Thermal Performance of Building Envelope in Residential Buildings in New Administrative Capital in Egypt

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Abstract:
Global warming and environmental challenges are becoming major issues in every aspect of our life and specially in architectural design. The need to follow environmental architecture standards is crucial issue in this time. Egypt has a code for improving the energy efficiency of all building types. However, the residential sector doesn't fully comply to these standards and measurements. This research explores the compliance of the building envelope of R3 residential complex project in the administrative capital as it represents a prototype that will widely be implemented in different areas across the new administrative capital. The research also studies the potential energy savings resulting from optimizing the building envelope to comply with the Egyptian Code for Improving Energy Efficiency in Buildings. The research analysis and simulation revealed that the building envelope is not compatible with Egyptian Code for Improving Energy Efficiency in Buildings for residential buildings. Following the code for the building envelope elements can achieve annual energy consumption savings that are up to 20%.

Keywords:
Building Envelope,
Thermal Performance,
New Administrative Capital

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1- Introduction:
The residential sector in Egypt is featured with low thermal performance [(1)]. Many countries in the Middle East and North Africa (MENA) region are known for their outdated and poor construction quality. Furthermore, the MENA area have tremendous population increase and urbanization, which is accompanied by economic growth [(2)]. Egypt, being a member of the MENA area, is working to improve building energy efficiency, as is the rest of the world. Due to the rising burden of energy use in the construction industry, particularly residential buildings [(3)], energy conservation is gaining traction among the public, designers, and decision-makers [(4)]. Furthermore, residential buildings account for a significant component of Egypt's building stock, accounting for 83.2% of all existing buildings, with 13,467,333 million units out of 16,185,063 million total. As a result of several factors, the residential sector is the largest energy consumer when compared to other sectors, accounting for about 51 percent of total electricity supplied to grid in 2016-2017[(5)]. This is due to several factors, the most important of which is the excessive use of air conditioning during the cooling season [(6)].

As stated by Y. Serag (2017), the new administrative capital in Egypt is expected to propose a frog leap in the Egyptian economy providing valuable opportunities in the economic development of Egypt. Having a new capital will provide a capacity to discharge the over-population from Cairo- the current capital- [(7)]. As per the New Urban Communities Authority, the R3 district in the New Administrative Capital was planned to deploy high technological smart systems to monitor and optimize energy consumption through the operation of the building, yet these systems were not installed due to financial issues. The design of

[(1)] GamalEldine, M.; Corvacho, H. (2022) Compliance with Building Energy Code for the Residential Sector in Egyptian Hot-Arid Climate: Potential Impact, Difficulties, and Further Improvements. Sustainability 14, 3936.
[(2)] Florentine, V.; Caterina, S.; Kurt,W.; Riadh, B. (2013) Energy Efficiency Building Code A Roadmap for Implementation in the MENA Region; UN-CTCN: Copenhagen, Denmark.
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[(4)] CAPMAS (2017). Annual Bulletin of Environment Statistics-Part One: Environment Conditions & Quality; Central Agency for Public Mobilization and Statistics: Cairo, Egypt.
[(5)] Egyptian Electricity Holding Company (2017), Annual Report, 2016/2017, Ministry of Electricity & Renewable Energy, Egypt.
[(6)] Ministry of Energy (2018) Egyptian Electricity Holding Company Annual Report 2017/2018; Ministry of Energy: Cairo, Egypt.
[(7)] Serag, Yehya. (2017). The New Administrative Capital of Egypt a Critical Review from the Regional. SSRN Electronic Journal. 10.2139/ssrn.3162316.

the building envelope of this project wasn't tested for the thermal performance of it and was not compared against the Egyptian Code for Improving Energy Efficiency in Buildings. Since the New Administrative Capital is a new City that is under construction since 2015, no significant research has been done yet on and the efficiency of the buildings designs and their capability of providing thermal comfort to the users without consuming large amount of energy. This research aims at providing an analytical study of the building envelope components of the R3 buildings, being a generalized sample of residential buildings construction by the New Urban Communities Authority, and comparing it against the Egyptian Code for Improving Energy Efficiency in Buildings to check their compliance. Moreover, the research proposes solutions on how to follow the Code and simulates the energy consumption reduction potential resulting from the adjustment of the building envelope.

Using passive strategies in similar climatic zones (hot arid) have the ability of reducing electricity consumption in buildings [(1)]. Abdulsada, Ghanim & Mohammed Salih, Tawfeeq. (2022) concluded that the use of suitable insulation for the building elements of buildings in hot arid climates decreases the energy consumption and positively affects the economy and environment [(2)]

As stated by Al-homoud (2004), The thermal properties of building envelope determine the level of thermal comfort achieved in buildings according to their climate zone and climate conditions [(3)]. Previous research has been done in similar climates, Aboulnaga and Moustafa (2016) in their research studying the effect of adding insulation materials to higher education building external wall (building envelope) stated that it reduced the annual energy consumption by 15% from the base case wall [(4)].

As per Sharma, S.K. et al (2022), Applying thermal insulation to the opaque components of the building envelope has a great potential in enhancing the thermal performance of the building envelope [(5)]. Previous research study about residential buildings in Egypt and the importance of adopting proper technologies in the building envelope, Khalil, A. et al. (2018) concluded that achieving thermal comfort in residential buildings in the climate of Egypt can be implemented without relying on HVAC systems and it can be achieved using low technology as referred by them to the use of natural local resources along with passive strategies [(6)]. Shehata, Ahmed & Waheeb, Sahl. (2018) proved that, in Makkah, hot arid zone which is similar to the case study of this research, applying insulation to the walls improves the thermal performance and reduces the energy consumption of the building. They stated that in such climate, it is recommended to have a window to wall ratio of 10% only [(7)]. While Huang et al (2021) stated that improving the thermal insulation by adding more insulating materials is considered effective way of improving the thermal performance of opaque building elements (walls) [(8)]. And as mentioned by Shi, L., Zhang et al in 2018, improving the thermal performance of building envelopes by increasing the thermal insulation of them can decrease the heat loss through the building fabric and reduce heating and cooling loads [(9)]. As people spend almost 90% of their time indoors, studying thermal comfort is essential as it represents the satisfaction of the person about the surrounding thermal

(1) Mohammad Yusoff, W.F.; Mohamed, M.F. (2017) Building Energy Efficiency in Hot and Humid Climate. In Encyclopedia of Sustainable Technologies; Elsevier: Amsterdam, The Netherlands.

(2) Abdulsada, Ghanim & Mohammed Salih, Tawfeeq. (2022). The impact of efficient insulation on thermal performance of building elements in hot arid region. Renewable Energy and Environmental Sustainability. 7. 2. 10.1051/rees/2021050.

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(9) Shi, L., Zhang, H., Li, Z., Luo, Z., & Liu, J. (2018). Optimizing the thermal performance of building envelopes for energy saving in underground office buildings in various climates of China. Tunnelling and Underground Space Technology, 77, 26 35.

environment[1].

2- Methodology:

This research studies the compliance of the building envelope of the case study building with the Egyptian Code for Improving Energy Efficiency in Buildings ECP 306-2005.

2.1 Case Study Selection:

The case study building was selected to represent a prototype of a residential building in the New Administrative Capital, which is considered the promising future of Egypt that will house several mega projects that differ from residential, commercial, and administrative buildings. Working on the enhancement of buildings in the New Administrative Capital is essential in terms of their energy consumption and their thermal performance. Th R3 residential project is currently under construction and will be further implemented in different locations in the New Administrative Capital. The R3 OC- type building is a building prototype represents the mainstream residential building structures in Egypt in terms of building materials and structure system. The case study choice is in a semi desert zone climatic zone which is the main climate zone where Egypt is situated representing a wide range of regions in Egypt with results that can easily be applied to different projects in different locations.

2.2 Compliance of the building envelope with energy code:

The building envelope of the case study building was analyzed to determine the R-value of the opaque elements (walls), the Window to Wall Ratio (WWR) and the Solar Heat Gain Coefficient (SHGC) of the openings and to compare them against the Egyptian Code for Improving Energy Efficiency in Buildings ECP 306-2005. The SHGC is a value between 0 and 1. Low SHGC value means less solar heat and greater shading.

2.3 Case Study Energy Simulation:

The case study building was modeled in Design Builder software as it is accurate and provides thermal simulation of spaces, it is a trusted tool based on Energy plus[2]. The modeling of the building includes inserting the weather file representing the climatic zone, the construction of the building, construction materials, thermal data, activity, and occupancy schedules.

An annual energy simulation was conducted to display the energy consumption of the building throughout the year. First, The base case was simulated to determine the energy consumption of the existing design of the R3 OC-type building. Then the optimization strategies were applied to the building to make it comply to the energy code. The energy consumption was investigated after the retrofit of the building envelope elements were applied.

3- Case Study Climatic Context:

The New Administrative Capital has a hot arid climate and according to Egyptian Organization for Energy Conservation and Planning (EOECP), it is classified as semi desert zone. It is located in Longitude: 31.7308237 and Latitude: 30.0087918 Its elevation is 317 m above sea level. Figure 1 shows the wind rose of the New Administrative Capital. Figure 2 shows the location of it among the seven climatic zones of Egypt as per the Egyptian Organization for Energy Conservation and Planning (EOECP). Table 1 shows the Monthly average temperature and precipitation in the New Administrative Capital.

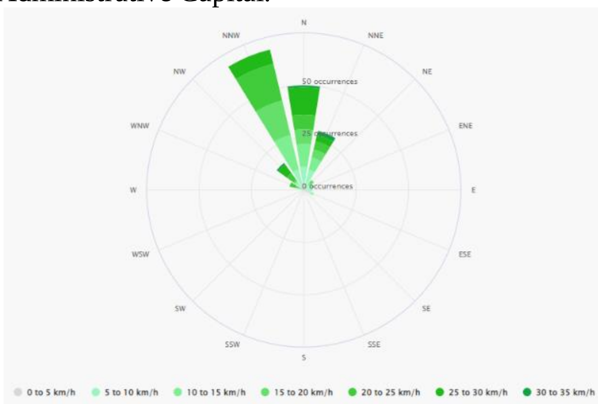

Fig. 1: New Administrative Capital wind rose Source: Produced by researchers using weather tool

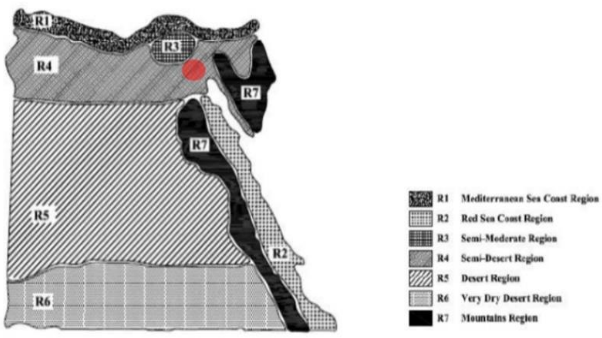

Fig. 2: Egypt's climatic zones with New Capital location Source: Osman, 2011 adapted by researchers ( )

(1) Hoof, Joost & Mazej, Mitja & Hensen, Jan. (2010). Thermal comfort: Research and practice. Frontiers in Bioscience. 15. 765-788. 10.2741/3645.

(2) Mohamed, Edeisy & Cecere, Carlo. (2017). Envelope Retrofit in Hot Arid Climates. Procedia Environmental Sciences. 38. 264-273. 10.1016/j.proenv.2017.03.075.

Table 1: Monthly average temperature and precipitation in the New Administrative Capital
Source: Geotsy database- countries and territories-www.geotsy.com

Climate Table • New Administrative Capital (Egypt)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MAX	19°	21°	24°	28°	32°	34°	34°	34°	33°	29°	24°	20°
MIN	4°	6°	8°	13°	17°	19°	21°	21°	19°	16°	11°	6°
PRECIPIT...	7	5	5	2	1	0	0	0	0	1	4	5
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

4- Case Study Overview

R3 district in the New Administrative Capital is one of eight districts first phase. This district is divided into three parts, al maqsad residential compound, 61 residential apartments of many types and a zone of services and amenities. The chosen OC type represents the other types as well from construction and finishing materials. Figures 3,4,5 show the R3 district, type OC new capital elevation, building floor plan and 3D model. Table 2 displays the building data of it. According to the New Urban Communities Authority, the building envelope is as shown in Table 3.

Table 2: R3 OC type Building Data

Owner	New Urban Communities Authority
Consultant	5+UDC
Building Type	Residential
Number of Floors	9
Floor Area	902 m^2
Number of Apartments per floor	8
Location	New Administrative Capital, Egypt 30.001270 Latitude/ 31.432470 Longitude
Climate Zone	Hot arid, semi desert zone
Construction	Skeleton building, Reinforced concrete, Egyptian hollow clay bricks

Fig. 3: R3 district, type OC new capital 3D model
Source: Engineering management of Project consultant- 5+UDC

Fig. 4: R3 district, type OC new capital Elevation
Source: Engineering management of Project consultant- 5+UDC

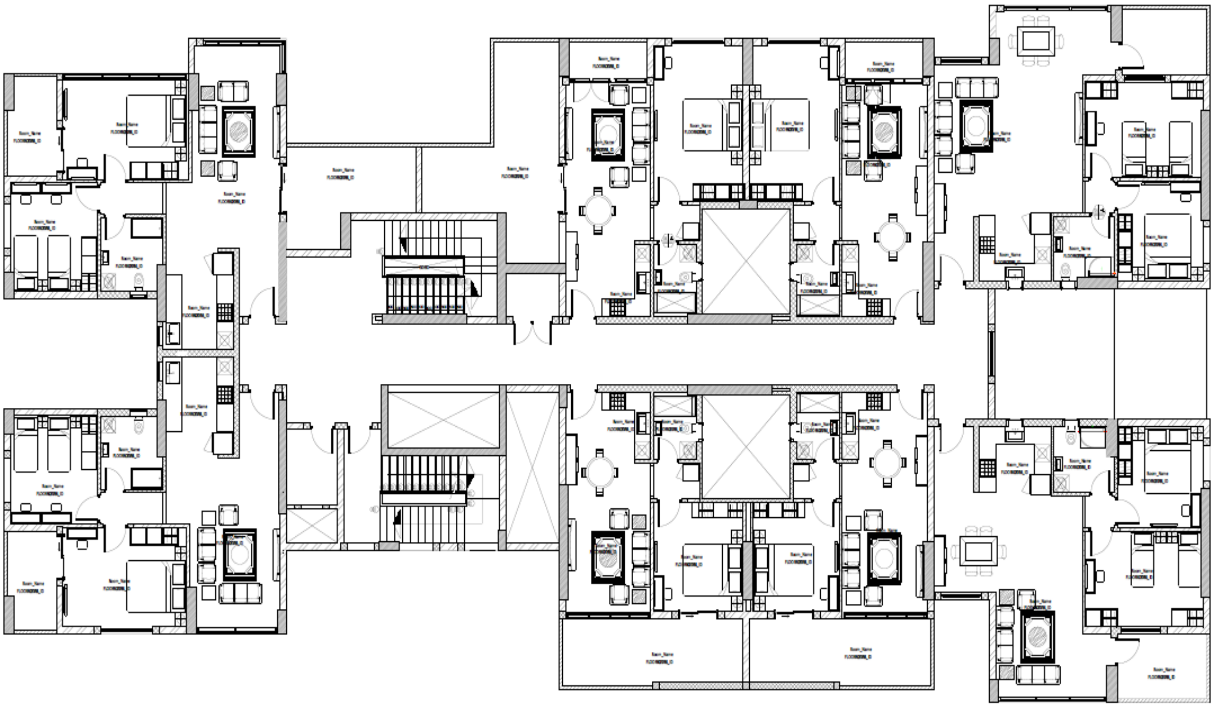

Fig. 5: R3 district, type OC building floor plan
Source: Engineering management of Project consultant- 5+UDC

Table 3: R3, OC type Case study, building envelope material thicknesses
Source: Engineering management of Project consultant- 5+UDC

Material	Thickness (m)
Internal plastic paint	0.002
Cement mortar	0.02
Egyptian hollow clay bricks	0.25
Cement mortar	0.02
Dry mix	0.003
Glazing: single clear glass	0.006

5- Building Compliance with Energy Code

5.1 Compliance with Energy Code for The Opaque Elements (walls)

For Cairo and delta climatic zone, according to the Egyptian Code for Improving Energy Efficiency in Buildings (1), the R value of the north elevation should be 0.35-0.47 m2.K/W, the east and west elevations should be 0.92- 1.35 m2. K/W, and the south elevation should be 0.67- 0.89 m2. K/W as shown in table 4.

Table 4: Required R-value of the opaque elements (walls) in each orientation
Source: The Egyptian Code for Improving Energy Efficiency in Building

Orientations	North	East	South	West
Required R-value	0.35-0.47 m2.K/W	0.92-1.35 m2K/W	0.67-0.89 m2K/W	0.92-1.35 m2K/W

The case study building has an external wall made of 2 millimeters internal plastic paint, 20 millimeters of cement mortar, 25 centimeters Egyptian hollow clay bricks, 20 millimeters of cement mortar and 30 millimeters dry mix external finishing with a total U-value of 2.25 W/m2K, and a total R-value of 0.73 m2K/W. U-value is the thermal transmittance, which is considered the most important feature of building elements that determines its thermal performance(2).

The R-value of the external wall is only compatible with the energy code in case it is oriented towards North or South directions, while it is less that the requirement in east and west elevations. R-value is the thermal resistance of a material (3).

(1) The Egyptian Code for Improving Energy Efficiency in Buildings ECP 306-2005. First part: residential buildings.

(2) Giama, E. & Kyriaki, Elli & Papadopoulos, Agis. (2020). U-Value: A key role parameter for sustainable buildings. Journal of Sustainable Architecture and Civil Engineering. DOI: https://doi.org/10.5755/j01.sace.16.3.15442

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5.2 Compliance with Energy Code for the Openings:

As shown in table 5, the building main elevation area is 1716 m2, the windows area is 664 m2, The Wall (opaque part) area is 1052 m2 and the Window to Wall Ratio (WWR) is 0.63 63%.

Table 5: R3 new administrative capital OC type building, main elevation data
Source: Engineering management of Project consultant- 5+UDC

Whole main elevation area	1716 m2
Windows area	664 m2
Wall (opaque part) area	1052 m2
Window to Wall Ratio	63%
Solar Heat Gain Coefficient (SHGC)	0.85

Table 6: Required SHGC for openings in elevations
with WWR more than 30% in Cairo and delta climatic zone
Source: The Egyptian Code for Improving Energy Efficiency in Building

	North	East	South	West
Required SHGC for WWR > 30%	0.67		0.5	

As seen from the analysis of the main building elevation, the window to wall ration of 63% represents a great glazed area that is not compatible to this climatic zone guidelines according to the code. As shown in table 6, the SHGC of the openings which is 0.85 doesn't comply with the requirements of The Egyptian Code for Improving Energy Efficiency in Buildings. In case of North oriented main façade exceeding 30% WWR, the SHGC should be 0.67. As for the south orientation, the SHGC should be 0.5. The East and west orientations should not have more than 30% WWR as this will increase the solar heat gain from the openings which will cause overheating in the spaces. The east and west oriented main façades should be adjusted to have WWR that is less than 30% in order to be compliant with the code.

6- Modeling and Simulation Results:

A three- dimensional model was built on Design Builder software for the whole building. The building model was simulated with the main elevation in the four main orientations. Annual energy consumption of the building in the base case was calculated.

The building envelope opaque elements (walls) were modified to increase the R-value in order to comply with the energy code. The first simulation was that of the base case model with 0.73 m2K/W showing the annual energy consumption.

As shown in table 7 and figure 6, the first optimization strategy was adding an air gap that increased the R-value to be 0.91 m2K/W which is still not compatible with the requirements of the energy code for east and west elevations. This strategy decreased the energy consumption of the east oriented main façade from 99375 Kw.h to 90505 Kw.h with a reduction of 9% of the annual energy consumption, it decreased the energy consumption from 133050 Kw.h to 122550 Kw.h for the west oriented main façade with a reduction of 8% of the annual energy consumption.

The second optimization strategy was adopted after Attia et. al (2012) and the choice of materials was adjusted after their research(1). As per Motawa, I., et al. (2021), it was tested that using polystyrene thermal insulation achieved significant energy consumption reduction in the same climatic zone but being integrated with other different alternatives (2). The strategy in this research was adding polystyrene thermal insulation to the wall between the brickworks and the internal plaster layer. which increased the wall R-value to be 1.15 m2K/W which made it compatible with the energy code for the east and west elevations. This strategy decreased the energy consumption of the east

(1) Attia, S., Evrard, A., and Gratia, E. (2012), "Development of benchmark models for the Egyptian residential buildings sector". Applied Energy 94 (2012) 270–284, doi:10.1016/j.apenergy.2012.01.065

(2) Motawa, I., Elsheikh, A., and Diab, E. (2021). Energy Performance Analysis of Building Envelopes. Journal of Engineering, Project, and Production Management, 11(3), 196-206.

oriented main façade from 99375 Kw.h to 85675 Kw.h with a reduction of 14% of the annual energy consumption. It decreased the energy consumption from 133050 Kw.h to 120225 Kw.h with a reduction of 10% of the annual energy consumption in the west elevation.

Table 7: Annual energy consumption of the case study building in R3 new capital- Type OC building before and after improving the building envelope
Source: Researchers using DesignBuilder software

	Annual Energy Consumption			
	Exposed wall North orientation	**Exposed wall East orientation**	**Exposed wall South orientation**	**Exposed wall West orientation**
Base case wall R-value = 0.73 m2K/W	93100 Kw.h	99375 Kw.h	115075 Kw.h	133050 Kw.h
Base case wall + air gap R-value = 0.91 m2K/W	89050 Kw.h	90505 Kw.h	108572 Kw.h	122550 Kw.h
Base case wall + 13mm Polysterene 0.73 +0.42 Total R-value= 1.15 m2K/W	84300 Kw.h	85675 Kw.h	103875 Kw.h	120225 Kw.h

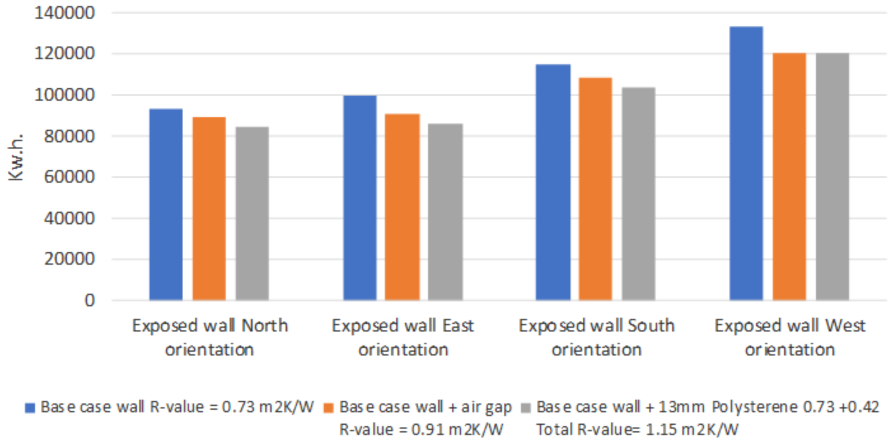

Fig. 6: Annual energy consumption of the case study building in R3 new capital- Type OC building after improving the building envelope
Source: Researchers using Design Builder Software

The optimization of the openings of the building to determine the best glazing type in the four main elevations occurred in two steps. As shown in table 8 and fig. 7, the first step is using double clear glass with SHGC= 0.76. The second step is using Triple glazing, Low-e with SHGC= 0.49. The double-glazing case does not comply with the code as it only provides SHGC of 0.76 while it is needed to be 0.67 in north orientation and 0.5 in south orientation. As for the east and west elevations, the building design should comply with the code and the maximum WWR which is 30% in this climatic zone.

Table 8: Required SHGC for openings in elevations
with WWR more than 30% in Cairo and delta climatic zone
Source: Researchers using Design Builder software

	Annual Energy Consumption			
	Exposed wall North orientation	**Exposed wall East orientation**	**Exposed wall South orientation**	**Exposed wall West orientation**
Base case Single clear glass SHGC= 0.85	93100 Kw.h	99375 Kw.h	115075 Kw.h	133050 Kw.h
Double clear glass SHGC= 0.76	85098 Kw.h		104006 Kw.h	
Triple glazing, Low-e SHGC= 0.49	81367 Kw.h		91843 Kw.h	

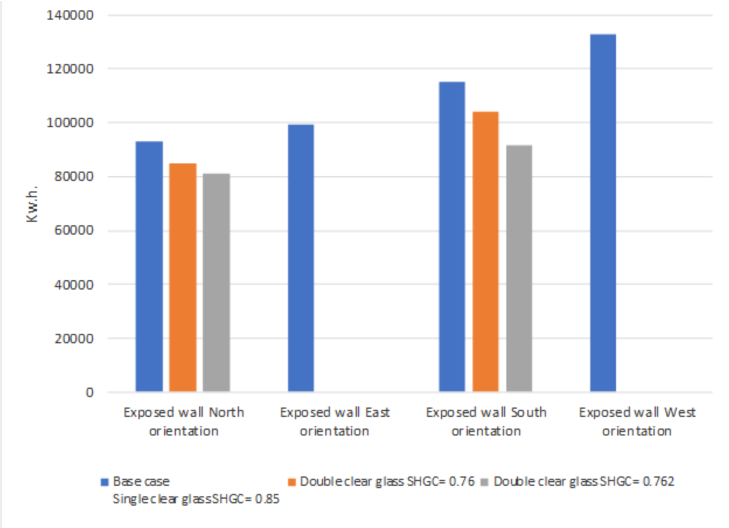

Fig. 7: Required SHGC for openings in elevations with WWR more than 30% in Cairo and delta climatic zone
Source: Researchers using Design Builder Software

The solar heat gain through openings is calculated using different mathematical methods and is presented in values of Solar Heat Gain Coefficient (SHGC).(1)

As shown in table 8, the simulation results of the double clear glass with Solar Heat Gain Coefficient (SHGC) of 0.76 show a reduction in the annual energy consumption of the north oriented main façade from 93100 Kw.h to 85098 Kw.h with a reduction of 8.6%. The east and west orientations should not have WWR more than 30%, so the percentage of the glazed area is not compatible with the code. The south oriented main façade had a reduction from 115075 Kw.h to 104006 Kw.h with 10% reduction. The second optimization strategy which is triple glazing low-e with Solar Heat Gain Coefficient (SHGC) of 0.49 resulted in reductions in the annual energy consumption of the north oriented main façade from 93100 Kw.h to 81367 Kw.h with 12.7 % reduction in the annual energy consumption. In the south oriented main façade, this strategy reduced the annual energy consumption from 115075 Kw.h to 91843 Kw.h with reduction of 20%.

7- Results:

Thermal performance of building envelope is a crucial factor determining the energy consumption. Following the energy code ensures considering the optimal scenario for designing an energy efficient building. Building envelope design has a great impact on the energy consumption of buildings specially in hot arid climates represented in the New Administrative Capital in Egypt. Considering the energy code in terms of R-value of opaque elements (walls), and the solar heat gain coefficient (SHGC) of openings have the potential of achieving great energy savings.

Full compliance with the energy code resulted in improving the R-value of the external wall while achieving 9% annual energy consumption reduction in the east oriented main façade and 8% in the west oriented main façade. The choice of materials achieving the required R-value by the code reduced annual energy consumption for the east oriented main façade by 14% and 10% in the west oriented main façade.

The large, glazed area of the building and the high WWR of the building reduced the potential energy savings from optimizing the building opaque elements (walls), while the optimization of the glazing became more effective. Using Double clear glass for the north oriented main façade achieved 8.6% annual energy consumption reduction while the double glazing didn't comply with the energy code.

East and west main façades require decreasing the glazed area to comply with the code as they shouldn't exceed 30% WWR.

Using triple Low-E glazing in the in the north oriented main façade and the south oriented main façade achieved 12.7% and 20% annual energy consumption reduction respectively.

8- Conclusion:

A key advantage of the full compliance to The Egyptian Code for Improving Energy Efficiency in Building is improving the thermal comfort and achieving occupant satisfaction as well as achieving energy efficiency and maintaining the energy resources. The proposed research work suggests

(1) Chen, F., Wittkopf, S. K., Khai Ng, P., & Du, H. (2012) Solar heat gain coefficient measurement of semi-transparent photovoltaic modules with indoor calorimetric hot box and solar simulator. Energy and Buildings, 53, 74–84. doi: 10.1016/j.enbuild.2012.06.00

alternatives to the existing building envelope of residential buildings in the New Administrative Capital in Egypt which can be generalized for use in the rest of the project and the repeated prototype throughout the new capital as it resembles the mainstream construction model for this project which will be widely spread under the same climatic conditions. This research paves the way for future research concerning the energy efficiency of buildings in the new capital as it is still under construction having significant potential for improving their energy performance. It is also a great start enabling other researchers to calculate the embodied energy of the building envelope materials to evaluate them during excavation, production, and transportation.

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