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Research Article

Thermal Performance of Different Types of Engineering Materials in Basra City

Noor B Sakran* and Salih I Najim

Department of Mechanical Engineering, University of Basra, College of Engineering

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Abstract

*The present work is aimed to reduce the annual electric energy consumption in a residential building in Basra city through introducing a standardized rule for the annual electrical consumption for the cooling and heating purposes. This work will concentrate on all parameters which help to go toward the optimum use of thermally efficient house. The building energy analysis program **HAP 4.9** was used to simulate the annual energy consumption for a typical residential house built with six types of building materials. Building systems included a conventional building material (common brick) as base case, three types of common insulations (polyurethane, polystyrene and Cellulose fiber insulation), a flat type of Insulating Concrete Form (ICF) wall, and an Autoclaved Aerated Concrete (AAC) block wall. This research showed alternating significance between two different building techniques utilized in the study in terms of space cooling, heating and total annual energy consumption. These building techniques are (AAC and ICF) with liquid insulation coating which showed respectively (32.1%) and (26.83%) energy savings compared with the base case. Also, this study demonstrated the significance of the building techniques which utilize (window shading by overhangs and building orientation) where (33.45%) and (34.6%) respectively energy savings was shown for the AAC building system compared with the base case.*

Keywords: *AAC, ICF, polyurethane, polystyrene, Cellulose fiber insulation.*

1. Introduction

There is still an obvious and indisputable need for an increase in the efficiency of energy utilization in buildings. Heating, cooling and lighting appliances in buildings account for more than one third of the world's primary energy demand and there are great potentials, which can be obtained through the better applications of the energy use in buildings (Schmidt D, 2004). Residential buildings are distinguished by being envelope – load dominated building, hence are greatly affected by the outside climatic conditions. In Iraq, due to the harsh climate, residential building consumes maximum amount (more than half) of the total consumed energy by the air-conditioning systems which is required to remove main amount of gained heat due to poor thermal envelope performance (Hattab, K. M, 2010). In residential buildings, energy consumption and also electricity demand can reduce significantly by implementing proper envelope thermal characteristics, use modern building models. One important element in the concept of sustainable building is the use of materials. Rational selection of building materials for their optimal performance and minimal environmental impact is complex, as materials are multifunctional. Today, there is development of new and innovative of building materials and its envelope surface finishes. Most of the building codes for energy saving are focused on strengthening the insulation by using the hybrid insulations which are consisting of internal insulation and external thermal reflective coating (Pezeshki Z, 2018). In Iraq, there is decreasing in electricity generation and increasing in electric demand especially in the last decade. **Fig. (1)** explains comparison between electricity production and demand in Iraq from 1990 to 2017 therefore; all these reasons push forward more thinking in using new efficient building materials in Iraq (Ali, H. M, 2018).

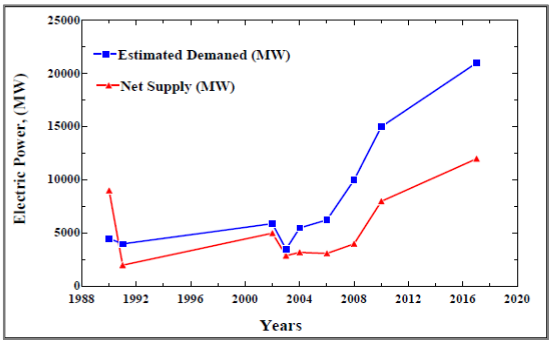

Fig.1.1 Comparison between electricity production and demand in Iraq

*Corresponding author's ORCID ID: 0000-0001-6110-7416
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In the field of using different type of building materials and insulation there are many experimental and numerical studies were conducted.

Al-Sherefy (2005) designed a new software which was used as a power tool for architect and mechanical engineers to test and correct the design of building elements such as windows, walls, ...etc. He concluded that it is possible to improve the thermal performance of a residential building in Basrah City by avoiding the large windows in eastern and western sides and using overhang with length equal to (25%) of the window height. He also found that the thermostone walls have the best performance as it resists the heat flow through it.

Amjed (2005) studied the effect of location of the insulation layer in building walls on the initial transient heat transfer response. This reference used the finite volume implicit method. Using the climatic data of Makka , the results showed that the insulation layer location had a minimal effect on the daily mean heat transmission load , with a slight advantage for the outside insulation in summer and inside insulation in winter . The outside insulation gave smaller amplitude of load fluctuation and smaller peak loads in both summer and winter for all wall orientations.

Naseer (2009)used eQuest software to test a single storey house built with thermostone which cause (5.9%) reduction in the annual cooling energy consumption, and (12.4%) in the annual heating energy consumption. However, insulating the base house with (50 mm) of polystyrene causes a significant reduction of (23%) and (42.8%) respectively in cooling and heating energy consumption. If the wall exterior color is changed to white, the annual cooling energy is reduced by (10.9%). Another reduction was done to the annual cooling and heating energy consumption by (4.2%) and (6%) respectively with percentage of glazed area not exceeding (15%) in the south and north directions and (2%) in the east and west directions.

Hattab (2010) studied seven different building systems. Building systems included a conventional building material (common brick) as base case, an Autoclaved Aerated Concrete (AAC) block wall, a flat type of Insulating Concrete Form (ICF) wall, two types of Sandwich Panel (Engineered and Typical), and two types of Cast in Place concrete walls (with exterior or interior insulation). She used **eQuest** energy simulation software for calculations. This research showed alternating significance between two different building techniques utilized in the study in terms of space cooling, heating and total annual energy consumption. These building techniques are AAC and ICF which showed respectively (29.4%) and (26.08%) energy savings compared with the base case. She also studied the effect of building orientation, where she found that the optimum orientation was in (270^o) anticlockwise.

Hasan.M(2018) conducted an experimental study for using phase change materials (PCM) as thermal insulation materials by its incorporating with layers of the walls and the ceiling. In this research two room's models have been built, the first model is a standard room for comparison and the second model is an experimental room for testing. Wasit university in Kut city, (32.5° N) latitude, was the place of the building models and testing of PCM. Many cases were studied according to the thickness of the PCM (1and 2 cm) and according to the orientation (North wall, South wall, East wall, West wall, and ceiling). Results obtained showed insulating the south wall (with 2cm of PCM) lead to higher reduction in the indoor temperature, the best case in cooling load reduction of the zone for peak hour was 1cm thickness of PCM for all wall 20.9% and they also found that the maximum saving in electricity cost of zone was (1.35 Dollar/Day m3) when using 1cm thickness of PCM for all walls.

2. Methodology

2.1 Selected city for modeling

The base house investigated in this work is located in Basra, Iraq (Lat. 30° 34´N, Long. 47° 47´ E). The climate in Basra is very hot in summer and fairly cold in winter. As a result, a considerable amount of energy is consumed in both summer and winter season for cooling and heating residential building.

2.3 Selecting a tool

Several computer programs are available for the calculation of building cooling and heating loads, one of this program was **Hap 4.9**. The HAP has the ability to simulate a wide variety of energy conservation measures in buildings and it has been widely tested for accuracy. Energy simulations for buildings using **HAP 4.9** have been carried out for many climatic conditions.

It performs an hourly simulation of the building design for a one-year period. It calculates heating or cooling load for each hour of the year, based on the factors such as: walls, windows, glass, people, and ventilation. It also simulates the performance of fans, pumps, chillers, boilers, and other energy consuming devices. During the simulation, it also tabulates the building's projected energy use for various end uses.

The following assumptions that made for (HAP 4.9) calculations in this study are:

1) The house is a single thermal zone, that is the indoor temperature is the same in all parts inside the house.
2) The comfortable temperature level is taken to be (25°C).
3) Heat flow through walls, windows and doors is in one dimension only, and its direction is perpendicular to the wall.
4) Ventilation is assumed to take place through infiltration all time.

3. Energy simulation

3.1 Methodology of Transfer Function

The transfer function method (TFM) or weighting factor method is a simplification of the laborious heat balance method. The wide application of the TFM is due to the user-friendliness of the inputs and outputs of the TFM software and the saving of computing time. In this method, interior surface temperatures and the space cooling load were first calculated by the exact heat balance method for many representative constructions. The transfer function coefficients (weighting factors) were then calculated which convert the heat gains to cooling loads.

3.2 Transfer Function and Time Function

The transfer function K of an element or a system is the ratio of Laplace transform of the output Y to the Laplace transform of the input or driving force G, or

$$Y = KG \tag{1}$$

When a continuous function of time f(t) is represented at regular intervals Δ t and its magnitudes are f(0), f(Δ), f(2 Δ), ..., f(n Δ), the Laplace transform is given as

$$\varphi(z) = f(0) + f(\Delta)z^{-1} + f(2\Delta)z^{-2} + ... + f(n\Delta)z^{-n} \tag{2}$$

Where Δ = time interval, h

$z = e^{s\Delta}$

The preceding polynomial in z^{-1} is called the transform of the continuous function f(t).

In Eq. (1), Y, K, and G can all be represented in the form of a z transform. Because of the radiative component and the associated heat storage effect, the space sensible cooling load at time t can be related to the sensible heat gains and previous cooling loads in the form of a continuous function of time f(t), which can be expressed as a z transform.

Weighting factors are transfer function coefficients presented in the form of z transform functions. Weighting factors are so called because they are used to weight the importance of current and historical values of heat gain and cooling load on currently calculated cooling loads.

4. The Average House (Base House)

The dimensions of the chosen house as shown in **Fig. (2)**. The characteristics of the base house and air conditioning system suggested are given in Tables (1,2).

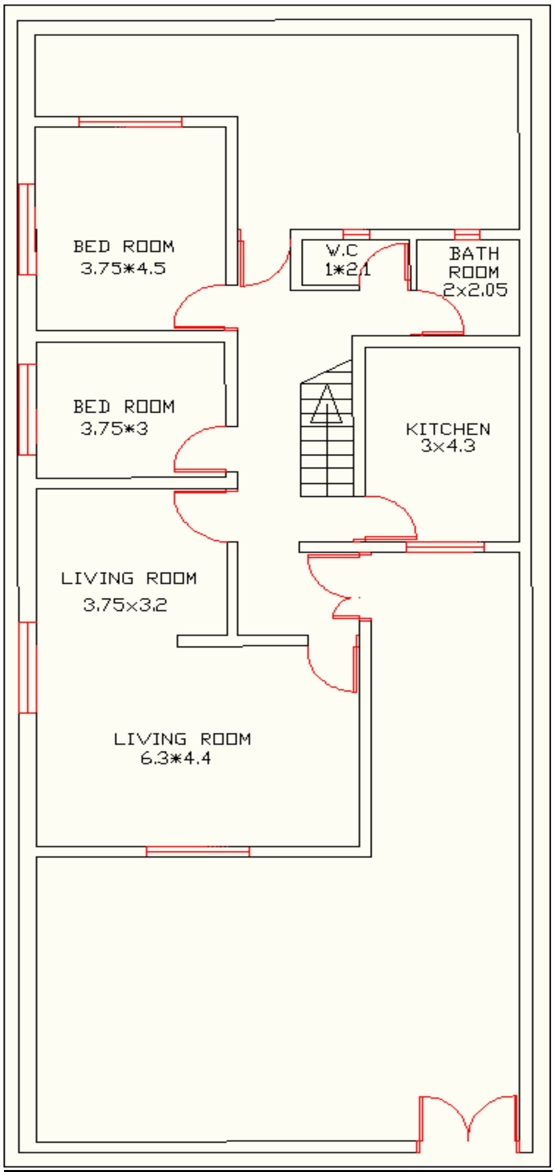


Fig.2 Ground Floor Plan for the Base House

Table 1: Characteristics of the Base House

Characteristics	Description (for Base House)
Orientation	Front elevation facing the south
Plan shape	Rectangular
Number of stories	2
Total height	6
Type of glass	Single pane with indoor shading by Venetian blinds (SC=0.67)
External shading devices	None
External walls	25 mm Stucco outside + 240 mm Common Brick + 25 mm Plaster inside
Internal walls	25 mm Plaster outside + 240 mm Common Brick + 25 mm Plaster insid
Roof	25 mm Tile+ 10 mm Sand + 100 mm Clean Earth+ 5 mm Asphalt + 150mm Concrete + 25mm Cement Plaster inside
Floor	25 mm Tile + 37 mm low weight concrete+ 240 mm sand
People living in it	8
Lighting	5.4 W/ m²
Infiltration	0.35 Air Changes per Hour

Table 2: The air conditioning system Characteristics of the Base House

Characteristics	Description
A/C System Type	DX Air-Cooled with Electric Heating
Thermostat type	Two – position with dual (heating and cooling) set point
Thermostat setting	25°C for cooling and 20 °C for heating
COP	2.9
Ventilation	None
Heating and cooling	Available all over the year

5. Results and discussion

5.1 Validation of HAP 4.9 Program

The HAP 4.9 program is used in the present study carry out the analysis for the total annual electric energy consumption. The HAP 4.9 program was validated by comparing the monthly total energy consumption for AAC and ICF (without liquid insulation coating) against the result computed by Hattab. This can be seen in (Figs. 3,4).

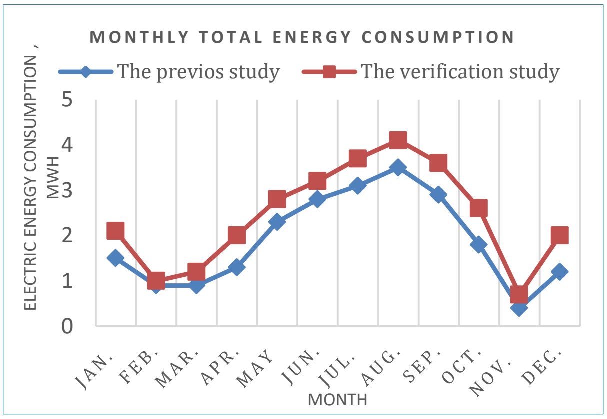


Fig.3 Comparison between the results of previous study and verification case for AAC building system

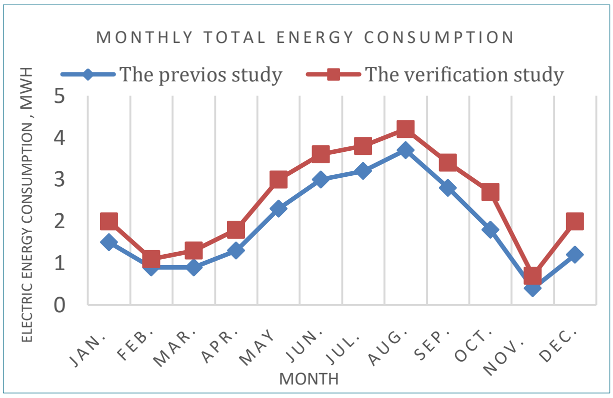


Fig.4 Comparison between the results of previous study and verification case for ICF building system

5.2 Test case 1 (Base- House)

The thermal performances of the Base House are given in **Fig.s (5,6,7)**. **Fig.5** shows the monthly total energy consumption for the base house which was built with the traditional material (common brick). It is noted that the maximum energy consumption takes place in August, it's value is about (6.3MWh). it is obvious that the cooling system consumes (19.62MWh) which conforms (62%) of the annual energy as given in **Fig. 6** and **Table 3** while the space heating load is about (2.45 MWh) which is equal to (7.8%) of the annual energy consumption. **Fig.7** show the annual peak demand by enduse where the annual peak demand is about (10.3 kW) in August which is equal to (79%) of the annual peak demand.

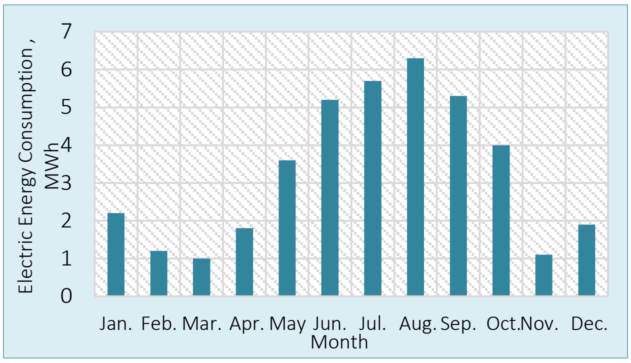


Fig.5 Monthly Total Energy Consumption

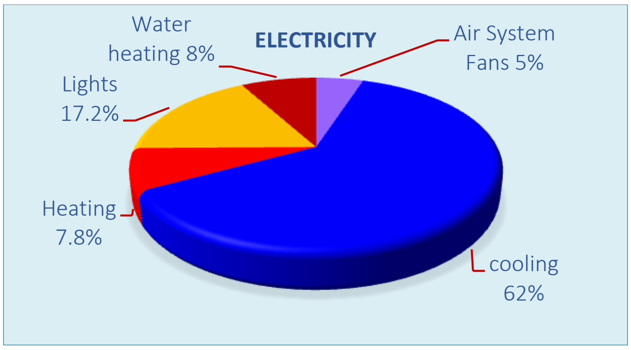


Fig.6 Annual Energy Consumption by End use

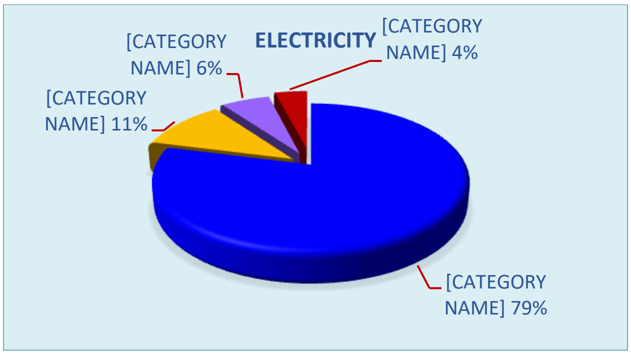


Fig.7 Annual Peak Demand by End use

5.3 Effect of Building Materials

The thermal properties of building materials are taken from references Hattab, K. M, Hasan, M.I and http://www.safecrete.com. Different types of materials effect are tested on the monthly and Annual Energy Consumption by end use as shown below.

5.3.1 Common Brick with polystyrene wall insulation

The thermal performance of this system is given in **Figs. (8,9,10)** where the monthly total energy consumption is shown in **Fig.8** which illustrate a maximum energy consumption of (5.6MWh). It is obvious that the space cooling conforms the high percentage of the total energy, this is indicated in **Fig. 9** and **Table 3** where the space cooling / heating loads contribute respectively (57.4%) and (4.98%) of the annual energy consumption, so, there are energy savings about (4.6%) in cooling and (2.82%) in heating compared with the base house. The annual peak demands by enduse are given in **Fig.10** where the space cooling load of about (7.2kW) contributes with (76%) of the electric demand.

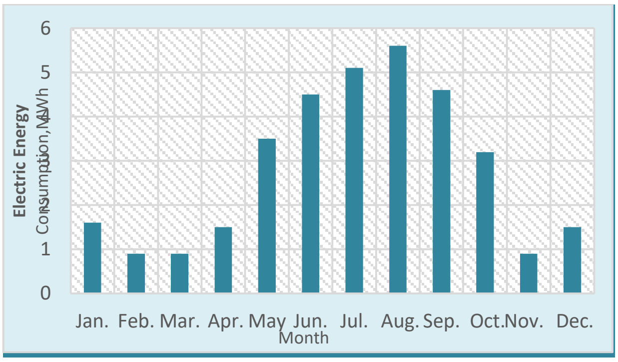


Fig.8 Monthly Total Energy Consumption

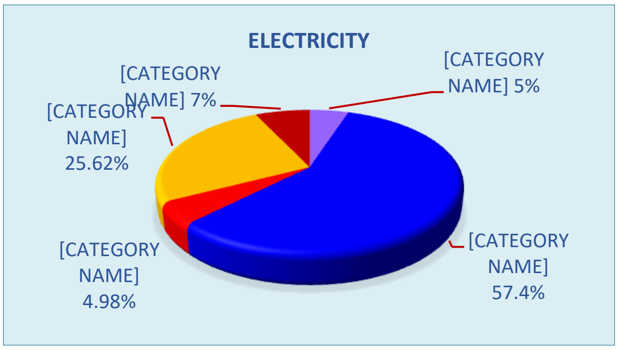


Fig.9 Annual Energy Consumption by End use

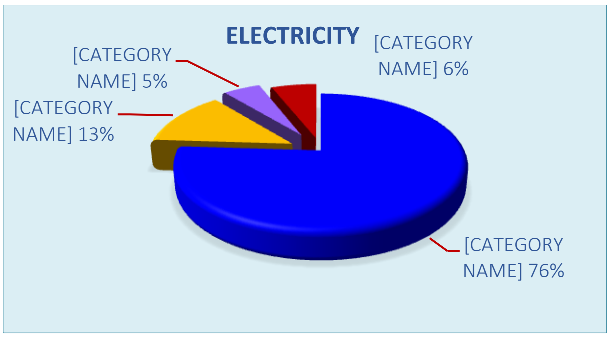


Fig.10 Annual Peak Demand by End use

5.3.2 Common Brick with polyurethane wall insulation

Figs. (11,12,13) present the thermal performance of the common brick with polyurethane wall insulation system where the total energy consumption for each month is shown in **Fig.11** which refers to maximum value of (5.3MWh) It seems clear that the maximum energy is consumed in August and the cooling load of (14MWh) is equal to (56.6%) of the total annual energy consumption as it is given in **Fig.12** and **Table 3** while the heating load energy of (1.22) MWh) conforms (4.93%).

The annual peak demand by enduse are shown in **Figs. 13**. It is obvious from Fig. (12) that the high cooling load energy conforms (75%) of the annual peak demand.

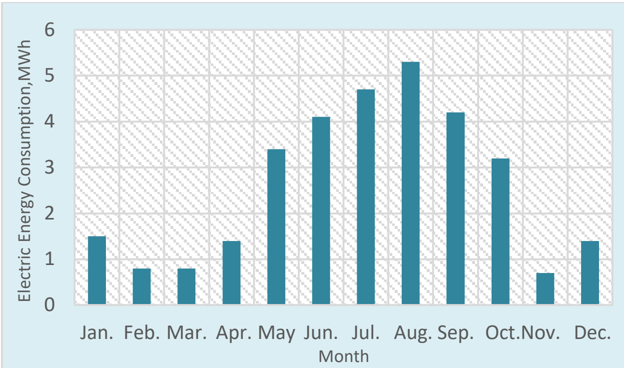


Fig.11 Monthly Total Energy Consumption

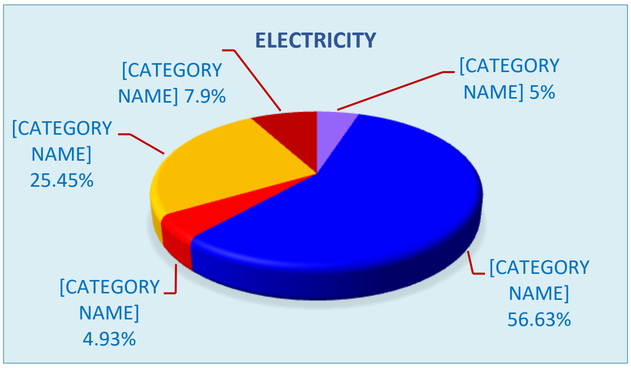


Fig. 12 Annual Energy Consumption by End use

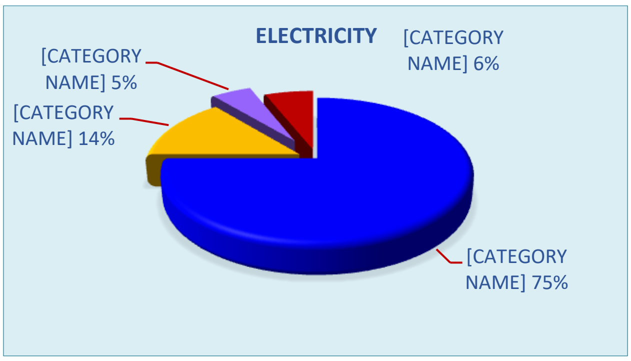


Fig.13 Annual Peak Demand by End use

5.3.3 Common Brick with Cellulose fiber insulation (C.F.I)

The monthly total energy consumption for this system is given in **Fig.14** where the maximum energy consumption is about (4.5 MWh) in August, the cooling energy consumption is about (13.13 MWh) and the heating system consumes (1.14 MWh), see **Table 3. Fig. 15** shows the annual energy consumption by endues where the space cooling load is about (55.24%) of the total annual energy consumption with saving of (6.76%) as compared with the base case while the space heating load is about (4.79%) of the total annual energy consumption with (3%) saving compared with the base case. **Fig.16** show annual peak demand by endues where the space cooling load is about (6.2 kW) and it conforms (74.8%) of the annual peak demand which is equal to (7.8 kW).

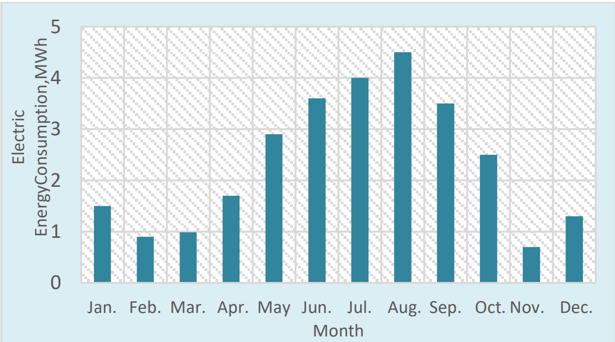


Fig.14 Monthly Total Energy Consumption

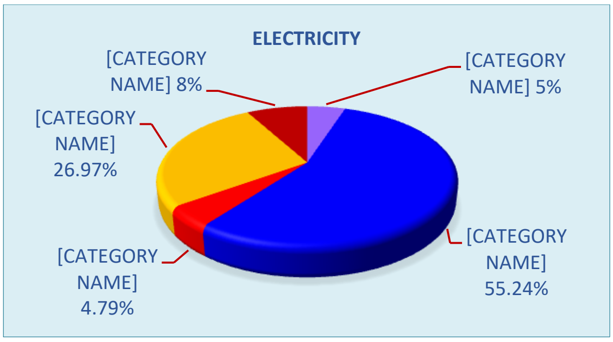


Fig.15 Annual Energy Consumption by End use

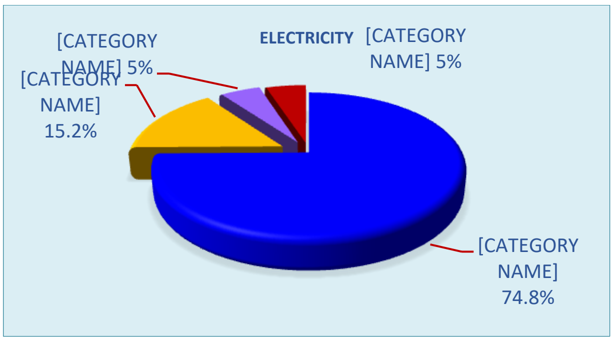


Fig.16 Annual Peak Demand by End use

5.3.4 Insulated Concrete Form Building System (ICF) With L.I.C

For this building system, the total energy consumption for each month are shown in **Fig. 17** which indicates the maximum value of (3.5 MWh). It is obvious that the space cooling load conforms (54.11%) of the annual energy consumption which is about (12.5MWh) and the space heating load is about (4.7%) as shown in **Fig. 18** and **Table 3**. The annual peak demands for each component are illustrated in **Fig.19** where (74%) of the annual peak demand.

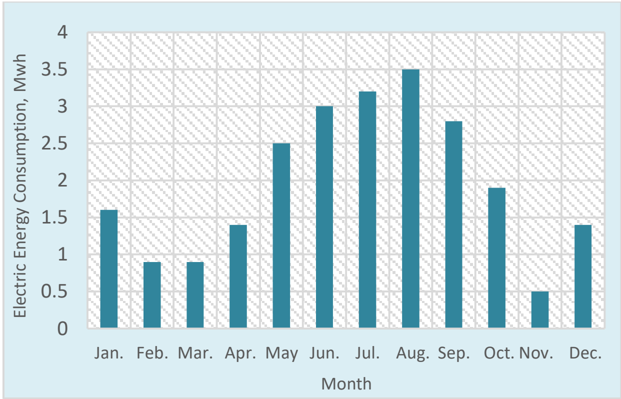


Fig. 17 Monthly Total Energy Consumption

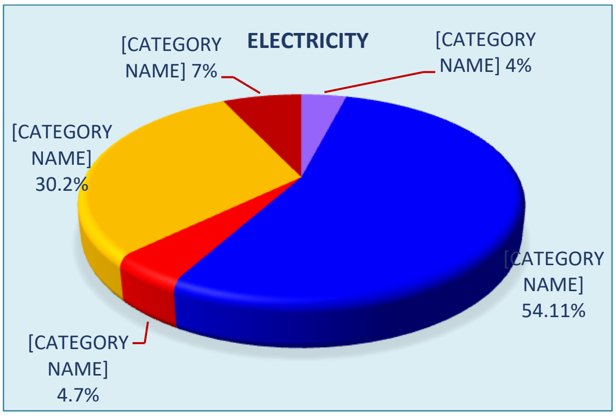


Fig. 18 Annual Energy Consumption by End use

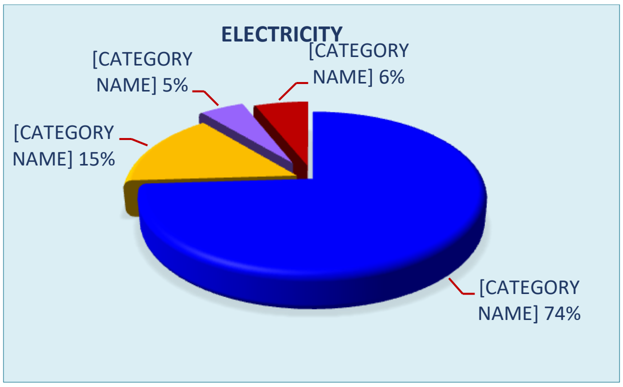


Fig.19 Annual Peak Demand by End use

5.3.6 Autoclaved Aerated Concrete Building System (AAC) With L.I.C

The monthly total energy consumption for AAC building system is given in **Fig.20** which shows the maximum energy consumption of (3MWh) It is clear that the maximum total energy takes place in August also where the cooling load is about (11.39 MWh) which is equal to (53.1%) of the annual energy as given in **Fig. 21** and **Table 3** while the heating load is about (0.56 MWh) and this is equal to (2.6%) of the annual energy with saving of (9%) in cooling load and (5.2%) in heating load compared with the base house. The annual peak demand by endues is shown in **Fig.22** where the maximum space cooling energy is (4.6 kW) which conforms (73.4%) of the annual peak demand.

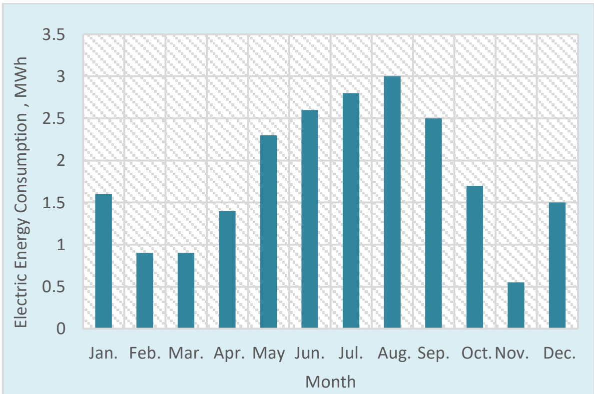


Fig.20 Monthly Total Energy Consumption

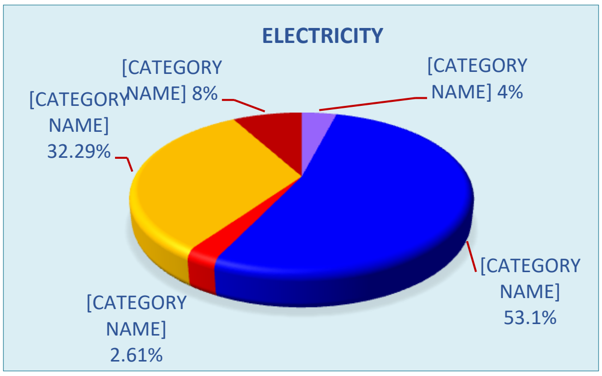


Fig. 21 Annual Energy Consumption by End use

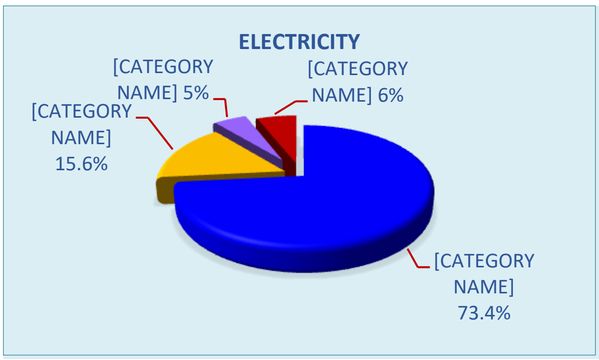


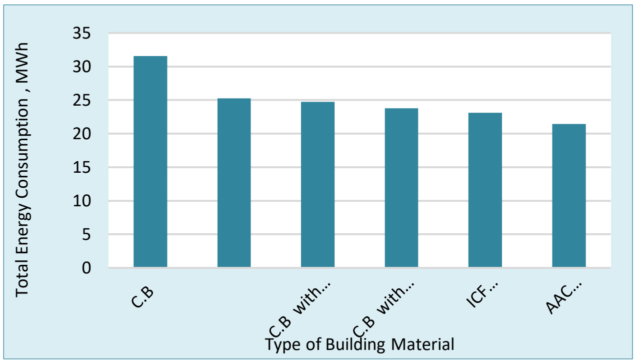
Fig.22 Annual Peak Demand by End use

Table 3 Annual Electric Energy Consumption obtained by (HAP 4.9) Program for a Typical House Built with Different Types of Building Materials

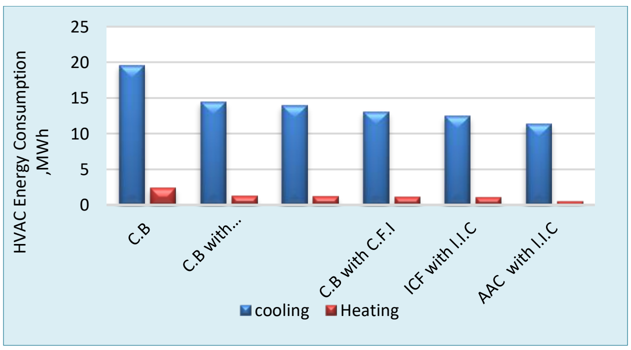
Type of building system	Cooling	Heating	Total	% Change of total Energy consumption
Common Brick	19.62	2.45	31.57	____
C.B with polystyrene insulation	14.5	1.26	25.26	-19.98%
C.B with polyurethane insulation	14	1.22	24.72	-21.69%
C.B with Cellulose fiber insulation	13.13	1.14	23.77	-24.71%
ICF with L.I.C	12.5	1.1	23.1	-26.83%
AAC with L.I.C	11.39	0.56	21.45	-32.1%

5.4 Analysis of the Simulation Results for Heating and Cooling Loads

A comparative chart for cooling, heating, and total energy consumption of all building systems without having any improvements is given in **Fig. 23(a,b).** This figure shows the maximum energy saving in the case of using AAC building system, it's about (42%) for cooling, (77%) for heating, and (32.1%) for total annual energy consumption compared to the base case. So, it can be concluded that low thermal conductivity of AAC can give better performance.



(a)



(b)

Fig.23 Effect of Building Material on the: a) Total Annual Energy Consumption b) HVAC Energy Consumption

5.5 Different Design Strategies

5.5.1 House Performance Due to Effect of Orientation

The effects of orientation of the (AAC with L.I.C) (Optimum case) is shown in **Fig. 21**. The model building is situated as it is illustrated in Fig. (24), with long external surfaces that face east (E) and west (W), and short building surfaces that face north (N) and south (S). The reference surface is south representing (0 º) in the graphic, and the model building is rotated every (45º) anticlockwise. **Table 4** gives the cooling, heating, and total annual energy consumption in the case of rotating the AAC model building.

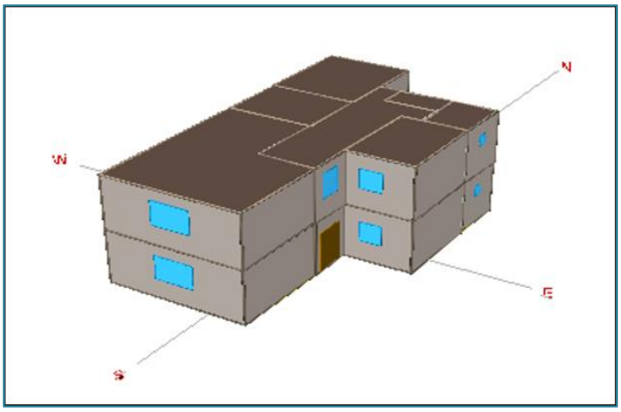


Fig. 24 Geometrical Model of the Building

Figs.25 present the thermal performance of this building when it is rotated with (45º) anticlockwise. It is obvious that the cooling energy is about (53.1%) of the annual energy consumption while the heating energy conforms only (3%).

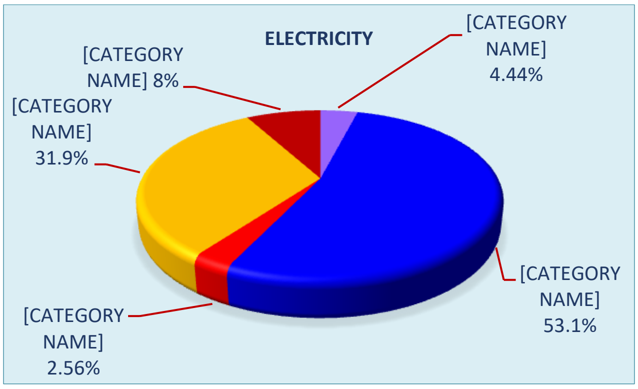


Fig.25 Annual Energy Consumption by End use

When the AAC building model is rotated (90º) anticlockwise, its thermal performance is given in **Fig. 26** From these figures, it is noted that the cooling system consumes about (52.3%) of the total annual energy while (2.47%) is consumed by the heating system.

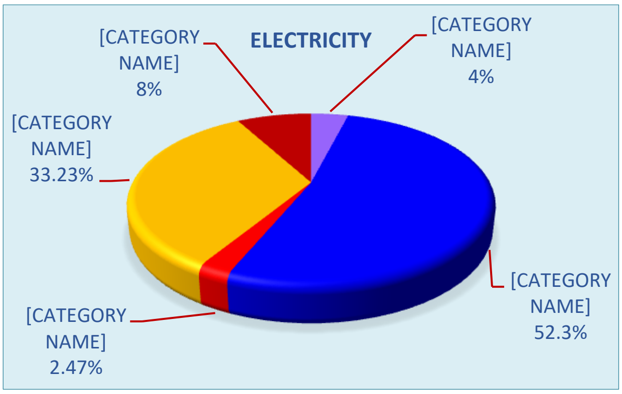


Fig .26 Annual Energy Consumption by Enduse

In the case of rotating the AAC building model with (135º), the cooling energy is slightly increased to (53.2%) of the annual energy consumption and the building performance is indicated in **Fig. 27.**

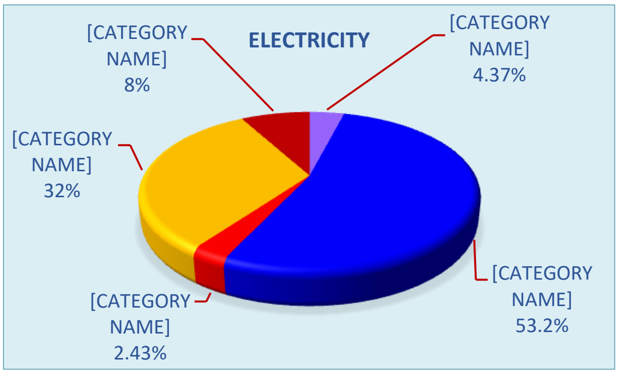


Fig.27 Annual Energy Consumption by Enduse

When the AAC building model is rotated with (180º), it is obvious that (53%) of the annual energy is consumed for cooling system or (2.66%) of the annual peak demand. see **Fig.28.**

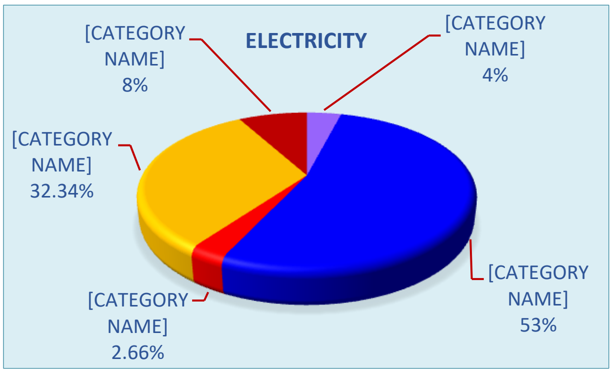


Fig .28 Annual Energy Consumption by Enduse

Fig.29 illustrate the annual energy consumption by enduse. in the case of rotating the AAC building model with (225º) where (53%) of the annual energy is consumed for cooling system and (2.66%) for heating system.

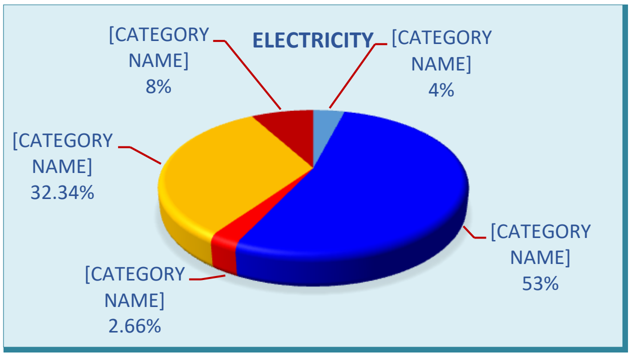


Fig.29 Annual Energy Consumption by End use

When this building system is rotated with (270°) anticlockwise or (90 °) clockwise, there is a reduction in energy consumption as shown in **Figs.30** where about (52.36%) of the annual energy is consumed by the cooling system and (2.43%) for heating system.

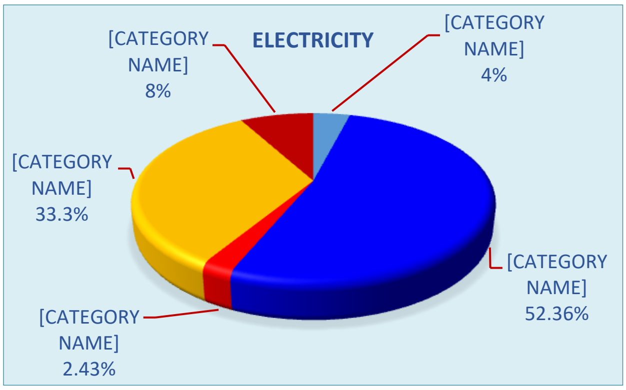


Fig.30 Annual Energy Consumption by End use

In the last stage, the building model is rotated with (315°). **Fig. 31** illustrate the thermal performance in this case. It is obvious that (53.15%) of the annual energy is consumed by the cooling system while the heating system consumed (2.56%).

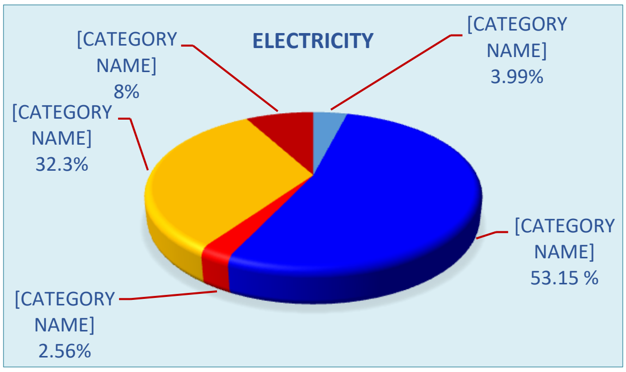


Fig.31 Annual Energy Consumption by End use

The impact of orientation on energy consumption of the AAC building model is shown in **Fig.32**. Note is observed here that greatest energy saving can be achieved by rotating the building (270 o anticlockwise. This is due to the short building surfaces which face east and west with low percentage of glazing (1%E and 12%W). Thus, east and west surfaces of the building do not receive high solar radiation. The worst orientation variables are when the building is rotated (45 o) and (135 o) due to higher solar heat gain from the large surfaces and windows.

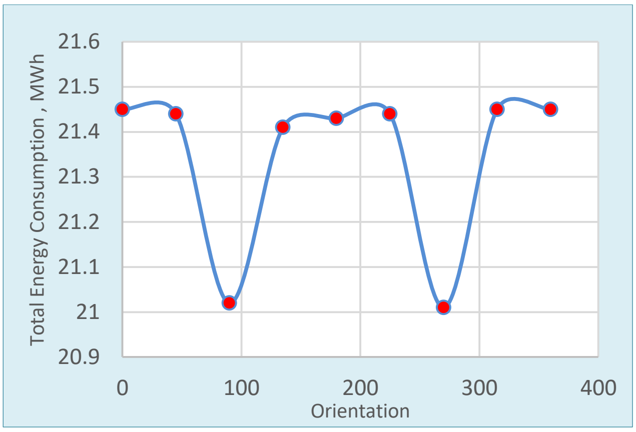


Fig. 32 Effect of Orientation on the Total Energy Consumption for AAC Building System

Table 4 Effect of Orientation on the Annual Electric Energy Consumption for a Typical House Built with AAC Building Material

Orientation (o)	Cooling	Heating	Total	% Change of total Energy consumption *
Base Case (0)	19.62	2.45	31.57	____
0 **	11.39	0.56	21.45	-32.1%
45	11.39	0.55	21.47	-32.1%
90	11	0.52	21.02	33.42%
135	11.39	0.52	21.6	-32.18%
180	11.36	0.57	21.43	-32.12%
225	11.37	0.57	21.44	-32.1%
270	11	0.51	21.01	-33.45%
315	11.4	0.55	21.47	-32.1%

* Comparison of energy consumption was made against the base house (Case1).
** The reference surface is south and the model building is rotated anticlockwise.

5.5.2. House Performance Due to Effect of Shading

The shading factor is assumed to be (0.67) in the simulations by **HAP 4.9** and the overhang depth of horizontal shading device was equal to (0.5m) for all windows.

The shading effect for the AAC building system on the total energy consumption and peak demand in a hot climate are displayed in **Table (6)** and **Figs.33**. It is obvious that shading with overhangs leads to annual energy consumption of (20.63 MWh) and cooling load about (10.76MWh). This means an average of (5.5%) reduction in cooling loads and about (3.82%) reduction in annual energy consumption compared with AAC building system without overhangs.

Table 6 Effect of Shading by Overhangs on the Annual Energy Consumption for AAC Building System

Type of House	Cooling (MWh)	Total (MWh)
AAC (without overhang)	11.39	21.45
AAC (with overhang)	10.76	20.63
% of Saving	5.5	3.82

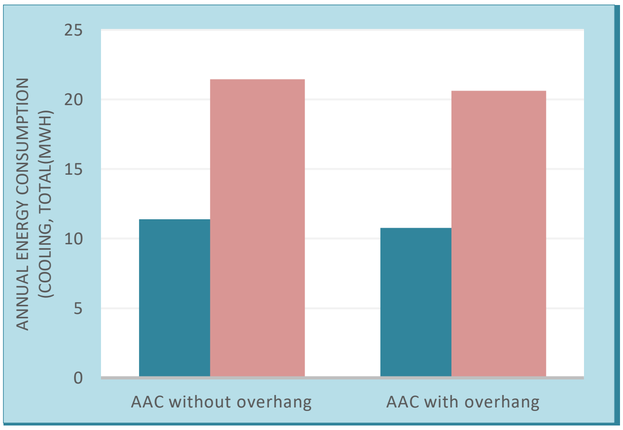


Fig. 33 Annual Energy Consumption by End use.

Conclusions

The important remarks of the results that have been built in the current study could be summarized as follow:

1) Within the Autoclaved Aerated Concrete (AAC) with L.I.C building system, the cooling, heating and total annual energy savings were significantly noticed. They were greater than other building systems which studied in this research.
2) The Insulated Concrete Form (ICF) with L.I.C building system with higher R-value better than Common Brick (C.B) with (polyurethane, polystyrene and Cellulose fiber) building systems. Therefore, for climates with hot summer, R-value are important in reducing annual energy consumption.
3) Orientation of the building with the long exposure facing south was found to be the optimum. The simulation results show that when the building model is oriented (90 o) anticlockwise, we achieve an average reduction of (33.42 %) in total annual energy. When the building is oriented with (270 o) anticlockwise, an average reduction of (33.45 %) in the total annual energy consumption, is achieved.
4) Shading should be essential strategy for house energy conservation in hot climate. The simulation results show that in the overhangs case we achieved an average saving of (5.5%) in cooling load while the annual energy saving is found to be (3.82%).

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