Received 13 January 2024: accepted 30 March 2024.
Available online 9 April 2024

THE SOUTHERN WALLS AS AN ENVIRONMENTAL DETERMINANT A CASE STUDY: SAKAN MISR PROJECT

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ABSTRACT

Egypt is interested in providing suitable housing for individuals in a manner befitting the decent life required. For achieving that, it has been providing typical housing projects for citizens. Despite the multiplicity of places in which these projects are carried out, they were not provided by climate considerations in the design. The building envelope has a direct impact on the energy consumed for the cooling and heating. The study aims at examining the following: the impact of the southern wall design as an example for facades impact on the environmental behavior in terms of the design's ability to provide appropriate shading , the impact of increasing the percentage of shading on the southern wall, and the compatibility of the design according to the environmental recommendations of the Egyptian Energy Code to rationalize energy consumption in residential buildings. The study concluded that the southern facades do not comply with the recommendations of the code, while studying the effect of modifying the facade according to the code and the effect of increasing the percentage of shading. It was concluded that adherence to the recommendations of the Egyptian Energy Code contributes to rationalizing consumption by 16% for cooling works and 24% for heating works with a total of 17% reduction in the total energy required. However, increasing the percentage of shading contributes to reducing the energy needed for cooling when increasing the energy needed for heating, with a total energy saving that is relatively limited according to the percentage of shading on the facade.

KEY WORDS

Environmental shading impact, facades environmental design, shading as an environmental impact, facade compliance with energy code requirements

الحوائط الجنوبية كمحدد بيئي
دراسة حالة مشروع سكن مصر

الملخص

إهتمت الدولة المصرية في الفترة الأخيرة بتوفير الإسكان المناسب لكافة أفراد الشعب بما يليق بالحياة الكريمة المطلوبة للمواطن، وفي تحقيق ذلك قامت ومازالت توفر المشروعات السكنية النمطية للمواطنين باختلاف طبقاتهم ومستوياتهم المادية، وبالرغم من تعدد أماكن تنفيذ تلك المشروعات إلا أنه لم تحظى بتوفير الإعتبارات المناخية في تصميم الغلاف الخارجي ذو التأثير المباشر على الطاقة المستهلكة لأعمال التبريد والتدفئة اللازمة. وتهدف الدراسة البحثية إلى دراسة تأثير التصميم الحالي للحائط الجنوبي كمثال تطبيقي لعنصر مؤثر من عناصر الغلاف الخارجي على السلوك البيئي للمبنى السكني من حيث قدرة التصميم على توفير الإظلال المناسب مع دراسة تأثير زيادة نسبة الإظلال على الحائط الجنوبي، بالإضافة إلى دراسة توافق تصميم الحائط مع التوصيات البيئية للكود المصري لترشيد إستهلاك الطاقة بالمباني السكنية. حيث خلصت الدراسة إلى عدم توافق الواجهات الجنوبية مع توصيات الكود مع دراسة تأثير تعديل الواجهة طبقا للكود بالإضافة إلى دراسة تأثير زيادة نسبة الإظلال، حيث تم التوصل إلى أن الإلتزام بتوصيات الكود المصري للطاقة يساهم في ترشيد الإستهلاك بنسبة ١٦٪ لأعمال التبريد ونسبة ٢٤٪ لأعمال التدفئة بإجمالي ١٧٪ ترشيد في الطاقة الإجمالية المطلوبة لأعمال التبريد والتدفئة مجتمعة، في حين أن زيادة نسبة الإظلال تساهم في تقليل الطاقة اللازمة للتبريد مع زيادتها في الطاقة اللازمة للتدفئة بإجمالي ترشيد للطاقة محدود نسبيا طبقا لنسبة الإظلال على الواجهة.

الكلمات الدالة

التأثير البيئي للإظلال، التصميم البيئي للواجهات، الإظلال كمؤثر بيئي، توافق الواجهة مع اشتراطات كود الطاقة

INTRODUCTION

Providing suitable housing is considered one of the main requirements for all members of society, as it can be considered one of the most important factors for the survival of nations. Housing is exposed to many design challenges, whether on the economic or social level or other factors on which the success of these housing projects depends. Environmental factors can be considered one of the most important requirements of the users of these spaces depend on all the design determinants that have a direct impact on the quality of the internal climate of the space, such as the external envelope of the building, including walls, ceilings, and external openings. Therefore, it is possible to study one of these elements of the external envelopes to show the extent of its impact on the environmental behaviour of the internal space and the thermal comfort required for users of these spaces.

1. THE BUILDING ENVELOPE

The building envelope is defined as the sum of all elements that make up the building's outer shell; including: solid walls, openings, ceilings, and floors that are exposed to the surrounding external conditions. The building envelope is considered one of the most important engineering systems that performs several functions, including:

- Structural support as a major component of the building.
- Controlling the quality of the climatic conditions of the interior space and the ability to reduce the negative impact of the climatic conditions surrounding the building.
- Aesthetics and the building's appropriate appearance to appear more attractive.

The building envelope function in controlling the quality of climatic conditions is considered one of its most important properties which works to manage relative humidity, regulate temperature and air flow rates, and achieve natural and healthy ventilation for the building. Thus, the control function leads to an energy-efficient sustainable building and achieves the thermal comfort required for the users of interior spaces as well.

Accordingly, the building envelope must meet a set of requirements to adapt to the region climate where the building is located, so that the total thermal resistance of each element of the envelope is not less than the minimum permissible for each climate region.

2. THE SOUTHERN WALLS AS AN ENVIRONMENTAL DESIGN DETERMINANT

The space facing south is exposed to solar radiation in the middle of the day, as the angle of sun incidence is high in summer, which leads to a direct impact on the southern wall and its temperature rises and transfers to the internal spaces (Eslamirad, 2018). Many design methods and concepts have emerged concerned with increasing the environmental efficiency of southern facades, the most important of which can be mentioned as follows:

2.1 Providing Adequate Shading

Due to the high angle of incidence of solar radiation on the southern facade in summer, which makes protecting it from direct solar radiation easy by simple architectural devices that provide adequate shading most hours of the day, such as using fixed or mobile horizontal sun breakers, balconies, overhangs, and pergolas. Figure (1) shows the simplified method for designing horizontal sun breakers based on the height of the window and the Vertical Sun Angle (VSA) according to the worst solar radiation determined by the climatic zone of the building. Based on that, many different configurations of horizontal breakers can be obtained, as some examples of them are obvious in Figure (2).

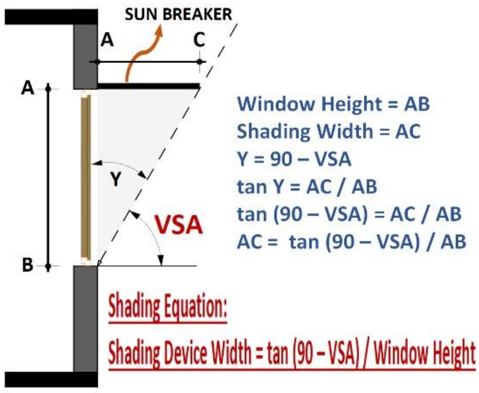


Figure (1). Sun breakers simple design at south elevations, Source: The author.

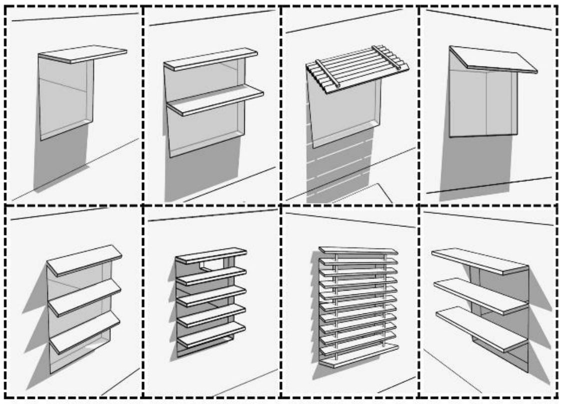


Figure (2). Sun breakers examples, Source: Ngungui, 2018

2.2 Using Thermal Break Materials

Thermal break materials for double walls, as shown in Figure (3) (Ari, et al. 2008), are characterized by providing the appropriate thermal resistance to the facades according to the rates required for each climatic region. The placement of break has three states that differ from each other in shaping the thermal performance of the wall as follows:

- **External Thermal Break:** In this state, the inner covering layer stores a large portion of the internal heat of the space while heating the building; making it more suitable in winter. The insulating layer also prevents the transfer of heat to the inner covering layers in summer.
- **Central Thermal Break:** This state is easy to implement and provides thermal comfort throughout the year.
- **Internal Thermal Break:** This method is not suitable for non-air-conditioned buildings, as the response of the insulating layer to the heat is low in thermal storage leading to a rapid rise in the temperature of the internal space when the cooling devices stop, in addition to the slow thermal response of the insulation layer while regulating the heat leaking from outside thorough the thermal break of the external openings.

The appropriate insulation state can be determined according to the nature of the building's occupancy. For example, in the case of residential buildings with permanent occupancy, central thermal break is one of the most appropriate insulation states, while the thermal break state is most appropriate in the case of buildings with permanent heating (Linhares, et al. 2021).

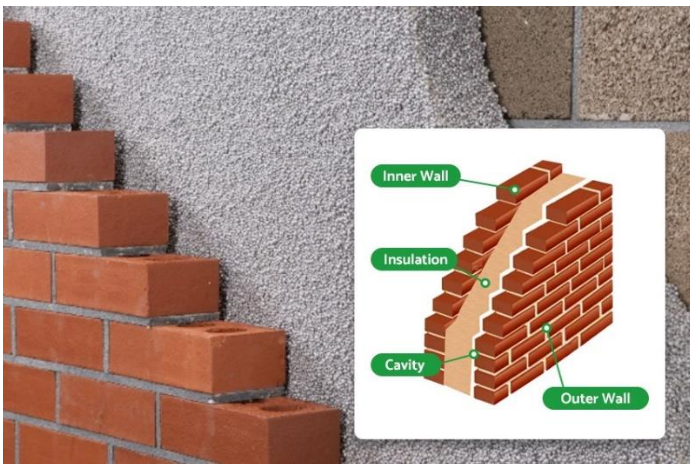


Figure (3). Heat insulated wall section, Source: The author.

2.3 Using Thermal Break

The external wall contains a number of thermal bridges that cause increased heat transfer across its layers. Examples of thermal bridges for walls include the following (Stavrakakis, 2012):

- Reinforced columns in walls.
- The external wall meets the concrete ceiling.
- The external wall meets the floors.
- Window frames and external openings.

The Thermal Break is a low-value thermal conductivity element that is placed to reduce or prevent the flow of thermal loads in the areas of Thermal Bridges (Eljojo, 2017). Figure (4) shows how to treat thermal bridges through the Thermal Break System Techniques used in window frames and external openings.

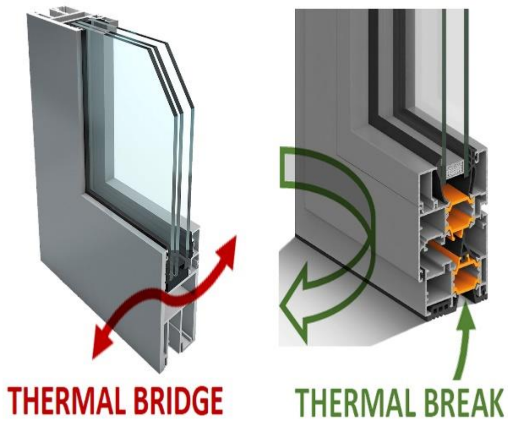


Figure (4). Thermal bridge & thermal break at aluminium windows, Source: The author.

2.4 Air Infiltration Control

Air Infiltration is defined as the amount of air, measured in cubic feet, that can pass through the window panes and frames in a given period of time divided by the total window area (Karunathilake, 2018). Its value must not exceed the range between (0.10 to 0.30) (Araji, 2016), considering that the lower value is better. Figure (5) shows one example of the data sheets attached to the window frame in which the value of the air infiltration rate is specified of (0.20), which is acceptable because it is less than the upper limit specified at (0.30).

Air seals are implemented using materials suitable for closing joints, characterized by high sustainability properties that are not affected by external weather factors and have high thermal properties.

Figure (5). Air infiltration data sheet for the aluminium windows, Source: Ministry of Local Government, 2004.

2.5 Using Heat Reflective Materials

These materials are characterized by the properties of high reflection of solar radiation and the least amount of heat absorption. Accordingly, the surface that contains these materials has a lower temperature compared to surfaces that do not contain heat-reflecting materials. A study prepared by researchers at Stanford University in 2011 found out that although reflective surfaces reduce temperatures in buildings, they increase the temperature of the ground surrounding the building (Cool roof rating council, 2022).

The Solar Reflectance Index (SRI), which expresses the ability of the outer surface of a material to reflect solar energy falling on it (Housing and Building National Research Center, 2001), is the digital measure to determine the feasibility of a heat-reflecting surface, as materials with higher values are characterized by a lower surface temperature. That value is calculated based on the thermal properties and the value of both Solar Index (SR) and Thermal Emittance (TE) (Shahdan, 2018). Table (1) shows examples of these values and the extent of their impact on the value of the Solar Reflectance Index.

Table (1). Solar Reflectance Index (SRI) materials properties.

Material	Thermal Emittance (TE)	Solar Reflectance (SR)	Solar Reflectance Index (SRI)
White EPDM	0.87	0.69	84
Gray EPDM	0.87	0.23	21
Unpainted cement tile	0.90	0.25	25
White cement tile	0.90	0.73	90
Gray asphalt shingle	0.91	0.22	22
White granular surface bitumen	0.92	0.26	28
White gravel	0.90	0.65	79
Light gravel	0.90	0.34	37
Red clay tile	0.90	0.33	36
White PVC	0.92	0.83	104
Aluminum	0.25	0.61	56
White paint (1 layer – 8 mm)	0.91	0.80	100
White paint (2 layers – 20 mm)	0.91	0.85	107

Source: Berdahl, 1997.

2.6 External Openings Design

Due to the greater effect of glass openings on heat transfer compared to the solid parts of the building envelope, many design principles emerged for the external openings of the southern facades; including (Uribe, 2018), for example:

- Selecting an appropriate type of glass with thermal properties that increase the thermal resistance value of the openings.
- Providing an appropriate shading through sun breakers and horizontal louvers.
- Reducing the number and surface of the southern external openings.
- Using architectural elements that limit the impact of direct solar radiation, such as the Wooden Shutter Window and the Mashrabiya (Yousef, 2002).

Many research studies have addressed the effect of some of the previous elements on the environmental efficiency of the building. For example, Figure (6) shows the effect of the window plane on the southern facade of a residential building on the loads required for heating and cooling the interior space.

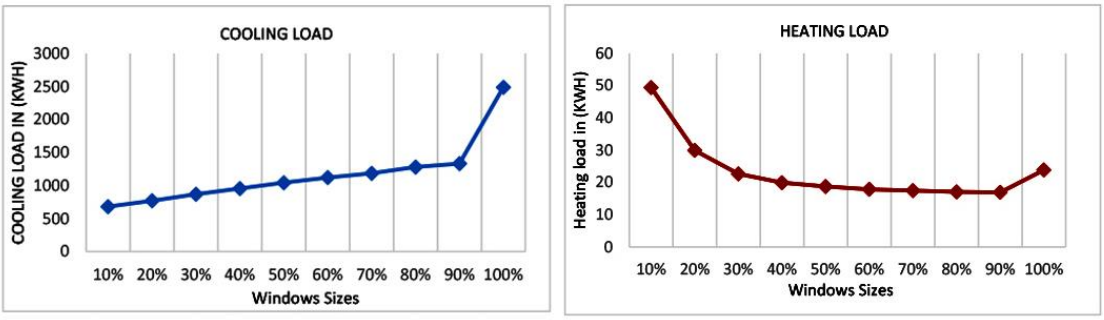


Figure (6). The impact of south window size on cooling & heating loads, Source: Eskandari, 2017

2.7 Thermal Properties of the Wall

The appropriate design of the sectors and materials of the southern wall is made to achieve a suitable thermal resistant coefficient according to the climatic region in which the building is located, for all solid parts of the building, in addition to achieving the Solar Heat Gain Coefficient (SHGC). These values are determined based on studies and simulations, as stipulated in the Egyptian Energy Code recommendations regarding the energy standard for residential buildings, which is shown in Table (2).

Table (2). Suitable thermal coefficients for the south elevation.

Climate zone	Surface absorbance (a)	Required Thermal Resistant (TR)	Required SHCG Window Wall Ratio (WWR) WWR < 10%	10 < WWR < 20%	20 < WWR < 30%	WWR > 30%
North coast	0.38	0.47	Not Required	0.71	0.64	0.55
	0.50	0.55				
	0.70	0.69				
Cairo	0.38	0.67	0.71	0.64	0.55	Not Allowed
	0.50	0.75				
	0.70	0.89				
North upper Egypt	0.38	0.70	0.68	0.61	0.52	Not Allowed
	0.50	0.80				
	0.70	0.90				
South upper Egypt	0.38	0.70	0.65	0.58	0.50	Not Allowed
	0.50	0.80				
	0.70	1.10				
East coast	0.38	0.80	0.68	0.61	0.52	Not Allowed
	0.50	0.90				
	0.70	1.00				
Desert	0.38	0.80	0.59	0.55	Not Allowed	Not Allowed
	0.50	0.90				
	0.70	1.00				

Source: Housing and Building National Research Center, 2004.

Based on the above-mentioned part, it is clear that there are many positive devices of environmental design for the southern facades, which dealt with all the architectural elements of the façade; including: the characteristics of materials, formation, proportions, and surfaces (Housing and Building National Research Center, 2008). The following applied study deals with examining the environmental impact of wall shading in addition to achieving design compatibility with the wall in accordance with the Egyptian Energy Code recommendations for energy efficiency in residential buildings.

3. THE APPLIED MODEL OF SAKAN MISR PROJECT

One of the typical housing projects was chosen, which the country implemented on a large scale in several stages throughout the Republic in a national project to raise the living standard of citizens, which is the Sakan Misr Project.

3.1. Sakan Misr Project Background

The New Urban Communities Authority adopted the establishment of new cities and urban communities in desert lands with the aim of moving away from the agricultural area and disrupting the population distribution outside the borders of the Nile Valley and the Delta, to get out of the narrow horizon within which Egyptian urbanism has been expanding since time immemorial. Many housing units were offered in the previous phases. A new phase, announced in January 2023, is now being offered in 11 new cities.

The project is an urban complex surrounded by a fence and security gates that includes a number of residential buildings. Each building consists of a ground floor and five recurring floors. Each floor includes four fully finished residential units with areas ranging from 106 to 118 square meters. Figure (7) shows the horizontal projection and general perspective of the residential units (Ministry of Housing, Utilities and Urban Communities, 2023).

Figure (7). Egyptian housing project, Source: Ministry of Housing, Utilities and Urban Communities, 2023.

3.2. Shading devices for the Existing Situation of the Southern Façade

The design facade of the Sakan Misr Project is distinguished by its containment of a number of overhangs and trims that act as horizontal sun breakers, in addition to a number of vertical trims that can be considered as vertical sun breakers. It is worth noting that the focus will be on studying the effect of horizontal sun breakers only for their primary role on the southern facades according to what was mentioned in the previous parts. The total length of all horizontal overhangs and trims was studied and compared to the total width of the facade for all floors. Figure (8) and Table (3) show these values and their ratio to the total width of the facade for each floor.

It is clear that the facade consists of three architectural elements for shading, including terraces, overhangs, and trims. The study of shading on the facade will address fixing the architectural design of the terraces and overhangs, while evaluating the availability and lengths of the trims as horizontal breakers with a width of 250 mm, as it is clear that their current ratio in the original design in relation to the lengths of solid walls reaches up to 40.75%.

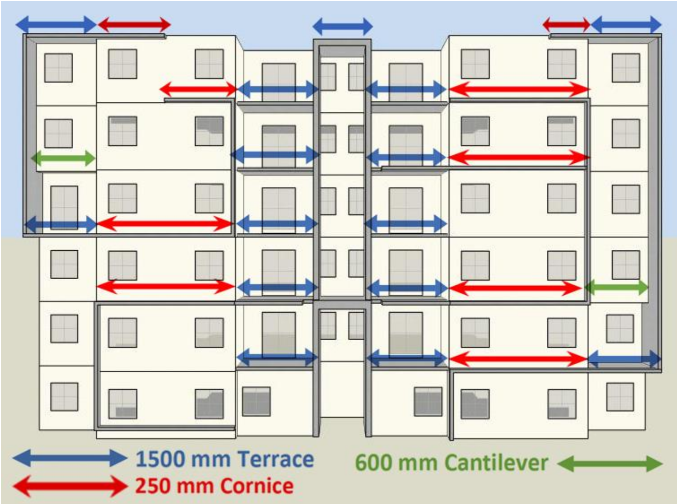


Figure (8). Existing shading devices at south elevation, Source: The author.

Table (3). Existing shading devices lengths at south elevation.

Floor	Residential south elevation width (m)	1500 mm Terrace	600 mm Cantilever	250 mm Cornice
			length (m)	
Ground	25.60	10.05	----	6.20
First	28.25	6.90	3.15	12.40
Second	28.25	10.05	----	6.20
Third	28.25	6.90	3.15	6.20
Fourth	28.25	6.90	----	9.30
Fifth	28.25	8.95	----	4.85
Total	**X 166.85**	**Y1 49.75**	**Y2 6.30**	**Z 45.15**
Total elevation width (m)			X	166.85 m
Total terraces & cantilevers width (m)			Y (Y1+Y2)	56.05 m
Clear total elevation width without terraces and cantilevers (m)			X-Y	110.80 m
Total percentage of cornice to the clear total elevation width (%)			**Z to (X-Y)**	**40.75 %**

Source: The author.

3.3 Studying the Effect of Shading devices on the Existing Situation on the Southern Façade

Through the use of Design Builder simulation program, a model of the project's residential building was prepared to evaluate the external decorations as one of the available devices of shading within the original design of the model. The study dealt with their impact on both the available shading and the energy required for cooling and heating.

3.3.1 Shading pattern for the current situation

To study the shading ratios on the southern facade based on the presence of trims as horizontal sun breakers, August 15 was selected as an illustrative example to study shading pattern and ratios, because it is the worst time of the year, as the following can be obvious:

- The effect of solar radiation on the southern facade begins from eight in the morning until four in the afternoon. Figure (9) shows the pattern of solar radiation during those times.
- The surface of the shaded area varies according to the time; as its highest surface is at eight in the morning, amounting to (479.65 m2), or (89.83%) of the total surface of the facade, while the lowest shaded area is at one o'clock in the afternoon, amounting to (177.75 m2), or (33.29%), as shown in Table (4): the surface shading and its ratio to the surface of the facade.
- The percentage of shadings varies throughout the day depending on the time, as shown in Figure (10), and the average percentage of shading on the facade is (50.41%) of the total surface area.

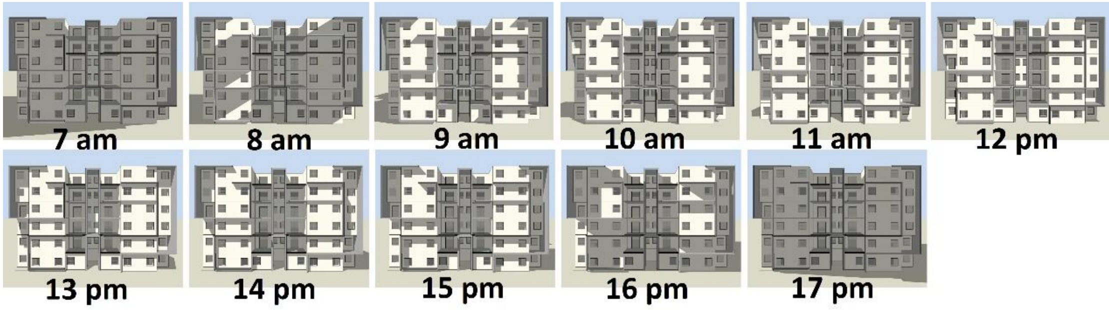


Figure (9). Existing shading pattern at south elevation in 15th august, Source: The author.

Table (4). Existing shading areas at south elevation.

Date: ……………………………………………………	**15th August**
South elevation total area: ……………………….……..….	**533.95 m2**

Time	**Shaded Area (m2)**	**Percentage of shaded area (%)**	**Time**	**Shaded Area (m2)**	**Percentage of shaded area (%)**
7 am	533.95	**100.00**	13 pm	177.75	**33.29**
8 am	479.65	**89.83**	14 pm	200.00	**37.46**
9 am	265.37	**49.70**	15 pm	229.99	**43.07**
10 am	236.37	**44.27**	16 pm	437.44	**81.93**
11 am	204.86	**38.37**	17 pm	533.95	**100.00**
12 pm	190.88	**35.75**			

Average percentage of the shaded area all over the day	**50.41 %**

Source: The author.

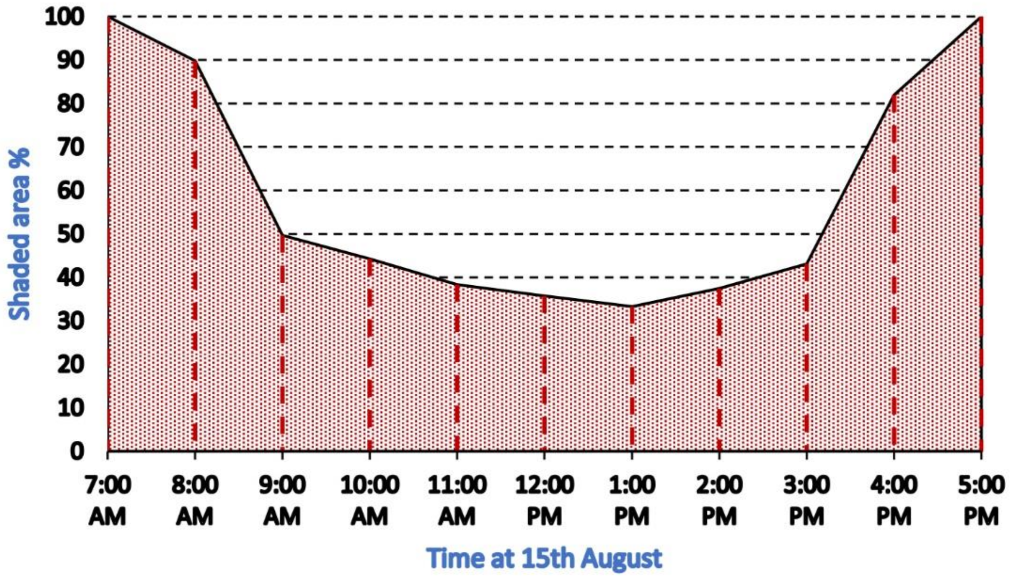


Figure (10). Existing shading percentage at south elevation in 15th august, Source: The author.

3.3.2 The energy consumed for the current situation

The energy, required for cooling and heating works required for the southern residential units, was only studied for all floors of the residential building throughout the year according to the original design. The main results were illustrated in Figure (11), and the following results were found out:

- The total energy required for cooling for the southern residential units throughout the year is (11,192.04 kWh).
- The total energy required for heating for the southern residential units throughout the year is (2513.68 kWh).
- The highest energy needed for heating in January was (1313.32 kWh); representing (52.25%) of the total energy needed for heating.
- The highest energy needed for cooling in August was (2857.71 kWh); with a percentage of (25.53%) of the total energy needed for cooling.
- The total energy required for heating and cooling is (13,705.72 kWh); of which cooling represents (81.66%), while heating represents (18.34%).

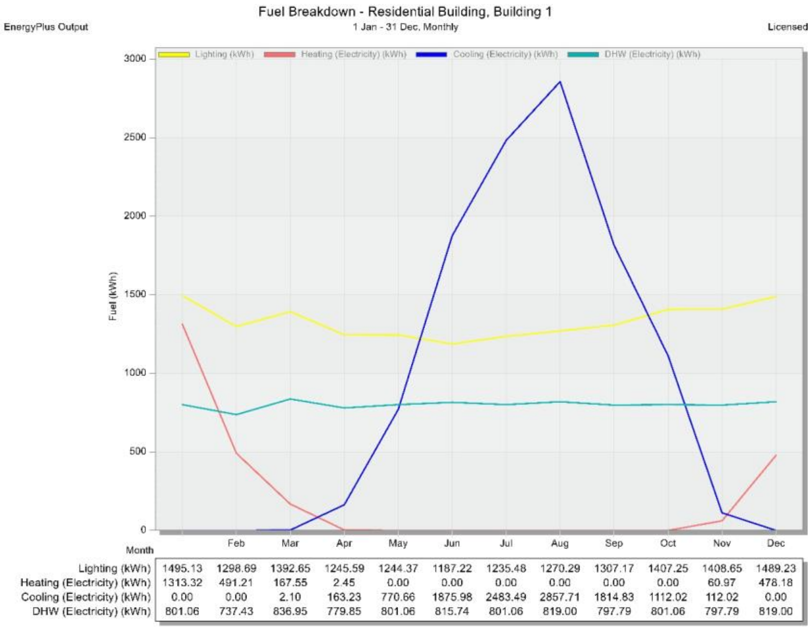


Figure (11). Fuel breakdown for the base case, Source: The author.

3.4 Evaluating the Effect of Shading Methods on the Current Situation

The previous study clarified the current situation for shading the southern facade and monitored the expected consumption of cooling and heating for the southern residential units throughout the year. To demonstrate the effect of shading devices on the energy consumed of the residential building, a similar simulation model was prepared and all external shading devices, represented by trims only, were excluded, as all architectural elements were retained; including: terraces and overhangs because they are a part of the original architectural design of the residential unit. Figure (12) shows the original design model of the residential building and the alternative model without shading.

Figure (12). South elevation (with/without) shading devices, Source: The author.

3.4.1 Shading pattern for the new situation

A simulation study was conducted for the alternative model to study shading pattern and surface, guided by studies of the shading ratios on August 15 according to the previous calculations, and the following can be indicated:

- The surface area exposed to solar radiation on the facade increases compared to the original design. For example, Figure (13) shows an illustrative example of the difference between shading on the facade at 12 pm, for both the original design and the alternative model. Table (5) shows the percentage of the shaded area on the facade during all day hours for both the original design and the alternative model without shading devices.

- The highest percentage of facade shading decreased to (31.95%) in the alternative model instead of (89.83%).
- The lowest percentage of facade shading decreased to (18.99%) in the alternative model instead of (33.29%).
- The average percentage of shading on the facade decreased to (25.64%), after it was (50.41%) in the original design. Figure (14) shows a comparison of the shading gradation for both the original model and the alternative model.

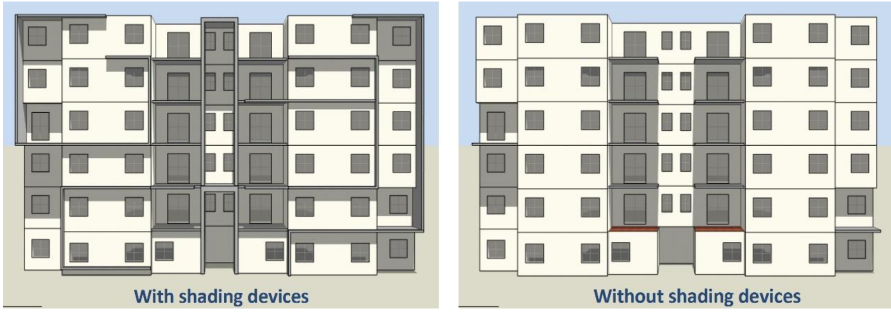


Figure (13). Shading pattern (with/without) shading devices, Source: The author.

Table (5). The impact of lacking of the shading devices.

Date: ………………………………………………………	**15th August**
South elevation total area: …………………………	**533.95 m²**

Time	**Percentage of shaded area (%)**		**Time**	**Percentage of shaded area (%)**	
	With shading devices	**Without shading devices**		**With shading devices**	**Without shading devices**
7 am	**100.00**	**100.00**	13 pm	**33.29**	**20.67**
8 am	**89.83**	**31.95**	14 pm	**37.46**	**23.67**
9 am	**49.70**	**28.48**	15 pm	**43.07**	**28.24**
10 am	**44.27**	**25.97**	16 pm	**81.93**	**31.06**
11 am	**38.37**	**21.75**	17 pm	**100.00**	**100.00**
12 pm	**35.75**	**18.99**			

Average percentage of the shaded area at south elevation all over the day	**Base Case**	**50.41 %**
	Without shading devices	**25.64 %**
The change between the two cases		**- 24.76 %**

Source: The author.

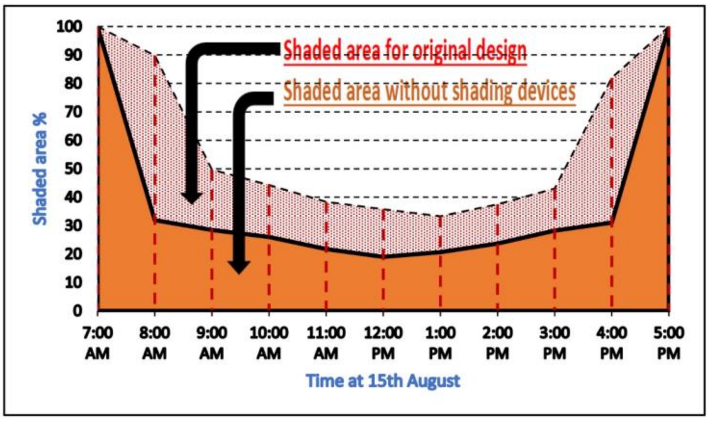


Figure (14). Shading percentage in 15th august (with/without) shading devices, Source: The author.

3.4.2 Evaluation the effect of shading methods for the current situation on the consumed energy

Figure (15) shows monitoring the study results of the energy required for the cooling and heating works required for the southern residential units in the alternative model without shading devices. Due to the increased surface area exposed to solar radiation on the southern facade, the following results were reached:

- The total energy required for cooling increased by (+551.59 kWh).
- The total energy required for heating decreased by (474.76 kWh).
- The total energy required for the residential units amounting to (13,782.55 kWh); an increase of (76.83 kWh) over the energy required for the original design, which was (13,705.72 kWh).

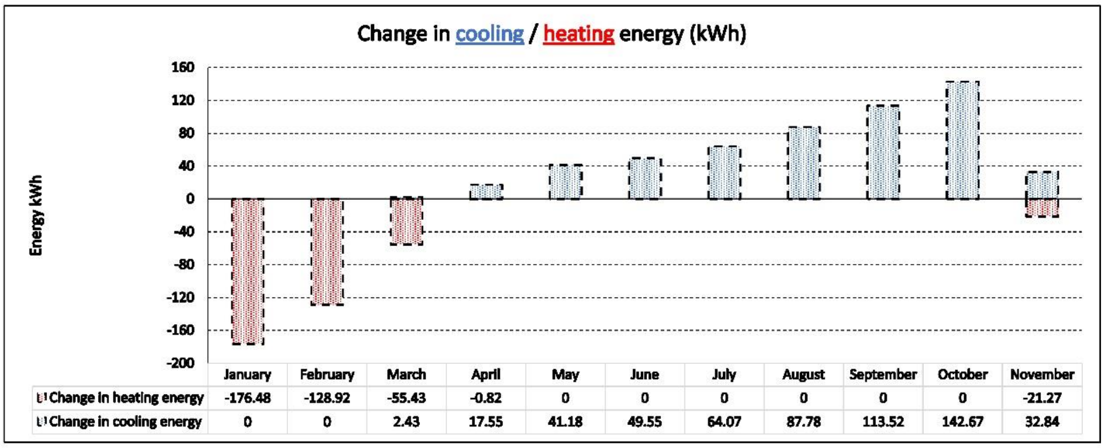


Figure (15). Change in energy consumption for the alternative south elevation, Source: The author.

4. THE EFFECT OF SHADING RATIO

The next part deals with the effect of increasing the shading ratio of the southern facade on the percentage of energy consumed for cooling and heating works, as a number of values were determined for the prominence value of the trims to increase the shading ratio to include four successive alternatives in which the prominence value is, respectively: 40 cm - 60 cm - 80 cm - 100 cm, made of light materials suitable as horizontal sun breakers in the same places specified by the horizontal trims of the original design. It is clear from Table (6) and Figure (16) the energy value consumed for cooling and heating works in the absence of shading on the southern wall, compared to providing (25 cm) of shading according to the original design and the values of the previously specified prominence alternatives.

Table (6). The effect of the shading value on the energy consumption at south elevation.

		Shading cantilever value (cm)					
		0	25	40	60	80	100
Total energy (Kwh)	Cooling	11743.63	11192.04	11095.09	10975.45	10857.92	10762.39
	Heating	2038.63	2513.68	2575.02	2658.65	2762.29	2883.63

Source: The author.

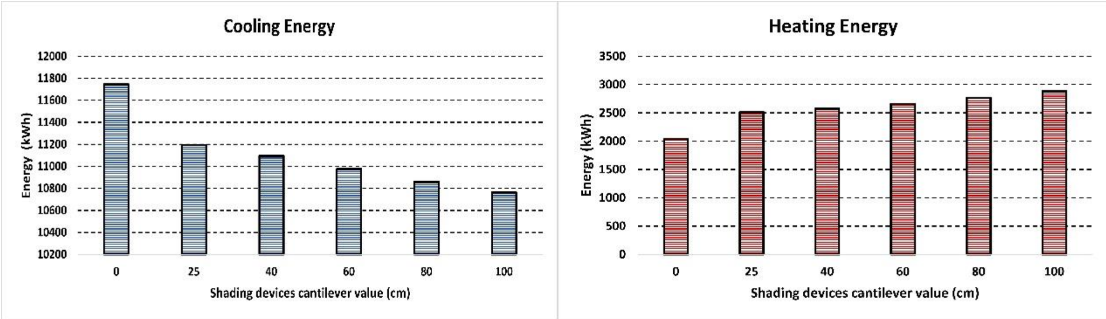


Figure (16). The effect of the shading value on the energy consumption at south elevation, Source: The author.

Studying the effect of shading percentage on the southern facade reveals the direct relationship to the energy consumed for cooling and heating works, as the following is indicated:

- In general, increasing the percentage of shading on the southern facade reduces the energy required for cooling work, and increases the energy required for heating work.
- For example, the amount of cooling energy saved by increasing the shading to (100 cm) compared to no shading is (981.24 Kwh). Its value compared to shading in the original design specified at (25 cm) is (429.65 Kwh). While the amount of heating energy increased by increasing the shading to (100 cm) compared to no shading is (845.00 Kwh). Its value compared to shading in the original design specified at (25 cm) is (369.95Kwh).
- It is clear from the previous calculations that the noticeable effect of shading is greater in the case of the original design with shading of (25 cm) prominence, as the value of the energy saved for cooling works is (551.59Kwh), while the saving value increases with the increase in the shading percentage at the values specified in the alternatives, with an average value of approximately (107.45Kwh) with each previous alternative.

5. IMPLEMENTING THE EGYPTIAN ENERGY CODE REQUIREMENTS

The next part deals with evaluating the existing architectural design of the southern walls with the recommendations stated in the Egyptian Energy code to improve energy use efficiency in residential buildings. Due to the difference in recommendations according to the environmental area in which the building is located, the existing design will be evaluated in accordance with the code requirements of the environmental area in Cairo region. The recommendations address two elements: the first element includes the solid parts of the walls, and the second one deals with the external openings design of windows. Table (7) shows the required recommendations for both elements based on the architectural values of the original design, which include the following:

- Outside finishing color: **medium color**.
- Surface absorbance: **50%**.
- Total south wall area (solid walls + windows): **533.95 m2**.
- Total windows area: **115.74 m2**.
- Window wall ratio (WWR): **21.68 %**.

Table (7). Egyptian energy code recommendation for the housing building in Cairo.

Climate zone	Surface absorbance (a)	Required Thermal Resistant (TR)	Required SHCG Window Wall Ratio (WWR)			
			WWR < 10%	10 < WWR < 20%	20 < WWR < 30%	WWR > 30%
Cairo	0.38	0.67				
	0.50	**0.75**	0.71	0.64	**0.55**	Not Allowed
	0.70	0.89				

Source: Housing and Building National Research Center, 2004.

5.1 Compatibility of Solid Parts

Through studying the thermal characteristics of the solid southern wall, as shown in Figure (17), to compare the extent of compatibility of the environmental characteristics with the requirements of the Egyptian Energy Code for improving energy efficiency, the following points can be obvious:

- Existing external wall layers: 25mm cement plaster + 250mm brick work + 25mm cement plaster (including paints for finishing).
- Existing U-value = 1.638 (W/m2. k).
- Existing R-value = 0.61 (m2. K/W).
- Recommended minimum R-value as per energy Egyptian Energy code = 0.75 (m2. K/W).
- Needed action: Wall layers are to be modified as follow = 25mm cement plaster + 120mm brick work + 10mm extruded polystyrene insulation + 120mm brick work + 25mm cement plaster (including paints for finishing).

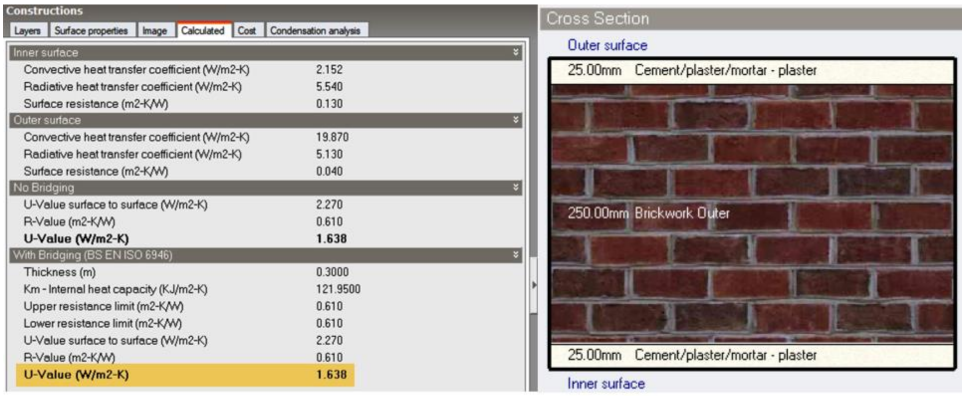


Figure (17). Existing U-value & wall layers for the south elevation, Source: The author.

5.2 Compatibility of External Openings

Through studying the surfaces and characteristics of the external openings of the southern wall, to compare the extent to which the environmental characteristics are compatible with the requirements of the Egyptian Energy Code for improving energy efficiency, the following points can be indicated:

- Windows description: sliding aluminum window with 6mm tempered clear glass.
- Existing (SHGC) as per Egyptian energy code shown in table No. (8) = 0.71.
- Maximum allowed (SHGC) as per Egyptian energy code shown in table No. (6) = 0.55.
- Needed action: shading devices are to be applied.
- Shading type: horizontal sun breaks.
- Recommended (SGR) as per Egyptian Energy code shown in figure No. (18) = 0.27.
- Shading device deign:

- Calculating (PF) as per Egyptian Energy code shown in table No. (9) = 0.156 to achieve the recommended (SGR).
- As per figure No. (19), assuming A= 0 cm & the windows heights (B) within 130 cm & 200 cm.
- According to the equation shown in figure No. (20), (W) values within 20.28 cm & 31.20 cm.
- The suitable (W) for all windows will be the largest = 31.20 cm.

Table (8). Physical glass properties.

Glass type	Shading coefficient (SC)	Solar heat gain coefficient (SHGC)				Visible light transmission (VLT)	
		Aluminum frame		Other frames			
		Movable	Fixed	Movable	Fixed	Movable	Fixed
6mm clear	0.89	**0.71**	0.74	0.60	0.71	0.65	0.78
6mm bronze	0.55	0.55	0.57	0.46	0.54	0.40	0.48
6mm green	0.74	0.51	0.53	0.43	0.51	0.54	0.64
6mm gray	0.43	0.50	0.51	0.42	0.49	0.31	0.37

Source: Housing and Building National Research Center, 2004.

Table (9). The impact of the projection factor (PF) on the shaded glass ration (SGR).

Projection factor (PF)	Window orientation				
	East	South/East	South	South/West	West
0.10	0.19	0.15	0.17	0.11	0.13
0.20	0.37	0.30	0.35	0.23	0.25
0.40	0.65	0.60	0.69	0.46	0.45
0.60	0.81	0.78	1.00	0.61	0.57
0.80	0.90	0.89	1.00	0.77	0.66
1.00	0.90	0.96	1.00	0.78	0.72

Source: Housing and Building National Research Center, 2004.

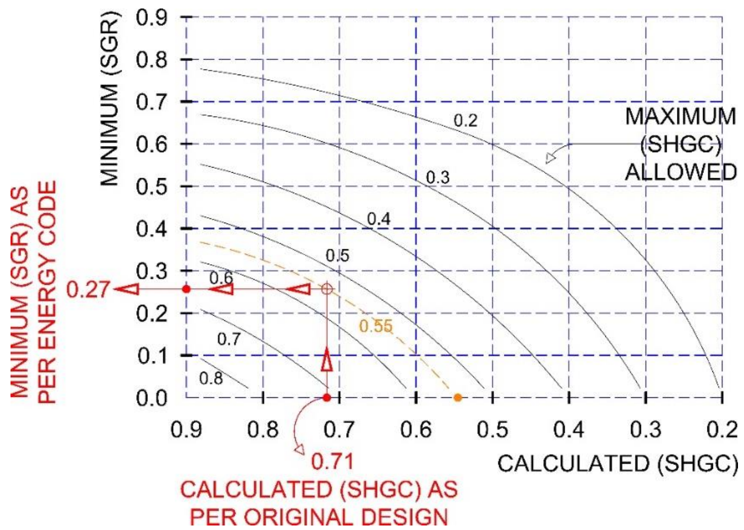


Figure (18). Calculation of minimum (SGR) according to actual (SHGC), Source: The author.

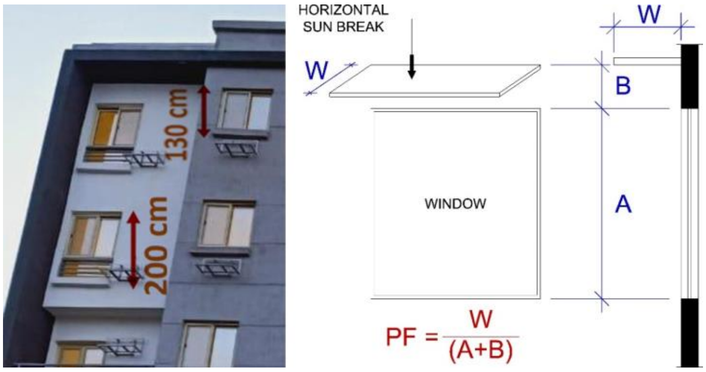


Figure (19). Sun break design, Source: The author.

5.3 The proposed modifications to the southern wall in accordance with the recommendations of the code for improving energy efficiency:

According to the previous calculations, by applying the recommendations of the Egyptian Energy Code to improve the efficiency of energy use in residential buildings, it is recommended to modify the southern wall design, as shown in Figure (19), to become as follows:

1. External Openings: Horizontal sun breakers with a prominence of (32 cm) were used according to appropriate calculations for the maximum height of the windows in the facade.
2. The layers of the building envelope were modified as follows: 25mm cement plaster + 120mm brick work + 10mm extruded polystyrene insulation + 120mm brick work + 25mm cement plaster (including paints for finishing)

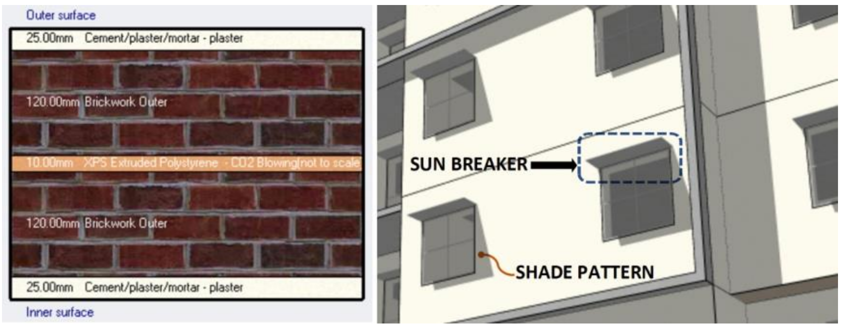


Figure (20). The updated south wall design as per the Egyptian energy code requirements, Source: The author.

The simulation was studied in two successive steps. The first step includes modifying the external openings only to identify the effect of shading individually in accordance with the code recommendations. The second step includes modifying the solid walls in addition to the external openings. The following points explain the simulation results for both cases.

5.4 Shading Effect of External Openings in Accordance with Energy Code Requirements

The results of the applied study on the modified model for the external openings are clear from the simulation results for energy consumption as shown in Table (10) and Figure (21). By comparing them to the energy consumption rates of the original design, the following points can be concluded:

- The highest cooling energy consumed in August decreased to (2546.36 kWh) instead of (2857.71 kWh); by an amount of (10.45%).

- The highest heating energy consumed in January decreased to (1175.99 kWh) instead of (1313.32 kWh); by an amount of (10.89%).
- The total energy required for cooling works decreased by (1311.29 kWh) with a percentage of (11.72%); to become (9880.75 kWh) instead of (11192.04 kWh).
- The total energy required for heating works decreased by (233.42 kWh) by a percentage of (9.29%), to become (2280.26 kWh) instead of (2513.68 kWh).
- According to what is mentioned above, the total energy consumed for all cooling and heating works decreased by an amount of (11.27%).

Table (10). The reduction in the energy consumption due to openings shading as per energy code standards for the south elevation.

	Base design		Energy code standards effect		Reduction in energy consumption	
	Cooling kWh	Heating kWh	Cooling kWh	Heating kWh	Cooling kWh	Heating kWh
Jan.	0	1313.32	0	1175.99	**0**	**137.33**
Feb.	0	491.21	0	467.98	**0**	**23.23**
Mar.	2.1	167.55	0.8	173.96	**1.30**	**-6.41**
Apr.	163.23	2.45	123.37	3.03	**39.86**	**-0.58**
May	770.66	0	685.44	0	**85.22**	**0**
Jun.	1875.98	0	1691.58	0	**184.40**	**0**
Jul.	2483.49	0	2230.06	0	**253.43**	**0**
Aug.	2857.71	0	2546.36	0	**311.35**	**0**
Sep.	1814.83	0	1573.94	0	**240.89**	**0**
Oct.	1112.02	0	938.15	0	**173.87**	**0**
Nov.	112.02	60.67	91.05	50.11	**20.97**	**10.56**
Dec.	0	478.19	0	408.90	**0**	**69.29**

Source: The author.

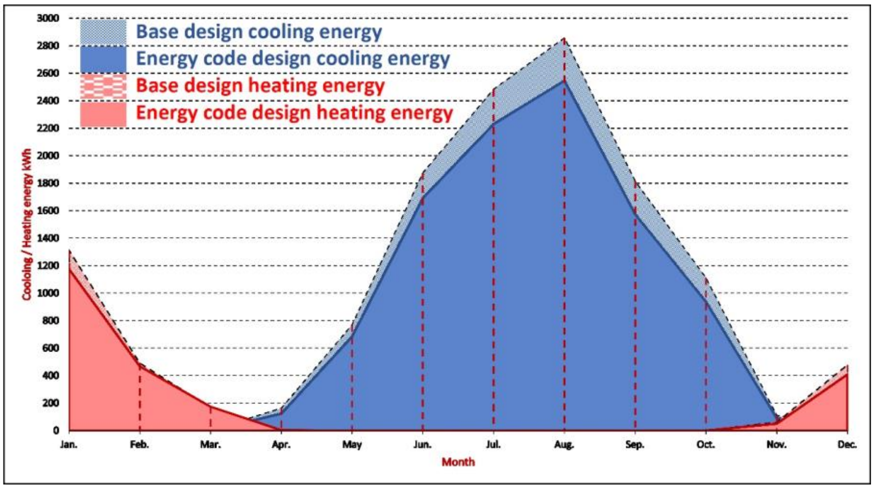


Figure (21). The impact of the openings shading as per the Egyptian energy code standards at the south elevation on the energy consumption, Source: The author.

5.5 The Overall Design Effect of the Building Envelope in Compliance with the Energy Code of the Openings and South Walls

With further improvement of the properties of the building envelope, through the previously proposed modification to both the external openings and the solid shell to achieve the required thermal properties in accordance with the appropriate rates in the energy code, in order to study the impact of the energy code recommendations, the results are indicated in Table (11) and Figure (22), which can be mentioned as follows:

- The highest cooling energy consumed in August decreased to (2396.04 kWh) instead of (2857.71 kWh) by an amount of (16.15%).
- The highest heating energy consumed in January decreased to (1008.70 kWh) instead of (1313.32 kWh) by an amount of (23.19%).
- The total energy required for cooling works decreased by (1841.03 kWh) by a percentage of (16.44%) to become (9351.01 kWh) instead of (11192.04 kWh).
- The total energy required for heating works decreased by (607.73 kWh) by a percentage of (24.17%) to become (1905.95 kWh) instead of (2513.68 kWh).
- According to what is mentioned above, the total energy consumed for all cooling and heating works decreased by an amount of (17.86%).

Table (11). The reduction in the energy consumption due to south elevation modifications as per energy code standards.

	Base design		Energy code standards effect		Reduction in energy consumption	
	Cooling kWh	Heating kWh	Cooling kWh	Heating kWh	Cooling kWh	Heating kWh
Jan.	0	1313.32	0	1008.70	**0**	**304.62**
Feb.	0	491.21	0	390.54	**0**	**100.67**
Mar.	2.1	167.55	0.81	142.46	**1.29**	**25.09**
Apr.	163.23	2.45	111.02	2.89	**52.21**	**-0.44**
May	770.66	0	653.88	0	**116.78**	**0**
Jun.	1875.98	0	1599.18	0	**276.80**	**0**
Jul.	2483.49	0	2102.34	0	**381.15**	**0**
Aug.	2857.71	0	2396.04	0	**461.67**	**0**
Sep.	1814.83	0	1493.12	0	**321.71**	**0**
Oct.	1112.02	0	902.27	0	**209.75**	**0**
Nov.	112.02	60.67	92.35	35.28	**19.67**	**25.39**
Dec.	0	478.19	0	325.79	**0**	**152.40**

Source: The author.

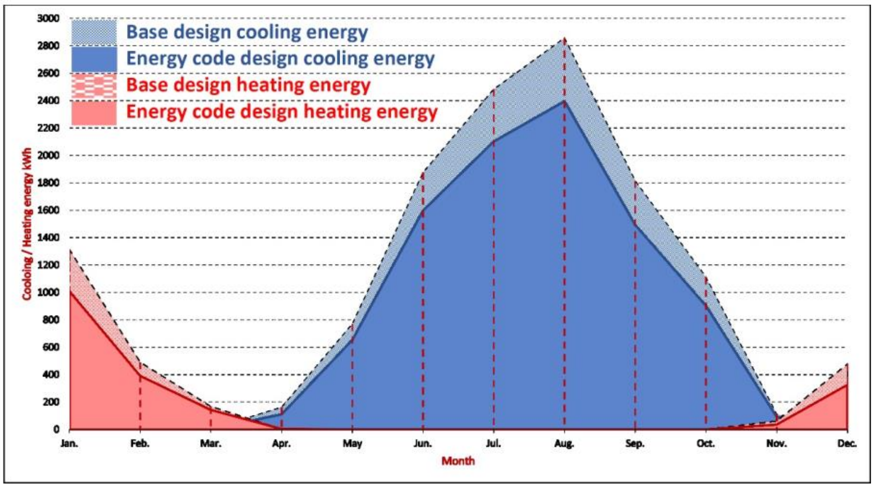


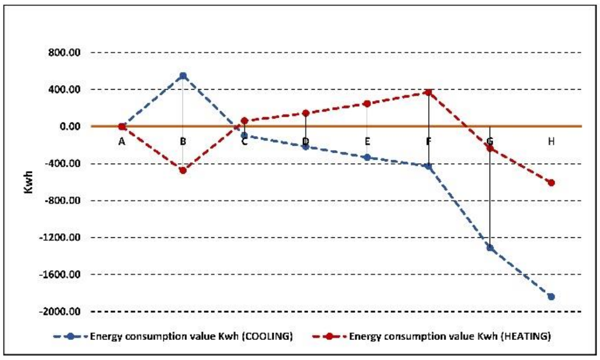
Figure (22). The impact of the modified south elevation as per the Egyptian energy code standards on the energy consumption, Source: The author.

Based on the previous results, it must be emphasized that studying the impact was carried out only to redesign the southern facade in accordance with the Egyptian Energy Code recommendations on the southern facade only; which means that these impacts will increase if all the code's recommendations are applied to design the entire building envelope; including: providing appropriate shading for all external openings and providing the required thermal resistance of the solid building envelope according to the previously mentioned tables above in the energy code.

6. EVALUATION RESULTS OF THE ENVIRONMENTAL DESIGN IMPACT OF THE SOUTHERN FACADE

Research studies examined the impact of the environmental design of the southern facade based on two main factors: shading and environmental recommendations of the energy code for residential buildings.

It is obvious from the mathematical results that the environmental impact of shading differs from the environmental impact of the energy code recommendations, as it is clear that the environmental impact of the energy code recommendations is positive in providing the energy required for both cooling and heating works. However, shading leads to a positive impact on the percentage of energy consumed for cooling works and increases the energy consumed for heating works. In addition, the effect values on the energy consumed are shown in Figure (23).



A Base case including shading devices 25 cm
B Without shading devices
C 40 cm Shading devices
D 60 cm Shading devices
E 80 cm Shading devices
F 100 cm Shading devices
G Base case + "Windows shading" as per energy code
H Base case + "Windows shading and external wall layers" as per energy code

	Cooling (Kwh)	Change Kwh (COOLING)	Heating (Kwh)	Change Kwh (HEATING)
A	11192.04	0.00	2513.68	0.00
B	11743.63	551.59	2038.92	-474.76
C	11095.09	-96.95	2575.02	61.34
D	10975.45	-216.59	2658.65	144.97
E	10857.92	-334.12	2762.29	248.61
F	10762.39	-429.65	2883.63	369.95
G	9880.75	-1311.29	2280.26	-233.42
H	9351.01	-1841.03	1905.95	-607.73

Figure (23). The impact of the environmental design for the south elevation on the energy consumption, Source: The author.

1. The environmental impact of increasing the shading ratio is positive in reducing the energy required for cooling works, while it leads to an increase in the energy required for heating works.
2. The overall effect of increasing the shading on the facade after calculating the amount of energy saved for cooling works, which was increased for heating works, has a positive result in reducing the total amount of energy required for the building.
3. It is clear from Figure (24) the total amount of energy that was saved after calculating the amount of energy that was saved for cooling works and the amount of energy that was increased for heating works. It is clear that the total result is a reduction in the energy required for the building. However, it is noted that the total amount of energy that was saved increases directly with the increase in the lighting percentage accompanying the increase in the prominence value, up to the prominence value of (80 cm). If the prominence increases beyond that, the relationship becomes inverse as the overall result begins to decrease; according to what is shown in the following Figure.
4. The environmental impact of designing the exterior facade in accordance with the Egyptian Energy Code recommendations to rationalize energy consumption in buildings has a positive impact on both the energy required for cooling and heating works.
5. The effect of shading windows according to the rates approved by the Egyptian Energy Code is positive and leads to reducing the energy required for both

cooling and heating works, unlike what happens in the case of increasing shading on external walls.

6. The effect of the environmental design of the external wall in accordance with the Egyptian Energy Code recommendations leads to reducing the energy required for both cooling and heating works, unlike what happens in the case of increasing shading on the external walls.
7. The percentage and quantity of change in the energy required for the building becomes clear with the change in the shading ratio and following the recommendations of the energy code according to what is shown in Figure (23).

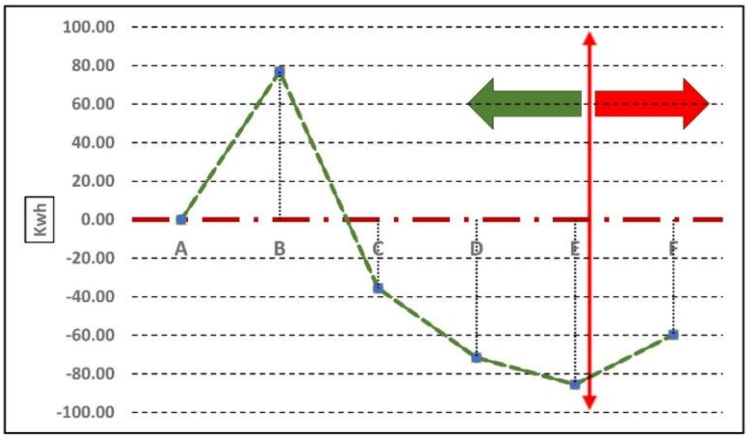


Figure (24). The total impact of the shading for the south elevation on the energy consumption, Source: The author.

7. RECOMMENDATIONS

According to the previous study and the calculations shown for the design of the southern facade, the following recommendations can be concluded:

1. The appropriate design of the external walls must be taken into account in accordance with the recommendations of the Egyptian Code for Energy Efficiency in Buildings, as they were not taken into account in the design of the openings and solid external walls of the typical Egyptian residential model.
2. The climatic region of the residential model must be taken into account and not to unify the sector and design of the building envelope of the residential units, as each region has the appropriate design for the building envelope in accordance with the requirements of the Energy Code, and with its positive impact on saving the energy required for the cooling and heating works of the building.
3. Due to the tangible effect of the presence of shading on the external walls when compared to the absence of shading, consideration must be given to providing appropriate shading on the external facades through various devices of overhangs, terraces and external trims that are compatible with the architectural design of the building.
4. The effect of increasing shading is through a direct relationship up to a certain percentage after which the relationship reverses. However, according to the previous calculations, it is sufficient to provide shading through trims and cornices by only (25 cm), as increasing the value of trims beyond that has a limited effect that can be ignored and contented with the trims specified by the Unified Building Code by (25 cm).
5. The most appropriate design for the external facades of residential buildings according to the climatic region, which includes the following: providing

appropriate shading for the external openings in accordance with the code + providing the appropriate sector for solid walls in accordance with the code + providing a percentage of not less than (40%) of the total length of the combined external facades for all floors of the building. They are designed as exterior trims of 25 cm in accordance with the Unified Building Code.

6. As for the previous residential buildings of Sakan Misr Project, they already contain a sufficient percentage of trims to provide appropriate shading. The efficiency of the environmental performance of the existing building envelope can be increased by providing appropriate shading for the external openings in accordance with what the Energy Code stipulates, while keeping the same section of the existing wall due to the difficulty of making appropriate modifications to it.
7. All previous calculations and results were through the environmental design of the southern wall only, which means increasing energy saving in the residential building when designing the rest of the walls of the building envelope for all geographical directions in accordance with what is stated in the Energy Code.
8. It is worth noting that energy consumption in such type of housing is quite low compared to other types of building functions such as: office buildings, hotels, hospitals, ……. etc. Or high type residential buildings. It means that this analysis would give better performance but with a very long payback period due to low energy consumption.

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