, a Simulink model was developed for both light weight and heavyweight construction with the properties described in tables 1 and 2.

High Thermal Mass			
Code No.	**Construction Component**	**Rt [m^2 K/W]**	**Ct [kJ/m^2 K]**
E0	inside surface resistance	0.121	0
E1	20mm light plaster	0.026	25.8216
C3	100mm heavy concrete block	0.125	83.2104
B24	70mm mineral wool insulation	1.584	5.3256
B1	25mm air gap	0.16	0
A2	100mm outer brick	0.076	187.22
A0	outside surface resistance	0.059	0
Total		**2.2**	**301.6**

Table 1. Source: ASHRAE 28.19, 1997

Low Thermal Mass			
Code No.	**Construction Component**	**Rt [m^2 K/W]**	**Ct [kJ/m^2 K]**
E0	inside surface resistance	0.121	0
E2	12mm slag	0.009	18.7374
B1	10mm air gap	0.16	0
C2	100mm light concrete block	0.266	52.0632
B24	70mm mineral wool insulation	1.584	5.3256
B1	25mm air gap	0.16	0
A3	2mm metal clad	0	4.9182
A0	outside surface resistance	0.059	0
Total		**2.4**	81.0

Table 2. Source: ASHRAE 28.19, 1997

It was of interest to compare these two wall constructions because thermal mass can inform many design decisions by impacting the time and amplitude of peak heating and cooling loads. It was also of interest to study the effect of concentrating thermal mass on the interior versus the exterior of the space on wall surface temperature.

Methodology

To meet the goals discussed in the introduction, wall heat transfer system was modeled as a 3-resistor, 2-capacitor thermal network. This second order approach was taken because it has been shown to be more accurate than 1st order methods, while maintaining the same level of computational complexity. The thermal network used for both the light and heavy weight walls is shown below in figure 1.

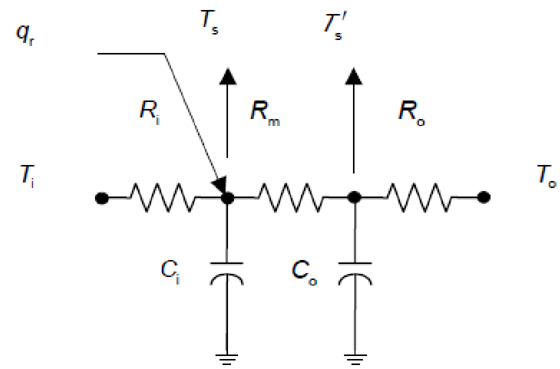


Figure 1. A 3R2C circuit with Ri and Ro representing the thermal resistance of the air film on the wall inter and exterior, and Rm indication the resistance of the wall construction

The values of Ri, Rm, Ro, Ci, and Co can be thought of as percentages of the total resistance and capacitance of the wall. Specifically,

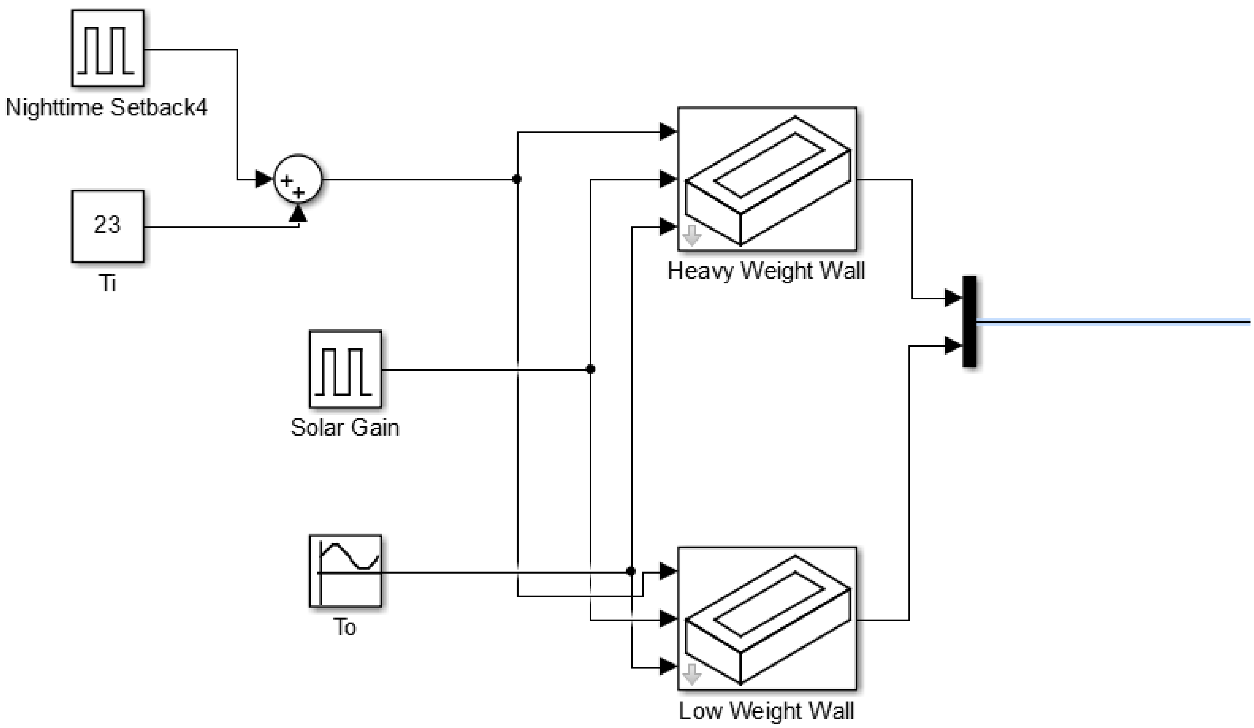
$$R_{total} = \alpha R_{Total} + \beta R_{Total} + (1 - \alpha - \beta) R_{total} = R_i + R_m + R_o \qquad [1]$$

$$C_{total} = \gamma C_i + (1 - \gamma) C_0 \qquad [2]$$

With each of the parameters in equations 1 and 2 defined, the laws of thermodynamics allow the wall surface temperatures to be computed using equations 3 and 4 as defined on the problem statement. The system was modeled using three different values of gamma, 0.15, 0.5, and 0.8. These were chosen because they cover the range of reasonable gamma values and give a good since of the effect of placement of thermal capacitance.

The following variables were then applied to excite the system. A representative Simulink schematic is shown in the next page.

- An interior temperature of 23 C with a nighttime setback down to 15 C
- An diurnal sinusoidal exterior temperature varying from 10 C to 30 C
- A solar gain of 12 W/m^2 applied for 50 % of the day/night cycle (12 hours)
- An initial condition of 20 C on both the interior and exterior surface.



Nighttime Setback4
23
Ti
Solar Gain
To
Heavy Weight Wall
Low Weight Wall

Results

The systems were studied the three ways, specifically the temperature response, the step response and using a bode magnitude plot.

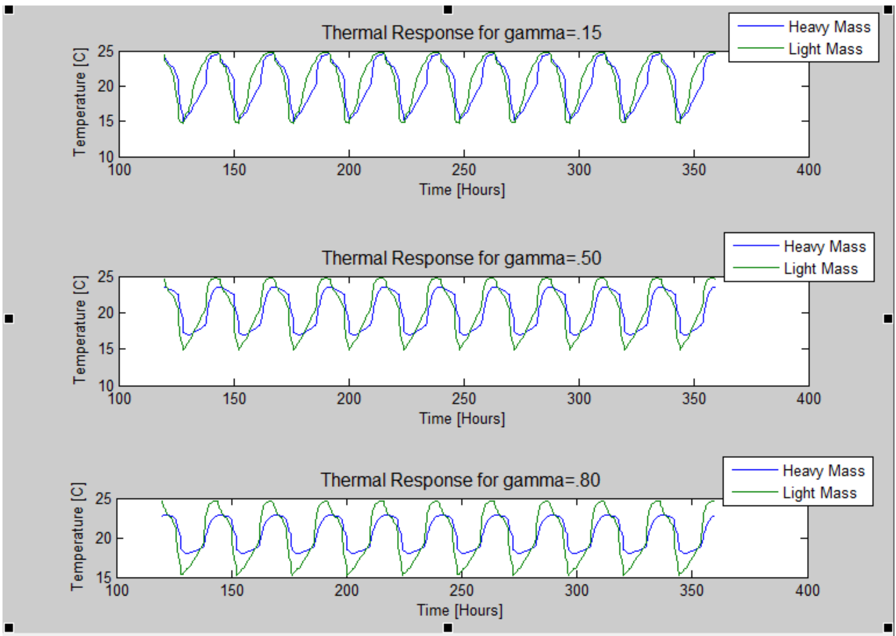


Figure 2. Temperature plots

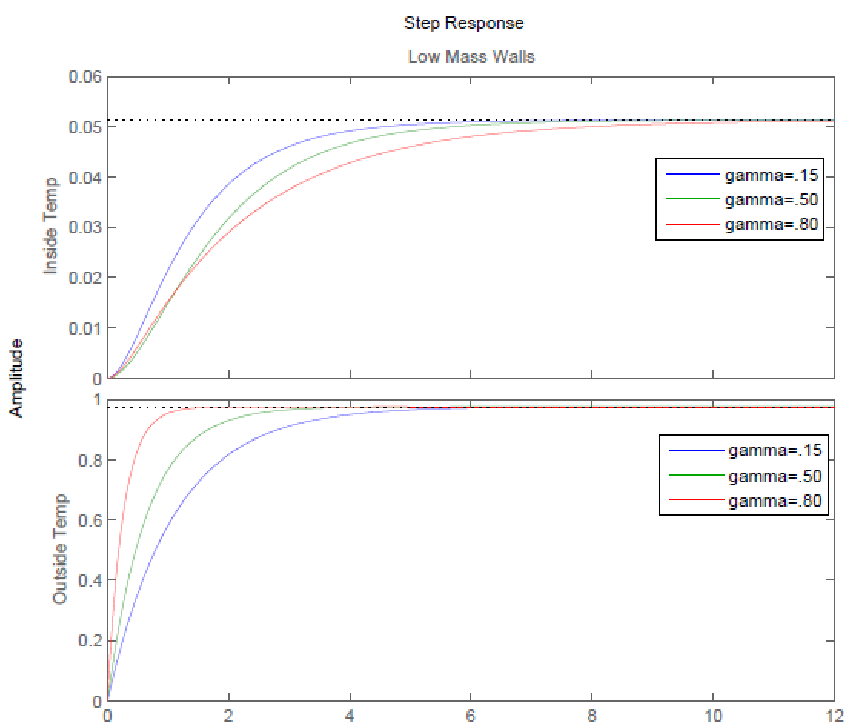


Figure 3. Step response showing unit change for low mass walls.

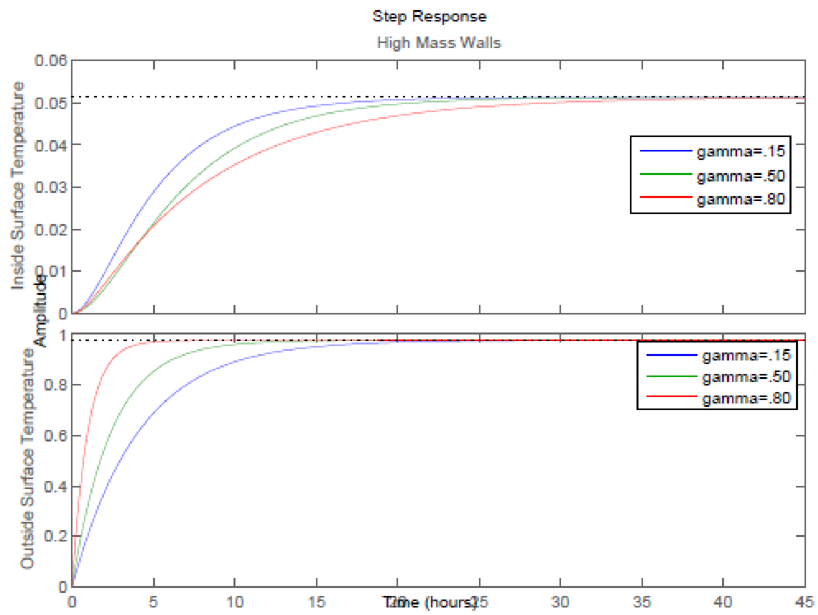


Figure 4. Step response showing unit change for high mass walls

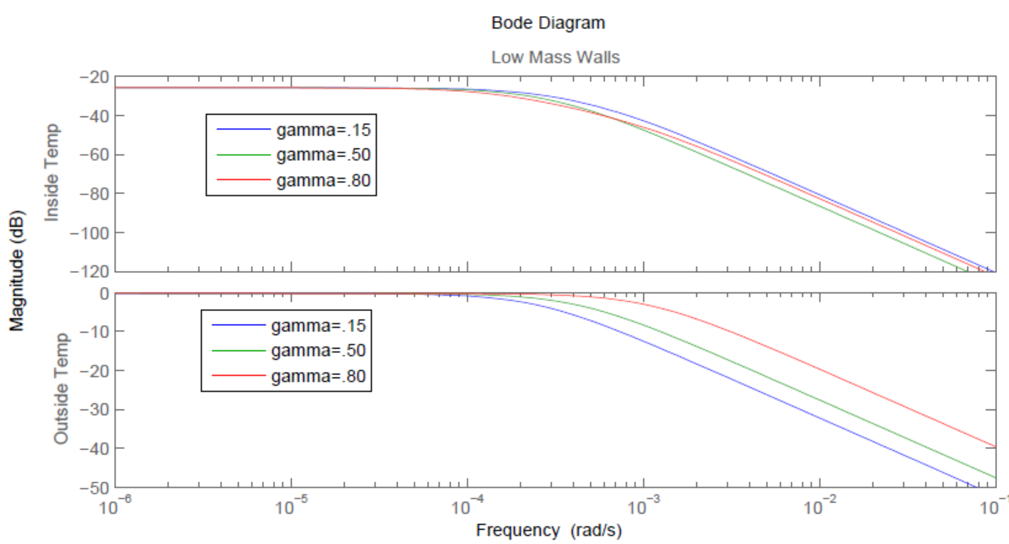


Figure 5. Bode diagram showing response of low mass walls.

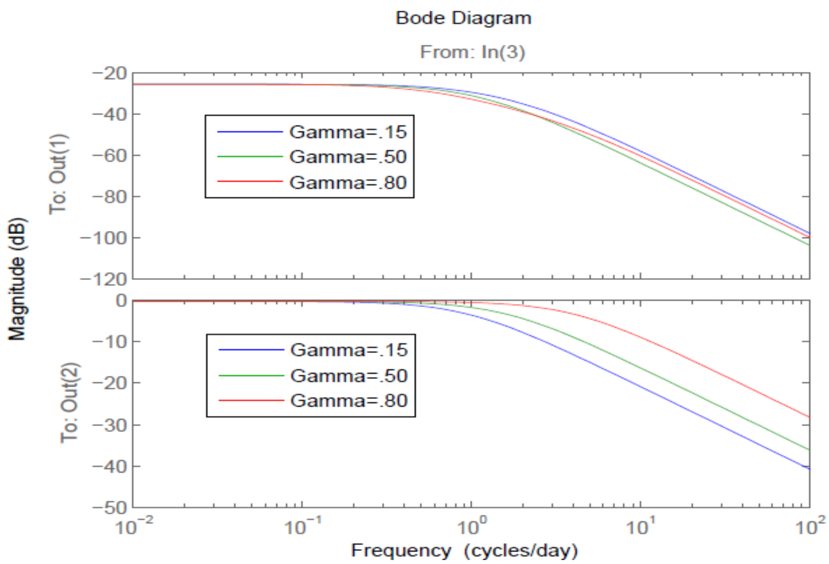


Figure 6. Bode Diagram showing response of high mass walls

Conclusions

It can be seen in the figures of the results section that the quantity and placement of thermal mass has a significant impact on system response. The thermal plots in figure 2 show a phase shift and attenuation of the thermal response depending of the weight of the wall. The low mass construction showed a larger amplitude indicating that it is more sensitive to changes in ambient conditions. This is also seen when the step diagrams of figures 3 and 4 are compared. The knee of the curve is brought closer to the y-axis for the light-weight system and steady state is achieved more rapidly.

Furthermore, it is show that concentrating mass on the exterior of the wall (ie increasing gamma) results in the system being more susceptible to variations in interior temperature and less sensitive to exterior excitations such as temperature and solar gain. This is seen especially well in the bode diagrams of figures 5 and 6.