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Energy Analysis of A Building Based on Outdoor Air Temperature and Insulation Thickness

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ABSTRACT

The thermal performance of buildings is of great importance to the world because we have limited sources of fossil fuels. Thermal performance should be investigated with respect to parameters such as outdoor air temperature, insulation thickness, building materials, types of combustor and fuel. In this study, the effects of the outdoor air temperature and insulation thickness on the total radiator length, the annual fuel consumption and CO_2 emission were investigated for a three floor building, fueled by natural gas, located in Corum, Turkey. In order to do that, a computer code was developed by using of EES (Engineering Equation Solver) which is commonly used in the analysis of thermal systems.

The outside air temperature and the insulation thickness were varied from -15 to 4°C and 2 to 18 cm, respectively. It was observed that the total length of the radiator and the annual fuel consumption and CO_2 emission decreased with the increase of outdoor air temperature and insulation thickness. As the outside air temperature was varied, the total radiator length, the annual fuel consumption and CO_2 emission decreased by 33%, 30% and 30%, respectively. Increasing the amount of the insulation thickness resulted in an approximate decrease of 49% in the total radiator length, the annual fuel consumption and CO_2 emission.

Key Words: Heating; Outdoor Air Temperature; Insulation Thickness; CO_2 Emission.

NOMENCLATURE

a	Air leakage coefficient, m^3/mh
A	Heat transfer area, m^2
B_y	Fuel consumption per year, $m^3/year$
FSEG	CO_2 emission conversion factor based on the type of fuel, kg equivalent of CO_2/kWh
H	Building coefficient, Wh $/m^3K$
H_u	Lower heating value of fuel, kj/m^3
L	Length of opening side of window or door, m
R	Room coefficient
$SEGM_y$	Annual amount of CO_2 emission, kg equivalent of CO_2
Q_T	Total heat loss, W
Q_{inc}	Increased heat loss from building elements, W
Q_{inf}	Infiltration heat loss, W
Q_0	Heat loss from building elements, W
T	Temperature, °C
U	Heat transfer coefficient, W/m^2 K
Z_d	Working hours per day, h/day
Z_e	Infiltration coefficient
Z_y	Working days per year, day/year
Z_D	Combined incremental coefficient
Z_H	Floor incremental coefficient
Z_W	Direction incremental coefficient

Greek Symbols

η	efficiency

Subscripts

b	boiler	f	floor
d	door	o	outer
r	roof	w	window

INTRODUCTION

The consumption of underground resources, by means of the industrial revolution, rapid urbanization and population growth, have detrimental effect on the environment as the greenhouse gases. As a result, theoretical and experimental studies related to the energy saving and the usage of alternative energy sources such as solar, wind, geothermal, etc. have started to spread from Europe to the rest of the world.

Noteworthy amount of CO_2 emission is caused by the residential and commercial heating systems. Therefore, energy saving of buildings is currently one of the important issues. The studies related to the energy performance of the buildings in the literature are generally based on the design variables such as building shape, insulation level and materials, construction materials, height of floor, windows type, area, CO_2 emission, type of heating systems, type of fuel and application of renewable energy sources to the building[1].

Most of the studies in the literature are based on determining the optimum insulation thickness and the type of insulation. Natural gas and polystyrene were used as a fuel and insulation material, respectively, the thicknesses of insulation materials for outer walls were observed by means of "degree-day method". It was found that insulation thicknesses of the outer walls of the building in Turkey range from 2.8 to 9.6 cm [2]. In order to increase the thermal performance of the buildings, the insulation material must be mounted in the shape of a bundle. Detailed thermal energy and economic analyses are required for selecting an optimum thickness of insulation material. The optimum insulation thicknesses were calculated for three different walls in Athens by using hourly weather data and it was found that the optimum insulation thickness ranges from 7.1 to 10.1 cm for these walls [3]. It was pointed out that the window-to-floor area ratio, type and thickness of insulation material are very important from an energy point of view. A computer code was developed based on TS (Turkish standard) 825. By means of this code, the graphics for "fourth climatic zone of Turkey" were formed for selecting optimum insulation thickness with respect to the window-to-floor area ratio, type and thickness of the material. It was shown that the insulation thickness increases as the window-to-floor area ratio increases [4]. The effect of insulation thickness on CO_2 emission was investigated by using styropor as an insulation material and fuel oil as fuel. In a study based on degree-day method was carried out in Erzurum, that is one of the coldest cities of Turkey, it was found that CO_2 emission was reduced 27% by optimizing the insulation thickness. In a similar study in which expanded polystyrene and coal were used as an insulation material and fuel, the effect of optimum insulation thickness on the energy consumption and emissions of CO_2 and SO_2 was observed in Denizli, Turkey. It resulted that energy consumption and emissions of CO_2 and SO_2 were reduced 46.6% and 41.53%, respectively [5]. There are several studies in order to observe the insulation thickness and fuel type on energy saving and payback period [6-8]. A theoretical study aiming to investigate the insulation thickness and fuel type on the heating and cooling loads of outer walls, payback period and energy saving was carried out for four cities of Turkey, namely Mersin, Elazığ, Şanlıurfa, and Bitlis and for various types of fuel such as coal, natural gas, fuel-oil, liquefied petroleum gasoline and electricity. It was observed that the energy saving varied from 4.2\$/m^2 to 9.5\$/m^2 for optimum insulation thickness [6].

A few studies in the literature are related to the effect of outdoor air temperature on the building energy performance. A control algorithm was developed by Byun et al. for minimizing the heat transfer loss in building hot water distribution pipes as a function of outdoor air temperature and the variation of heat transfer was determined with respect to the outdoor air temperature, and the heat loss in the distribution lines was reduced by 11.5% [9]. Computer simulations were carried out in order to predict the heat and moisture transfer in the buildings with the experimentally measured values. Temperature and moisture content of the indoor air depending on the outdoor air temperature, relative humidity, wind speed and solar radiation were determined [10]. The effect of outdoor air conditions such as temperature and velocity on the building energy performance and fuel economy was investigated by means of various automatic control systems [11]. The capacity of an outdoor air controlled boiler of a central heating system was observed and it was resulted that the indoor air temperature increased beyond the comfort conditions as the boiler was controlled with respect to the outdoor air temperature. Later, the outer wall was insulated and the heating system was equipped with "on-off control system" and as a results of these changes, the fuel requirement of the system decreased [12].

In this study, for a three floor apartment, having nine dwellings, located in Corum, Turkey and using natural gas as a fuel, the effects of the outdoor air temperature and insulation thickness on the total radiator length, the annual fuel consumption and CO_2 emission were investigated by a computer code developed by means of EES [13] that is commonly used in the analysis of thermal systems.

MATERIAL AND METHOD

There are several steps to carry out this theoretical study. The first step is to calculate the heat transfer with respect to the selected building elements and construction materials details of which are given in M.Sc. thesis [14]. The second step is to investigate the effects of outdoor air temperature and insulation thickness on the total radiator length, fuel consumption, CO_2 emission and annual heat requirement, and thereby contributing the energy saving in the buildings and investigating to decrease CO_2 emission caused by heating in the buildings. In order to perform the methodology in this work, a detailed computer code, consisting of all of the information about the thermal conductivities of building materials, solar data, fuel properties, physical properties of the building, etc., was developed by means of EES. EES has a library including thermo-physical properties of fluids and it has a capability of solving simultaneous equations, and forming graphics.

In this theoretical study, a three floor apartment, having nine dwellings and a base area of 264 m^2, located in Corum-Turkey, was selected. Natural gas is used as a fuel in the boiler. The following chapters will consist of the subsections of this work.

Heat Transfer Calculations

Heat loss calculations are performed with respect to Turkish Standards (TS) 2164. Total heat loss, Q_T, can be expressed by the following equation,

$$Q_T = Q_{inc} + Q_{inf} \qquad (1)$$

Where;
Q_{inc} : Increased heat loss from building elements
Q_{inf} : Infiltration heat loss
Increased heat loss can be written as

$$Q_{inc} = Q_0(1+\%Z_D+\%Z_W+\%Z_H) \qquad (2)$$

By using the following equation, nonincremental heat loss can be calculated

$$Q_0 = \Sigma AU\Delta T \qquad (3)$$

$$\Sigma AU = U_oA_o + U_wA_w + U_dA_d + 0.8U_rA_r + 0.5U_fA_f \qquad (4)$$

Infiltration heat loss, caused by the leakages in doors and windows, can be expressed as [15],

$$Q_{inf} = \Sigma\, aL\, R\, H\, \Delta T\, Z_e \qquad (5)$$

Total Radiator Length

Total radiator length is determined with respect to the panel radiators. The manufacturer catalogs give the heating capacity of a radiator per unit length for different room temperatures.

As the total incremental heat loss is divided by the heating capacity of a radiator per unit length, the total radiator length is obtained. In this study, the tables used for determining the total radiator length are taken from the M.Sc. thesis [14].

Fuel consumption

Fuel consumption per year, B_y, can be calculated by the following equation [15].

$$By = 3600\,(Q_T Z_d Z_y)/(2H_u \eta_b) \qquad (6)$$

CO_2 Emission

Natural gas is used as a fuel in this study. The boiler efficiency and lower heating value of the natural gas are 0.9 and 34485 kj/kg, respectively. Flue gas emissions from a heating system consist of 85% CO_2, 15% other gases, namely, SO_2, CO, particulate matter (PM10 and PM2.5) and NO_x. But, CO_2 emission is only taken into consideration in the calculations. CO_2 emission can be expressed with respect to the type of fuel, lower heating value of fuel and fuel consumption [16],

$$SEGM_y = 0{,}001163x\, B_y\, x\, H_u\, x\, FSEG \qquad (7)$$

RESULTS AND DISCUSSIONS

Figure 1 shows the variation of total radiator length as a function of outdoor air temperature for insulated and uninsulated walls. As the outdoor air temperature increases, total radiator length decreases for both insulated and uninsulated walls. At the outdoor temperatures between -15°C and +4°C, total radiator length changes from 43.1 to 69 m for uninsulated wall and 32.4 to 46.2 m for insulated wall. The decrease in total radiator length is 60% for uninsulated wall and 48% for insulated wall. At the lower outdoor temperatures, the total radiator length is much more dominant as shown in Figure 1.

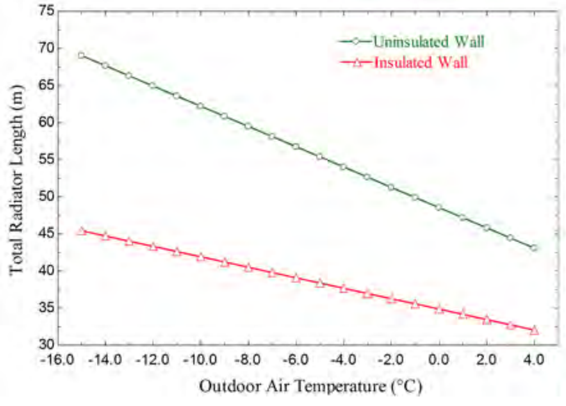

Figure 1. Total radiator length versus outdoor air temperature for insulated and uninsulated walls.

B. Tunay and A. Kilicarslan / Hittite J Sci Eng, 2015, 2 (2) 145–150

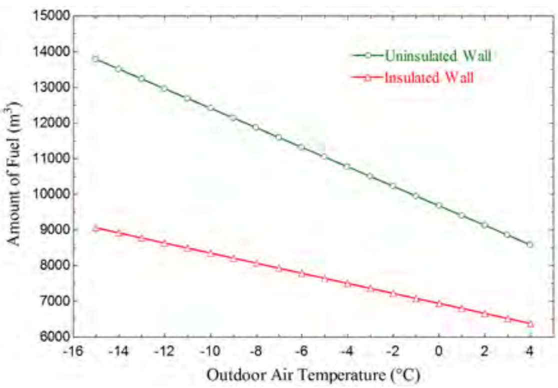

Figure 2. Fuel consumption versus outdoor air temperature for insulated and uninsulated walls.

Figure 2 shows the variation of fuel consumption as a function of outdoor air temperature for insulated and uninsulated walls. Natural gas is used as a fuel and insulation thickness is 6 cm. The effect of outdoor temperature on the fuel consumption is similar to that on the total radiator length. It is clear from Figure 2 that the consumption fuel decreases as the outdoor temperature increases. The fuel consumption changes between 13786 m^3 and 8585 m^3 for uninsulated wall at the outdoor temperatures of -15ºC and +4ºC and the decrease in the fuel consumption is 37% while changing between 9210 m^3 and 6447 m^3 for insulated wall and the decrease in the fuel consumption is 30%. As the outdoor temperature goes down, the saving from the fuel consumption increases more for insulated wall. At an outdoor temperature of -15ºC, the saving is 66% as it is compared to the uninsulated wall.

Figure 3 depicts the change of CO_2 emission as a function of outdoor air temperature for insulated and uninsulated walls in the case of natural gas. As the outdoor air temperature increases, CO_2 emission decreases. This is because the fuel consumption decreases, and thereby decreasing the firing rate as the outdoor temperature increases. CO_2 emission is directly related to the fuel consumption, so Figures 2 and 3 show similar trends. CO_2 emission decreased from 30952 kg equivalent CO_2 to 19274 kg equivalent CO_2 for uninsulated wall at the outdoor air temperatures of -15ºC and +4ºC. In other words, it is decreased by 37%. CO_2 emission decreased from 206782 kg equivalent CO_2 to 14474 kg equivalent CO_2 for insulated wall. In other words, it is decreased by 30% for insulated wall. CO_2 emission is directly related to the fuel consumption.

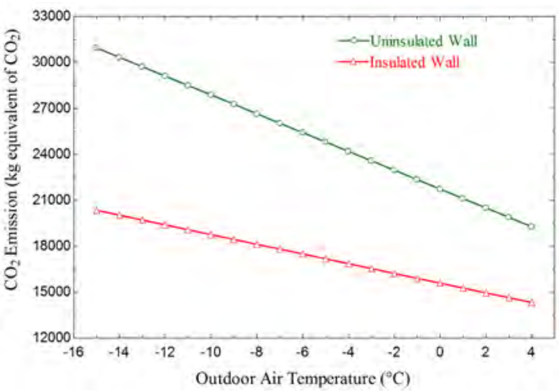

Figure 3. CO_2 emission versus outdoor air temperature for insulated and uninsulated walls

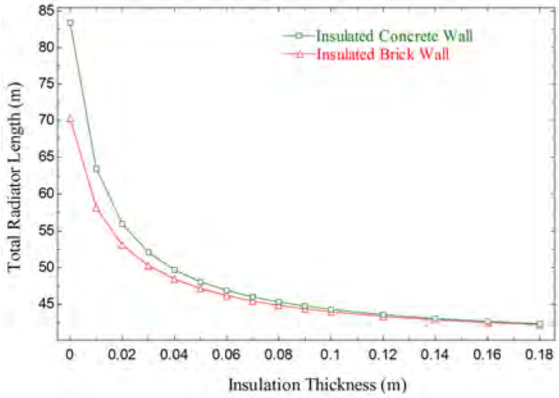

Figure 4. Total radiator length versus insulation thickness for insulated concrete and brick walls.

Figure 4 shows the change of total radiator length as a function of insulation thickness for insulated concrete and brick walls. As it is shown in Figure 4 that, total radiator length decreases for both insulated concrete and brick walls as the insulated thickness increases. Total radiator length changes between 70.4 m and 42.2 m for insulated brick wall at the insulated thicknesses of 0 and 18 cm and the decrease in the total radiator length is 67%. It changes between 83.4 m and 42.5 m for insulated concrete wall and the decrease in the total radiator length is 96%. As the minimum insulation thickness of 6 cm is taken into consideration for the heat transfer requirement of the building in this study, the difference in the total radiator length for insulated concrete and brick walls is only 1.5%. Above the insulated thicknesses of 6 cm, the difference in the total radiator length can be

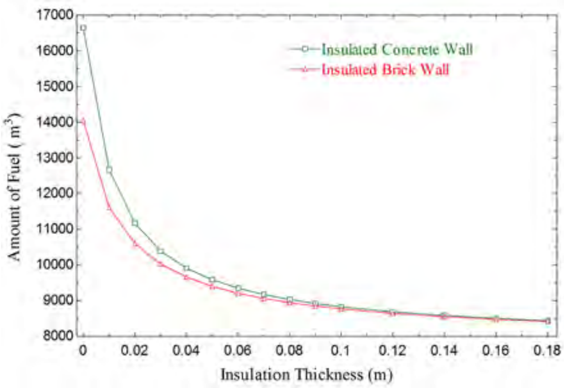

Figure 5. Fuel consumption versus insulation thickness for insulated concrete and brick walls

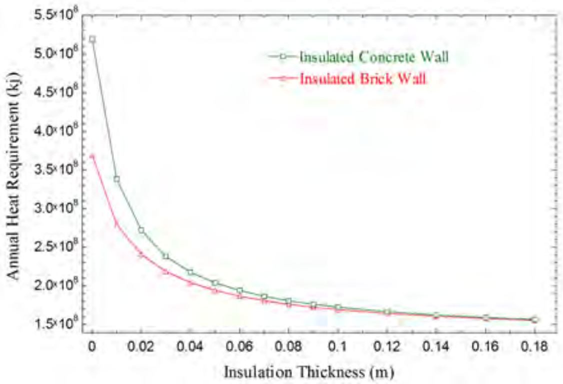

Figure 6. Annual heat requirement versus insulation thickness for insulated concrete and brick walls.

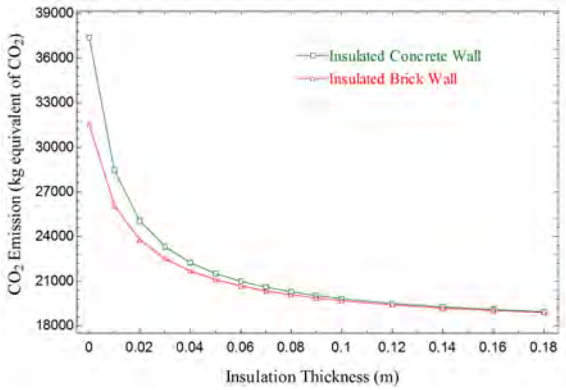

Figure 7. CO_2 emission versus insulated thickness outdoor air temperature for insulated concrete and brick walls.

ignored for both walls. It is also clear from Figure 4 that it is advantages to select brick wall for energy saving below the insulation thicknesses of 6 cm.

Figure 5 depicts the variation of fuel consumption as a function of insulation thickness for insulated concrete and brick walls. Fuel consumption and total radiator length are related to each other. As the total radiator length decreases, fuel consumption also decreases for the increasing values of insulation thicknesses. Therefore, Figure 5 depicts the same trend with Figure 4. Fuel consumption decreases from 14049 m^3 to 8418 m^3 for the insulated brick wall while it decreases from 16650 m^3 to 8440 m^3 for the insulated concrete wall between the insulation thicknesses of 0 and 18 cm. The percent decrease at the insulation thickness for the insulated brick and concrete walls are 67% and 97%, respectively. At the selected insulation thickness of 6 cm, the fuel saving is 140 m^3 if the insulated brick wall is selected for the building material.

Figure 6 shows the variation of annual heat requirement with respect to the insulation thickness for the insulated concrete and brick walls. As the annual heat requirement increases, this causes the fuel consumption to increase, similar results can be concluded as in Figure 5. Annual heat requirement decreases as the insulation thickness increases for both insulated concrete and brick walls. The annual heat transfer requirement decreases from 3,69x10^8 kj to 1,55x10^8 kj, 58% decrease, for the insulated brick wall and it decreases from 5,19x10^8 kj to 1,56x10^8 kj, 70% decrease, for the insulated concrete wall at the insulated thicknesses of 0 and 18 cm. Below the insulation thicknesses of 6 cm, the gap between the insulated brick wall and insulated concrete wall increases as shown in Figure 6. Figure 7 depicts the variation of CO_2 emission with respect to the insulation thickness for the insulated concrete and brick walls. As the insulation thickness increases, the heat transfer rate decreases. This causes the fuel consumption to increase, and thereby decreasing CO_2 emission as shown in Figure 7. CO_2 emission decreases from 31543 kg equivalent CO_2 to 18900 kg equivalent CO_2 for the insulated brick wall at the insulation thicknesses of 0 and 18 cm while decreasing from 37382 kg equivalent CO_2 to 14474 kg equivalent CO_2 for insulated wall. At the insulation thicknesses larger than 6 cm, the difference in CO_2 emission for both types of walls can be neglected, but the difference under the values of 6 cm becomes larger.

CONCLUSIONS

The effects of outdoor air temperature and insulation thickness on the total radiator length, the fuel consumption and CO_2 emission were observed by a computer program. The effect of the insulation thickness on the annual heat requirement was also studied. At the outdoor air temperatures ranging from -15°C to 4°C, it was concluded that the fuel consumption and CO_2 emission were decreased by 30 % in the case of insulated brick wall while they were decreased by 37% in the case of uninsulated brick wall. It was also observed that 50% of fuel was saved as the insulated brick wall was used instead of uninsulated brick wall at the outdoor air temperature of -15°C. It was observed that the decrease in the total radiator length, fuel consumption and CO_2 emission is 96% for the insulated brick wall at the insulated thicknesses between 0 and 18 cm while it was 67% for the insulated concrete wall. For the insulation thickness of 6 cm, the annual heat requirement was decreased by 4% for the insulated brick wall as it is compared to the insulated concrete wall.

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