Developing a thermal model for a residential room using Simulink/Matlab

Mohamad Kheir Mohamad[1]

[1] Brno University of Technology, Faculty of Mechanical Engineering, Energy Institute, Technická 2896/2, Brno, y119834@stud.fme.vutbr.cz

Abstract Heating, ventilation and air conditioning (HVAC) systems in buildings aim to control the indoor climate in order to keep occupants comfortable by control the temperature and air flow. To achieve this purpose, it is necessary to have adaptable control systems that could deal with the parameters required to control the indoor climatic conditions. There are for this purpose computer models that could simulate indoor climatic processes and how to control their parameters. The success of the modeling process depends on the ability to deal with changing conditions and respond effectively as much as possible so as to maintain the necessary conditions for comfort of the occupants taking into account the cost. In this paper a thermal model for a residential room has been developed using Simulink/MATLAB trying to deal mainly with the issue of maintaining the desired indoor temperature in spite of the change in outdoor conditions.

1   Introduction

There is a wide variety of software could offer the possibility to create thermodynamic models for indoor climatic conditions so that it would be possible to simulate them on graphs or some other data, in addition to control these conditions so that would be compatible with the occupants comfort. Simulink/Matlab is one of the effective software that has advanced possibility to design thermodynamic models for indoor climatic conditions. Control indoor temperature is a major issue of control indoor conditions, this process has a problem of the severe and frequent change in the indoor temperature. This problem may be solved by modeling of the real parameters in order to be as close as possible to the ideal parameters.

2   Methods and data

It is assumed the thermal zone is a room with known dimensions, external walls consist of two layers: gypsum and tile. The heat balance within the room is represented by the equation [1]:

$$\frac{d(1.293.V.c_p.T_i)}{dt} = \eta Q_h + K_l(T_o - T_i) \tag{1}$$

T_i [K] is the indoor temperature; c_p [J/kg.K] is the specific heat capacity of air; V[m³] volume of air in the room; ηQ_h [J]: is the heat generated from the heating system; η is the efficiency of the heating system; T_o [K]: is the outdoor temperature; K_l [W/m²K] is the overall heat transfer cofficient. By applying Laplace transforms on this first order differential equation we will have:

$$T_i(s) = \left(\frac{K}{Xs+1}\right)Q_h(s) + \left(\frac{1}{Xs+1}\right)T_o(s) \tag{2}$$

where: $X = \dfrac{1.293 c_p.V}{K_l}$, $K = \dfrac{\eta}{K_l}$.

This equation confirms that the outdoor temperature is related to the heat generated from the heating system and the outdoor temperature both.

3   Experiments and results

By numerical substitution we will have:

$$T_i(s) = \left(\frac{0.0208}{3184.239s+1}\right)Q_h(s) + \left(\frac{1}{3184.239s+1}\right)T_o(s) \qquad (3)$$

By simulating this equation on Simulink/Matlab we could simulate indoor and outdoor temperatures **Fig. 1**, and also the amount of heat used in this process **Fig. 2**, where vertical axis represents values of temperature, and horizontal axis represents time offset.

In the created model, the thermostat is set to 20 °C. Changes in outdoor temperature are simulated by a sine wave with amplitude of 3 degrees to a base temperature of 12 degrees.
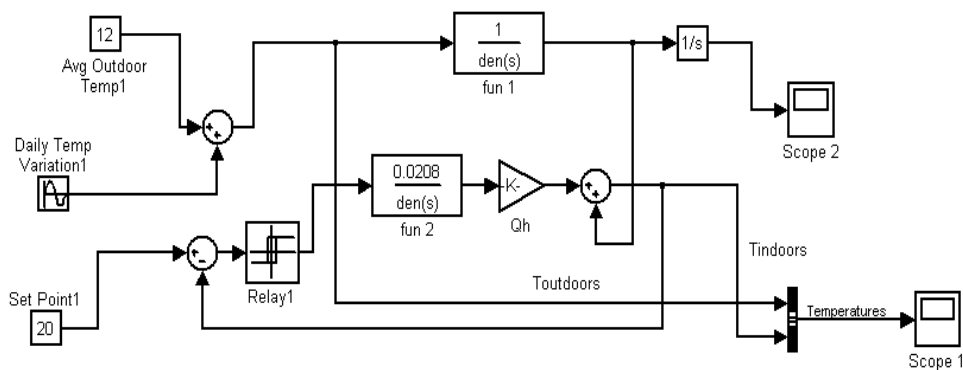
Fig. 1 Thermal model of the room

The temperature outdoor varies in a sinusoidal manner, whereas the indoors temperature is maintained within 3 °C of "Set Point" 20 °C.
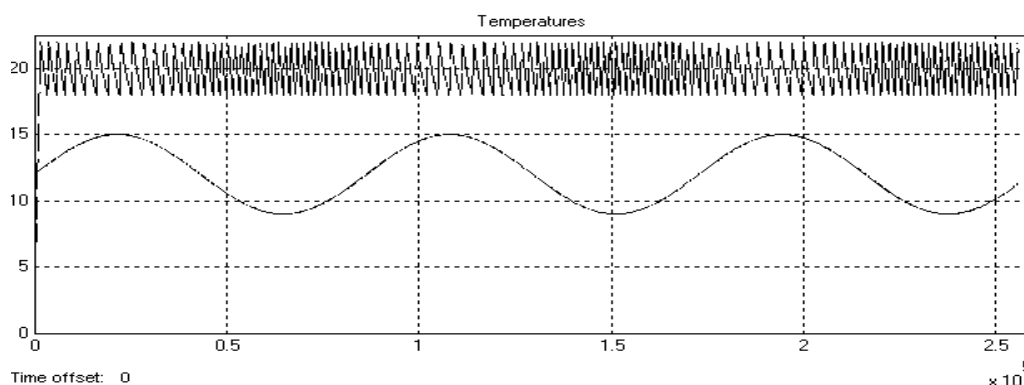
Fig. 2 Indoor (dotted curve) and outdoor (continuous curve) temperatures

We could see how heat consumption has changed over time **Fig. 3**, where model is set so that the simulation runs for three days.
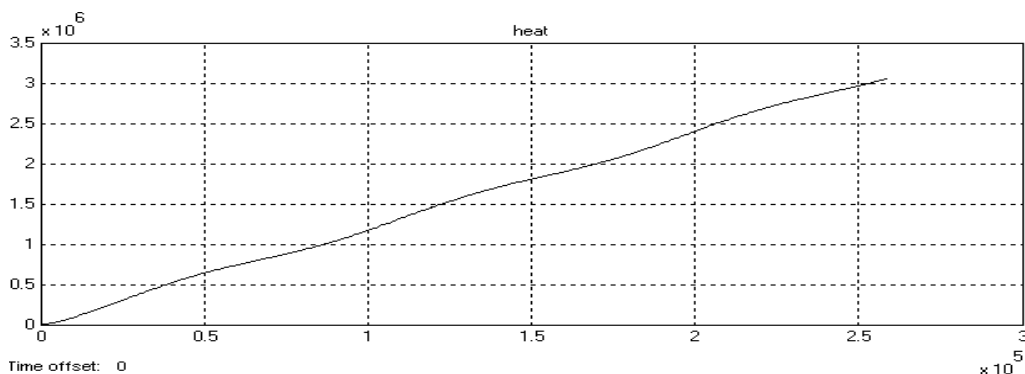
Fig. 3 Heat consumption (vertical axis) changing over time (horizontal axis)

3.1 Optimization of the model

It is possible to optimize indoor temperature by using a PID controller. Function of the process after numerical substitution:

$$G(s) = \frac{41.6}{3184.239s + 1} \tag{4}$$

where: Q_h=2000 [W]. This function is a first order transfer function that has this form [2]:

$$G(s) = \frac{K}{Ts + 1} \tag{5}$$

where: K is the system gain, T is the system time constant.

Skogestad's method is applied here to tune PID controller, where its relations to calculate proportional gain K_P, Integral gain T_i, and derivative gain T_d for this function could be summarized as follows:

Skogestad's method [3]:

$$K_p = \frac{T}{K.T_C} \tag{6}$$

$$T_i = \min[T, k_1 T_C] \tag{7}$$

$$T_d = 0 \tag{8}$$

$$T_C = 1 \tag{9}$$

$$k_1 = 4 \tag{10}$$

where: T_C and k_1 are standard factors.

K=41.6;T=3184.239. By calculation: K_P=76.544,T_i=4

PID controller could be added after rearranging the model so that PID controller leads to the desired control as shown in **Fig. 4**

By run simulation again, we could see how the real indoor temperature is very close to the desired temperature (Thick line) **Fig. 5**
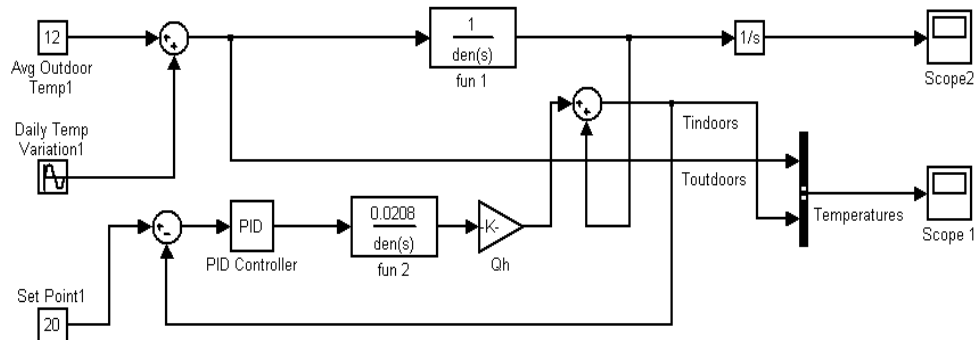
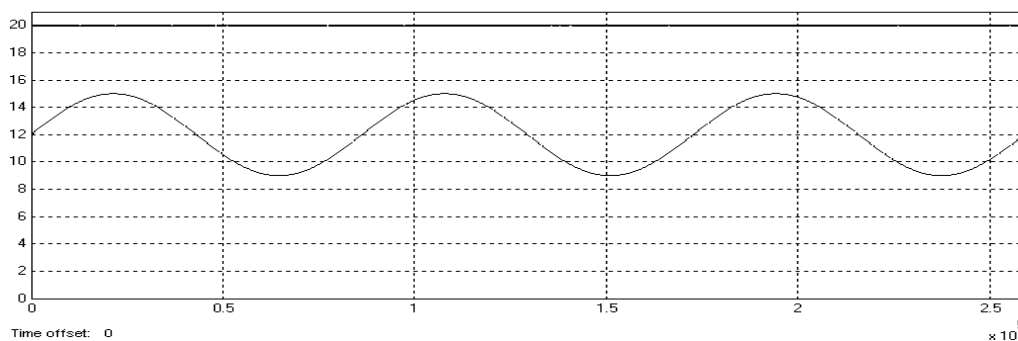**Fig. 4** Optimized model by using PID controller

Fig. 5 Optimized indoor temperature (Thick line)

4   Discussion

It is possible to develop a thermal model for indoor temperature by evaluating the thermal balance equation within a room and simulate it using Simulink/Matlab. The resulted model could be optimized by PID controller tuned using Skogestad's method, where the function of the process of the model is a first order transfer function. By the optimization, indoor temperature will be very close to the "Set Point". This model offers the ability to change input parameters, e.g. the amount of heat generated from heating system, daily temperature variation, average outdoor temperature and thermostat setting, this means the ability to adapt to the data.

5   Conclusion

Developing of a thermal model of indoor temperature using Simulink/Matlab, in addition to simulating of heat consumption during this process. The outdoor temperature changes sinusoidally, whereas the indoors temperature is maintained within 3 °C of "Set Point" 20 °C. This process could be optimized by using PID controller tuned depending on Skogestad's method, this optimization makes indoor temperature very close to the "Set Point" which means optimal comfort for the occupants.

References

[1]   YAO, Jian and Jin XU. Indoor Thermal Environment Simulation by using MATLAB and Simulink. *Applied Mechanics and Materials*. 2010, vol. 29-32, pp. 2785-2788. DOI: 10.4028/www.scientific.net/AMM.29-32.2785.

[2]   MADHURANTHAKAM, C.R, A ELKAMEL and H BUDMAN. Optimal tuning of PID controllers for FOPTD, SOPTD and SOPTD with lead processes. *Chemical Engineering and Processing*. 2008, vol. 47, pp. 251–264.

[3]   HAUGEN. *PID Control*. Norway: Tapir Academic Press, 2004. ISBN-10: 8251919452.