Experimental and Theoretical Investigation of Reducing Energy Consumption for a Building using Geothermal Water through the Glass

Amer Matrood Imran¹, Khalid Almusawi¹ and Jaafar Ali Mahdi¹
¹Mechanical Engineering Department, College of Engineering, University of Kerbala, Iraq

Abstract. Electricity consumption is the main criterion for identifying green buildings that contribute to the sustainable development of the world. The aim of this study was to reduce the utilization of electrical energy by air-conditioning devices, by decreasing heat gain via the glass of buildings. The study found that the maximum energy consumption for air conditioners was 48% of total energy in a building. The glass significantly contributes to waste and electrical energy heat loss by heat transfer to the inside of the building. The study showed that the largest surplus of cooling load for a glass type (triple glazing 4/12/4/12/4mm air-filled clear glass) is 44.7 tons, and the lowest simple payback period is 2.19 years for glass type double glazing 5/12/5 mm air-filled clear glass, when the current glass in the building was replaced with six different types of glass. Finally, double glass is improved by adding geothermal water into the heat sink, to remove some of the heat that comes from out. Experimental and numerical results (ANSYS -15) showed that the use of geothermal water decreased heat transfer through glass by nearly 6%.

Keywords: Cooling load, simple payback period, heat conduction, geothermal and electrical energy consumption.

1. Introduction

The global demand for electric power is increasing due to the increase in the population, the improvement of living standards and the large number of electrical appliances which are used to provide high standards living. This has led to an increase in environmental pollution and reduced levels of fossil fuels (oil, coal and natural gas) that are used in most power plants. The generation of nuclear electric power is costly, and the use of uranium and plutonium elements threaten living organisms via radiation and the difficulty of radioactive waste disposal [1] [2].

Alternative sources of energy (renewable energy) such as solar, wind, hydropower and others have been sought, to meet the energy shortfall. Renewable energy is characterized as a permanent energy source rather than a temporary one compared to fossil fuels and nuclear fuel, is scarce in third world countries due to the high cost of construction and production [3] [4] [5].

Most of the electricity consumption in the world is residential/occupational, rather than from to the industrial, transport and commercial sectors, because most people spend most of their time in buildings [6]. Therefore, it is important to find the solutions to reduce electricity consumption in buildings and these solutions must be low cost and environmentally friendly [6].

Examination of building energy use shows the biggest consumption of electric power is by the air conditioning devices, the rest being use for equipment and lighting. In some countries, air-
conditioners account for more than 60% of the power capacity of buildings, due to high temperatures in most months of the year [7] [8]. The largest heating load is by conduction, convection or thermal radiation heat transfer through walls, ceilings and glass. In the most modern buildings, the various shapes of glass and windows are designed with a large area of wall, to increase the aesthetics of the buildings, and to ease the implementation and structure [9] [10].

The cooling load of glass has the greatest value compared to other thermal loads in some buildings, which have a large proportion of windows [11]. It has been found that the cooling load may be reduced about 1647 kWh per year, while the heating load was increased about 723 kWh per year, in the case were thin films were fixed to the glass from the outside, to control the rate of solar radiation in a building located in Duhok City, Iraq. The recovery period for retrieval of the initial cost was less than two years [12].

The use of membranes reduces the shading coefficient and the coefficient of solar heat gain by 44% from the outside and 22% from the inside. Also, it was observed that the cooling load through the windows decreased 27.5% and 2.2% with membranes on the outside and inside, respectively, for a large commercial building located in Shanghai, China [13]. It has also been claimed that the most balanced technical solution to protect a building from direct solar radiation, and to reduce the energy consumption by air-conditioners, is the use of venetian blinds. Energy consumption dropped by around 55% when this approach used inside the buildings [14].

This work studies the consumption of electrical power in a residential building, identifies the percentage of energy consumption in the building, calculates the cooling load of the glass currently in the building and when it is replaced by other types of glass which are compatible the building. The payback period for the glass is calculated and compared with the results to determine the best type of glass that helps to reduce heat transfer and thus reduce power consumption. Finally, the glass type that has the shortest payback period is enhanced by using geothermal water to cool the window.

2. Methods

The first step of this work was to choose a residential building in which the windows are of single glass, 4mm thickness. After that, the electrical load was analyzed for all electrical devices and showed that the air-conditioning devices accounted for most consumption.

The cooling load was calculated for the current glass, and the study was carried out to replace it with other types available in the Iraqi market, to determine which type best provides a surplus cooling load and short payback period. The selected type was improved, to obtain the best result, by adding geothermal water. The results and the conclusion are the final steps. The process is shown in Figure 1.
2.1 Specifications of the selected building

The selected building is of four-story construction with a total area of 5146 square meters. The building is located in the middle of Iraq, at a latitude 33.2 degrees north. Iraq is in a semi-tropical region, the climate is hot and dry in the summer (which continues for seven months per year), the number of sunlight hours can reached 12 hours / day and the temperatures are around 50 C° in the shade on some days [12] [15].

The building was constructed of the raw materials found in Iraq, by the traditional method. Reinforced concrete was used for the ceilings and columns, while the bricks were used for walls. The building contains a large number of windows that fit the modern designs of residential buildings in all countries of the world such as skyscrapers and other buildings, and provide a beautiful view. The type of glass used is clear single glass.

2.2 Heat gain of the glass

The building has concrete structures for foundations, roof and columns. The walls are made from bricks of 24 mm thickness and beautiful finishes were added to the building from the inside and outside. After checking the building, the designer added a large area of glass to provide daylight and enhance the interior and exterior appearance of the building. The type of glass used is a clear glass of thickness 4 mm and the cost per meter less than 9300 Iraqi dinar. This type of glazing will transfer a large amount of heat into the building.

It is known that the glass represents a separation between the internal and exterior environment of the building. The windows are the largest source by which to increase the heat in buildings, hence the best type of glass represents the worst insulation, compared to the weakening of a wall [11]. The thermal performance of windows can be compared by two indicators: light permeability and heat permeability.

When solar radiation falls on the glass, a part of the radiant energy is reflected in air and another portion is absorbed by the glass. The rest is transferred directly into the indoor space, and the absorbent part exits again and flows either outward or inward. The temperature transmission through
the windows is affected by the latitude, time of the year, the weather conditions, the intensity of the solar radiation and the angle of fall, the difference in internal and external temperatures, the speed and direction of the air flow through the external and internal surfaces of the glass, and the low temperature radiation between the surfaces and the shading of the glass. This is shown in Figure 2 [16] [17].

![Diagram showing solar radiation on glass](https://via.placeholder.com/150)

**Figure 2: The solar radiation on glass [20].**

The solar heat gain through the glass is the sum of the transmitted radiation and part of the absorbed radiation that flows into the interior space. Solar heat gain is calculated through two steps: 1) conduction and 2) solar radiation through the glass.

The first step is conduction: heat flow mode through the windows is calculated by only conduction, which is similar to walls and ceilings [17]:

\[ Q_c = U \times A \times \text{CLTD}_c \]  \hspace{1cm} (1)

Where \( Q_c \) is conduction heat, \( U \) is the total heat transfer coefficient of the glass, \( A \) is glass area includes frame area and \( \text{CLTD}_c \) is temperature difference for cooling load of window.

The second step is solar radiation: glass transfers a portion of solar radiation through it. This is known as the solar heat gain coefficient (formerly the shading coefficient). Shading devices usually prevent direct solar radiation, but not diffuse. Solar gain transmitted through windows is calculated separately for different directions. The heat flow through the window is calculated by the following formula [17]:

\[ Q_r = A \times \text{SC} \times \text{SHG} \times \text{CLF} \]  \hspace{1cm} (2)

Where \( Q_r \) is radiation heat, \( A \) is glass space includes frame space, SC is shading coefficient, \( \text{SHG} \) is solar heat gain and \( \text{CLF} = \text{cooling load factor.} \)

### 2.3 The experimental work

Double glass with filled air 5/12/5 mm was used to measure temperature distribution by data logger temperature device and thermocouples. Then the total heat of conduction through the window was calculated. The inside temperature (room temperature) was kept at 25 C° by an air-conditioning device and the outside temperature was maintained at 60 C° by an electrical heater.

The window was improved by adding copper pipe (10mm) on the inner window frame. There was a pump to draw geothermal water from a water well to the insulated tank, to maintain the temperature
of the geothermal water at 22°C [18]. The connecting pipes was insulated. The water came from the tank by gravity to the copper pipe in the window then to the ground again. Therefore, the reduction of heat is accomplished by subtraction of a part of the total heat conduction to the geothermal water, as shown in Figure 3.

![Figure 3: The experiment parts and sketch (SolidWorks software).](image)

3. Results

3.1 Payback period

At this stage, the target was to find the best and shortest payback period by calculating the annual saving energy in Iraqi dinar, and the cost of replacing the current glass with six new types that are found in the Iraqi market.

3.1.1 Analysis of electricity consumption of the building

After monitoring and verification of different types of devices in the building, and after calculating the number of hours of actual operation of the equipment, it was found that the percentage of real electrical consumption of air conditioners was 48% of the total consumption by the building. Lighting accounted for 15% of the consumption and 37% was other household appliances, as shown in Figure 4. Therefore, it was important to find a solution to reduce the cooling load and electricity consumption, thus the cost of electricity would be minimized.

![Figure 4: Analysis of electricity consumption in the building.](image)
3.1.2 Cooling load (TR)

After calculating and analyzing the building’s electricity consumption and having determined the maximum consumption and the cooling load, conduction and radiation heat transfer for each type of glass was calculated by the CLTDe method to identify conduction heat, radiation heat and total heat transfer. Figure 5 illustrates.

![Figure 5: Conduction heat, radiation heat and total heat transfer.](image)

This study found the lowest value of cooling load to be 42.02 TR, using triple glass filled with air 4/12/4/12/4mm. The highest value was 84.43 TR using 6mm clear single glass, as shown in Figure 6. The cooling load through the glass in the building (4 mm clear single glass) was calculated as 86.74 TR.

![Figure 6: Cooling load (TR).](image)

3.1.3 The savings of Cooling Load (TR)

The savings of the cooling load comprise the difference in value between the cooling loads through the glass currently installed in the building (single net glass with a thickness of 4 mm) and the cooling loads through each type of potential replacement glass (six types of glass).
Figure 7 shows the savings in cooling load. The maximum saving is 44.72 TR and the minimum saving is 2.3 TR. This difference in values arises from the ability of glass to prevent and reduce the heat transfer between outside and inside spaces.

![Figure 7: The savings of cooling load (TR).](image)

### 3.1.4 Energy saving

The hourly energy saving is obtained by calculating the electrical power consumption for every ton of refrigeration in hour. The biggest amount of energy saving was obtained by using triple glass filled with air 4/12/4/12/4mm, meanwhile the smallest amount was achieved by using 6mm clear single glass, as shown in Figure 8.

![Figure 8: The savings of energy (Kwh).](image)

The months of summer in Iraq are more numerous than other seasons (spring, autumn and winter), and the number of daylight hours exceed those of night. Therefore, to ensure indoor environmental quality, residents must run air conditioning devices throughout the summer season. Annual energy saving (kWh per year) is represented by the number of operational hours in (kW) for summer, as shown in Figure 9.
The ministry of electricity in Iraq has four tariffs for electricity, which are 10 Iraqi dinar, 35 Iraqi dinar, 80 Iraqi dinar and 120 Iraqi dinars for each kWh, depending on the volume of electrical power consumed.

The figures describe all electricity tariffs with all suggested alternative types of glass, as found in Iraqi markets. The maxim annual saving energy benefit (IQD per year) is with triple glass filled with air 4/12/4/12/4mm, but the minimum annual saving energy benefit (IQD per year) is obtained by using 6mm Clear Single glass at all figures. Figure 10 illustrates this.

**Figure 9: Annual energy saving (kWh per year).**

**3.1.5 Annual energy saving (IQD per year)**

The simple payback period is the period of time required for recovery of the money invested. The payback period is simply the length of time for any investment to reach the break-even point. The

**Figure 10: Annual energy saving (IQD per year).**
payback period formula depends on whether the cash flow of projects is equal and equivalent, or not (Payback Period = Initial Investment / Net Cash Flow per Period) [19].

By knowing the cost and implementation price for each type of glass sold on the Iraqi market in IQD, with which it is suggested the current glass in the building (4mm clear single glass) should be replaced, and the annual energy saving benefit (IQD per year), it becomes possible to determine the simple payback period.

![Figure 11: Simple payback period (years).](image)

The research shows that the briefest simple payback period is for double glass filled with air 5/12/5 mm, for all electricity tariffs, due to the low cost and good insulation properties of double glass.

It is noticed that the simple payback period is 17 years at 10 Iraqi dinars. That is very long period and the replacement will be without benefit. The simple payback period is 4.86 years, 2.12 years and 1.41 years at 35 Iraqi dinars, 80 Iraqi dinars and 120 Iraqi dinars, respectively. This brings the amount of time below 5 years, so the change will be useful for reducing heat loss through glass and the energy consumption for air conditioning devices.

3.2.2 The double glass without geothermal water

Figure 12 shows the case of the double glass filled with air 5/12/5 mm without pipe of geothermal water. The total heat transfer to the inside of building is one dimensional, as shown in Figure 14 and Figure 13, which describes the temperature distribution along the two layers of glasses and gap of air. The steady state thermal ANSYS-15 software was used to simulate heat transfer analysis.
3.2.2 The double glass with geothermal water

The challenge in this study was to reduce the heat transfer across the window, therefore the geothermal water was added to experiment work as shown in Figure 15 to remove a part of the total heat which comes from the outside of the building, because the temperature of geothermal water is nearly 22°C [18]. So, the reduction of heat is accomplished by subtraction of some of the total heat to the geothermal water. The heat transfer mode changes from one dimension to three dimensions as shown in Figure 15. The reduction in heat transfer percentage was 6% using geothermal water.
Figure 15: The heat transfer with and without geothermal water.

Figures 16 and 17 show the temperature distribution within inner and outer glass and the air gap. It is shown that the isothermal line in the hot side starts with a horizontal line, which curves when approaching geothermal water, so that the temperature of the air gap decreases. Accordingly, the heat transfer divided into two directions: one way to the inner of building and the other is to geothermal water.

Figure 16: Temperature distribution for double glass with geothermal water.
4. Conclusions

A conclusion of this study is that the rationalization of electric consumption of buildings is necessary to the sustainability of electricity and its continuity, and that preservation of the environment is accomplished by reducing the gases that are emitted by generating electricity.

The highest percentage of consumption of electric power of the building was by air conditioners, and amounted to 48% of total consumption of the building. The analysis and calculation of the cooling load through the current glass. It was found that glass contributes to the waste of electric energy as a result of its quality, so the best solution was to replace the current glass with other types to reduce the transfer of heat into the building. It was found that-

1. The maximum savings cooling load was 44.72 TR by using triple glass filled with air 4/12/4/12/4mm, and the minimum savings in cooling load was 2.3 TR by using 6mm clear single glass.

2. The biggest energy saving was achieved with triple glass filled with air 4/12/4/12/4mm, while the least amount was at 6mm clear single glass, as well as the annual energy saving benefit (IQD per year) for all electricity tariffs.

3. The minimal simple payback period is for double glass filled with air 5/12/5 mm at all electricity tariffs being 17 years, 4.86 years, 2.12 years and 1.41 years at 10 Iraqi dinar, 35 Iraqi dinar, 80 Iraqi dinar and 120 Iraqi dinar, respectively.

4. The use of geothermal water reduced the conduction heat transfer across the window.

5. The temperature distribution of a window with geothermal water was less than one without geothermal, for double glass.

6. The experimental and numerical results showed that the heat transfer conduction for double glass was reduced by about 6% when the geothermal water was used.

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