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Effect of paper waste reinforced clay bricks on building energy cost

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Abstract – In this article, the influence of the use of three different bricks on the building heat performance is compared for use on wall surfaces as a building construction element. At the beginning of the analysis, the thermal analysis of the building was carried out for both bricks with different heat transfer coefficients. Within the scope of the analysis, depending on the building material used, changes in the total fuel cost were observed with the help of the Engineering Equations Solver (EES) program by changing the brick thickness at certain rates in both cases. As a result of these observations and analyzes, the choice of paper reinforced clay bricks instead of standard wall bricks has resulted in a significant reduction in fuel costs. Also, as a result of this work, the use of paper waste reinforced clay bricks instead of normal wall bricks as building materials will contribute to saving energy by reducing both production costs and recovering waste by recycling.

Keywords – thermal insulation, clay brick, paper waste, thermal performance, fuel cost

I. INTRODUCTION

In parallel with the developments in the technology, the need for energy is also increasing continuously. In the world where resources are getting smaller, there are many studies to meet the growing need for energy. However, as long as energy saving and energy efficiency are not taken into consideration, the rapid depletion of energy resources will continue.

Buildings are very important in terms of energy efficiency because they are the longest-lived and large-scale energy consumption in the economy sector. At the forefront of the fight against climate change by the EU and developed countries is the increase in energy efficiency in the buildings [1]. Because the energy consumption from the buildings is about one third of the total consumption. In addition, heat losses in the buildings occur through the wall surfaces. For this reason, in order to minimize the energy consumption caused by the buildings, the losses on the wall surfaces must be reduced to the minimum. This is possible by heat insulation in buildings. For this reason, thermal insulation is very important and various insulation materials and building materials with different heat transfer coefficients are used in insulation.

Most of the insulation materials commonly used in building constructions consist of materials produced from non-renewable sources. These materials, which generally consume high energy in their production, cause problems in the recycling stage after the end of life [2]. For this reason, the production and application of recycled building materials can both reduce energy demand and contribute to the environment. In addition, waste recycling covers a variety of areas of interest, from engineering to social life. This is inevitable for sustainable living in the world [3].

Many works have been done within the context of insulation and building materials used in buildings. Soumia Hakkoum et al. [4] have produced clay bricks with good mechanical and thermal properties in order to increase thermal comfort and energy saving in the harsh climate conditions. The clay bricks prepared in this study were subjected to some mechanical and thermal tests. They set the percentage of sand of the brick to 30% and the percentage of the fibers from 0% to 3%. As a result of these tests, they have been observed that the increase in the percentage of fibers contributes to the development of acceptable mechanical strength thermal properties.

Mohammed Boukendil et al. [5] examined the effects of mortar joint thickness and emissivity in numerical simulation of double heat transfer via double cavity brick walls. In this context, numerically investigate the combined heat transfer with conductivity, natural convection and surface radiation in two-dimensional double hollow brick walls, including the air layer. As a result, they concluded that the use of grout grout equal to 1 cm is suitable to calculate the required thickness of hollow bricks combined. This is because they have come to the conclusion that the mortar thickness, the low emission rate of the building surfaces, will help the buildings reduce energy consumption.

M. Sutcu et al. [6] examined the thermal performance of the bricks by the thermal behavior of clay bricks made of paper waste. They obtained the strength and thermal properties of different paper waste concentrations by laboratory tests. It has been observed that the thermal conductivity of the additive bricks decreases from 0.68 to 0.39 W/mK relative to the sample without additive. In addition, three different cavities, including radiation and convection in the brick holes, have been applied to nonlinear digital thermal analysis. In all cases analyzed, the reduction of the brick thermal conductivity to the minimum and the reduction of the radiation emissivity of the surface of the recesses resulted in a decrease in the heat conductivity of the bricks.

In this study, the energy costs associated with the use of paper waste reinforced clay brick as building materials were analyzed. In this study, three bricks with different transmission coefficients were used and the brick thickness was changed at certain rates and analyzed with the help of Engineering Equations Solver (EES) program. The properties of the bricks are described in detail in material and methods section. In the study, information was first given about the building to be analyzed. This sequence is followed by the bricks and properties to be used in the study, the method of calculation and the results achieved.

II. MATERIALS AND METHOD

A. Building to be analyzed at study

The building to be analyzed in the study is located in the third degree day zone. The building has been constructed as exterior to exterior 10 m wide, 12 m long and 6 m high two storey. This building is shown in Figure 1. It is also known that the window area 20 m^2 on the building and the outer door area 2 m^2.

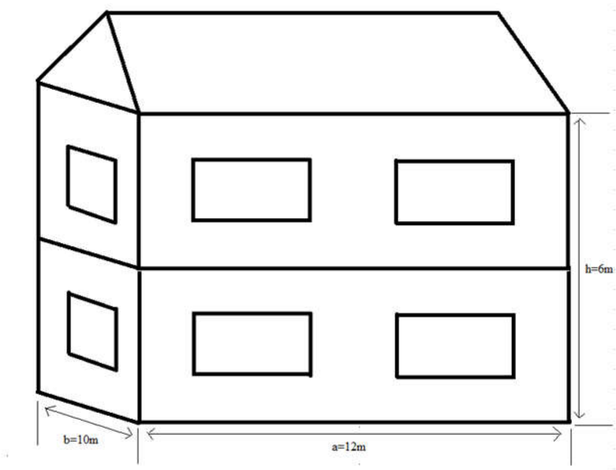

Figure 1. The building analyzed in the study

B. Bricks and properties to be used in study

In this study, three types of bricks were used. These ones standard wall bricks (k = 0.5 W/mK and k = 0.68 W/mK) and paper waste reinforced clay bricks (k = 0.39 W/mK). Paper waste reinforced clay bricks have a rectangular section and the chemical composition of the bricks is as follows. %61.7 SiO_2, %15.7 Al_2O_3, %0.8 TiO_2, %6.8 Fe_2O_3, %2.4 K_2O, %2,1 CaO, %2.3 MgO and %0.3 Na_2O. The chemical composition of the recycled paper waste used in brick making is as follows: %6.4 SiO_2, %4.1 Al_2O_3, %0.1 TiO_2, %0.3 Fe_2O_3, %0.1 K_2O, %32.9 CaO, %1.5 MgO and %0.1 Na_2O. From these values, it is stated that the minerals in the brick kiln contain a large number of quartz and clay minerals. Paper wastes mainly contain calcium carbonate, cellulose and a small amount of clay [6].

C. Calculation method

Providing thermal conditions in the inner environment is one of the most important functions of the buildings in terms of thermal comfort. The most important element in the provision of thermal condition is the building facade because it distinguishes the interior and the exterior environment from each other. Considering the energy problem arising from today's buildings, the use of minimum energy in the thermal comfort of building facades is of great importance [2]. For this reason, the main targets for heat insulation are to save energy and to minimize the cost.

In this study, the insulation and related cost account for the sample building was analyzed with the Engineering Equation Solver (EES) program. In the calculations, heat losses from wall surfaces, reinforced concrete, ceilings, flooring, doors and windows in building were examined one by one. In addition, solar energy gains are calculated and the building's annual heating energy requirement is achieved. In connection with all these losses and gains, the cost analysis of the fuel system used in the heating system of the building has been determined. All these calculations and results have been obtained by following the path. First of all, with the help of EES program, thermal insulation analysis was done by calculating all the heat losses and gains for the sample building where standard bricks were used as building element. The same process is then carried out for the same building with recycled paper waste and chalk brick; a yearly total heat loss, heat demand, solar acquisition rates and fuel costs have been analyzed. Finally, the brick thickness used was compared at d = 0.1 m - 0.25 m and the gains achieved in terms of energy and cost were determined when we used paper waste reinforced clay brick as building material.

The general equations that form the basis of the analysis can be described as Eqs. 1- 3 [8] , 4-8 [7] and 9[9]. The amount of heat energy transferred from unit time can be calculated by the following equation:

$$Q = \frac{A . \Delta T}{R} \quad (1)$$

where Q, A, ΔT and R are respectively, the unit temperature transient (Watt), the surface area through which heat is passed (m^2), the temperature difference (℃ or K) and the thermal resistance (m^2K/W).

Total heat transfer coefficient can be defined as:

$$U = \frac{1}{R} \quad (2)$$

where U and R are respectively, total heat transfer coefficient (W/m^2K) and thermal resistance of the wall (m^2K/W).

$$R = \frac{1}{h_{in}} + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{d_3}{k_3} + \cdots + \frac{1}{h_{out}} \quad (3)$$

where h_{in} and h_{out} are respectively, surface heat transfer coefficient on inner and outer surfaces (W/m^2K). $d_{1\text{-}2\text{-}3}$ are represent the thickness of the structural component (m) and k is the thermal conductivity coefficient (W/m^2K).

The specific heat loss of the building can be defined as:

$$H = H_T + H_v \quad (4)$$

where, H, H_T , H_V are respectively, total specific heat loss (W/K), heat loss through conduction and convection (W/K) and heat loss through ventilation (W/K).

$$H_T = \sum AU + IU_l \quad (5)$$

$$\sum AU = U_D A_D + U_P A_P + U_K A_K + 0.8\, U_T A_T +$$

$$0.5\mathrm{U_t A_t} + \mathrm{U_d A_d} + 0.5\,\mathrm{U_{ds} A_{ds}} \quad (6)$$

where, U_D, U_P, U_K, U_T, U_t, U_D, U_{ds}, A_D, A_p, A_K, A_T, A_t, A_d, A_{ds} respectively, thermal conductivity coefficient of outer wall (W/m^2K), window thermal conductivity coefficient (W/m^2K), thermal conductivity coefficient of outer door (W/m^2K), thermal conductivity coefficient of the ceiling (W/m^2K), coefficient of thermal conductivity of the upholstery on the floor (W/m^2K), coefficient of thermal conductivity of the floor in contact with the outside air (W/m^2K), thermal conductivity coefficient of building components in contact with indoor environments at low temperatures (W/m^2K), outside wall area (m^2), window area (m^2), outer door area (m^2), ceiling area (m^2), floor area (m^2), outside air-contacting floor/upholstery area (m^2), is the area of building elements that come into contact with indoor environments at low temperatures (m^2). *I* is refers to the heat bridge length (m) and U_l is refers to the linear permeability of the heat bridge (W/mK).

$$H_V = \rho . c . V' \quad (7)$$

where ρ is unit volume of air (kg/m^3), *c* is specific heat of the air (J/kgK) and V' is volumetric air change (m^3/h).

The monthly average solar energy gain is calculated with the following equation:

$$\emptyset_{ay} = \sum r_{i,ay} \times g_{i,ay} \times I_{i,ay} \times A_i \quad (8)$$

Where, $r_{i,ay}$ is *i* mean average shading factor of transparent surfaces in *i* direction, $g_{i,ay}$ is the solar energy transmission factor of the i-direction transparent elements, $I_{i,ay}$ is monthly mean solar radiation intensity from vertical surfaces in *i* direction (W/m^2) and A_i is total window area in the *i* direction (m^2).

$$\mathrm{C = m.c} \quad (9)$$

Where *C,m* and *c* respectively, fuel cost (TL), the amount of fuel consumed per year ($N.m^3$, kg or kWh) and unit price of fuel (TL/m^3, TL/tonne or TL/kWh) .

III. RESULTS

In this section, the effect of using recycled paper waste and clay made from brick in the energy and cost analysis is realized according to TS 825 standard. The graphs resulting from the analysis are shown in this section.

The change in one year natural gas fuel cost due to brick thickness is given in Figure 2.

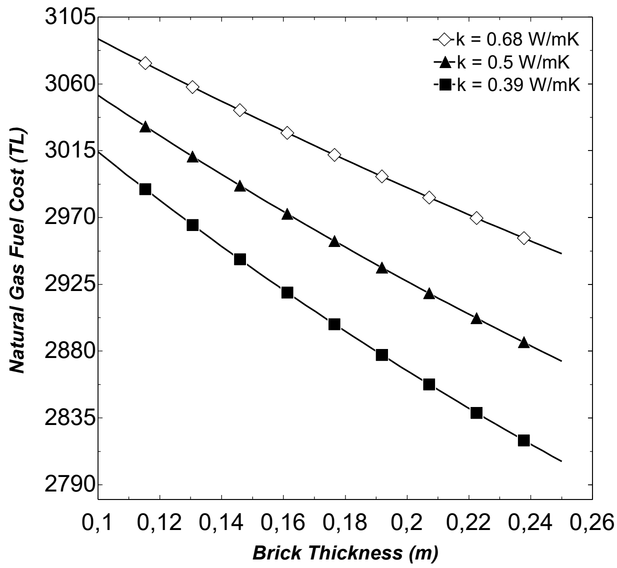

Fig. 2. Change in natural gas fuel cost due to brick thickness

Here, the annual natural gas fuel cost is expressed in TL. As can be seen, when comparing according to the change of the brick thickness, the natural gas fuel cost corresponding to each thickness is less in clay bricks made of wastes.

The change in cost of one year of coal due to brick thickness is shown in Fig 3. Here, the annual cost of coal is expressed in TL, and the coal used is lignite coal. When the use of paper waste reinforced clay brick is preferred instead of normal wall brick, the reduction in coal fuel cost is very important.

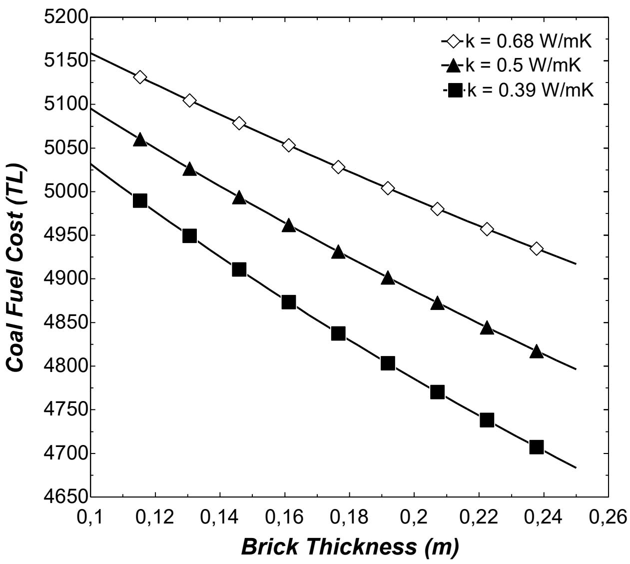

Fig. 3. Change in coal fuel cost due to brick thickness

The change in electrical fuel cost, depending on the brick thickness, is shown in Fig 4. Here again, if paper waste reinforced clay brick are used as building material, the fuel savings to be obtained from the electricity fuel cost can be observed clearly.

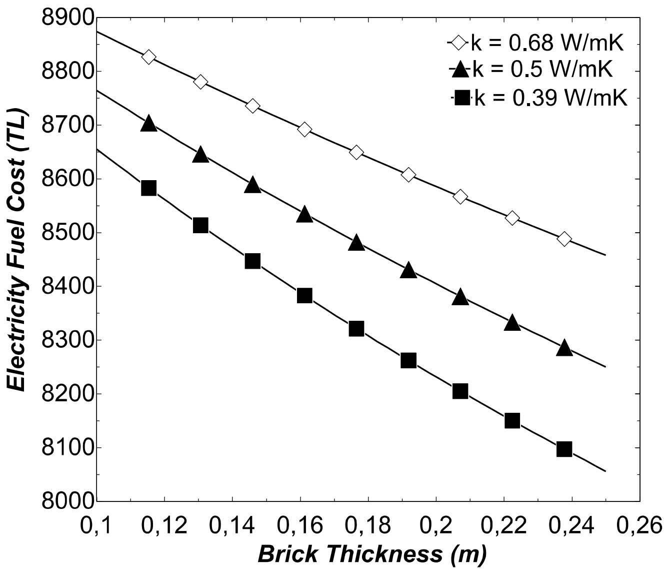

Fig. 4. Change in electricity fuel cost due to brick thickness

When three bricks are compared; the change in the cost of natural gas, coal and electricity is given in Figure 5. Here again, if paper waste reinforced clay brick are used as building material, has been found to be more profitable for all fuels.

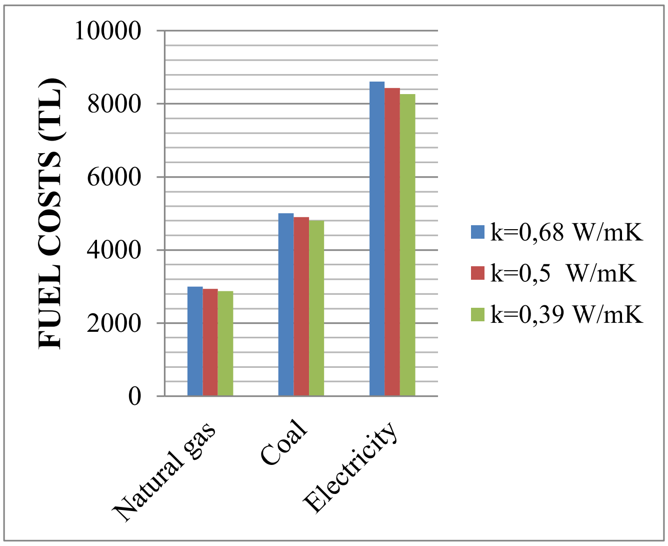

Fig. 5. Change in natural gas, coal and electricity fuel cost due to brick thickness

IV. DISCUSSION

When all the results are evaluated, it is inevitable to achieve many advantages by using paper waste reinforced clay bricks for insulation. Depending on the use of paper waste reinforced clay bricks, instead of the standard wall bricks, respectively; it has been observed that the natural gas fuel cost decreased by 4.75%, coal fuel cost decreased by 4.76% and electric fuel cost decreased by 4.75%. So it seems clear that when this brick is preferred, it saves natural gas, coal and electric fuel costs.

Moreover, this brick, which saves energy-related cost, is made of paper waste and clay instead of artificial material. Therefore, the use of these bricks has an important place in terms of recycling waste. This is crucial for the efficient use of energy and for the assessment of consumed resources.

V. CONCLUSION

In this study, fuel analysis was carried out by emphasizing the importance of thermal insulation of building materials used in construction. The main results of the study can be summarized as follows:

- First, considering that about one-third of the heat losses originate from buildings, thermal insulation is crucial for energy conservation around the world. If heat insulation is done using healthy insulation techniques, an important step will be taken to improve our country and world economy.
  - Building materials as well as insulation materials used in heat insulation are also very important. Because the correct insulation is achieved only when the insulation and building materials are correctly selected.
  - When it is preferred to use as paper waste reinforced clay brick building material which is expressed in the work, since it increases energy saving and reduces fuel cost compared to standard bricks, the conservation of energy has a valuable place in terms of cost.
  - Finally, if the thermal insulation and building materials used are derived from natural resources and waste, a major step will be taken towards becoming a society that is focused on using energy resources in the most effective way in the world that worries about the future.

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