Energy saving in air conditioning of buildings

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Abstract. The external heat load of residential buildings in summer is the dominant parameter of the required cooling load and refrigeration capacity of air conditioning systems. The consumed energy of air conditioning system is proportional to the outside conditions and intensity of solar radiation. The maximum heat load of building may occur at 3 O'clock PM, although the peak of solar radiation occurs at noon. The construction materials of building is playing an important rolls of heat transmission through buildings outside walls and glazing windows. The walls thermal insulation can be effective in energy conservation by reducing the cooling load and required electrical energy. The building is constructed from common materials with 0~12 cm thermal insulation in outside walls, ceilings, and double layers glazing windows. The building heat loads are calculated for two models of walls. The optimum thickness of thermal insulation is also determined and is found between 6~8 cm for insulation of thermal conductivity of 0.039 *W/m.K* the energy saving is 50.45% at 6 cm insulation thickness.

1 Introduction

The buildings heat load is proportional to the heat transmission through outside walls, ceiling, floor, and glasses windows. The heat transmission is positive in summer and negative in winter to the internal heat load. The thermal insulation is an effective tool to achieve the minimum heat transmission in buildings. The heat transmission is expressed in U-values or R-values which related to the thickness of thermal insulation. On the other hand, increasing the thickness of thermal insulation will increase the investment cost. Thus, it is inevitable to determine an optimum insulation thickness by considering economic analysis.

Recently, many authors have studied the minimum thermal insulation thickness [1-10]. Most of studies estimated the transmission load through the exterior walls into room by using the degree-time concept (degree-day/degree hour) which is one of the simplest methods that applied in static conditions [1-4]. A few studies estimated the transmission load through the exterior wall into room by using numerical method [5-6], which neglects the effect of moisture transfer on heat transmission. Furthermore, the optimum insulation thickness of the external wall for different energy sources and different insulation materials was found [11-13]. Moreover, the energy sources and energy savings were used to obtain the optimum insulation thickness [14-16]. The results showed that the increase of insulation thickness has a significant effect on the building heat load. The analysis indicates that the building energy savings are different for a given wall insulation and building conditions. A numerical solution of transient heat transfer through a multilayer walls submitted to the average outdoor temperature and solar radiation specific has been presented [17]. The inside surface heat flux of two common uninsulated walls was predicted. The results presented for the representative day of the hottest month of the considered climate showed that the significant effect of walls orientation and solar shading on the thermal performance of the two walls.

The objective of the present study is to determine the optimum thermal insulation thickness of building walls. The analysis is conducted using one type of insulation material with various thickness and two type walls of building with and without insulation. The hourly buildings heat load with cooling load temperature deference, CLTD method are estimated at various thermal insulation thickness. The optimum insulation thickness and percentage decrease of the building heat loads are also investigated.

2 Building models

The building heat load is calculated according to the buildings specification and construction materials. Fig. 1 shows the layout of a residential buildings we used as shown in [18-19]. The building is constructed from a common construction materials and single layer glass

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windows with wooden doors. Two walls Models, A and B are used as Fig. 2.

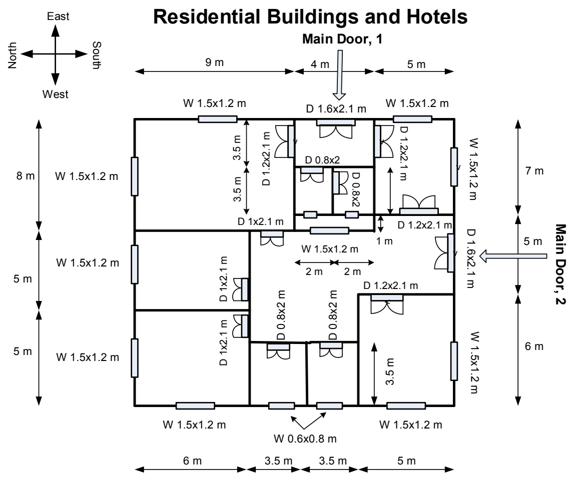

Fig. 1 Layout of residential buildings

The building is constructed from common materials; hollow bricks, heavy concrete, single layer clear glazing windows, and wooden doors as illustrated in Fig. 2. The walls Model B is typical as Model A of construction materials in addition of 0~12cm thermal insulation of 0.039 W/m.K in outside walls, floor, and ceiling. The glazed windows are double layers clear glass with air gab of 1~3 cm [19].

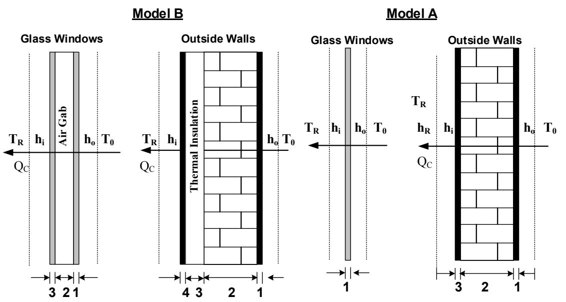

Fig. 2 Walls Models A and B with common construction materials and thermal insulation

The building heat load is the amount of heat removed or added to the conditioned space to maintain the thermal comfort. The building heat load is divided in two parts, the first is the sensible heat load which is a function of temperature difference between outside and inside condition, and radiation heat through glazing windows. The second is the latent heat load which is a function of humidity ratio difference between outside and inside condition, and moisture content of conditioned space. The building heat load in summer is the summation of external and internal heat loads. But, the building heat load in winter is the difference between the external and internal heat loads. The building heat load in summer is calculated using appropriate cooling load temperature difference, CLTD method [20]. A computer program is prepared and examined under the constraints of the building location of four directions, and latitude and longitude. The data needed according to CLTD method for outside environment and building specification are inserted as subroutine to get the final results of hourly building heat load.

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3 Walls heat transmission model

The outside walls are subjected to variations of temperature $T_o(t)$ and solar radiation $I(t)$. The inside faces of walls comes in contact with the indoor air which maintained at a fixed temperature of T_i to have a better thermal comfort. The one dimensional transient heat conduction equation for this problem is as follows:

$$\frac{\partial T(x,t)}{\partial t} = \frac{k}{\rho c}\frac{\partial^2 T(x,t)}{\partial x^2} \tag{1}$$

The outdoor boundary condition is,

$$-k\frac{\partial T(x,t)}{\partial x}\bigg|_{x=0} = h_o\big(T_o(t) - T_{x=0}(t)\big) \tag{2}$$

The indoor boundary condition is,

$$-k\frac{\partial T(x,t)}{\partial x}\bigg|_{x=L} = h_i\big(T_{x=L}(t) - T_i\big) \tag{3}$$

Where, h_o, h_i are the film heat transfer coefficient of outside and inside walls of building, and their values are $h_o = 22\,W/m^2.K$ and $h_i = 9\,W/m^2.K$. The instantaneous transmission heat transfer rate through walls from outside to inside is defined as,

$$Q_{trans}(t) = AU\big(T_o(t) - T_i\big) \tag{4}$$

Where, $T_o(t)$ is the instantaneous outside temperature, and T_i is the indoor temperature. In steady state condition, the temperature deference $\big(T_o(t) - T_i\big)$ is replace by ΔT as mention in [20] according to cooling load temperature deference, CLTD method and is defined as,

$$\Delta T = (CLTD + LM).K + (25.5 - T_i) + (T_o - 29.4) \quad (5)$$

Where, T_o is hourly outside temperature, A walls area, and U is the overall heat transfer coefficient as,

$$\frac{1}{U} = \frac{1}{h_i} + \sum \frac{\Delta x}{k}\bigg|_{\text{construction material}} + \frac{\Delta x}{k}\bigg|_{\text{thermalinsulation}} + \frac{1}{h_o} \quad (6)$$

To investigate the effect of thermal insulation thickness on the building heat load, we assumed all parameters are constant except insulation thickness, and the inside conditions are maintained at $24\ ^oC$ and $50\ \%$ relative humidity.

4. Building cooling load profile

The hourly outside conditions of dry bulb temperature and relative humidity are used in this analysis as illustrated in [19]. The average data of dry bulb temperature, and relative humidity for each season are illustrated in Figs. 3 and 4. The dry bulb temperature is increased hourly from sunrise to maximum value at 15:00 O'clock and decreased to initial value at night as shown in Fig. 3. Opposite trend of dry bulb temperature, the relative humidity decreased from sunrise to minimum value at 15:00 O'clock and increased to maximum value at night as shown in Fig. 4.

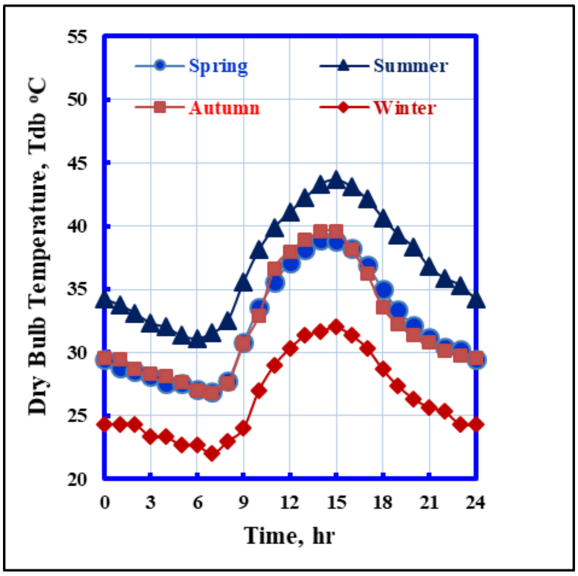

Fig. 3 Average of dry bulb temperature [19]

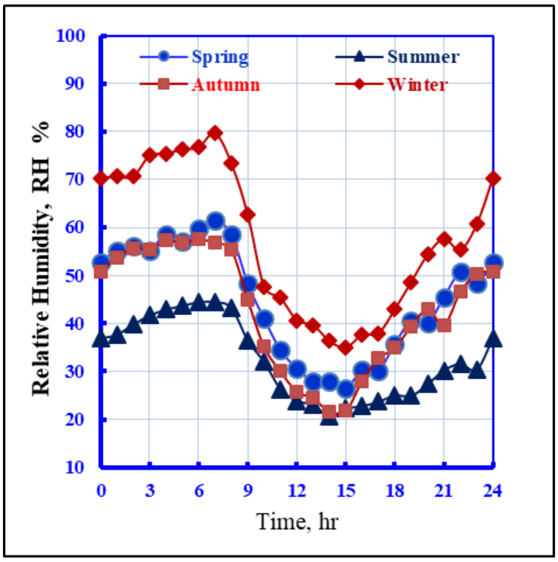

Fig. 4 Average of relative humidity [19]

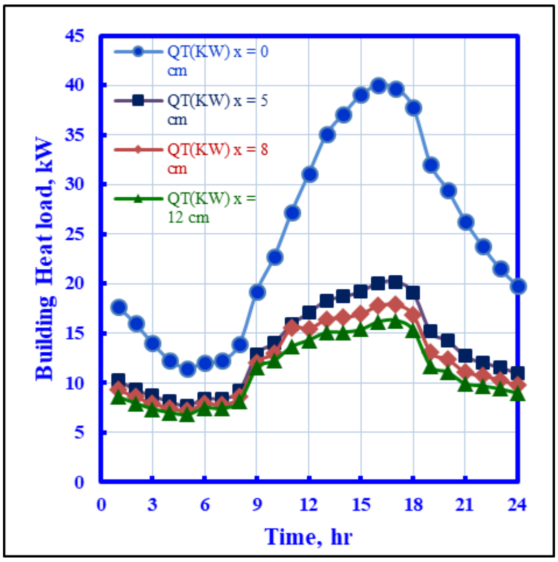

Fig. 5 Building heat load at various thermal insulation thickness

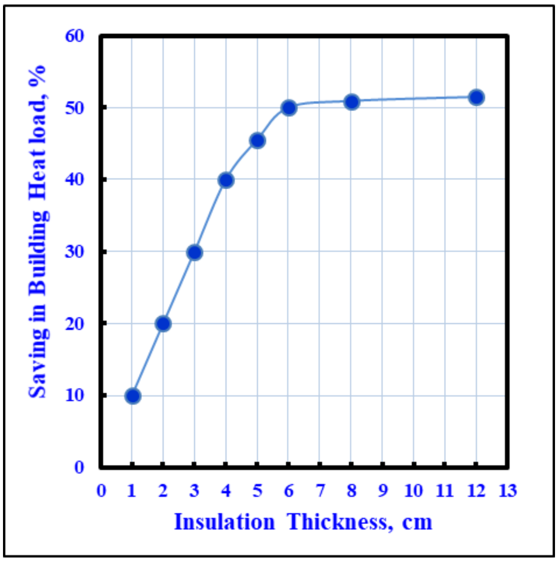

Fig. 6 saving energy in building heat load

5 Optimum thermal insulation thickness

The total building heat load consists of external heat load and internal heat load. The external heat load contains the heat transmission and direct solar radiation across the building envelope from outdoor to indoor conditions. The total building heat load with constant internal heat load are calculated at various thermal insulation thickness of 0 ~ 12 cm and the results are shown in Fig. 5. We can see a clear effect of thermal insulation thickness on the building heat load similar to the trend of outside dry bulb temperature in Fig. 3. The heat transmission through building walls decreased with increasing of insulation thickness.

The percentage saving in building heat load is the difference between building heat load without insulation and with insulation to the value without insulation as,

$$\left[\text{Saving energy} = \frac{Q_t\,(\text{without insulation}) - Q_t\,(\text{with insulation})}{Q_t\,(\text{without insulation})}\right] \quad (7)$$

Figure 6 shows the trend of energy saving in the residential buildings as a function of thermal insulation thickness. The energy saving increases with increasing of insulation thickness until 6 cm. Small increase in energy saving until 8 cm is found. So, the optimum thickness of thermal insulation is found between 6 ~ 8 cm and the energy saving my 50.46 %. Also, similar results are illustrated in [15-16] and the optimum thickness of extruded polystyrene (XPS) is between 0.053 and 0.069m and the optimum thickness of expanded polystyrene (EPS) is between 0.081 and 0.105m.

6 Conclusions

The external heat load of residential buildings in summer is the dominant parameter of the required cooling load and refrigeration capacity of air conditioning systems. The maximum heat load of buildings may occur at 3 O'clock PM, although the peak of solar radiation occurs at noon. The building is constructed from common materials; hollow bricks, heavy concrete, single layer clear windows, and wooden doors. The walls Model B is typical as Model A of construction materials in addition of 0~12 cm thermal insulation of 0.039 *W/m.K* in outside walls, floor, and ceiling. The glazing windows are double layers of clear glass with air gab of 1~3 cm. The optimum thickness of thermal insulation is also determined and is found between 6~8 cm for insulation of thermal conductivity of 0.039 *W/m.K*, and the energy saving is 50.46 % compared to the building heat load without thermal insulation.

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