Fayoum University Faculty of Engineering, 2023, Vol: 6(2), 32-45
https://fuje.journals.ekb.eg/
ISSN Online: 2537-0634
ISSN Print: 2537-0626

Improving Energy Efficiency of Buildings Through Applying Glass Fiber Reinforced Concrete in Building's Envelopes Cladding:
Case Study of Residential Building in Cairo, Egypt

Eslam Mohamed Moraekip. [1,*]

[1] Assistant Professor, Architecture Engineering Department, Faculty of Engineering and Technology, Badr University in Cairo (BUC), Cairo, Egypt.
* Corresponding Author: Eslam Mohamed Moraekip, E-Mail: (moraekip@hotmail.com), ORCID No.: (0000-0003-1756-4139).

How to cite this paper: **Eslam Moraekip (2023).** Improving Energy Efficiency of Buildings Through Applying Glass Fiber Reinforced Concrete in Building's Envelopes Cladding: Case Study of Residential Building in Cairo, Egypt. *Fayoum University Journal of Engineering, 6,* (2) 32-45
https://dx.doi.org/10.21608/FUJE.2023.200212.1045

Abstract.

Glass Fiber Reinforced Concrete has recently been highly considered by architects, engineers, and contractors according to its good features such as high tensile strength, durability, variety of shapes, sizes, and colours, and its environmentally friendly properties that make Glass Fiber Reinforced Concrete suitable for thin, light, and free-form building's envelope cladding.

Five types of building envelopes were simulated using building performance simulation software (Design Builder Software Ltd – V. 7.0.0.116) on a prototype residential building in Cairo, Egypt; one of them is using conventional envelope finishing materials and compared with the other four types using various types of Glass Fiber Reinforced Concrete envelope's cladding to detect the effects of using Glass Fiber Reinforced Concrete in building thermal performance, energy consumption, and also to choose the optimum type of them that will be suitable with local environments in Cairo, Egypt.

Study results showed a large amount of heat transfer between the building's internal spaces and the outdoor environment caused by building external walls construction materials in the conventional building that should be treated to improve building thermal performance. By using Glass Fiber Reinforced Concrete envelopes cladding types, the study observes a reduction of heat transfer up to 60.47% that results in a reduction of energy consumption up to 10.42%.

From these results, it is demonstrated that using Glass Fiber Reinforced Concrete in a building's envelope cladding can enhance a building's thermal performance and thus reduces its energy consumption, related CO_2 emissions, operating costs, environmental pollution, and other negative impacts on the environment.

Keywords.

Glass Fiber Reinforced Concrete - Building Envelope – Building Cladding – Thermal Performance - Energy Efficiency.

1. Introduction.

Building energy efficiency and related environmental concerns have gain a considerable interest in recent years around the world to produce environmentally friendly and sustainable buildings that achieve users' optimum needs while preserving local environments and resources [2].

Energy conservation in buildings is taking central attention from decision-makers in Egypt to face the global energy crisis because the building sector consumes about 42% of energy in Egypt, leading to the release of the Egyptian energy codes to guide stockholders towards energy efficiency and conservation of local environments. [5]

Residential buildings in Egypt are considered one of the biggest building types that consume a huge amount of energy in their operating systems especially in HVAC systems according to the hot weather in summer that should be considered to conserve energy, reduce CO_2 emissions, and decrease environmental negative impacts. [5]

Building envelope materials is one of the important building elements that control the whole building's performance because it controls the relationship between the building's indoor and outdoor environments which directly affects on building's performance, operating systems, and energy efficiency. Therefore, choosing and installing suitable environmentally friendly materials for building envelopes is critical to enhancing the overall building's performance. [16]

Glass Fiber Reinforced Concrete (GRC) products make a non-negligible contribution to the building environments because it is considered green construction materials that achieve renewable, recyclable, and reusable material and can be used indefinitely without negatively affecting the environment. [9]

(GRC) has recently been highly considered by building materials manufactories in Egypt and it is being manufactured on a large scale due to the availability of its raw materials, ease and speed of manufacture and implementation, and its good features for fixtures and applications. [15]

The main aim of this study is to evaluate the usage of Glass Fiber Reinforced Concrete (GRC) as an alternative cladding material for building envelope finishing materials. The sub-aim is to evaluate the capabilities of using it to improve the building's thermal performance, enhance energy efficiency, and decrease operating costs. So, this study will concern to recognize and analyze the effects of using (GRC) in building envelope cladding materials in Cairo, Egypt to enhance whole-building performance while conserving local environments.

2. Literature Review.

(GRC) began in 1960 when the Building Research Establishment translated the publication of the work carried out by K.L. and Yu.L. Biryukovich. [2] The International Glassfibre Reinforced Concrete Association (GRCA) was formed in 1975 to exchange knowledge and experience concerning (GRC). [2] (GRCA), Marco Dona, and Mauro Overend discussed the properties of (GRC) from materials, strength, moulding, fabrication, fixing connection, and other manufacturing views. [3] [8] [12] Vahidi, Malekabadi, White, and Che discussed the applications of (GRC) from environmental performance and sustainability views. [9] [13] Mohammad Fahmy, Mohamed M. Mahdy, and Marialena Nikolopoulou studied the usage of (GRC) to enhance the thermal performance of buildings by applying it as an alternative material to external wall conventional construction materials. [10]

This research will focus on recognizing and analyzing the benefits of using (GRC) as an alternative to conventional finishing materials and cladding for external walls in Cairo, Egypt to enhance the thermal performance of buildings, decrease energy consumption and related operating costs, and to choose the optimum type of them that will be suitable with local environments in Cairo, Egypt.

3. Glass Fiber Reinforced Concrete (GRC).

Glass Fiber Reinforced Concrete (GRC) is an ultra-strong composite manufactured material that was developed in the early 1970s and produced from cement, polymers, silica sand aggregate, water, and high-strength glass fiber that easily molded into a wide selection of thicknesses, shapes, surfaces, colours, forms, and textures. [15]

Glass fiber is made with available resources and recycled content, it can be locally or regionally produced, and it is a water-based material that gives off no pollutants or toxins when produced that make it an environmentally friendly material. [1]

Adding glass fiber to cement in (GRC) reinforces the concrete and increases its load-bearing capacity in addition to other significant advantages such as being up to 80% lighter than concrete, easier to install, and boasting superior strength and durability. (GRC) can be used as lightweight wall panels, wall finishing tiles, window and door surrounds, column covers, motifs, cornices, domes, and other variable useful usages. [8] [9]

4. Methodology.

This study aimed to compare the thermal performance of a building by applying different external wall finishing materials using performance simulation software.

To achieve the aim and objective of the study; a comparative performance analysis of a prototype residential building case study in Cairo, Egypt was simulated using building performance simulation software on five alternative types of external wall finishing materials. The first type used conventional materials (sand cement plaster). The other four types used Glass Fiber Reinforced Concrete (GRC) envelope cladding types; (GRC) ribbed panel (using a 0.03 m thick (GRC) ribbed panel), (GRC) sandwich panel filled with thermal insulation (using a 0.08 m thick (GRC) sandwich panel filled with a 0.05 m thick foam polyisocyanurate thermal insulation), (GRC) stud frame (using a 0.08 m thick (GRC) stud frame with a 0.05 m thick air gap), and (GRC) stud frame with thermal insulation panels (using a 0.08 m thick (GRC) stud frame with a 0.05 m thick foam polyisocyanurate thermal insulation).

According to this analysis, the study can identify the effects of using (GRC) on enhancing building thermal performance and determine the optimum type for the local environments based on thermal performance analysis.

5. Case Study Analysis.

Evaluating the performance of (GRC) envelope's cladding can be achieved by simulating a prototype residential building that uses local conventional materials and systems in Cairo, Egypt with an analytical comparison of the results while using (GRC) envelope's cladding in the same building. The simulation was carried out using building performance simulation software (Design Builder Software Ltd – V. 7.0.0.116) and applying a weather data file from Cairo, Egypt to conclude the effects of using (GRC) in building cladding to improve thermal performance.

This residential building is proposed to be located in a new residential compound in Cairo, Egypt with five residential floors, four apartments per floor, occupancy density of 0.0196 people/m^2, footprint area of 446.87 m^2, total built-up area of 2,247.01 m^2, floor height of 3.0 m, and building internal volume of 4,511.60 m^3. Energy supplies electricity in all building operating systems and natural gas in individual water heaters. HVAC systems of individual split HVAC units in living and sleeping spaces and lighting systems of led bulbs. External walls of 0.25 m thick solid burned bricks with 0.02 m thick internal sand cement plaster and painting. Conventional finishing materials, flooring layers, wooden doors, aluminium windows with 0.004 m thick clear glass panels, internal zones, activities, and devices. Operating schedule of from 07:00 am to 12:00 am in living spaces and from 12:00 am to 07:00 am in sleeping spaces. *(Figure 1)*

The strategy of the analysis is by comparing the results of simulating a conventional residential building (type A) with four methods of applying (GRC) in the building envelope cladding in the same building (type B, C, D, and E) that calculating and analyzing using building performance simulation software to conclude the capabilities of using (GRC) for enhancing building's thermal performance, energy efficiency, and to choose the optimum type.

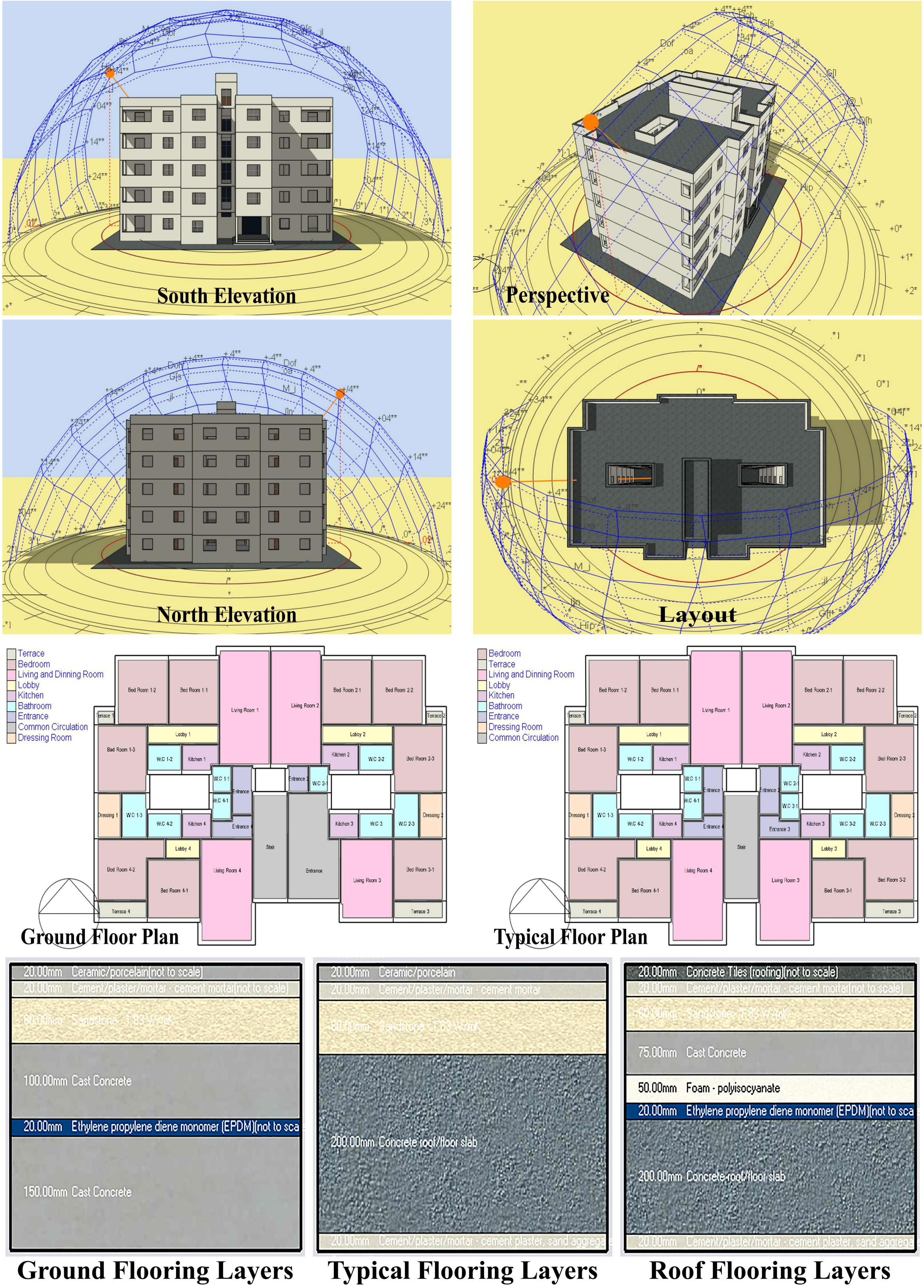


Figure (1). Prototype Residential Building Model [14]

5.1. Building Type (A).

In this building type, a whole building performance was simulated on conventional building envelope finishing materials using a normal 0.03 m thick external sand cement plaster and painting as external finishing material that estimates total R-Value = 0.534 m²K/W and U-Value = 1.874 W/m²K. *(Table 1) (Table 2)*

By simulating building envelope thermal performance on a peak day in summer and winter, the results referred to a huge amount of heat transfer from and to building internal spaces caused by external walls that should be treated to improve building thermal performance. *(Figure 2) (Figure 3)*

By analyzing the building type (A) external walls heat gain and loss, the amount of heat gain in the peak summer month was calculated as 3,158.49 Wh/m², the amount of heat loss in the peak winter month was calculated as 3,587.02 Wh/m², and the total amount of heat gain and loss in a whole year was calculated as 24,196.44 Wh/m². *(Figure 4)*

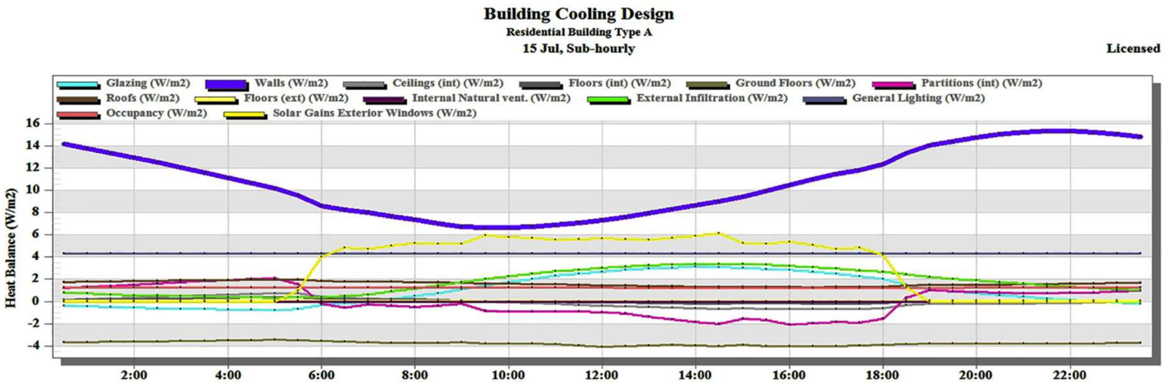


Figure (2). Building Type (A) Summer Peak Day Analysis [14]

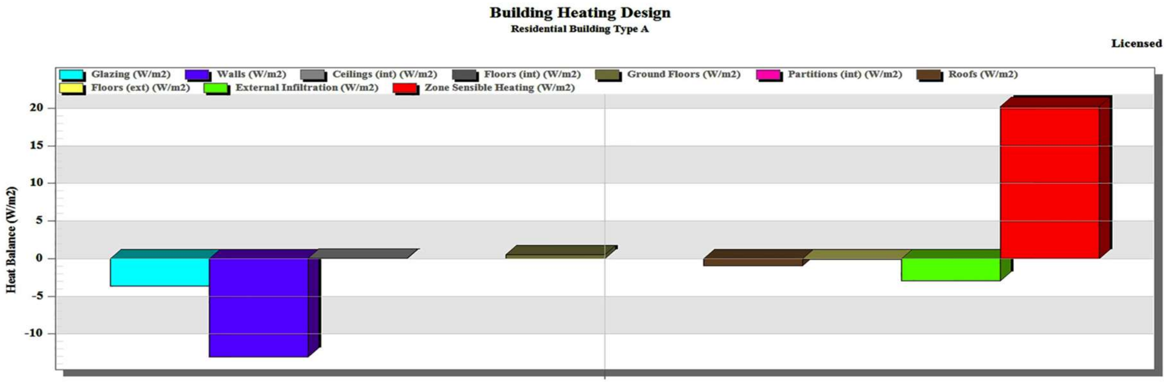


Figure (3). Building Type (A) Winter Peak Day Analysis [14]

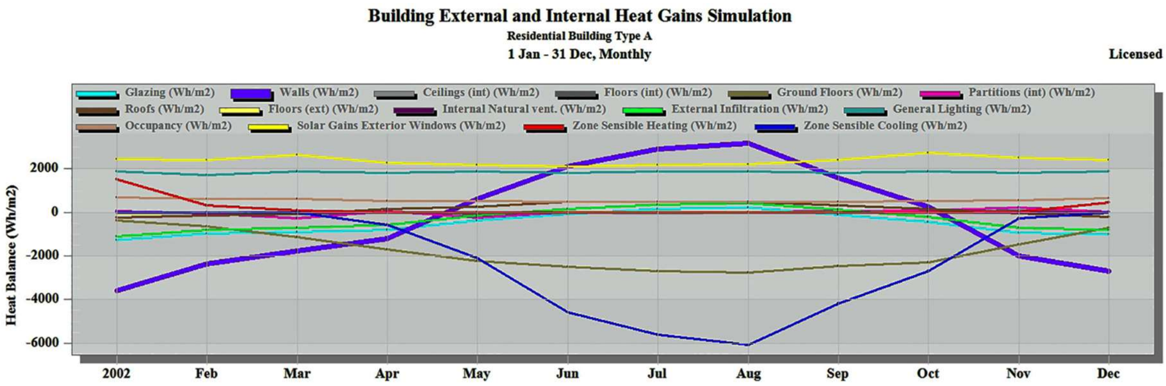


Figure (4). Building Type (A) Heat Gain Analysis [14]

5.2. Building Type (B).

In this building type, a whole building performance was simulated on building envelope cladding using a 0.03 m thick (GRC) ribbed panel as external finishing material that estimates total R-Value = 0.552 m^2K/W and U-Value = 1.812 W/m^2K. [12] *(Figure 5) (Table 1) (Table 2)*

By analyzing the building type (B) external walls heat gain and loss, the amount of heat gain in the peak summer month was calculated as 3,081.30 Wh/m^2, the amount of heat loss in the peak winter month was calculated as 3,519.81 Wh/m^2, and the total amount of heat gain and loss in a whole year was calculated as 23,725.82 Wh/m^2. *(Figure 6)*

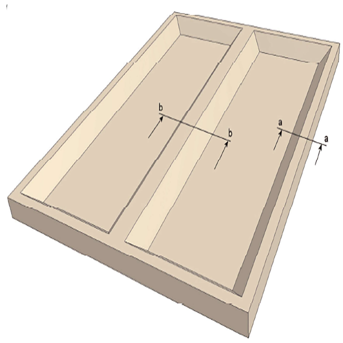


Figure (5). (GRC) Ribbed Panel [12]

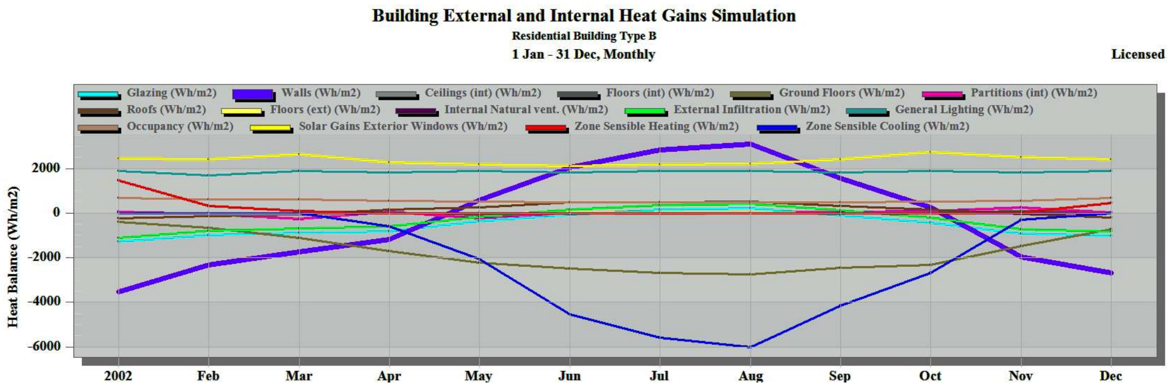


Figure (6). Building Type (B) Heat Gain Analysis [14]

5.3. Building Type (C).

In this building type, a whole building performance was simulated on building envelope cladding using a 0.08 m thick (GRC) sandwich panel filled with foam polyisocyanurate thermal insulation as external finishing material that estimates total R-Value = 2.219 m^2K/W and U-Value = 0.451 W/m^2K. [6] [12] *(Figure 7) (Table 1) (Table 2)*

By analyzing the building type (C) external walls heat gain and loss, the amount of heat gain in the peak summer month was calculated as 1,016.92 Wh/m^2, the amount of heat loss in the peak winter month was calculated as 1,499.04 Wh/m^2, and the total amount of heat gain and loss in a whole year was calculated as 9,593.53 Wh/m^2. *(Figure 8)*

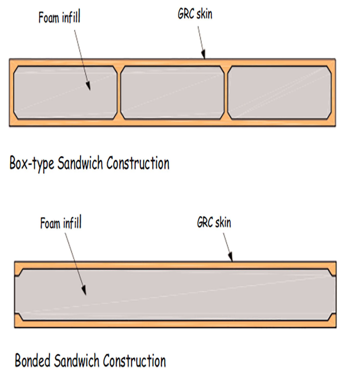


Figure (7). (GRC) Sandwich Panel [12]

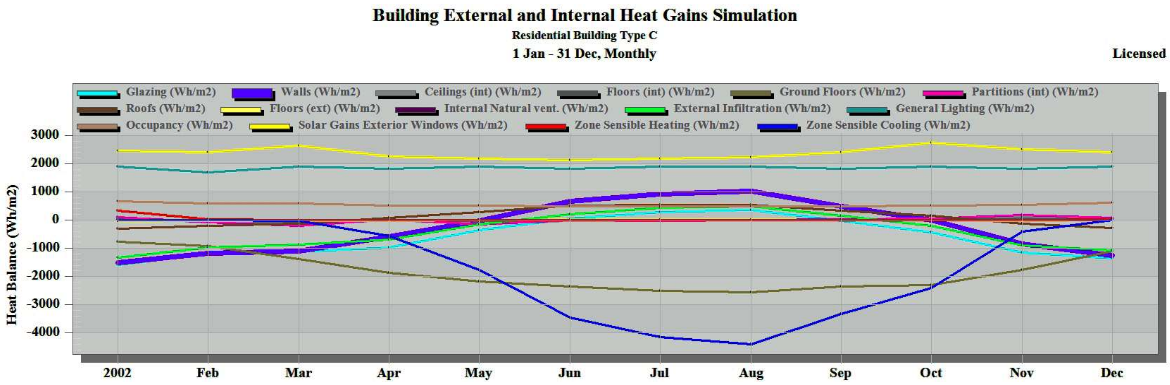


Figure (8). Building Type (C) Heat Gain Analysis [14]

5.4. Building Type (D).

In this building type, a whole building performance was simulated on building envelope cladding using a 0.08 m thick (GRC) stud frame as external finishing material that estimates total R-Value = 0.732 m^2K/W and U-Value = 1.366 W/m^2K. [12] *(Figure 9) (Table 1) (Table 2)*

By analyzing the building type (D) external walls heat gain and loss, the amount of heat gain in the peak summer month was calculated as 2,452.31 Wh/m^2, the amount of heat loss in the peak winter month was calculated as 3,009.98 Wh/m^2, and the total amount of heat gain and loss in a whole year was calculated as 19,886.38 Wh/m^2. *(Figure 10)*

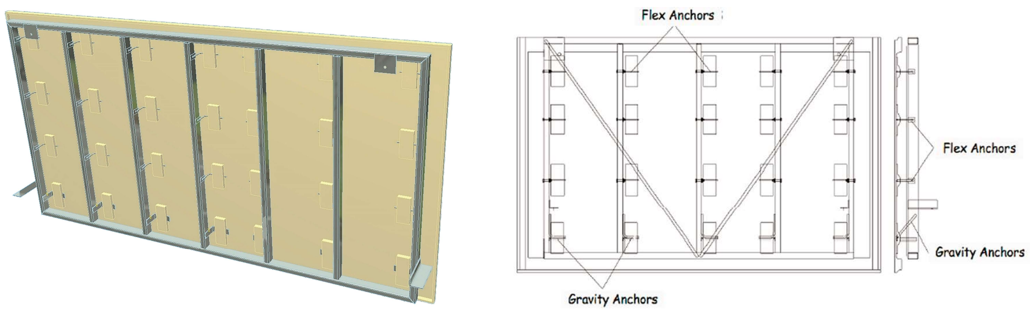


Figure (9). (GRC) Stud Frame [12]

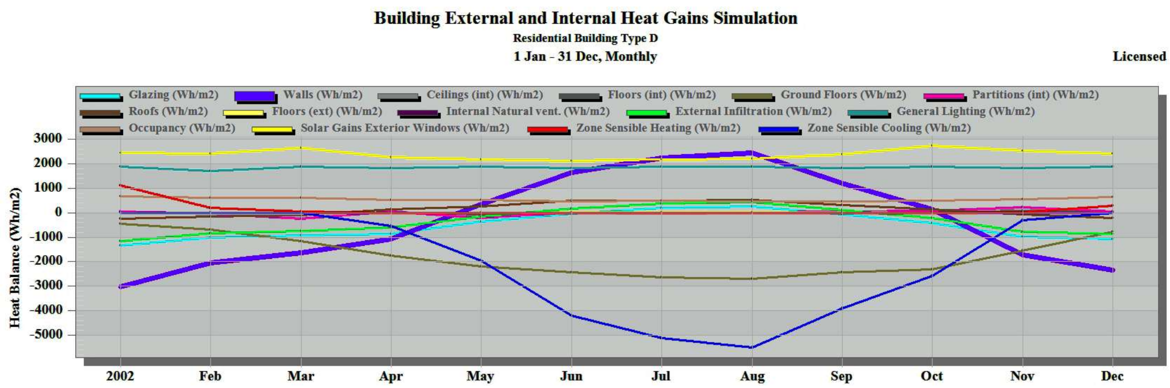


Figure (10). Building Type (D) Heat Gain Analysis [14]

5.5. Building Type (E).

In this building type, a whole building performance was simulated on building envelope cladding using a 0.08 m thick (GRC) stud frame with foam polyisocyanurate thermal insulation panels as external finishing material that estimates total R-Value = 2.219 m^2K/W and U-Value = 0.451 W/m^2K. [6] [12] *(Figure 11) (Table 1) (Table 2)*

By analyzing the building type (E) external walls heat gain and loss, the amount of heat gain in the peak summer month was calculated as 1,010.38 Wh/m^2, the amount of heat loss in the peak winter month was calculated as 1,502.45 Wh/m^2, and the total amount of heat gain and loss in a whole year was calculated as 9,565.01 Wh/m^2. *(Figure 12)*

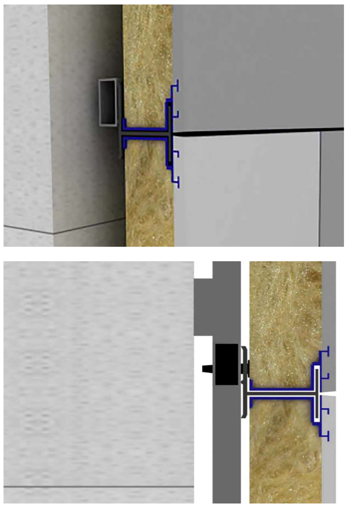


Figure (11). (GRC) Stud Frame with Thermal Insulation [6]

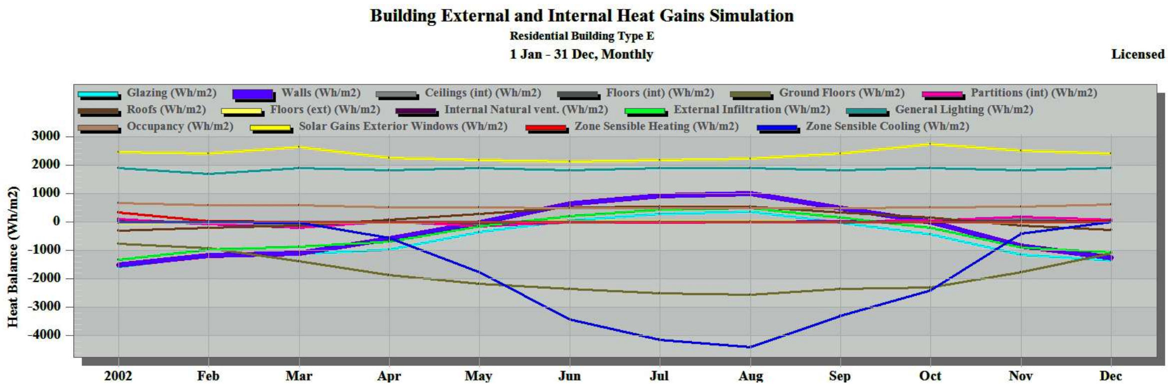
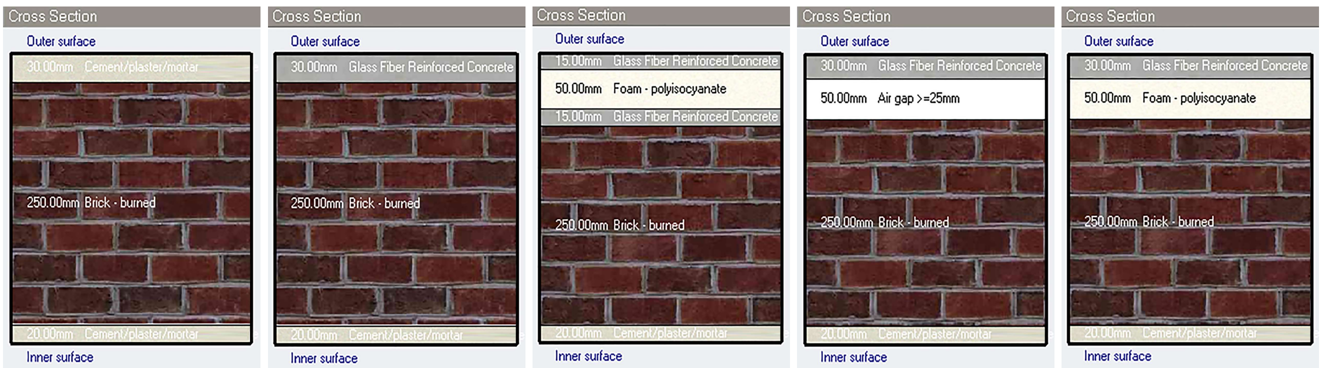


Figure (12). Building Type (E) Heat Gain Analysis [14]

Table (1). External Wall Types Construction Layers. [11] [14] [15]



	Wall Type (A)	Wall Type (B)	Wall Type (C)	Wall Type (D)	Wall Type (E)
Thickness (m)	0.3000	0.3000	0.3500	0.3500	0.3500
Km - Internal heat capacity (KJ/m2-K)	132.0480	132.0480	132.0480	132.0480	132.0480
Upper resistance limit (m2-K/W)	0.534	0.552	2.219	0.732	2.219
Lower resistance limit (m2-K/W)	0.534	0.552	2.219	0.732	2.219
U-Value surface to surface (W/m2-K)	2.751	2.619	0.488	1.780	0.488
R-Value (m2-K/W)	0.534	0.552	2.219	0.732	2.219
U-Value (W/m2-K)	**1.874**	**1.812**	**0.451**	**1.366**	**0.451**

Table (2). External Wall Types Thermal Characteristics. [11] [14] [15]

Wall Type	Total Thickness (mm)	Layers	Thickness (mm)	Thermal Conductivity (W/mK)	Specific Heat (J/kgK)	Density (kg/m³)	R-Value (m²K/W)	U-Value (W/m²K)
Type (A)	300	Sand Cement Plaster	30	0.720	840	1860	0.534	1.874
		Solid Burned Brick	250	0.850	840	1500		
		Sand Cement Plaster	20	0.720	840	1860		
Type (B)	300	Glass Fiber Reinforced Concrete (GRC)	30	0.500	840	2000	0.552	1.812
		Solid Burned Brick	250	0.850	840	1500		
		Sand Cement Plaster	20	0.720	840	1860		
Type (C)	350	Glass Fiber Reinforced Concrete (GRC)	15	0.500	840	2000	2.219	0.451
		Foam Polyisocyanurate	50	0.030	1470	45		
		Glass Fiber Reinforced Concrete (GRC)	15	0.500	840	2000		
		Solid Burned Brick	250	0.850	840	1500		
		Sand Cement Plaster	20	0.720	840	1860		
Type (D)	350	Glass Fiber Reinforced Concrete (GRC)	30	0.500	840	2000	0.732	1.366
		Air Gap	50	0.300	1000	1000		
		Solid Burned Brick	250	0.850	840	1500		
		Sand Cement Plaster	20	0.720	840	1860		
Type (E)	350	Glass Fiber Reinforced Concrete (GRC)	30	0.500	840	2000	2.219	0.451
		Foam Polyisocyanurate	50	0.030	1470	45		
		Solid Burned Brick	250	0.850	840	1500		
		Sand Cement Plaster	20	0.720	840	1860		

6. Results and Discussion.

By simulating and analyzing the results of a whole prototype residential building simulation located in Cairo, Egypt using building performance simulation software (Design Builder Software Ltd – V. 7.0.0.116); this study is focusing on building envelope thermal performance by analyzing the results of the five types of the building envelope (type A, B, C, D, and E) and the study observed that the heat gain and loss is reduced using (GRC) cladding types by varying values depending on the (GRC) envelope cladding type ((GRC) ribbed panel, (GRC) sandwich panel filling with thermal insulation, (GRC) stud frame, and (GRC) stud frame with thermal insulation panels) as following: *(Table 3) (Figure 13)*

Table (3). Building External Wall Type's Total Yearly Heat Gain and Loss. [14]

Building Type	Type of External Walls	Total Yearly Heat Gain and Loss (Wh/m²)	Percentage of Conventional Building External Walls
Building Type (A)	Conventional External Walls	24,196.44	100%
Building Type (B)	(GRC) Ribbed Panel Cladding	23,725.82	98.06%
Building Type (C)	(GRC) Sandwich Panel Filled with Thermal Insulation Cladding	9,593.53	39.65%
Building Type (D)	(GRC) Stud Frame Cladding	19,886.38	82.19%
Building Type (E)	(GRC) Stud Frame with Thermal Insulation Cladding	9,565.01	39.53%

This reduction of external wall's heat gain and loss directly reduced building HVAC system loads that reduced electricity consumption as follows: *(Table 4) (Figure 14)*

Table (4). Building Total Yearly Electricity Consumption. [14]

Building Type	Type of External Walls	Total Yearly Electricity Consumption (Wh/m^2)	Percentage of Conventional Building External Walls
Building Type (A)	Conventional External Walls	41,685.56	100%
Building Type (B)	(GRC) Ribbed Panel Cladding	41,515.42	99.59%
Building Type (C)	(GRC) Sandwich Panel Filled with Thermal Insulation Cladding	37,355.19	89.61%
Building Type (D)	(GRC) Stud Frame Cladding	40,129.92	96.27%
Building Type (E)	(GRC) Stud Frame with Thermal Insulation Cladding	37,341.45	89.58%

These results prove that using (GRC) in building envelopes cladding is reducing heat gain and loss that decreasing building energy consumption by 0.41% when using (GRC) ribbed panel, 10.39% when using (GRC) sandwich panel filled with thermal insulation, 3.73% when using (GRC) stud frame, and 10.42% when using (GRC) stud frame with thermal insulation.

From these results, study can conclude that using (GRC) can't enhance building thermal performance with acceptable value by itself as shown in building types (B) and (D) but it can give great possibilities to add thermal insulation layer for the (GRC) panels to achieve acceptable values as shown in building types (C) and (E) that consider the optimum types for this building envelopes in the local environments.

7. Conclusion.

Glass Fiber Reinforced Concrete (GRC) products make a non-negligible contribution to the building environments because it is considered green construction materials that achieve renewable, recyclable, and reusable material and can be used indefinitely without negatively affecting the environment.

This study evaluated the effect of using (GRC) in a building's envelope finishing materials to enhance building thermal performance and thus improve building energy efficiency by decreasing heat transfer from and to building internal spaces, enhancing building thermal comfort, decreasing HVAC system loads, reducing energy consumption, and decrease related negative impact to environments. The whole prototype residential building simulation process results referred to a huge amount of heat transfer from and to building interior spaces caused by external walls in a conventional building (building type A)

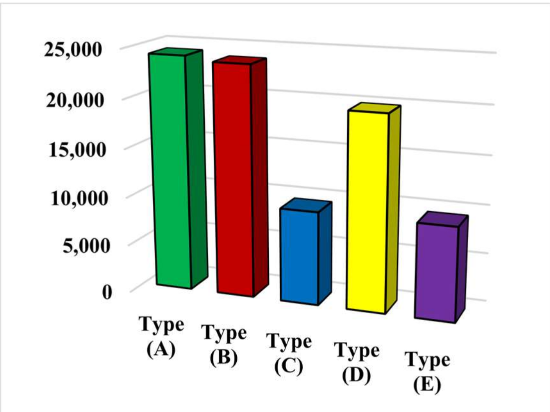


Figure (13). External Wall Types Total Yearly Heat Gain and Loss (Wh/m^2)

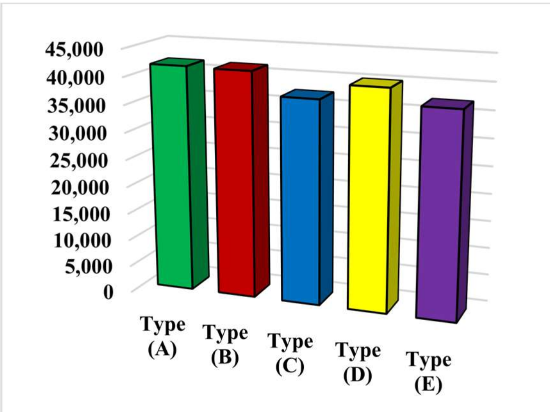


Figure (14). Building Types Total Yearly Electricity Consumption (Wh/m^2)

that should be treated to improve thermal performance and reduce energy consumption.

By using (GRC) envelope cladding as a finishing material in external walls; the study observes a reduction of heat transfer and thus a reduction of energy consumption in the proposed four cladding types as shown in: *(Table 5)*

Table (5). Heat Transfer and Energy Consumption Reduction.

Building Type	Type of (GRC)	Heat Transfer Reduction	Energy Consumption Reduction
Building Type (A)	Conventional External Walls	0%	0%
Building Type (B)	(GRC) Ribbed Panel Cladding	1.95%	0.41%
Building Type (C)	(GRC) Sandwich Panel Filled with Thermal Insulation Cladding	60.35%	10.39%
Building Type (D)	(GRC) Stud Frame Cladding	17.81%	3.73%
Building Type (E)	(GRC) Stud Frame with Thermal Insulation Cladding	60.47%	10.42%

From these results study can conclude that the optimum types of (GRC) cladding for the local environments in Cairo, Egypt is type (C) which uses (GRC) sandwich panel filled with thermal insulation and type (E) which uses (GRC) stud frame with thermal insulation which reduces building energy consumption up to 10.42% and its related CO_2 production, operating costs, environmental pollutions, and other negative impacts.

8. Recommendations.

This study is providing some recommendations for all sectors involved in the architecture and building construction field.

For governments and construction government agencies:

- Support all responsible institutions for follow-up the evolution of environmentally friendly building materials to improve the project's performance and thus the quality of life.
- Legalize all responsible institutions for the use of the building performance simulation software to improve project performance and conserve environments.

For manufactory institutions, research centers, researchers, and students:

- Innovate and develop new alternative building cladding materials that are expected to improve overall building performance.
- Expand the usage of the building's performance simulation software and tools within all building's lifecycle processes to be sure that the building will achieve high performance while conserving environments.

For designers, engineers, contractors, and other buildings construction professionals:

- Carefully design and select suitable cladding materials for the building envelope to control heat gain and loss and achieve high thermal performance for the building.
- Use building performance simulation software and tools within the building's design processes to be sure that the building will achieve high performance.
- Consider Glass Fiber Reinforced Concrete (GRC) when choosing building envelope cladding materials to enhance building thermal performance and reduce energy consumption and operating cost.

References.

[1] (GRCA), International Glassfibre Reinforced Concrete Association. 2018. *GRC In Action: Today's GRC for Architects and Engineers.* Northampton, United Kingdom: International Glassfibre Reinforced Concrete Association (GRCA), 2018. p. 26.

[2] (GRCA), The International Glassfibre Reinforced Concrete Association. [Online] The International Glassfibre Reinforced Concrete Association (GRCA). [Cited: 10 01, 2020.] www.grca.org.uk.

[3] (GRCA), The International Glassfibre Reinforced Concrete Association. 2017. *Specification for the Manufacture, Curing & Testing of Glassfibre Reinforced Concrete (GRC) Products.* Northampton, United Kingdom: The International Glassfibre Reinforced Concrete Association (GRCA), 2017. p. 15. ISBN: 0946691789.

[4] ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2014. *The standard for the Design of High-Performance Green Buildings.* Georgia, U.S.A: ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2014. p. 132. ISSN: 1041-2336.

[5] Buildings, The Standing Committee for The Preparation of the Egyptian Code to Improve Energy Efficiency in. 2006. *The*

Egyptian Code to Improve Energy Efficiency in Buildings. Cairo, Egypt: Housing and Building National Research Center - Ministry of Housing, Utilities, and Urban Development, 2006. p. 152. Vol. Part One: Residential Buildings. ECP 306 - 2005.

[6] C., Isikci. 2015. *Heat Insulated Fabrication GRC Panel.* Dubai, United Arab Emirates: International Glassfibre Reinforced Concrete Association (GRCA), 2015. p. 10.

[7] Council, U.S. Green Building. 2020. U.S. Green Building Council. *U.S. Green Building Council.* [Online] U.S. Green Building Council, 2020. [Cited: 10 01, 2020.] https://www.usgbc.org/.

[8] Dona, Marco, and Overend, Mauro. 2017. *Fatigue Performance of a Connection for GRC Cladding Panels.* Sheffield, United Kingdom: University of Sheffield, United Kingdom, 2017. p. 7.

[9] E., K. Vahidi, and M., M. Malekabadi. 2011. *GRC and Sustainable Building Design.* Istanbul, Turkey: International Glassfibre Reinforced Concrete Association (GRCA), 2011. p. 7.

[10] Fahmy, Mohammad, Mohamed, M. Mahdy, and Marialena, Nikolopoulou. 2014. *Prediction of Future Energy Consumption Reduction Using GRC Envelope Optimization for Residential Buildings in Egypt.* s.l. : Elsevier, 2014. p. 8. Vol. 70. ISSN: 0378-7788.

[11] Group, The GRCA Technical Working. 2018. *Practical Design Guide for Glassfibre Reinforced Concrete (GRC).* [ed.] Glyn Jones. 1.1. Northampton. United Kingdom: The International Glassfibre Reinforced Concrete Association (GRCA), 2018. p. 97. ISBN: 0946691789.

[12] Group, The GRCA Technical Working. 2018. *Practical Fixing Guide for Glassfibre Reinforced Concrete (GRC).* [ed.] Glyn Jones. 1.1. Northampton, United Kingdom: The International Glassfibre Reinforced Concrete Association (GRCA), 2018. p. 92. ISBN: 0946691789.

[13] I., White and Y., Che. 2011. *Is GRC a "Green" Building Material?* Istanbul, Turkey: International Glassfibre Reinforced Concrete Association (GRCA), 2011. p. 7.

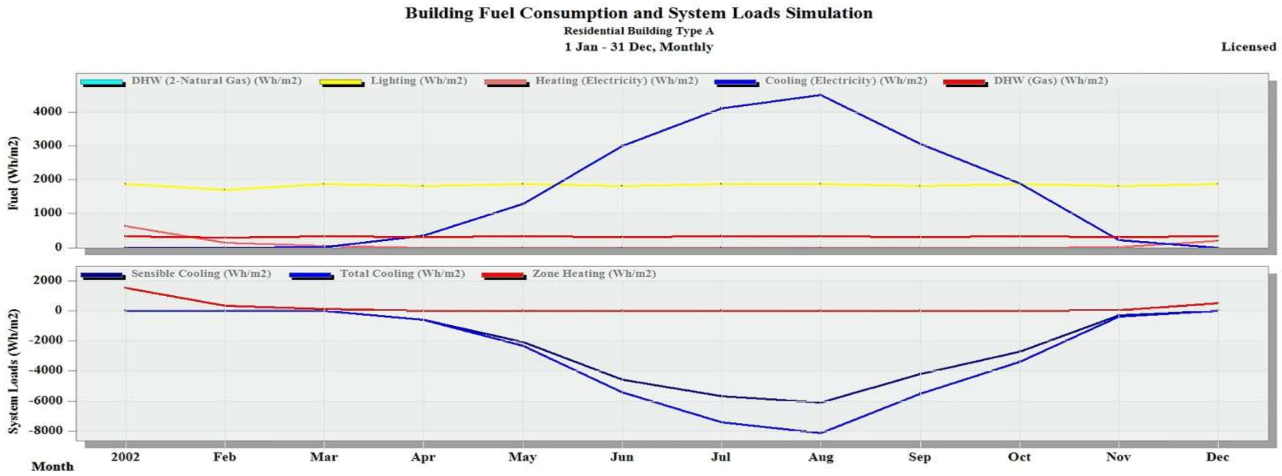
[14] Ltd, DesignBuilder Software. 2020. *DesignBuilder Software Ltd.* [dir.] Dave Cocking, Andy Tindale, and Steve Potter. [perf.] Eslam Mohamed Moraekip. Stroud, United Kingdom, Stroud, United Kingdom: DesignBuilder Software Ltd, 10 01, 2020.

[15] Lyons, Arthur. 2014. *Materials for Architects and Builders.* Fifth Edition. Oxford, United Kingdom: Routledge - Taylor and Francis Group, 2014. p. 495. ISBN13: 9780415704977 (pbk) - ISBN13: 9781315768748 (ebk).

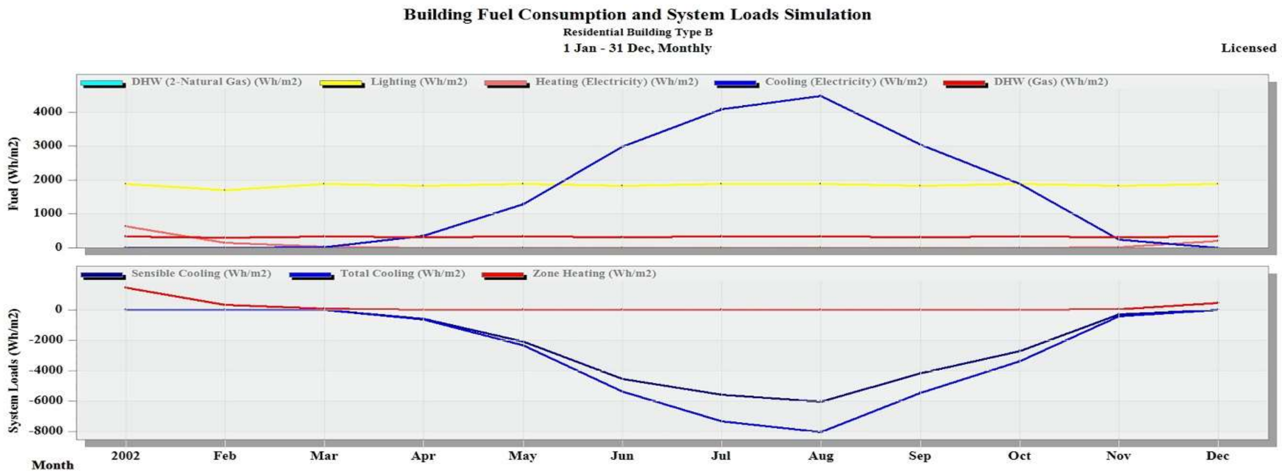
[16] Moraekip, Eslam Mohamed. 2013. *Sustainable Architecture Between Theory and Application in Egypt.* Berlin, Germany: LAP Lambert Academic Publishing, 2013. p. 352. ISBN: 978-3-659-48769-9.

Appendix: Building Types Fuel Consumption and System Loads. [14]

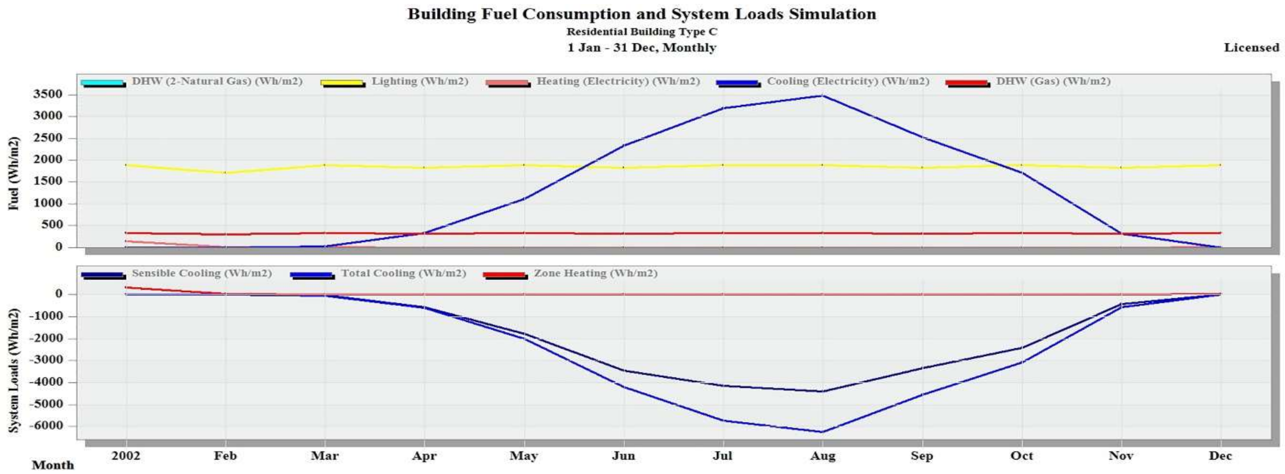
Building Type (A)



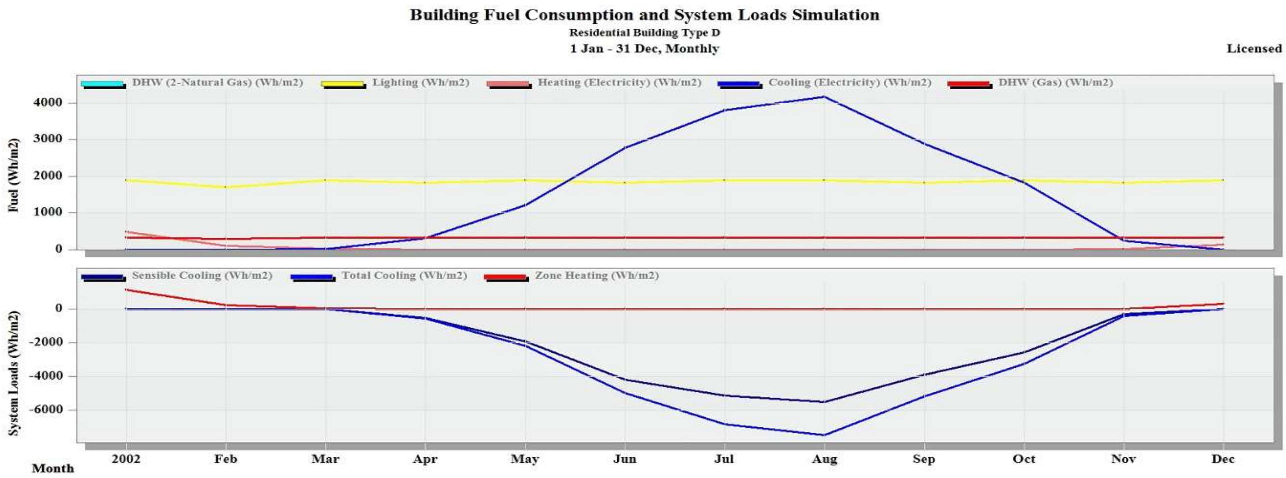
Building Type (B)



Building Type (C)



Building Type (D)



Building Type (E)