INVESTIGATION OF ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS IN HOT REGIONS

ABDULLAH OMAR ALHARBI[1], MARWAN ALREHAILI[1], MAMDOOH ALWETAISHI[2], AHMAD ALAHMADI[3], ASHRAF BALABEL[1] & ALI ALZAED[2]
[1]Mechanical Engineering Department, College of Engineering, Taif University, Saudi Arabia
[2]Civil Engineering Department, College of Engineering, Taif University, Saudi Arabia
[3]Electrical Engineering Department, College of Engineering, Taif University, Saudi Arabia

ABSTRACT

Residential buildings consume more than 40% of total energy worldwide. The aim of this research is to investigate the importance of energy consumed in residential buildings and how it may impact the indoor environment. In order to enhance the energy efficiency in the architectural design of a house, a detailed empirical analysis is provided, measurement instruments being used for a building with and without thermal insulation to evaluate the degree of its impact and the discrepancy of its effect. The study also provides some ideas for further future growth to reduce energy consumption. Finally, this research will provide an analysis in regard to reducing energy consumption in residential building. This paper limits itself to residential buildings rather than non-residential due to the large number of residents. In many poor countries, the residents are lacking in energy efficiency certificates, so they misuse energy by consuming tremendous amounts of power. This article will point out those categories and offer scientific solutions.

Keywords: renewable energy, energy efficiency, amount of power, residential buildings, building materials, building design.

1 INTRODUCTION

Energy usage is a globally sensitive issue and energy efficiency in residential buildings is important because domestic buildings account for 60% of the total energy consumed globally [1]. Even though the energy we use has made our life much better, the amount of power consumed could have a negative impact on our life. There is a general consensus in the world today that human activities are having a negative impact on the environment and have accelerated both global warming and climate change. These environmental threats have been intensified by the emissions produced by the energy required for the lighting and HVAC (heating, ventilation and air-conditioning) systems in building construction [1].

There are many forms of sources humans can convert into power, such as the sun, winds, biomass, and waves. All these sources, when converted into energy [2], should be well-treated and properly operated. The amount of energy consumed by buildings appears to be a serious issue and needs to be reduced significantly; according to Shoubi et al. [3], "currently concern about climate change and resource depletion issues is increasing around the world". The building is investigated since it has the main proportion of operational energy consumption. Every building is made up of a series of components, which have a role in thermal dissipation. The rate of energy dissipation in each of these building components depends on design and environmental conditions. Due to the importance of energy consumption in buildings, they decided to present the sum amount of energy in percentage. In addition, actions done in order to promote the quality of buildings in terms of heat exchanges can lead to significant energy saving [3].

Saudi Arabia's per capita primary energy consumption is 3.6 times higher than the world average with an average per capita consumption of 6.7 tons of oil equivalent (TOE) in 2010 according to the latest Saudi energy efficiency survey [5]. In order to ensure quality of

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buildings, building environmental assessment system (BEAM) is done as shown in Table 1. Increasingly, buildings have high-energy requirements in the Kingdom of Saudi Arabia (KSA), especially during the summer season due to high air conditioning requirements associated with extremely high outdoor temperatures in most of the Kingdom during the summer and at night. In 2010, about 65% of the total energy was used by buildings in the KSA, 47% higher than the world average [6]. Also, some studies have shown that, if energy efficiency measures for new buildings are implemented, the annual demand for KSA electricity from residential buildings can be decreased by 10% [6]. Components of the

Table 1: The building environmental assessment system (BEAS) [4].

A. Site selection and project planning	A1. Site selection	Use of land with high ecological sensitivity value; Land vulnerable to flooding; Land close to water endangered by contamination; Distance to commercial and cultural facilities; Distance to public green space etc.
	A2. Site development	Development of density; Possibility of change building purpose; Impact of the design on the existing streetscapes, etc.
B. Building construction	B1. Materials	Use of materials which are locally available; Re-use and recycling, etc.
	B2. Lifecycle analysis	Embodied energy of building materials; Global warming; Potential of materials for construction, etc.
C. Indoor environment		Thermal comfort; Humidity; Acoustic; Day lighting; Indoor air quality; Total volatile organic compound, PM_{10}, etc.
D.Energy performance	D1. Operational energy	Heating energy consumption; Energy consumption for domestic hot water; Energy for air handling unit; Energy for cooling, lighting, appliances, etc.
	D2. Active systems	Solar water heater; Heat pump; Photovaltaic technology; Using renewable energy sources; Heat recuperation, etc.
	D3. Energy management	Operation and management; Control of lighting systems; Occupant sensors and technical control appliances, etc.
E. Water management		Reduction and regulation of water flow: surface water run off, drinking water supply, filtration of “gray water”, etc.
F. Waste management		Measures to minimize waste resulting from building operation; Measures to minimize emission from building construction, operation and demolition; Handling risk of hazardous waste resulting from facility operation, etc.

building envelope, such as walls, roofs, floors, and windows, have other purposes than structural or architectural elements, so the energy required for thermal comfort inside buildings is influenced by these components. For example, without the need for mechanical systems, the heat storage capability of some building envelope elements, such as walls, can help regulate indoor temperature [6].

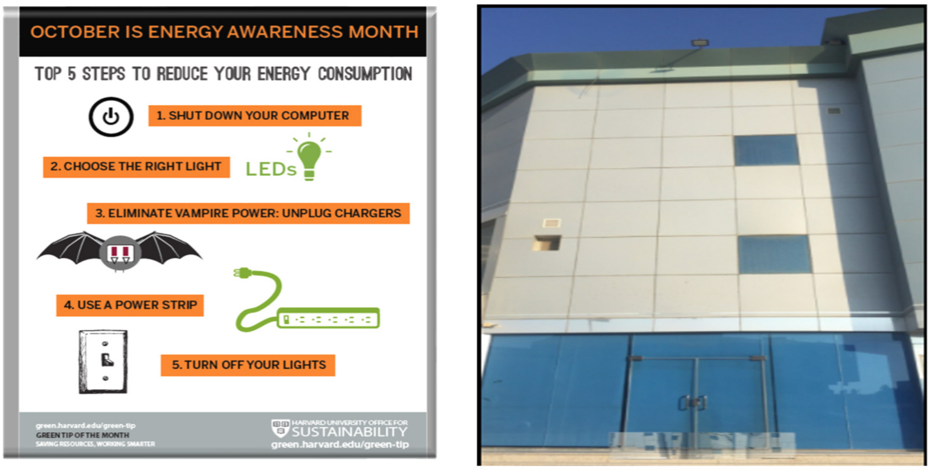
"Carbon dioxide is a potential carbon resource abundant on earth" [7]. It is also a greenhouse gas with a rapidly increasing atmospheric concentration during the last two centuries. Chemical fixation of CO_2 is an attractive technique for utilization of carbon resources, as well as for the reduction of the atmospheric concentration of CO_2. Nevertheless, CO_2 is the most stable among carbon-based substances under the environmental conditions. It has not been incorporated as a major industrial material. Carbon dioxide can be electrochemically reduced to useful products under mild conditions. However, the energy conversion efficiency, defined as the ratio of the free energy of the products obtained in electrochemical CO_2 reduction and that consumed in the reduction, would be roughly 30–40%. Such a low efficiency may discourage practical application of CO_2 reduction in the very near future [8].

The aspect that separates energy-efficient design from other architecture methods is that it seeks to reduce the volume and expense of energy in compliance with all building regulations in a broad region taking into account the human factor and offering advantages such as reducing electricity bills [9].

One of the most important means in generating power is electricity. The amount of electricity consumed in buildings is extremely high, so it will cause equally high electricity bills. Lights and air conditioners account for the biggest percentage of energy consumed in residential buildings. HVAC is the main end user with a weighting close to 50%, lighting follows with 15% and appliances with 10% [10]. Choosing the right lighting will reduce energy as can be seen in Fig. 1(a). For example, having LEDs instead of regular light bulbs will reduce the power consumed in a building, thereby immediately decreasing the electricity bills. According to Harvard University, "LED bulbs are the most energy efficient lighting option. LED bulbs use 75% less electricity than incandescent bulbs (Energy Star). Also have no mercury, and last about 25 times longer than traditional incandescent bulbs (DoE). Another factor to reduce energy consumed in residential buildings is to eliminate vampire power: unplug idle electronics. Devices like televisions, microwaves, scanners, and printers use standby power, even when off. Some chargers continue to pull small amounts of energy, even when plugged in (a good judge of this is if a charger feels warm to the touch). In the US, the total electricity consumed by idle electronics equals the annual output of 12 power plants (EPA)" [11]. If those steps are followed correctly, we would obtain an incredible result in our electricity bills.

2 EXPERIMENTAL BUILDING

This paper presents an analysis of energy consumption in residential buildings. A small hotel was picked, located in Jeddah, Saudi Arabia, as an example for the numerical experiment. The experiment took place in one room of 4 m × 5 m in size. The data collected in the room were with insulation and without insulation and for all seasons. The outside temperatures were collected as well as the cooling load using the TAS program. This software is good simulation tool from which to obtain data. The software is also not complicated so that anyone can obtain results from it. The data allowed a comparison of the cooling load for the room with and without insulation. As can be seen in Tables 2 and 3, there are two scenarios where the first one highlights the current case of thermal insulation, and the second one is



(a) (b)

Figure 1: (a) Reduced energy consumption [11]; and (b) Experimental building.

Table 2: Current case without the use of thermal insulation (single cavity).

	Layers	Width (mm)	Conductivity (W/m°C)	Total U value (W/m^2.°C)
External wall	Block	200	1.31	3.15

Table 3: Improved case with the use of thermal insulation.

	Layers	Width (mm)	Conductivity (W/m°C)	Total U value (W/m^2.°C)
External wall	Block	100	0.85	0.43
	Insulation	90	0.048	
	Block	100	0.85	

with the use of thermal insulation applied to the external walls. Recent studies explored the optimum thickness of thermal insulation where cost and energy efficiency are of prime importance. In the current study, thickness of thermal insulation of 90 mm was applied.

3 MODELLING PROCEDURES

The first step before doing the experiment is determining the characteristics of the building and ensuring it is suitable for the experiment. Second, selecting the perfect room, which should include air conditioning, lights, plugs and one window. Third, using the TAS program to measure the indoor temperature with weather data file derived from Meteonorm site [12]. Temperature and the cooling load for the room with and without insulation. Fourth, the room was built into a TAS program and, by applying the materials for the building, the program gave the degree of cooling load for the room with and without insulation. Finally, all data were compared, and the output showed that the room with insulation consumed less energy.

4 RESULTS AND DISCUSSION

The simulation findings prove the difference in energy consumption, showing that the room with insulation minimized the amount of energy as shown in the curves in Fig. 2. On the other hand, the room without insulation required a considerable cooling load. The attached plots from the TAS program show the results of the program's simulations for all seasons of the year in order for us to clearly see the difference between the amount of energy consumed with and without insulation and how to reduce it. The average temperature for all months in Jeddah, Saudi Arabia is found to be 20 to 40°C which is similar to data which were entered into TAS program for all seasons [13].

The results of simulations by the program, without insulation, for the seasons at a constant cooling load are shown in Figs 2–5.

The graph of Fig. 2 shows the temperature and load for a room without insulation in a building in Jeddah, Saudi Arabia, in the fall season, where the temperature can be seen as ranging from 34.5 to 23.5; the load difference over 24 hours can also be seen in Fig. 2.

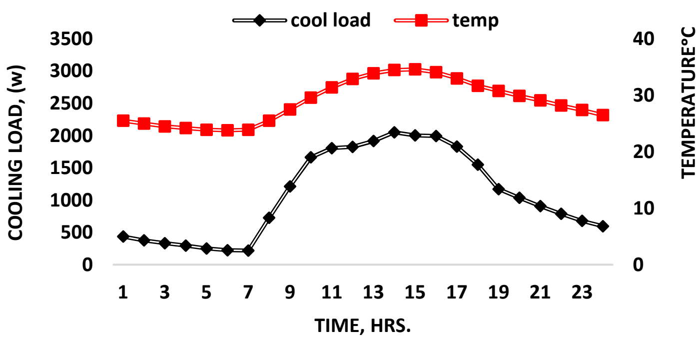


Figure 2: Cooling load and temperature without insulation during a typical day in fall.

The temperature and cooling load of a room without insulation during the winter season is shown in the graph of Fig. 3. The temperature decreases in winter and reverts to the direction of the sun. The temperature input ranging from 16.1 to 26.4 and the load difference within 24 hours can be seen in Fig. 3.

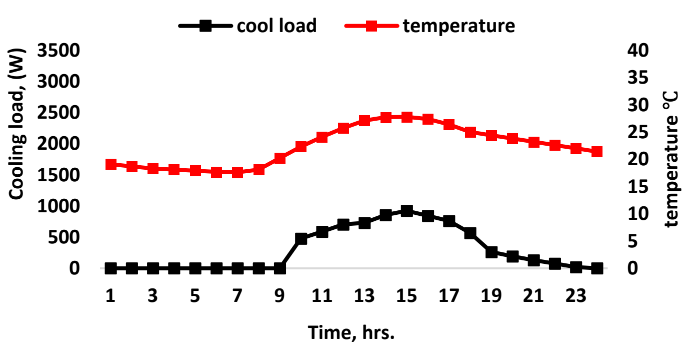


Figure 3: Cooling load and temperature without insulation during a typical day in winter.

The chart of Fig. 4 shows room temperature and load without insulation in the summer. In the summer, the temperature rises, and it returns to the direction of the sun and its proximity. The temperature ranging from 29.8 to 41.1 and the load difference within 24 hours can be seen in Fig. 4.

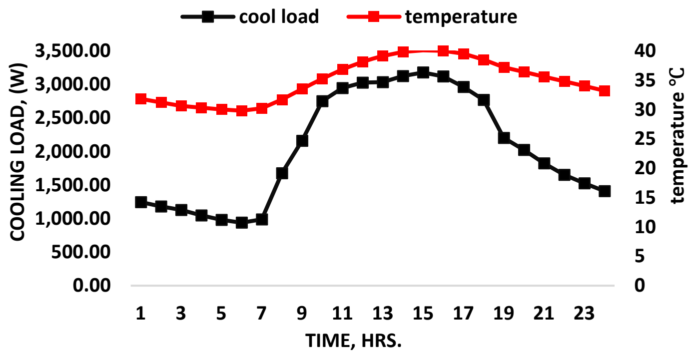


Figure 4: Cooling load and temperature without insulation during a typical day in summer.

In the spring, the graph of Fig. 5 indicates room temperature and load without isolation. The temperature ranging from 22.5 to 32.1, and the load difference is within 24 hours can be seen in this figure.

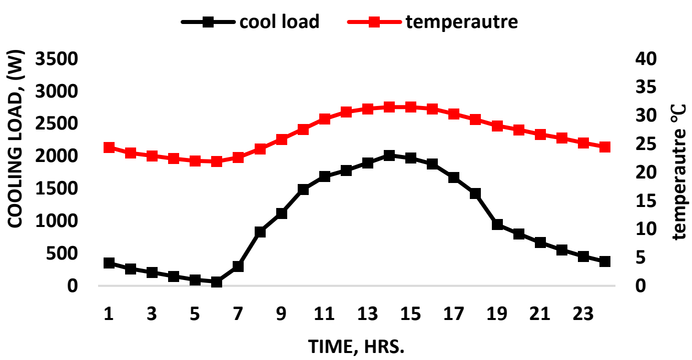


Figure 5: Cooling load and temperature without insulation during a typical day in spring.

The results of simulations using the program, with insulation, for the seasons at a constant cooling load are shown in Figs 6–9.

In the fall, in a building room in Jeddah, Saudi Arabia, these charts of Fig. 6 demonstrate the temperature and load for a room with insulation, where it showed the temperature range from 34.5 to 23.5 and the change in load within 24 hours.

During the winter, the chart of Fig. 7 reveals the temperature and load of the insulation space. The temperature decreases in the winter and the remining energy from the sun reflect

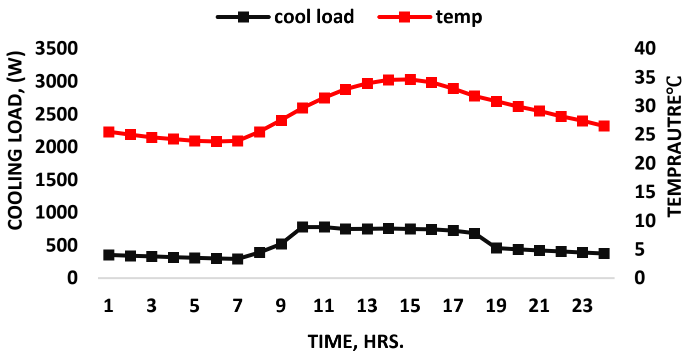


Figure 6: Cooling load and temperature with insulation during a typical day in fall.

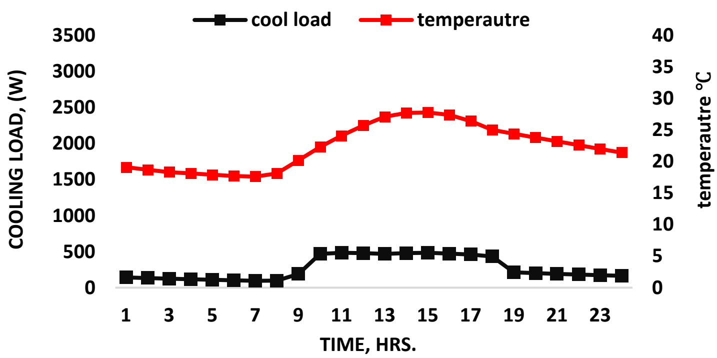


Figure 7: Cooling load and temperature with insulation during a typical day in winter.

back to space. One can see the temperature range from 16.1 to 26.4 and the load difference within 24 hours. Moreover, Balabel and Alwetaishi indicated thermal mass control energy consumption which is similar to the results obtained as represented in Fig. 9 [14].

Fig. 8 reveals room temperature and load during the summer with insulation. In the summer, the temperature increases and returns to the path of the sun and its vicinity. The temperature can be seen ranged from 29.8 to 41.1 and the load variation within 24 hours. Alwetaishi and Taki claim the maximum cooling load was observed when the thermal insulation is installed on the outside of external wall, while a reduction of 6.8% was achieved when the thermal insulation is installed on inside wall which is similar to the output data when the same conditions were applied for the results [15].

The line chart of Fig. 9 reveals room temperature and load with insulation in the spring. The temperature can be seen ranged from 22.5 to 32.1 and the load gap is within 24 hours. Alwetaishi et al. restated thermal mass is strongly connected to thermal comfort. 40% to 98% of thermal discomfort can be avoided when using thermal mass in buildings [16]. In fact, after applying thermal mass such as walls and roofs, the energy consumption was dropped.

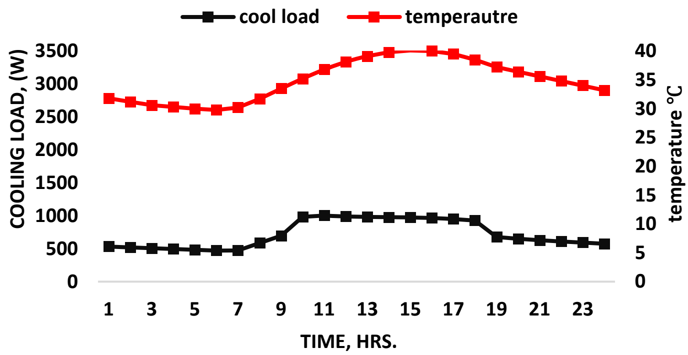


Figure 8: Cooling load and temperature with insulation during a typical day in summer.

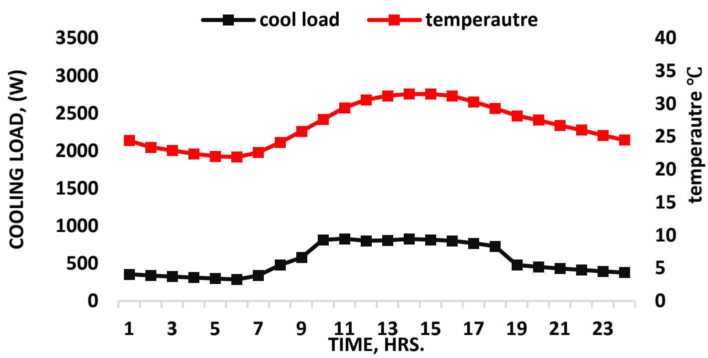


Figure 9: Cooling load and temperature with insulation during a typical day in spring.

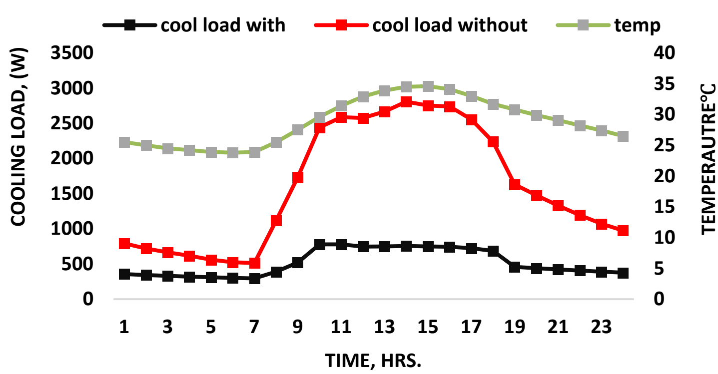


Figure 10: Cooling load and temperature with and without insulation during a typical day in fall.

The graph of Fig. 10 sets out the reference data for the experimental room, constructed with and without insulation, as well as the outside temperature for one season of the year, which is the fall, so that one can clearly see the difference. Thermal insulations save around 70% of the total energy consumption in residential building which is similar to results found previously [17].

After assessing the results, the room built with insulation saved considerable cooling load consumed in the experiment room. Therefore, in this hot climate city in Saudi Arabia, any building requires a considerable cooling load. This numerical experiment proved that the insulations used is a strong factor for reducing the amount of energy consumed. The reduction of the amount of energy consumed will cause a reduction of the electricity bills. In the experimental room, all forms of energy were properly used, including plugs, air conditioners and lights, which is why the energy consumed in the room was successfully increased. On the other hand, a room built without insulation will cost more energy, so it will lead to high electricity bills.

5 CONCLUSION

Extremely high energy consumption in residential buildings occurs in hot climates due to the high outside temperature. Although the energy makes residents comfortable, some side effects occur without their realizing, such as increase in electricity bills and CO_2 emissions. Consuming less energy affords us a healthier and cleaner environment. This numerical experiment and paper demonstrate the possibility of decreasing the amount of energy consumed in residential buildings by using the current building materials, which lead to lower electricity bills. Renewable energy sources such as solar and wind which generate electricity through solar panels and wind turbines are great options for clean and green energy in residential buildings.

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