

Assessment of energy saving in residential buildings using energy efficiency measures under Cairo climatic conditions

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ABSTRACT

This paper investigates the residential building energy needs in Egypt. Firstly, the energy needs of residential building are evaluated in compliance with Energy Efficiency Residential Building Code as a base case. Then, Energy Efficiency Measures (EEMs) defined as measures that reduce energy consumption whilst maintaining the same or better indoor climate conditions are implemented as a modified case using building simulation technique. The considered EEMs include adding thermal insulation to the exterior walls, adding external shading, using lighting fixture with high efficacy and using window glazing type with high thermal and radiation characteristic. Finally, a comparison between the base and modified cases is made. The reported results showed that the thermal cooling demand, heating demand and total electricity demand of the base case are 130 kWh/m².a, 6.5 kWh/m².a and 114 kWh/m².a, respectively. It is found that as the overall heat transfer coefficient of external wall decreases from 1.7 W/m²K to 0.58W/m²K causes the cooling and heating demands to decrease by 7% and 60%, respectively. Adding shading with a projection factor of 0.9 for all external windows decreases the cooling demands by 13%. Using double glazing decreases the cooling and heating demands by 14% and 30%, respectively. Installing LED lighting type reduces the annual space cooling demand and electricity consumption by 17% and 26%, respectively. The values of each EEM which are the lowest energy needs, combining to get the optimized case in which the cooling demand, total electricity and the heating demand decrease by 34%, 17% and 11% respectively.

1.1 INTRODUCTION

Buildings over the world consumes around 40% of the world’s total energy consumption [1]. The delivered energy consumption in the buildings worldwide increases annually by an average of 1.5% from 2012 to 2040 as reported in International Energy Outlook 2016[2]. In Egypt, the residential building consumes around 51% of the total electricity supplied to the grid during 2016/2017 [3] as shown in Fig.1

Implementing energy saving strategies is a pillar of “the Sustainable Development strategy, Egyptian Vision 2030. Energy Efficiency Measures (EEMs) can be implemented to achieve energy saving in the building sector. There are many strategies of building design to enhance the energy performance and reduce the energy consumption by implementing EEMs [4-5]. Comparison between different international building codes were reported in literature [6–8]. It was found that LEED, international green construction code (IGCC) and ASHARE have the same number of points of concerning materials category. Both IGCC and ASHRAE standards were recommended to be used for the design with high performance buildings while the LEED has got the highest points in social and economic aspects. In Egypt, Energy Efficiency Building Codes [9- 10] deal with the energy performance requirements of residential and nonresidential buildings.

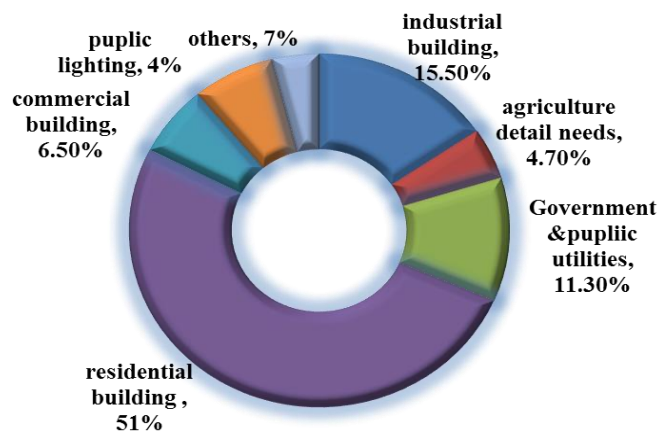


Fig.1 Total electricity in Egypt during 2016-2017 [3]

Optimizing the building envelope elements includes the exterior wall insulation, roof insulation, window area, window glazing, window shading and thermal mass as improvement of the energy performance in residential buildings [1, 11]. They reported that implementing energy efficiency measures as thickness of the exterior wall insulation layer can save up to 842 MW of peak demand energy, and 2190 kilotonnes /year reduction of CO₂ emission. This is equivalent to 3.37TWh of electricity consumption compared to the base case. Various investigations [11,12] presented increasing the energy efficiency in buildings by changing the overall heat transfer coefficient of thermal roof and exterior wall insulation. The increasing the thickness of the insulation layer of exterior wall insulation and using better material, reducing the heating and cooling demands.

The influence of variation in the shading projection factor on building energy consumption are carried out by Alghoul [13]. Their results showed that adding shading for a building reduction the cooling loads and energy savings. The influence of variation of windows shading with low-transmittance characteristics of glazing is predicted in [14]. It's found that the increasing of window shading reduced the cooling load from 26% to 31% compared to base case.

In Raslan [15] classified the residential building and input data into five blocks as high income high rise, low income high rise, low income low rise, high income villa and rural house. Marzouk and Metawie [16] Optimized the Low income housing as one of most important housing in Egypt. Several building simulation tools were used such as Energy-plus [13,17,18,19], eQUEST which is the acronym of the Quick Energy Simulation Tool [17] and design builder [1] to evaluate the buildings performance. The integrated tool of Open Studio and Energy-plus as the building simulation tool was used in various investigations [2,3,6,10,11, 20]. Egyptian code for the residential building has been issued in 2006 [4]. This code describes three different paths for the residential buildings. The first path is the descriptive path where the limitation of the thermal properties of envelope elements, air infiltration rates, natural ventilation rates. , artificial fixture lighting according space area should be followed.

The second path is the trade-off path where the overall thermal transfer value for the envelope has do not exceed than the code value. The third path is the whole building performance assessment using the building simulation tool. The third path doesn't indicate any limitation values for the building energy needs.

Therefore, the objective of this research is to assess the building energy needs of the residential building following the code descriptive path (2). Also, assessing the energy saving potential in result of implementing some considered Energy Efficiency Measures.

1.2 Research Methodology

In the present work, a low-income high-rise building is selected as a residential building to be investigated. The selected low-income high rise building has characteristic in compliance with the Energy Efficiency for Residential Building Code [9]. This building consists of 8 stores, each store has 4 apartments. Each story has the floor area of 386m². Each apartment has floor area of 90 m² and height of 3m as shown in Fig .2The apartment is divided into 6 spaces; namely two bed room, reception, kitchen, bath room and hall as shown in Fig 2. The air conditioning spaces are the bed room and reception, which represent 72.5% of the total apartment area. The un-air conditioning spaces are bath room, kitchen, vertical circulation space and halls, which represent 27.5% of the total apartment area.

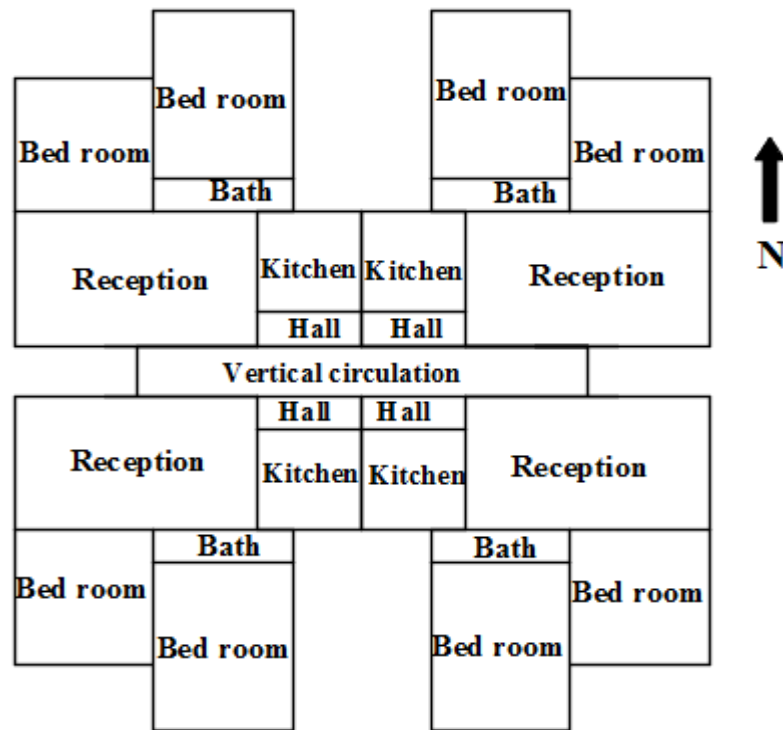


Fig.2 Plane space

The building components for this building are assumed to meet the requirements for Energy efficiency for residential building code [9].Characteristic of building components is given in Table 1.

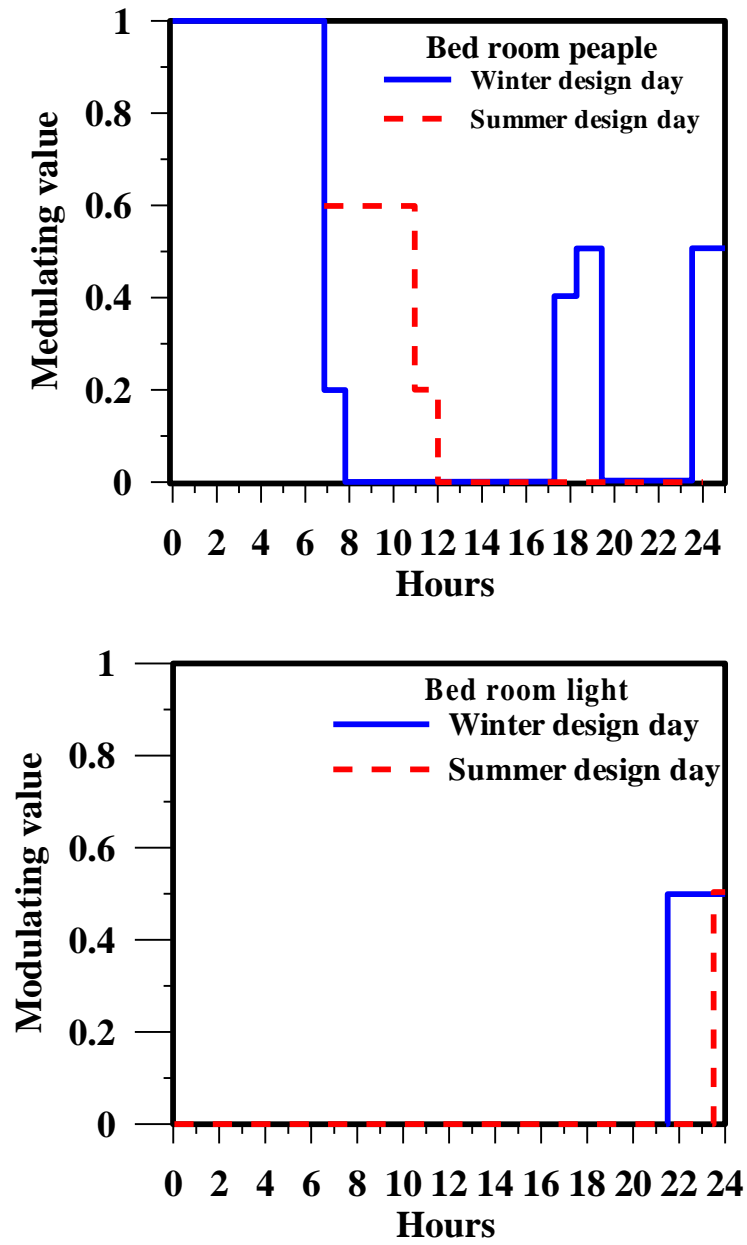
Table 1 Envelope performance characteristic [4]

Characteristics	Value
overall heat transfer coefficient	W/m ² .K
Exterior wall	1.7
Exterior roof	0.319
External glazing	5.05
The maximum leakage rate factor	L/s per square meter of fenestration area
Exterior wall	1.7
The window to wall ratio(WWR) with no shading	
Exterior wall	0.3

Table 2 gives the peak internal heat gain for each apartment space. Figure 3 shows the seasonally internal gain schedules for each apartment space [21]. The most set points were 21°C heating, 24°C cooling during occupied house. There is 2-hours the most warm-up period between 6 am and 8 am week day morning [9]. These internal gain schedules differ from space to another. Each space has its schedules of lighting, people and equipment loads as shown in Fig. 3. The people occupation of building defines the number of person and their activities. The Peak demands for some given months in the year and using this peak to make a fractional schedule for the hourly usage by dividing each consumption by the peak one and make a fractional percentage that could be used in domestic hot water (DHW) Schedules. It is found that hot water demand is 89 L/day in winter, while it is 54 L/day in summer [21].

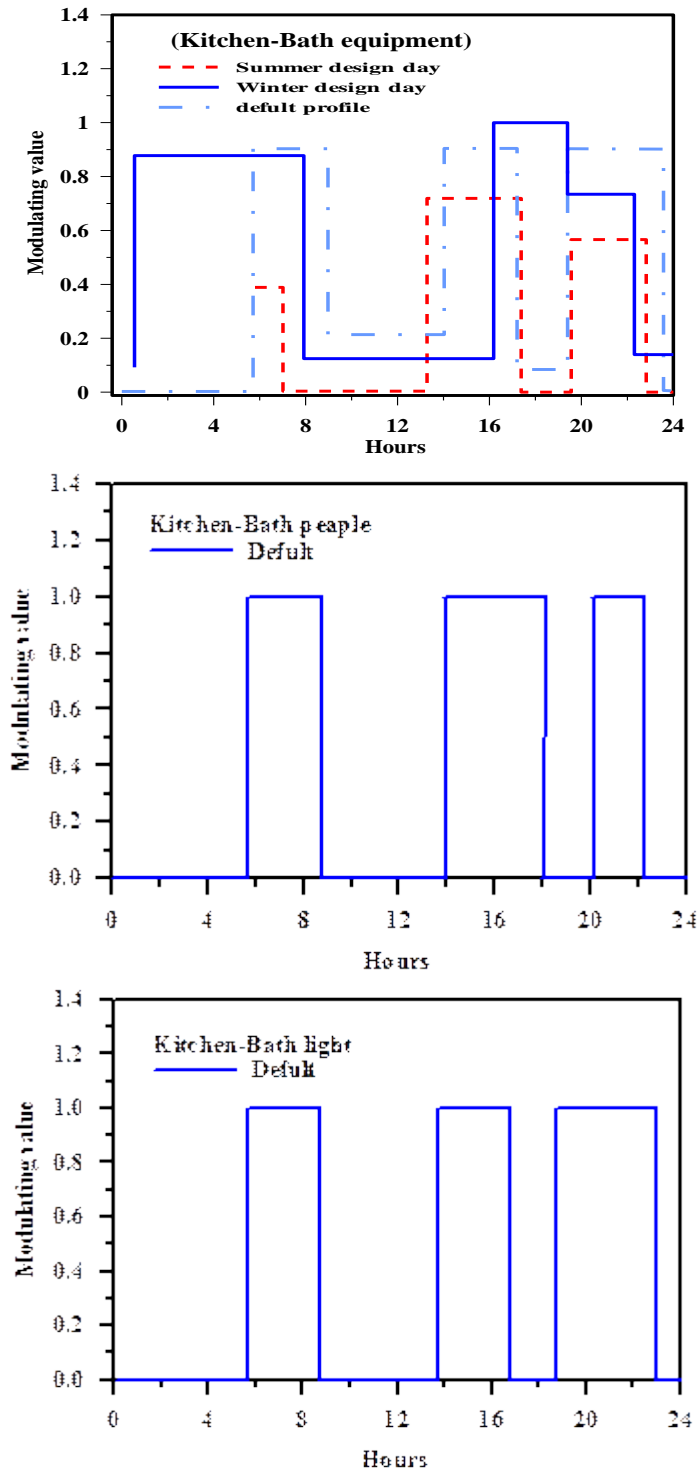
Table 2 The peak internal gains [4]

	Bed room-1	Bed room-2	Reception	Kitchen	Bath
Lighting W/m ²	10	10	19	11	14
occupancy W/m ²	7.4	12.8	18.3	21	26
Electrical equipment W/m ²	6	6	6	6	6



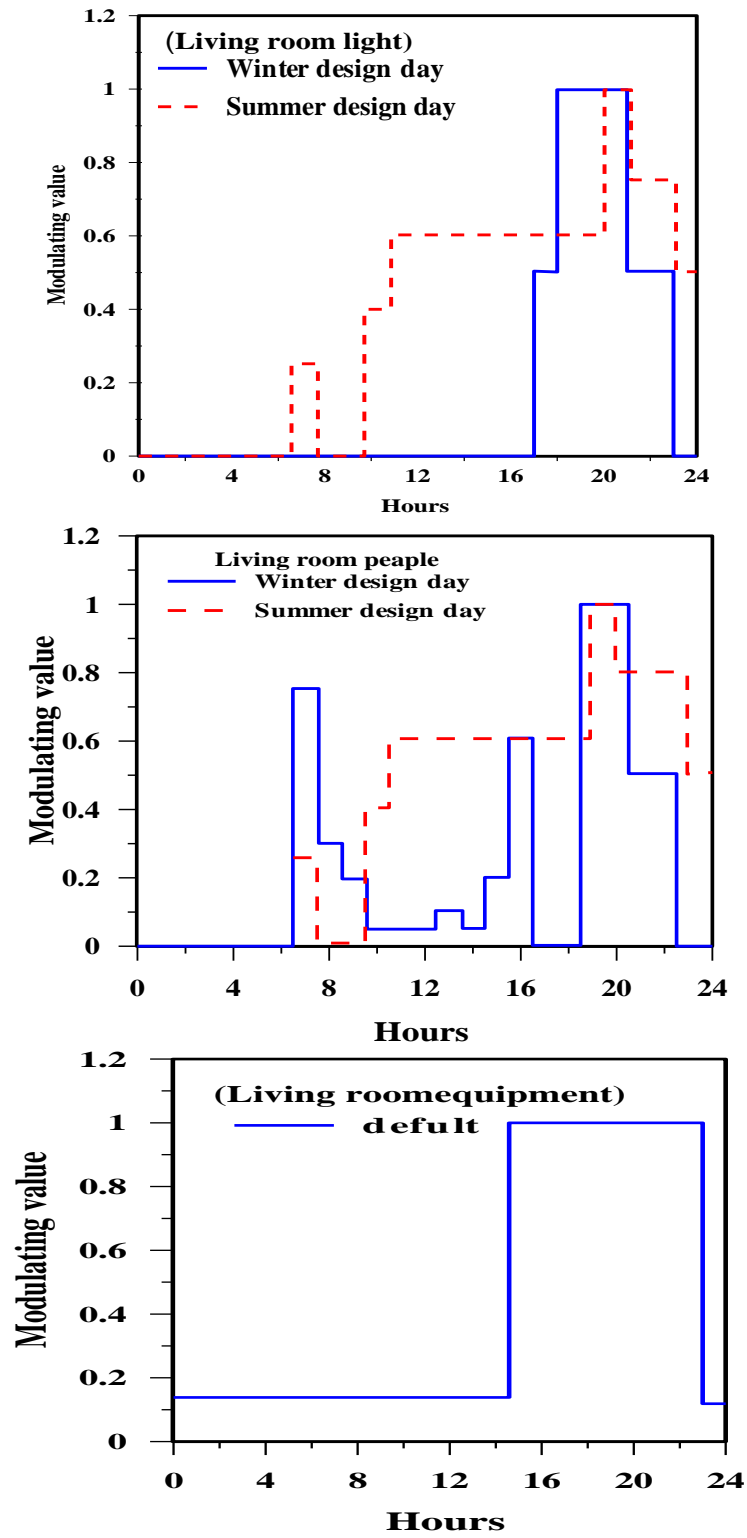
(a) Bed room schedules

Fig 3. 1 The hourly peak schedule [21]

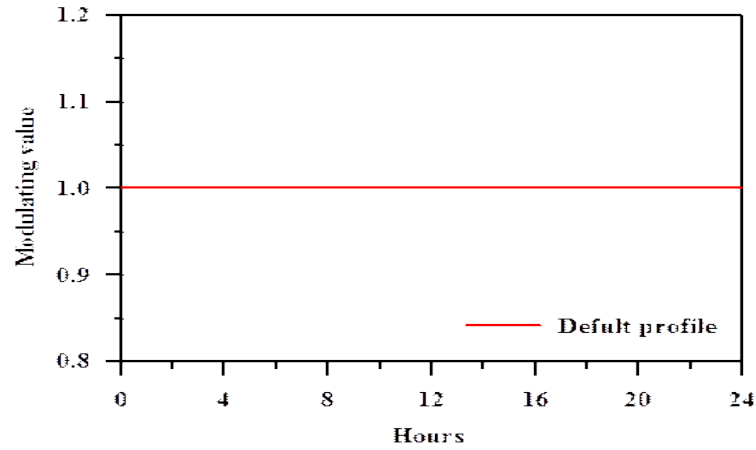


(b) Kitchen –bath schedules

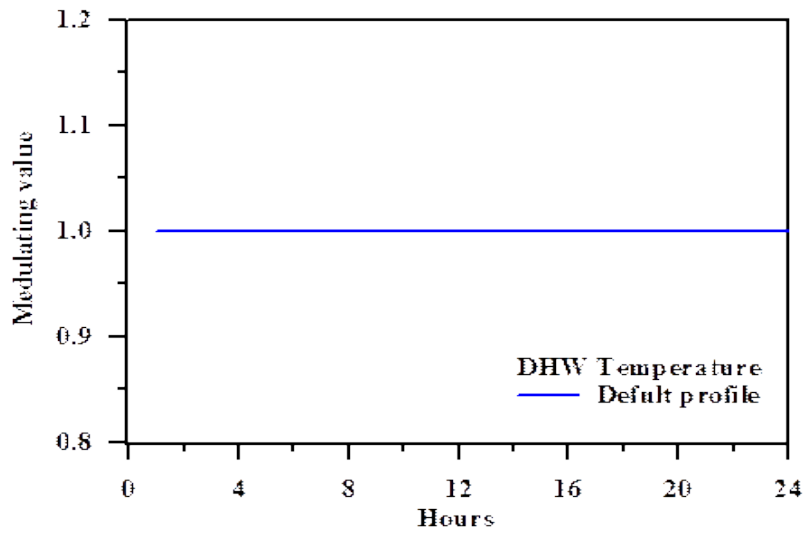
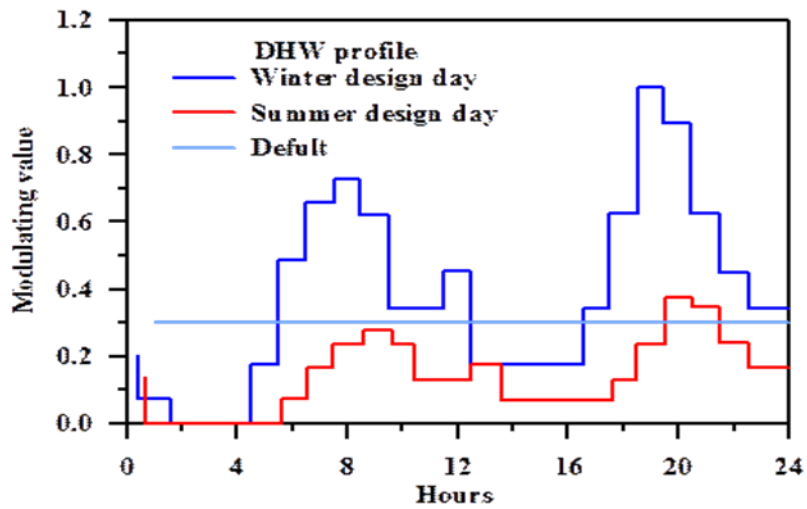
Fig. 3. 2 The hourly peak schedule [21]



(c) Living room schedules
 Fig 3. 3 The hourly peak schedule [21]

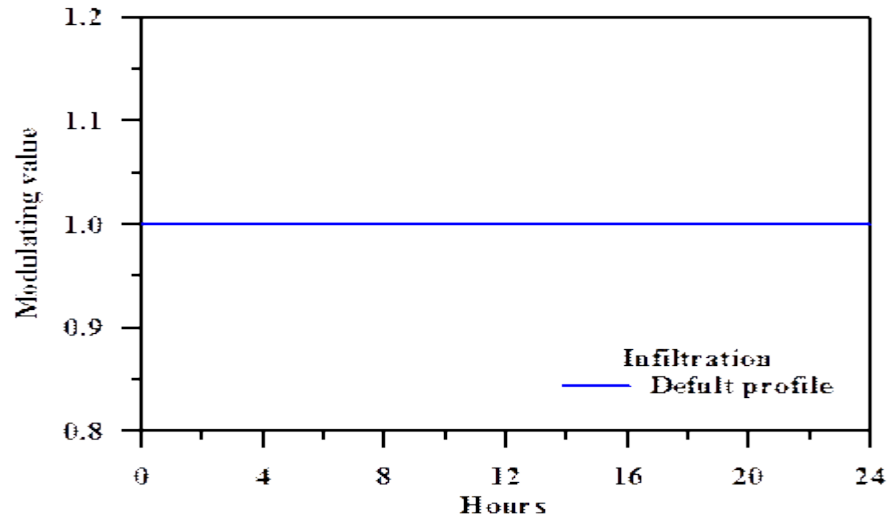


(d)Hall (corridor) schedules



(e)DHW schedules

Fig 3. 4The hourly peak schedule [21]



(f)Infiltration schedules

Fig.3.5 The hourly peak schedule [21]

1.2.1 EEMs description

There are many parameters are affecting the total heating and cooling energy consumption in buildings such as external shading, adding thermal insulation for exterior walls and roofs, etc. This section aims to predict the effect of implemented EEMs on the building demand whether cooling, heating and electrical demands. The implemented EEMs are adding external shading, adding thermal insulation for exterior walls, changing of the window glazing type and changing the type of fixture lighting. The first implemented EEM is adding external shading with different projection factors (from 0.1 to 0.9). The projection factor (P.F) is defined as the ratio between the horizontal distance of shading to the window height when the shading is installed to adjustment to the window top edge [11]. It may be noted that the shading is added to all windows of either each exterior wall orientation (North, south, east, west) or all exterior wall orientations.

The second implemented EEM is adding thermal insulation within the exterior wall. The insulation material, which has thermal conductivity 0.04 W/m K, density 16 kg/m³, specific heat 840 J/kg K, is added. The insulation thickness is changed from

0.01m to 0.045m with step 0.005m. The overall thermal resistance of the exterior wall is changed from 0.84 m².K/W to 1.7 m².K/W. The third implemented EEM is the window glazing type as shown in Table3.

The fourth implemented EEM is changing lighting fixture to be based on compact fluorescent lamp (CFL) and light emitting diode (LED) having high lighting efficiency. (i.e. low electrical wattage and high lighting lumens). Table 4 summarizes the wattage intensity in all spaces taking into consideration that the same lighting intensity must be achieved. Finally, it can be a make combination from all EEMs to reach the lowest energy needs.

Table 3 Glass types characteristics [4]

Name	Over all heat transfer coefficient, U (W/ m ² K)	Solar heat gain coefficient SHGC	The visible lighting transmittance TVIS
Single glazing clear	6.17	0.81	0.88
Single reflective (A) tint medium emissivity	5.11	0.25	0.09
Double Glazing tint low emissivity	1.78	0.28	0.44

Table 4 Different wattage intensity (W/m²) [4]

Space	Light type		
	Base case[Watt/m ²]	CFL [Watt/m ²]	LED [Watt/m ²]
Bedroom	14	1.28	1.07
Guest room	19	5.14	4.28
Living room	14	5.14	4.28
Bathroom	10	2.57	2.14
Kitchens	11	3.43	2.86
Corridors	14	2.57	2.14

Direct expanding split (DX) air conditioning unit without inverter is installed in the residential buildings. It is assumed to be used in the air conditioning spaces in the base model to calculate the delivered electricity. The coefficient of performance values of air-conditioning unit operating in cooling and heating modes are 3 and 4, respectively, in compliance with the Energy efficiency for residential building code [9].

Initially, the base case model of the residential building is defined and simulated to obtain its performance characteristics. The building simulation is carried out using combination of software tools. Sketch-up 2017 version Windows 64-bit 17.2.2555 is used to draw the building model. The basic characteristic of the building model envelope, internal gains, schedules ...etc. are defined using Open-Studio version 2.3.0. Finally, Energy Plus version V8-6-0 0 is used as a building simulation tool to get the simulation results. These three combined tools were used by several researches in literature [11,16,17].

1.3 Results and discussion

This section presents the energy demands in the base and modified cases of the low-income high rise residential building. The results are categorized into thermal and electrical demands. The thermal demands include space cooling and space heating, while the electrical demand includes lighting, equipment, domestic hot water heater, pump and fans.

Fig .4 indicates the annual space cooling of the base case of the low-income high rise residential building under Cairo climatic conditions. It is found that the space cooling demand increases to 50W/m^2 at 4000hour then decreases. The hourly annual space heating demands is presented in Fig.5 Clearly, it increases to 32.5W/m^2 at 2000hours (winter season) then decreases to 0 W/m^2 from 2000hours to 7500 (summer season) after that increases to 21 W/m^2 from 7500 hours to the end of the year (summer season). The peak of the thermal cooling and heating demands are 50 kW and 32.5 kW , respectively, as shown in Fig. 6.

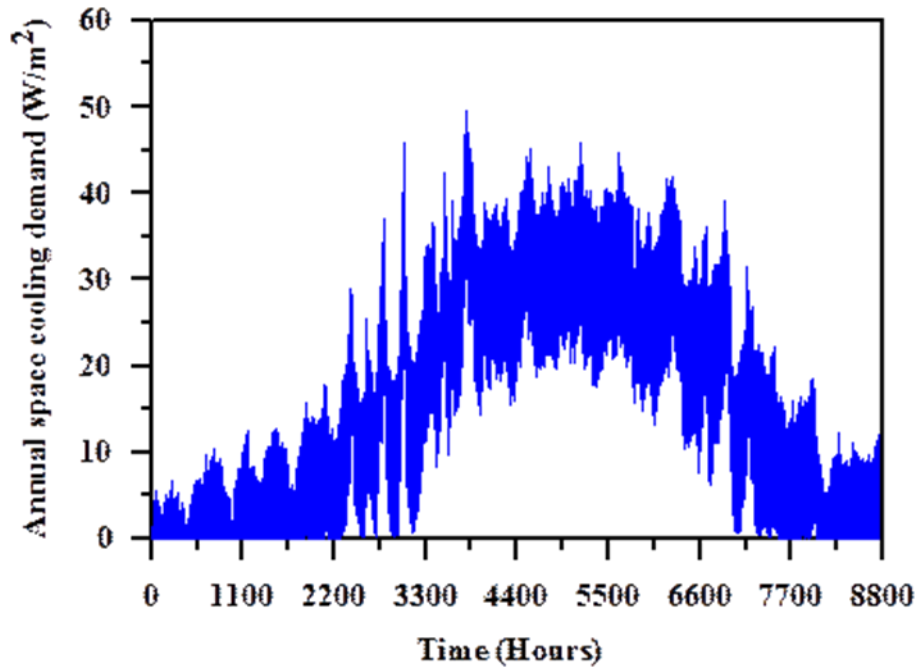


Fig .4 Base case normalized annual space cooling demand

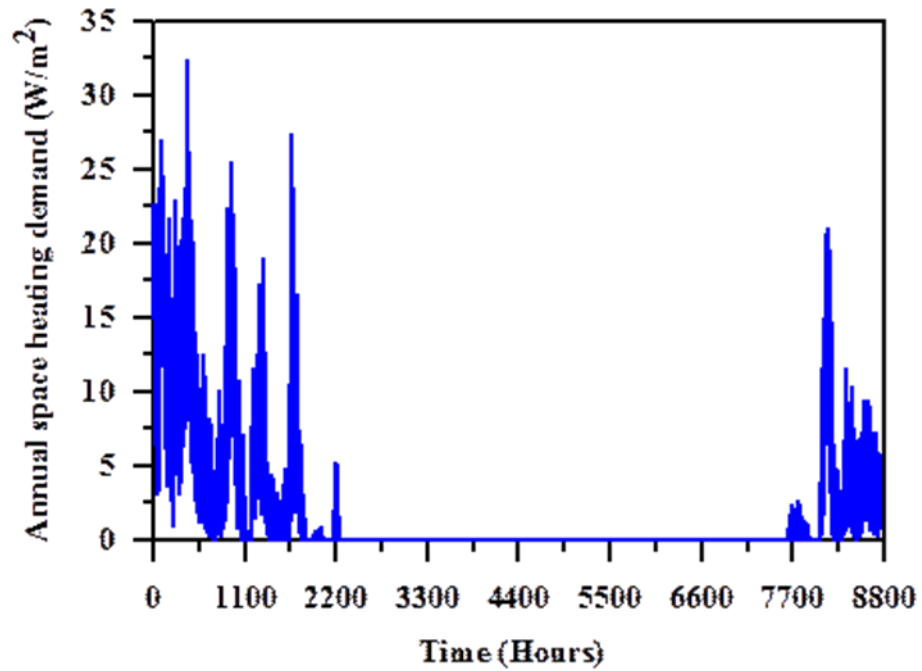


Fig 5 Base case normalized space heating demand

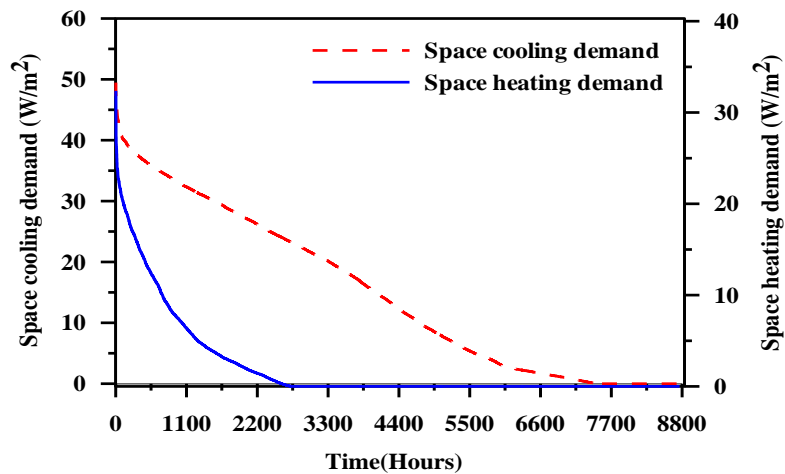


Fig.6 Duration time base case normalized space cooling and heating demand

Fig.7 shows monthly breakdown energy demands. It can be noticed that the space cooling demand reaches the peak monthly value of 18.5 kWh/m² in July. The space heating demand reaches the peak monthly value of 1.8kWh/m² in January, while the hot water demand reaches its peak value of 4 kWh/m² per month in winter months. Fig.8 reveals that the cooling and heating demand electricity are 130 kWh/m².a and 6.5 kWh/m².a, respectively. Fig. 9 indicates that the cooling and heating delivered electricity are 56 kWh/m².a and 5.7 kWh/m².a corresponding to 35% and 4% of the total annual delivered electricity, respectively. Fig.10 shows Average ambient Temperature used in this research and last 5 years of Cairo. In our case, the objective to study the annual performance demands of residential building in compliance with Energy Efficiency Residential Building Code, ECP-306 [4]. To validate our results, there was not enough published works that had quite similar or sufficient model inputs such as the investigated building typology, weather file used, load and occupancy schedule that can be compared with our case. However, in Attia [22] based on the electrical demand survey done depending on the utility bill for residential apartment (more than 500) in Cairo, it is noticed that the annual electrical demand varies from 90 to 18 kWh/m².a depending on the life style, appliances, DWH heater (gas heater or electrical one), and number of A/C per apartment. Our results indicated that the total

electrical demand of cooling, heating, appliances, and lighting is 107.2 kWh/m².a. The variation mostly is depending on differences of the building typology, load schedule, and in our case, we consider A/C is installed in bedrooms and living room. Other studied also presented the annual electrical demand is 110 kWh/m².a [23] and 45 kWh/m².a [24] for residential building in Cairo. Based on this clarification, it can be concluded that the results of this work are reasonable.

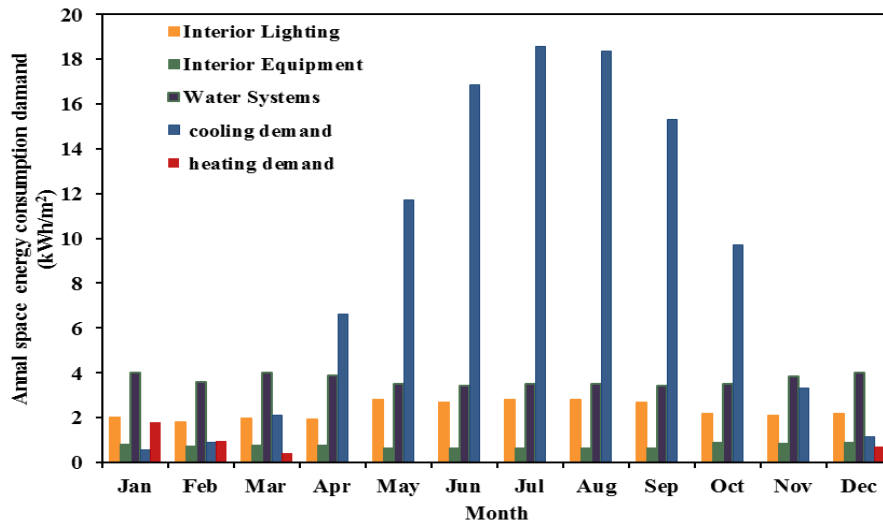


Fig. 7 Base case monthly space energy consumption (kWh/m² per month)

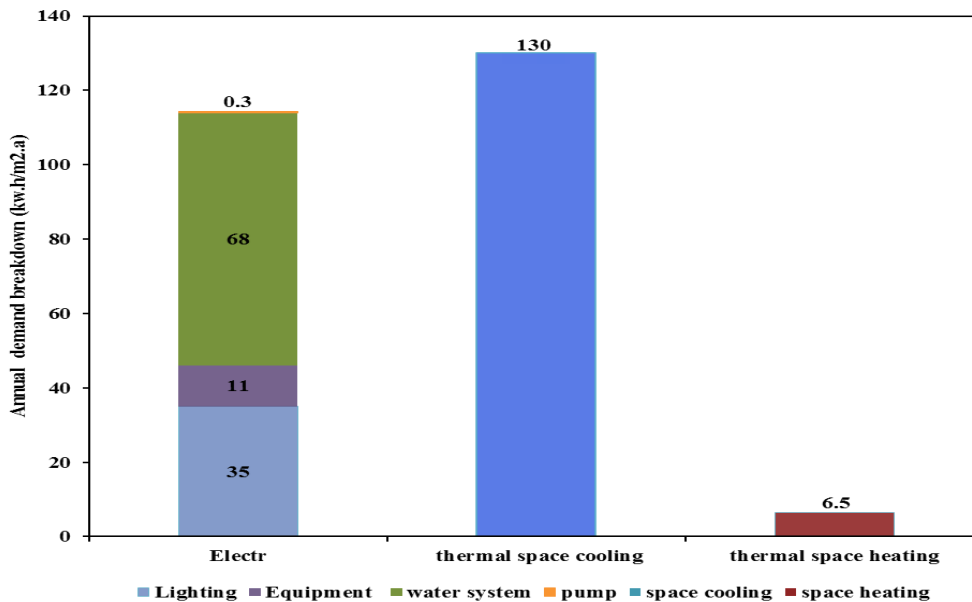


Fig. 8 Base case annual demand breakdown.

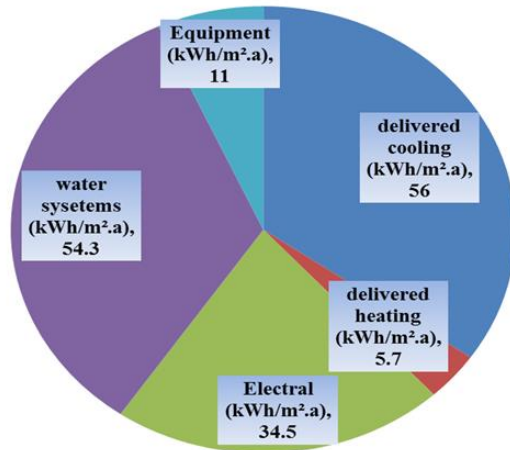


Fig. 9 Electrical delivered energy (kWh/m².a)

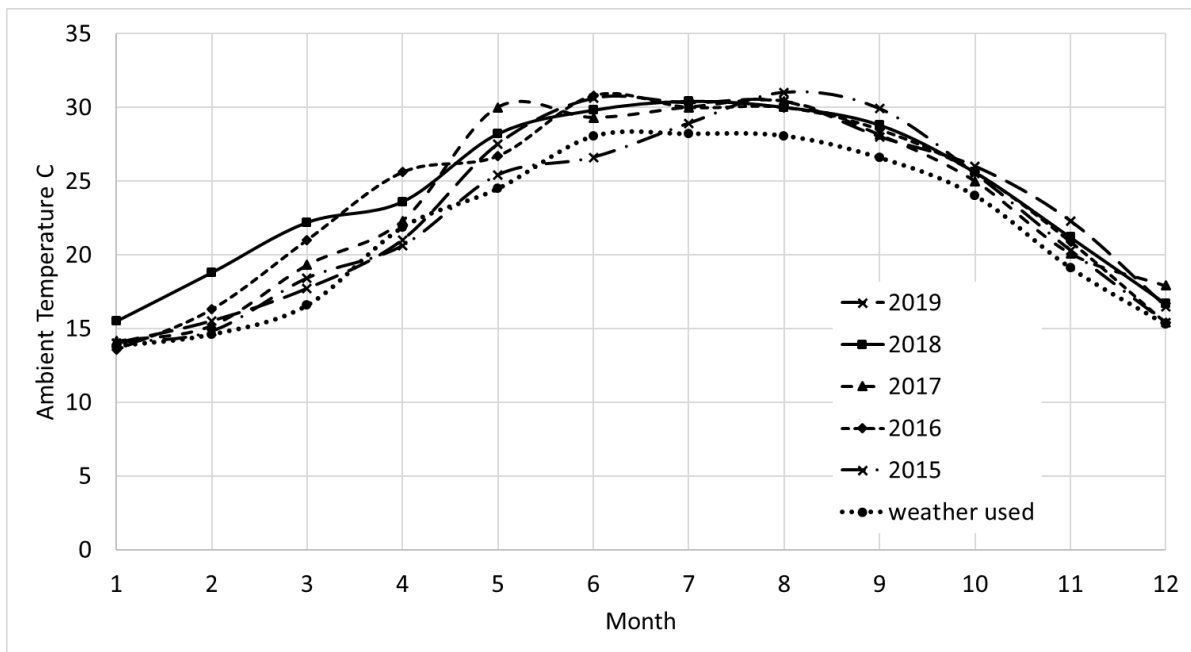


Fig. 10 Average ambient Temperature used in this research and last 5 years of Cairo [25]

1.3.1. Effect of external shading

Fig.11 illustrates the effect of shading projection factor (PF) on the annual space cooling demand. The results show that the PF has larger energy saving on the annual cooling demand when it is installed on the east and west façade where larger exterior glazing is existing. PF of 0.9 decreases the annual cooling demand by 5%, if it is used

whether on east or west façade while the energy saving increases to 13% by installing the exterior shading on all building façade.

Effect of shading projection factor on annual space heating demands is shown in Fig. 12, which confirms PF has larger energy saving on the annual heating demand when it is installed on the south, east façade where larger exterior glazing is exist. Clearly, PF of 0.9 increase the annual heating demand by 9% or 8% when it is used whether on south or east façade while the annual heating saving increases by 31% if the exterior shading is installed on all building façade

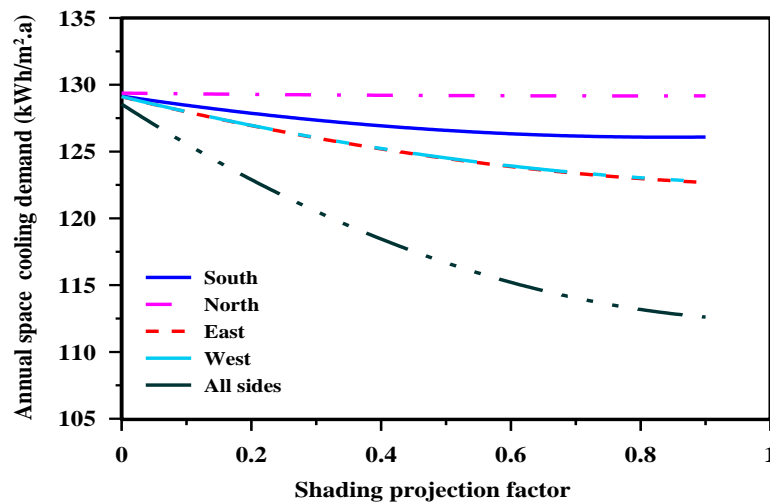


Fig. 11 Effect of shading projection factor on annual space cooling demand

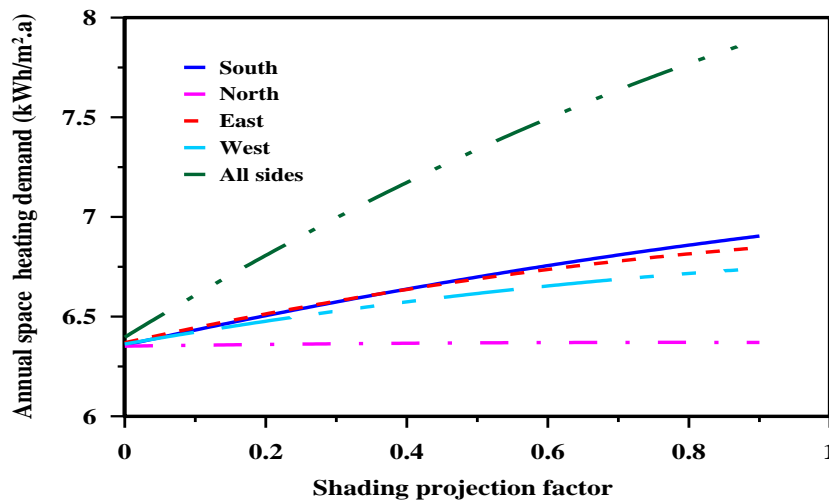


Fig. 12 Effect of shading projection factor on annual space heating demand

Table 5 shows the effect of increasing shading projection factor on the heating and cooling electrical delivered needs by air-conditioning system. Clearly, the external shading with PF of 0.9 maximum effects on all sides direction. The delivered heating increase with $0.9\text{kWh/m}^2.\text{a}$ (16%) due to increase in PF from 0 to 0.9. The delivered cooling decrease with $6\text{ kWh/m}^2.\text{a}$ (11%). The results show the external shading decreases the total electricity with $7.5\text{kWh/m}^2.\text{a}$.

Table 5 Effect of shading projection factor on annual space cooling, heating and total electrical delivered ($\text{kWh/m}^2.\text{a}$)

shading projection factor	Delivered space cooling [$\text{kWh/m}^2.\text{a}$]	Delivered space heating [$\text{kWh/m}^2.\text{a}$]	Total electricity delivered [$\text{kWh/m}^2.\text{a}$]
0.0	56	5.7	189
0.1	54	6	187
0.3	53	6.2	185
0.5	52	6.3	184
0.6	51	6.4	183
0.7	51	6.5	182.5
0.9	50	6.6	181.5

1.3.2. Effect of exterior wall insulation

Fig.13 indicates the effect of exterior wall insulation thickness on annual thermal space cooling and heating demands. As the exterior wall insulation thickness increases, the annual thermal space cooling decreases by 7 % of the total cooling demand, while the annual thermal space heating demand decreased by 60% of the total heating demand of the base case. These percentages represent $9\text{ kWh/m}^2.\text{a}$ and $3.85\text{ kWh/m}^2.\text{a}$. The reason is reducing the overall heat transfer coefficient of external wall reduces the external heat gain from outside in winter and heat loss from inside to outside in summer. That decreases the cooling demand and heating demand.

Table 6 illustrates the effect of exterior wall insulation thickness on cooling and heating electrical energy of air- conditioning unit. Clearly, the exterior wall with thermal resistance of $1.7 \text{ m}^2 \text{ K/W}$ implemented on all sides with insulation thickness of 0.045 has maximum energy saving. The delivered heating decreases with $1.9 \text{ kWh/m}^2.\text{a}$ (33%). The delivered cooling decrease with $4.7 \text{ kWh/m}^2.\text{a}$ (8%). The results show the increasing of exterior wall insulation thickness decreases the total electricity with $8.5 \text{ kWh/m}^2.\text{a}$ (4.5%).

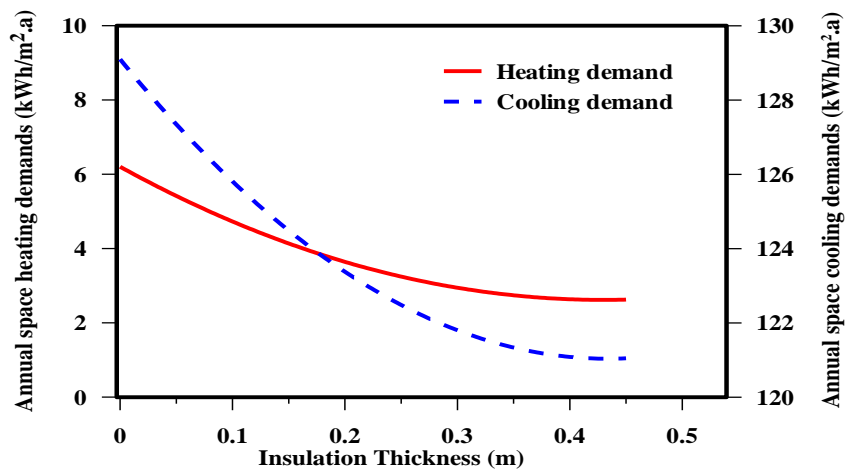


Fig. 13 Effect of wall insulation thickness on annual space cooling and heating demands

Table 6 Effect of shading projection factor on annual space cooling, heating delivered and total electricity consumption ($\text{kWh/m}^2.\text{a}$)

exterior wall insulation thickness[m]	Delivered space cooling[kWh/m ² .a]	Delivered space heating[kWh/m ² .a]	Total electricity consumption[kWh/m ² .a]
0	56	5.7	187
0.01	54	5	184
0.015	53.4	4.7	183
0.02	53	4.5	182
0.025	52.4	4.3	181
0.03	52	4.1	180
0.035	51.7	4	179.5
0.04	51.5	3.9	179
0.045	51.3	3.8	178.5

1.3.3. Effect of window glazing type

Fig.14 shows the effect of window glazing type on the total heating and cooling demands. The maximum energy saving of the annual space cooling demand is about 14%, as it decreases from 130 kWh/m².a in base case to 111.5 kWh/m².a when using double glazing type. The maximum energy saving in the annual space heating demand is nearly 31%, when the double glazing type is used. It decreases from 6.5 kWh/m².a to 4.5 kWh/m².a.

1.3.4. Effect of the type of fixture lighting

Fig.15 illustrates the effect of fixture lighting type on the annual space cooling and heating demand. Clearly, the best energy consumption when using LED lighting implementing CFL and LED lighting decreases the annual space cooling demand decreases with 22 kWh/m².a (17%) and 23 kWh/m².a (17%), respectively. The annual space heating demand increases with 1.5 kWh/m².a (23%) and 1.7 kWh/m².a (26%), respectively. Fig.16 presents the effect of lighting type on the building. It is clear that the electricity consumption decreases by 25.5 kWh/m².a (25.5%), when using CFL lighting and decreases with 27 kWh/m².a (27%) when using LED lighting to reach its minimum value with LED lighting 73 kWh/m².a.

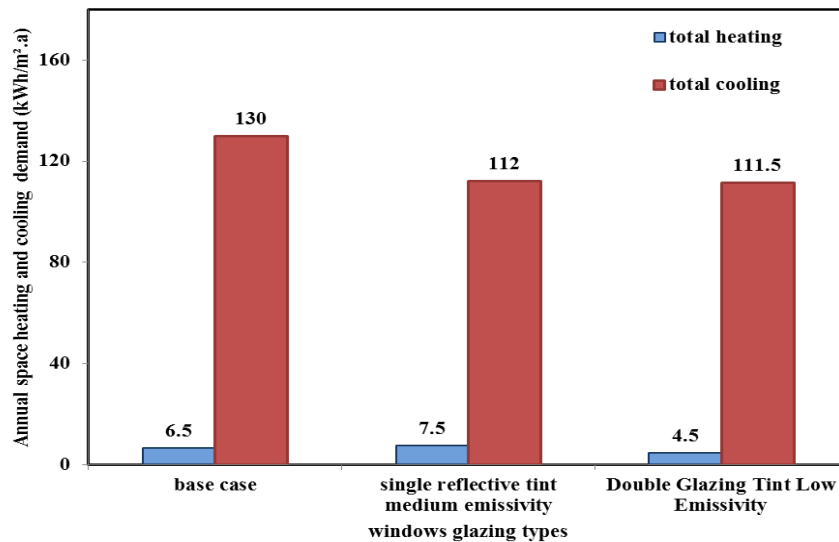


Fig. 14 Effect of window glazing type on annual space heating and cooling demand

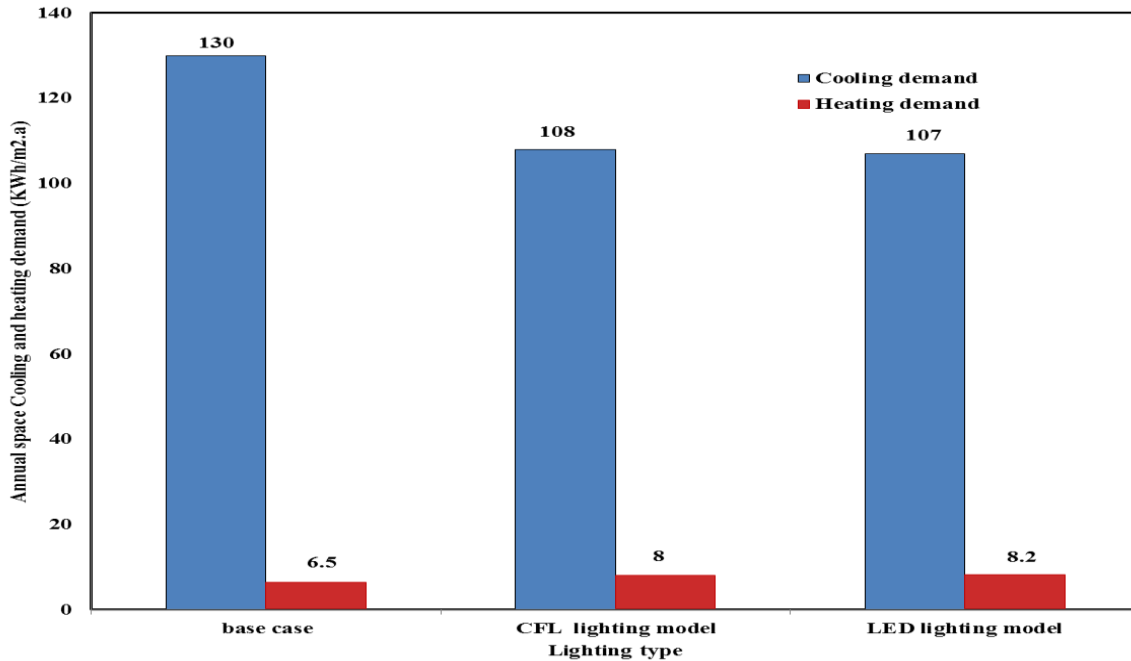


Fig. 15 Effect of lighting type on annual space cooling and heating demands

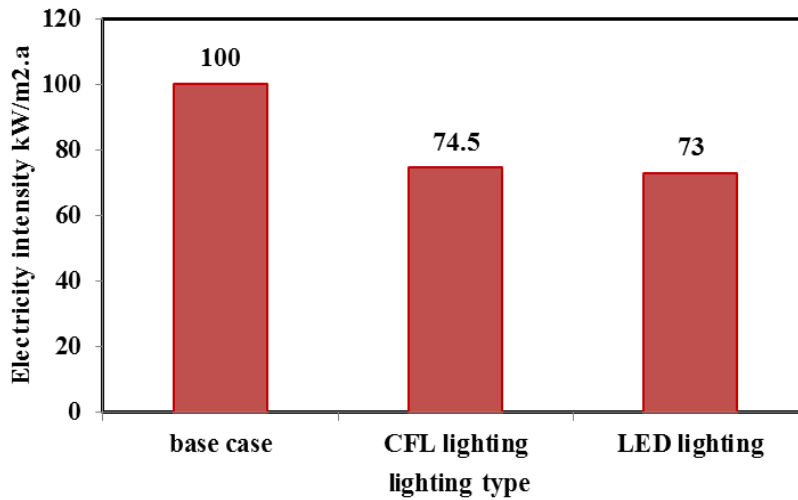


Fig. 16 Effect of lighting type on electricity intensity

Effect of lighting type on building with air conditioning system is shown in Fig.17, which reveals that the electricity consumption decreases by 32.5 kWh/m².a (17%) when using CFL lighting and decreases with 34 kWh/m².a (18%) when using LED lighting to reach its minimum value with LED lighting of 153 kWh/m².a. Fig.18 illustrates the influence of lighting type on the building with air conditioning system on

the delivered cooling and heating. It is found that when using CFL and LED lighting, delivered cooling decreases with 6.8kWh/m².a(12%) and 7kWh/m².a(12.5%), respectively. The delivered heating increases with 1.3kWh/m².a (23%).

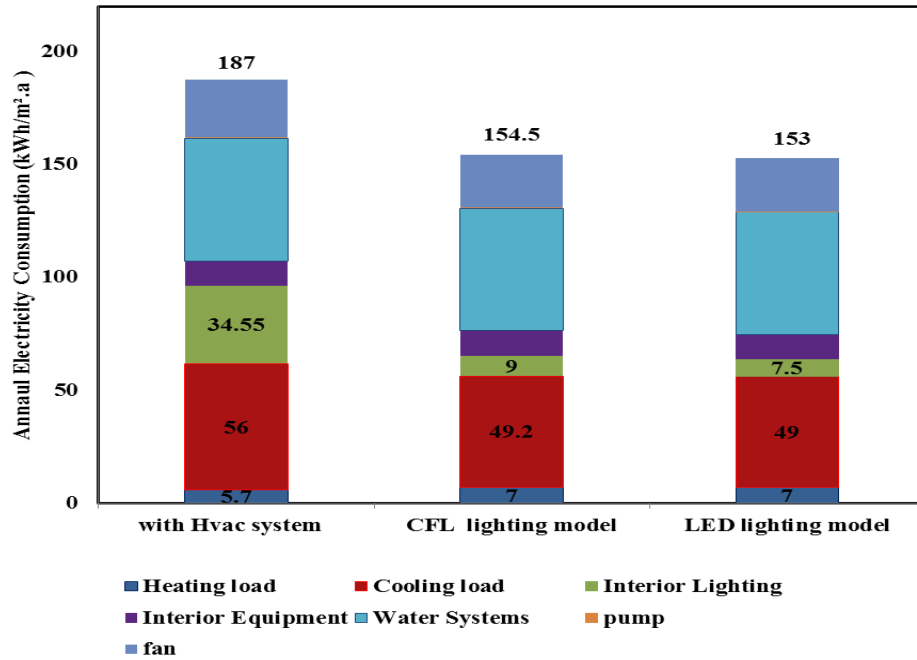


Fig. 17 Effect of lighting type on annual cooling and heating delivered

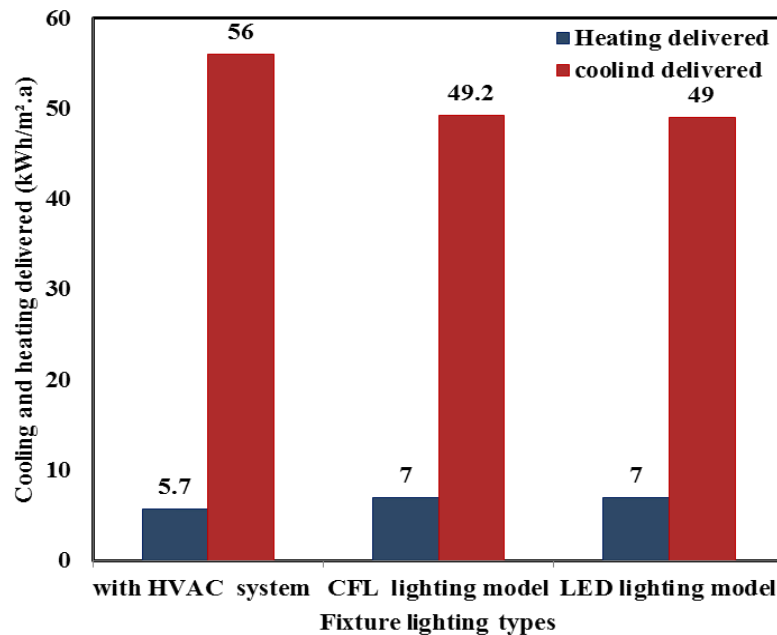


Fig. 18 Effect of lighting type on annual space cooling and heating delivered

1.3.5. Effect of all Energy Efficiency Measures

Finally, the optimized model characteristics are based on the combination of the value of all implemented EEMs as follow using LED fixture lighting, adding the exterior wall insulation is mineral wool blanket with thickness 0.045mm; adding the external shading projection factor is equal to 0.9 and using glazing type is double glazing type with medium emissivity and minimum SHGC.

Fig.19 indicates the result of the optimized model that reach the best model where the total electricity decreases by 54 kWh/m².a (29%) from the base case model. The lighting load decreases by 27 kWh/m².a (78%) where reaches to the minimum 7.5 kWh/m².a. Fig.20 shows the electrical cooling load demand decreases with 53.5kWh/m².a (41%) where reaches the minimum 76.5kWh/m².a. The electrical heating demand decreases by 1.5 kWh/m².a (23%) where reaches the minimum 5kWh/m².a.

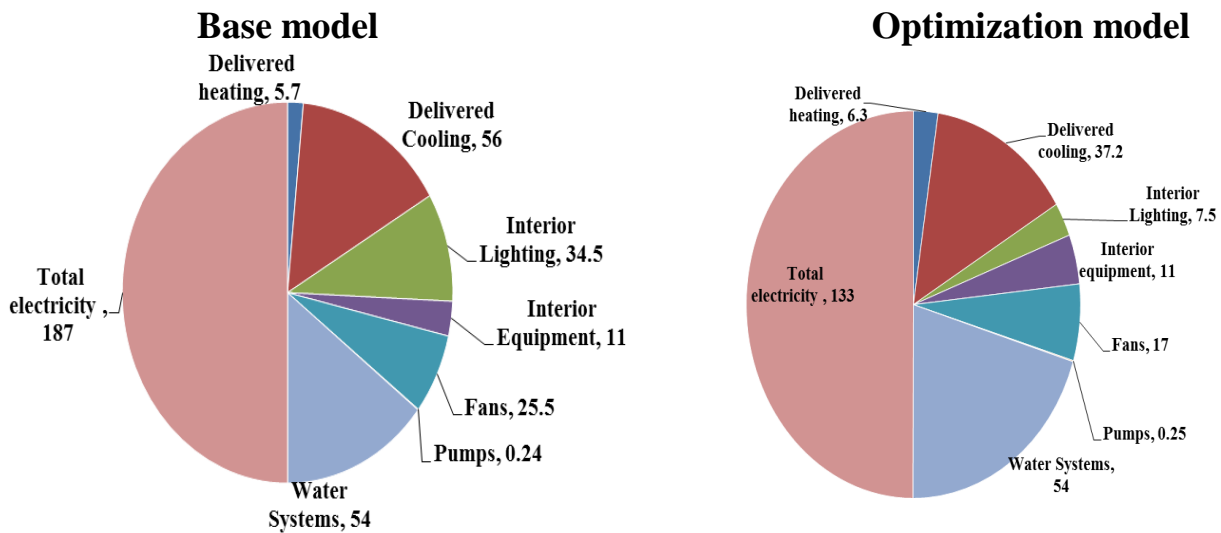


Fig. 19 Electricity break down for the optimized model and base case (kWh/m².a)

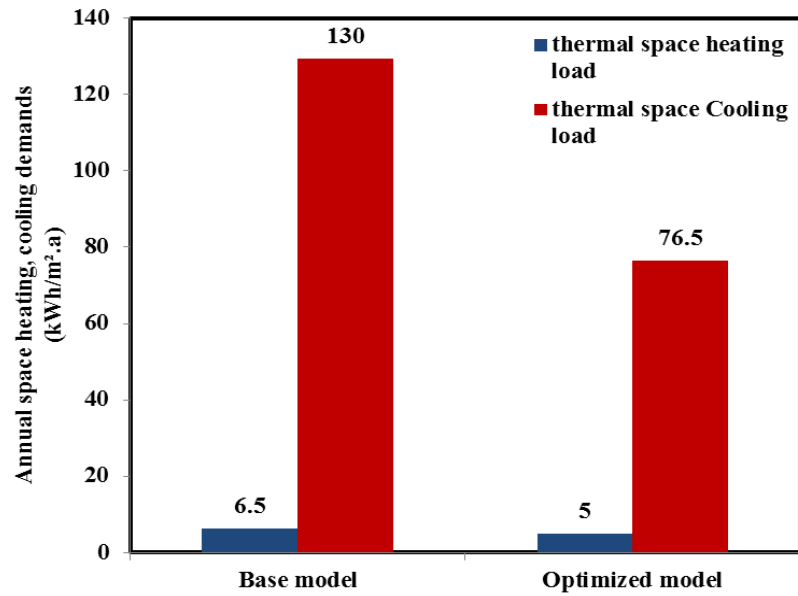


Fig. 20 Comparison between annual space cooling demand for optimized model and base case

1.4 Conclusions

The present work investigates the residential building energy needs in Egypt by implementing Energy Efficiency Measures (EEMs) under Cairo weather conditions using building simulation tool. The building simulation tool is Open-Studio software coupled by Sketch-up 2017 software and Energy plus software. The considered EEMs are adding external wall insulation, adding window shading, using efficient lighting fixture and selecting window glazing type. Based on the reported results, the following conclusions can be drawn;

- The annual thermal space cooling demand, heating demand and the total electricity consumption are 130kWh/m².a, 6.5 kWh/m².a and 114 kWh/m².a, respectively.
- Reducing the overall heat transfer coefficient of external wall by adding thermal insulation from 1.7 W/m²Kto 0.58W/m²K decreases the cooling and heating demands by 7% and 60%, respectively.
- Adding shading by projection factor of 0.9 for all external windows decreases the cooling demand by 13%.

- Double glazing type with medium emissivity and minimum SHGC decreases the cooling and heating demands by 14% and 30%, respectively.
- LED lighting type reduces the annual space cooling demand and electricity consumption by 17% and 27%, respectively and increases the annual thermal space heating demand by 26%.
- Electrical delivered cooling demand decreases by 19 kW/m².a (34%) and the electrical delivered heating demand increases by 0.6 kW/m².a (11%) while the lighting load decreases by 78%.

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