STEADY STATE THERMAL DYNAMIC ANALYSIS OF A TYPICAL RESIDENTIAL HOUSE IN GENOA USING STATE-SPACE MODEL

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ABSTRACT

In this research a typical room in Genoa has been simulated using the code Matlab Simulink. The first aim of this article was to found a new way to modeling a room with exact wall layers and controlling of thermal behavior. The multi-layer model helps to get the most accurate answers. To emulate the room in Genoa the better wall parameters and the measured environmental temperature were be found. To improve manage of energy consumption in residential houses, it's very important to recognize exact heat demand in buildings that they built in different decades so this model has been used a house on 70's decade. Finally, the temperature variations in different layers of the walls and the overall energy consumption has been calculated for the period of one week.

Keywords: Matlab, Simulink, Dynamic Analysis, State-Space

INTRODUCTION

About 40 percent of production energy has been used in residential houses, as well as about 40 percent of that energy is used for space heating. So the energy efficiency of residential houses is considered main priority in every country. The heat demand in a residential room dependent to some factors such as the number of inhabitants, outside temperature, number of wall layers, thickness and insulation. Considering to changes of above mentioned factors during the day and days of year, the thermal analysis of building requires a dynamic and unsteady model.

Several studies have been conducted in the field of heat transfer modeling in building and prediction of inside temperature at various times. The results of this study was provided methods for modeling and determination of the main changes in temperature equations. (Athientis et al,1990)

In recent years, due to the importance of energy saving and the high cost and time required for experiment works, the numerical methods usage has increased. Some factors such as the multi-layered walls, define the boundary conditions, difficult to determine the material properties, making that mathematical models and computer software has been developed on models to simulate the thermal behavior of buildings all over the world. The Matlab code, and in particular the Simulink tool, is evaluable software with ability of simulate energy systems and their controls. (Hittle,1977), (LBL, 1982), (BLAST,1986)

Achterbosch and Jong (1985) present a method to set up a thermal building model combining relative simplicity with high dynamic accuracy. The models were verified in two Dutch semi-detached dwellings characterized by extreme values of thermal capacity.(Achterbosch ad Jong,1985)

Athienitis and Dion (1990-1991) showed some models for thermal building simulation and HVAC advance control categories. (Athienitis et al, 1985)

Lever more (1992) develops optimizer of heating system that the equation solver were the first order description. The model has been done with variety of initial temperature. The various structure origin has been assumed to working to their relative steady-state temperature. The internal structure is assumed to be at the same consideration as the internal air and other internal resistance is removed to heat flow. (Levermore,1992)

Hudson and Underwood (1999) describe a mathematic model of simple building by using Simulink. In this research, the building is made using the electric similitude model, modeling the thermal problem via a RC circuit. They used the high mass building with one layer of walls.(Hudson et al,1999)

Mendes and Oliveria (2001) drives the energy balancing equations in the transient condition. The equations have been solved by CFD method and Simulink, also they have valuated theirs works with a controllable weather conditions test room. Comparison between the data of theory and test are illustrated that CFD model works well.(Mendes et al,2001)

Ramos and Delgado (2005) worked on the moisture buffer capacity of building materials in transient conditions was tested in small scale laboratory tests. Alongside, a numerical simulation tool for hygrothermal performance analyses of buildings and building materials and both results were compared. (Ramos and Delgado, 2005)

The present work describes the mathematic model for prediction the building thermal behavior. In the model proposed, the indoor air is assumed as an area and the walls of buildings are considered with exact-layer in Genoa 1980. Equations

Energy balances are implemented for all the main surfaces separately, as for roof, floor and external walls. A balance is implemented for internal walls and interior which in terms of thermal inertia of the building are important. Also written other equation for the source of energy. The mentioned equations as a system differential equations with time derivatives sorted and eventually they are written in the form of a state space matrix equation. To solve the resulting matrix, a computer model is derived in Matlab Simulink software.

The model is produced in a manner that the calculation gives the fastest and most accurate answer. According to the continuous changes of the outside temperature, this model has ability to calculate the temperature of different wall layers and the amount of changes inside temperature.

Room mathematical Model

The thermal dynamic model is considered for an old house that was built in Genoa in the '80. A general room exchange heat by its surfaces, as walls, floor, roof and windows. Also there are production and saver of energy in building same as heater, internal walls and furniture. In this paper the model has been made with different wall's layer and material also the internal energy in house is supposed monotone distribution.

According to the above descriptions, the general balancing energy equations for wall, roof and floor layers are:

$$\rho_i c_i v_i \frac{dT_i}{dt} = U_{i,i+1}(T_{i+1} - T_i) - U_{i-1}(T_i - T_{i-1}) \tag{1}$$

Where, ρ_i, c_i, v_i and T_i are respectively the air density, specific heat, volume and layer temperature of wall *i*. Also the thermal transmittance can be approximated by:

$$U_{i,i+1} = \frac{1}{\frac{L_i}{2\lambda_i A_i} + \frac{L_{i+1}}{2\lambda_{i+1} A_{i+1}}}, U_{i-1,i} = \frac{1}{\frac{L_{i-1}}{2\lambda_{i-1} A_{i-1}} + \frac{L_i}{2\lambda_i A_i}} \tag{2}$$

Where *L* explain the thickness of wall's layer and *A* describe the surface of wall's layer. The below equation is made for thermal source with constant temperature.

$$\rho_h c_h v_h \frac{dT_h}{dt} = Q + U_h(T_i - T_h) \tag{3}$$

Where *Q* is constant generation heat flux of the internal equipment, ρ_h heater density, c_h heater specific heat, v_h heater volume and heater transmittance is defined by:

$$U_h = A_h h_h \tag{4}$$

Finally for inlet air in the house the balancing of energy equation is derived by:

$$\rho_a c_a v_a \frac{dT_{inlet}}{dt} = U_{extw}(T_{5extw} - T_i) + U_{intw}(T_{3intw} - T_i) + U_{ir}(T_{6r} - T_i) + U_{if}(T_{6f} - T_i) + U_p(T_p - T_i) + U_h(T_h - T_i) + U_{glass}(T_o - T_i) + U_v(T_o - T_i) + Q_g = \sum_i Q_i + Q_{gen} \quad (5)$$

Where $\sum_i Q_i$ is the rate of heat transfer for walls, roof, floor, ventilation, windows and paraphernalia. Also Q_{gen} is the rate of thermal production due to the building's Indoor equipment. The set of differential equations with derivatives time are obtained which shows the exchange of heat and mass between the different components of the building. By solving these equations the changes of temperature is investigated in different components of the building. According to all above equations, there are 23 energy balance equations for the building (5 for external wall, 3 for internal wall, 6 for roof, 6 for floor, 1 for heater, 1 for internal air and 1 for internal equipment).

The obtained equations can be written in the State-Space as follows:

$$\dot{T}(t) = AT(t) + Bu(t)$$

$$y(t) = CT(t) \quad (6)$$

Where, $\dot{T}(t)$ is calculated for finding the inlet air temperature and $T(t)$ is the temperature of each layer. Also, $u(t)$ is a matrix related to the model inputs such as the boundary temperature condition on the wall surfaces and the internal heat gains due to people activities, lighting and other equipment. The $y(t)$ corresponds to the model outputs ad the room and layers temperatures. The matrix elements of A, B are explained the effects of physical properties and geometric characteristics of the system components on the temperature of different parts of the building.

The state space equations can be solved by using the state-space block in the Simulink library. The Fig.1 is shown the model implementation solver block diagram.

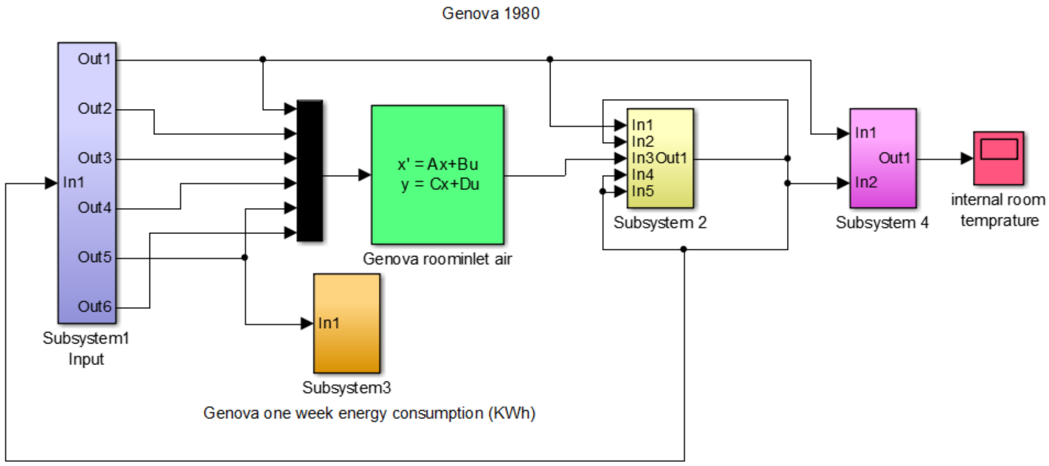

Figure 1. The block diagram for a building with heating control system by using Simulink

Model implementation for typical house

Instance model was prepared from a typical residential building in sea level at Genoa. The consider house is located in the middle of a three floors apartment. On the other hand, the house has two common walls with other neighbors and two walls are associated with the outside air. The Intended building plan is shown in Fig.2.

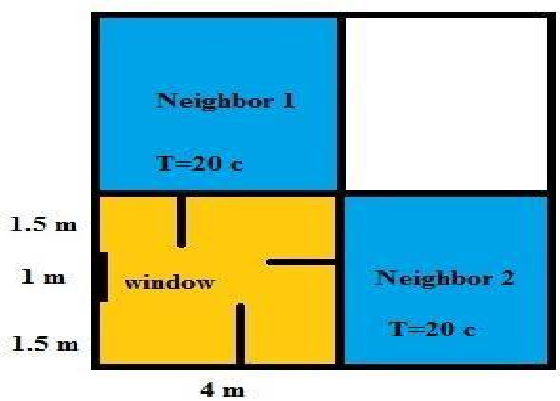

Figure 2. Building plan

The graph in figure 3 illustrates the inlet air temperature behavior of building in different days using a prepared computer model in Genoa for one week. To obtain accurate results and reducing initial errors at the steady state, the model running for 10 days and the first three days have been removed. Overall, the internal temperature variation keep between 19 to 21 degree, whereas the amount of out temperature have fluctuated. The highest temperature was happened during the third and fourth days, as well as the building saving much inertia therefore fluctuations have declined significantly over that period.

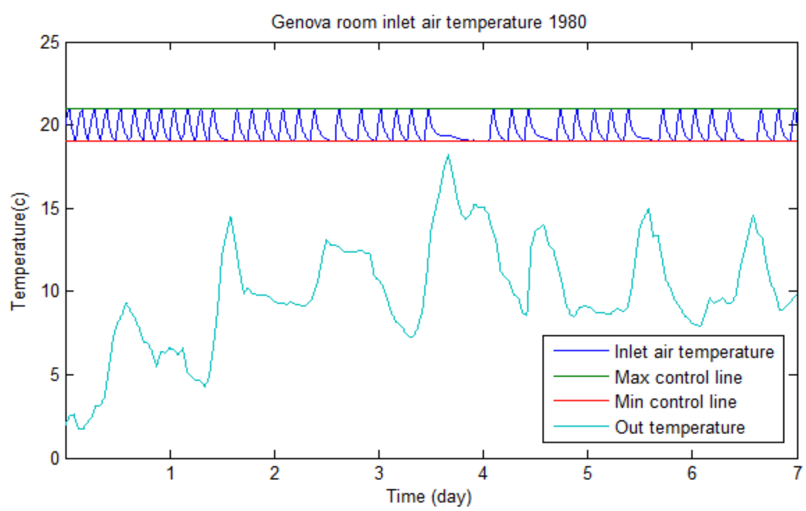

Figure 3. Inlet Air Temperature (c)

Layers thermal analysis of the wall is one of the most important calculated in construction management. The developed model was analyzed and evaluated all walls carefully.

In the room model for a Genoa ’80 building, there was six layer in the external walls. Figure 4 shown the variation of temperature in external wall layers during that model has been running. As the figure 4, the thermal variation of external layer is closed to the out temperature and fluctuate effective of this layer is higher than next layer. In fact each layer is decreased the rate of fluctuation.

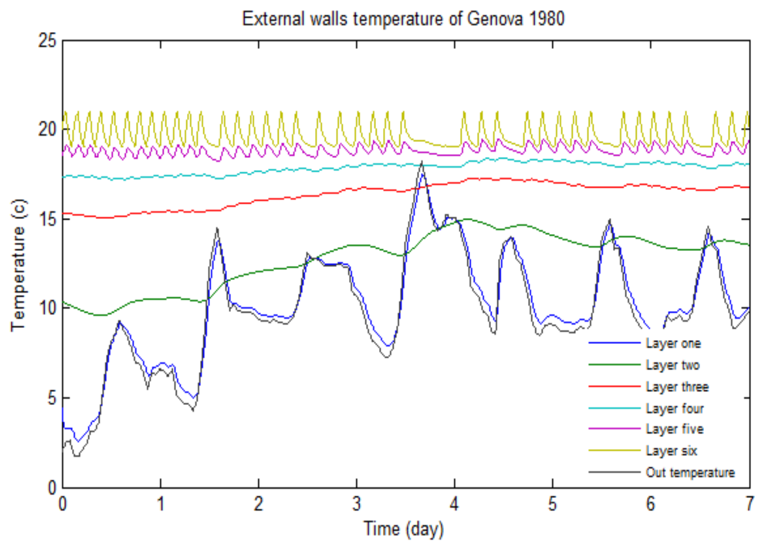

Figure 4. External walls temperature

The state-space model has been calculated the energy consumption for our model in Genoa. As would be expected, the energy consumption increased gradually until it reached to the fourth day. It the level off from middle of third to fourth day. The biggest rise was seen in primary days, increasing sharply throughout the first one and half day.

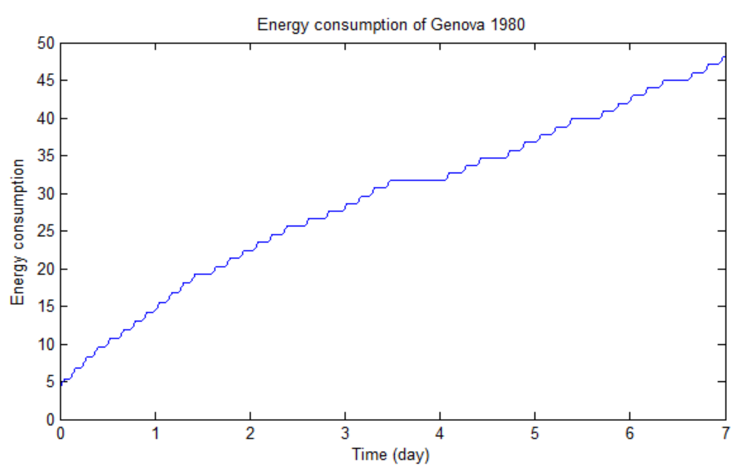

Figure 5.Energy Consumption (kwh)

CONCLUSION

The aim of this research was developed a steady state dynamic model for old residential house in Genoa. The model has been implemented as a state space block using Matlab Simulink. The model was used the variable out temperature and calculated the big matrix equations to find the air inside temperature and temperature between layers of the walls during the day. Insomuch the management of energy is very important for future residential building, so the model has been calculated the energy consumption of building. The highest energy is absorbed to the building during the first two days. In further works, the model will be extended in three types of house during tree different decade, also each house will have different layer of walls.

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