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The Effect of Different Techniques on Thermal and Cooling Energy Performance for Residential Building by Using Simulation Program

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ABSTRACT

Recently, the world needed a lot of energy to provide consumers' needs to compensate for a shortage of non-renewable resources represented in fossil fuels for energy production. This leads to climate change, the effect of greenhouse gases (GHG) that leads to damage to the environment and people's health .The research discusses the effect of the cooling loads on the building and applied as a case study of a residential building in Egypt as external walls, openings, roofs by using the simulation (Design Builder) program which can create a model housing unit to simulate and test of thermal behavior of building. The results were reached after the simulation process with the high total cooling load value of 2916.15 k.W/h, which can be considered the highest value of the cooling load without any appropriate treatments. After other cases, treatments were used in walls, windows, and roofs to reduce the total cooling Loads to 2207.93 k.W/h.

KEYWORDS: Energy efficiency; Residential building; Energy Simulation; Cooling Loads; Insulation Materials

تأثير التقنيات المختلفة على أداء طاقة التبريد والحرارية للمباني السكنية باستخدام برنامج المحاكاة

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الملخص

أصبح العالم في الآونة الأخيرة بحاجة إلى الكثير من الطاقة لتوفير احتياجات المستهلكين لتعويض النقص في الموارد غير المتجددة المتمثلة في الوقود الأحفوري لإنتاج الطاقة التي تسبب إلى تغير المناخ وتأثير الغازات الدفيئة مما يؤدي إلى الإضرار بالبيئة وصحة الإنسان. يناقش البحث تأثير أحمال التبريد على المبنى وتطبيقه كدراسة حالة لمبنى سكني في مصر كالجدران الخارجية، الفتحات والأسقف باستخدام برنامج المحاكاة (Design Builder) الذي يمكن من خلاله إنشاء وحدة سكنية نموذجية لمحاكاة و اختبار السلوك الحراري للمبنى. تم التوصل إلى النتائج بعد عملية المحاكاة حيث بلغت قيمة حمل التبريد الكلي ٢٩١٦,١٥ كيلووات/ساعة والتي يمكن اعتبارها أعلى قيمة لحمل التبريد بدون استخدام أي معالجات مناسبة. وبعد حالات أخرى، تم استخدام المعالجات في الجدران والنوافذ والأسطح لتقليل إجمالي أحمال التبريد إلى ٢٢٠٧,٩٣ كيلووات/ساعة.

الكلمات المفتاحية : كفاءة الطاقة؛ مبنى سكني؛ محاكاة الطاقة؛ أحمال التبريد؛ مواد العزل

Nomenclature

K.W/ h	Kilo watt per hour
w/m2-k	Watt per meter square per kelvin
U.	U-value

Acronyms

3D	Three-Dimensional
GHG	Greenhouse Gas
CO2	Carbon dioxide
IEA	International Energy Agency
TES	Total energy supply

1. INTRODUCTION

Today, in recent years, the world has been living in constant suffering from increased energy consumption, lack of resources, non-renewable energy sources, and also rapid climate change. Therefore, the environmental balance has become one of the most important requirements and interests in energy conservation, which increases the demand for energy to provide the living needs of users, and this requires designers to develop innovative solutions and alternatives to solve the problems of buildings in which energy consumption increases, including increasing thermal loads due to the use of daily cooling devices, especially in the summer. In which temperatures increase, and therefore people use mechanical devices such as air conditioners to cool the place and provide thermal comfort for users, and these results are considered large consumption of non-renewable energy sources [1,2,3,4,5].

In the summer, buildings consume a large proportion of energy due to high temperatures, and this leads to the use of active cooling methods resulting from the use of air conditioners, which represent 70% of the energy consumed [6,7]. There is a strong link between buildings in the ability to adapt to the environment to save energy, and to be a sustainable building that adapts to natural and local climatic conditions, so the designer should not ignore in designing the building that he uses materials and finishes that can interact with the environment, define closed and open spaces and design spaces in forms that achieve the function and beauty in appropriate proportions, as well as the use of renewable energy sources in buildings to provide thermal comfort and reduce carbon emissions [8,9,10]. The world faces an increase in energy consumption daily as a result of the great need to provide for the needs of users, and this leads to a shortage of non-renewable energy resources and an increase in daily prices. Many countries are working on energy production and storage, that is to produce adequate quantities that are sufficient for years to come sources and therefore many countries are unable to pay money to purchase products from countries that export those resources [11]. Therefore, many global conferences on climate change have been held, and recommendations have been made to reduce environmental impacts and work to meet challenges for each country that require it to resort to the use of clean and renewable energy sources to reduce gas emissions and to confront global warming to reach sustainability and preserve human health from the development of innovative solutions and benefit from modern technology that serves it [12]. The African continent suffers from poverty and high temperatures due to its proximity to the equator, despite its possession of many natural resources and wealth, so they can’t afford to pay for those energy sources that affect the African climatic environment, which has beautiful landscapes that carbon emissions can damage the environment but the culture of African peoples have been able to construct residential buildings from natural materials at a low cost that adapts to the culture and urban environment [13] as shown in Fig. 1

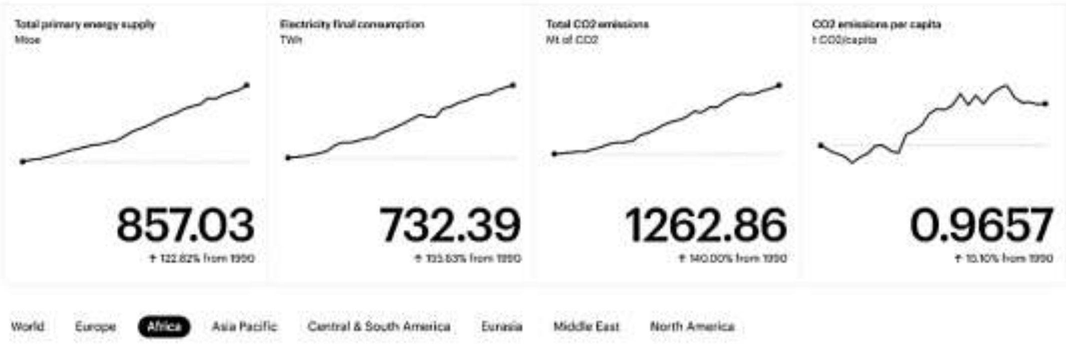


Fig. 1: Key energy statistics in Africa, 2022 according to the International Energy Agency's impact index.

Source: International Energy Agency, 2022 [13]

Over the past years, Egypt has relied mainly on non-renewable energy sources, such as fossil fuels, to produce about 95% of its energy, and thus as a result of the increased consumption, the need to import a large amount of oil to fill the deficit and the continuity of operation and productivity, which affected climate change due to different industries [11]. According to the International Energy Agency's 2022, Egypt has begun to reduce oil consumption and produce a large amount of natural gas that can replace the use of oil due to it being clean energy that does not emit carbon emissions and saves excess costs on the Egyptian government. and reducing the consumption of non-renewable energy sources as shown in Fig. 2

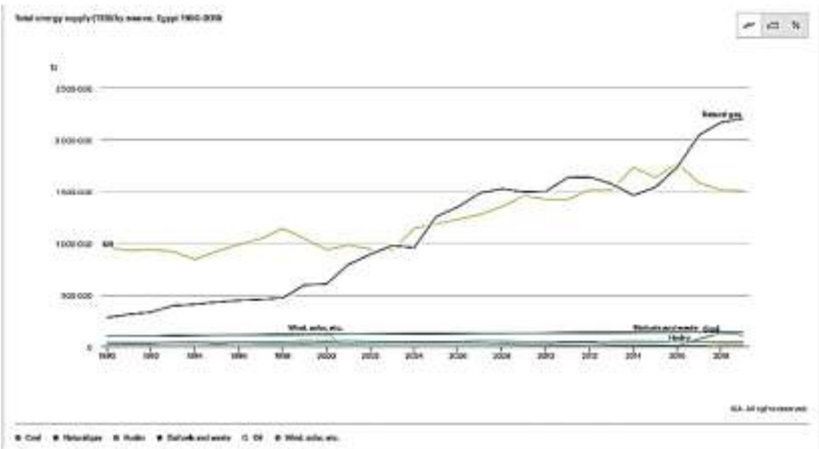


Fig. 2: Total energy supply (TES) by source, Egypt 1990-2019 according to the International Energy Agency's impact index.

Source: International Energy Agency, 2022 [13]

Through this, buildings in public have become need a lot of attention in reducing energy consumption and adapting to the environment and climate [14]. Users need adaptive buildings through good architectural design that takes into account the various environmental aspects behind innovative ways of building design, especially the external facades and roofs that are exposed to high sunlight [15]. Users resort to the use of cooling devices, so the values of cooling loads increase to reach thermal comfort within the spaces [1,16]. Therefore, the research aims to use various modern technologies of renewable energy systems to apply in a residential building in Egypt and use cooling devices to reach the lowest value of the cooling loads during the summer period [17].

2. Literature Review

A lot of recent research and studies dealt with bridging the gap between the designs of the envelope of buildings with the environment in a variety of ways and solutions that can interact with the climate and there are many solutions to save and conserve energy.

Khaled and others studied three sustainable energy systems that are combined with non-renewable and non-sustainable energies represented in the consumption of natural gas with renewable energy sources (sun - wind - biomass) for air conditioning, cooling, heating, and ventilation applications. Also, the average energy of the systems used was calculated and their efficiency ranged between 19.9% - 27.5%, taking into account the use of natural gas within the permissible limits so as not to increase the percentage of carbon dioxide emissions, which disrupts the system and the environmental balance while using another system It achieves sustainability in the integration of photovoltaic energy and solar energy to increase the efficiency of energy performance, which ranges from 1.2% to 3.9% [12].

Khaled discussed the topic of searching in depth for different energy systems that can meet current and future needs to reduce energy consumption in buildings. The study demonstrates the evaluation of multigenerational energy systems that integrate different energy sources from solar energy, bioenergy, wind energy, and underground energy, and comprehensive analyses of each of them. The economic and technical assessment was carried out using the HOMER program to reach the optimal level of energy and control the cost of electricity. The study area was identified in Oshawa, Canada to provide a solution in integrating solar energy and biomass collectors to reduce electricity consumption and cost [18].

Shu introduced the concept of the building's outer envelope to be able to adapt to the surrounding environment and climate. One of the case studies was applied in the Su-Zhou region in China. He studied and classified different types of outer shell systems within the region with a local climate. He included a study and field visit to perform heat transfer. In the building, the interactive environmental envelope reduces solar radiation and prevents the entry of heat significantly, thus providing thermal comfort and energy consumption [16].

Li worked at Tsinghua University in China in a focused study on the area of the building within Hospitals in the North to form the relationship between the external environment and the building to the internal environment and form communication between them to interact with the users inside the building with the surrounding environment to reduce energy during operation and provide thermal comfort [9].

Kharseh and Al-Khawaja studied the effect of different retrofitting techniques and methods for cooling requirements in buildings in Qatar using analysis models in the hourly HAP analysis program to create simulations in one of the residential buildings and calculate the cooling load and make variables using polyurethane insulation materials in the external walls with a thickness of less than 2 cm, which reached the results to reduce the cooling load to 27% [19].

Haravi and Qaimi identified different methods in design and construction that are more effective in increasing energy efficiency in Iran. Design Builder program was used, and the results concluded that the use of insulation materials for ceilings and walls raised their efficiency to reduce energy consumption in the building by 13.8% and 12.16%, respectively, and the research recommended the use of thermal insulation materials to increase the energy efficiency of the building [20].

3. The effect of the cooling loads on the building

Cooling loads represent a huge burden on the building in particular and on the economy in general, as buildings consume large amounts of energy, including excessive cooling loads in the summer due to the intensity of high sunlight, and consumption represents about 70% of the buildings consumption throughout Summer period [21].

Air conditioners represent the largest part of the energy consumption in the building, which represents 50%. Therefore, the residential sector is considered one of the largest sectors that produce greenhouse gas (GHG) emissions and high energy consumption in Egypt as a result of intense heat in the summer, and users resort to operating cooling devices between 7 to 8 hours a day to cool the place, and thus cooling consumption loads increase [22,23,24,25]. The architectural design requires great attention to environmental aspects to increase the efficiency of the building and reduce consumption throughout the operation period. Where each building performs its function according to the type of activity used, which varies in consumption and the quality of energy used by users [26,27].

This is done by introducing Different Techniques and recent research that have had a significant impact on the building and construction materials industry, where new materials of various types have been invented that have excellent thermal insulation properties compared to traditional building materials, thus reducing cooling loads, energy consumption and greenhouse gas emissions for buildings [28,29,30].

Phase change materials are materials that react to environmental changes, such as heat. They absorb high-heat energy to cool the interior space of the building, and they carry out the process of heat transfer to the material used, whether solid or liquid, and it changes to another state to reduce temperatures. These materials are divided into two categories: organic materials, which contain carbon that is extracted from nature or produced from products, whether solid or liquid. These materials absorb high temperatures exposed to sunlight in buildings and store thermal energy in various forms [31,32].

4. Methodology

At this stage, cooling loads for an existing residential building in Egypt are calculated during the summer period, which the simulation program is used by the Design Builder program to assess the values of the cooling loads, then some modern techniques are input from the materials in External walls, openings and roofs in different cases to evaluate the results after finishing Simulation Process in each case as Shown in Fig. 3

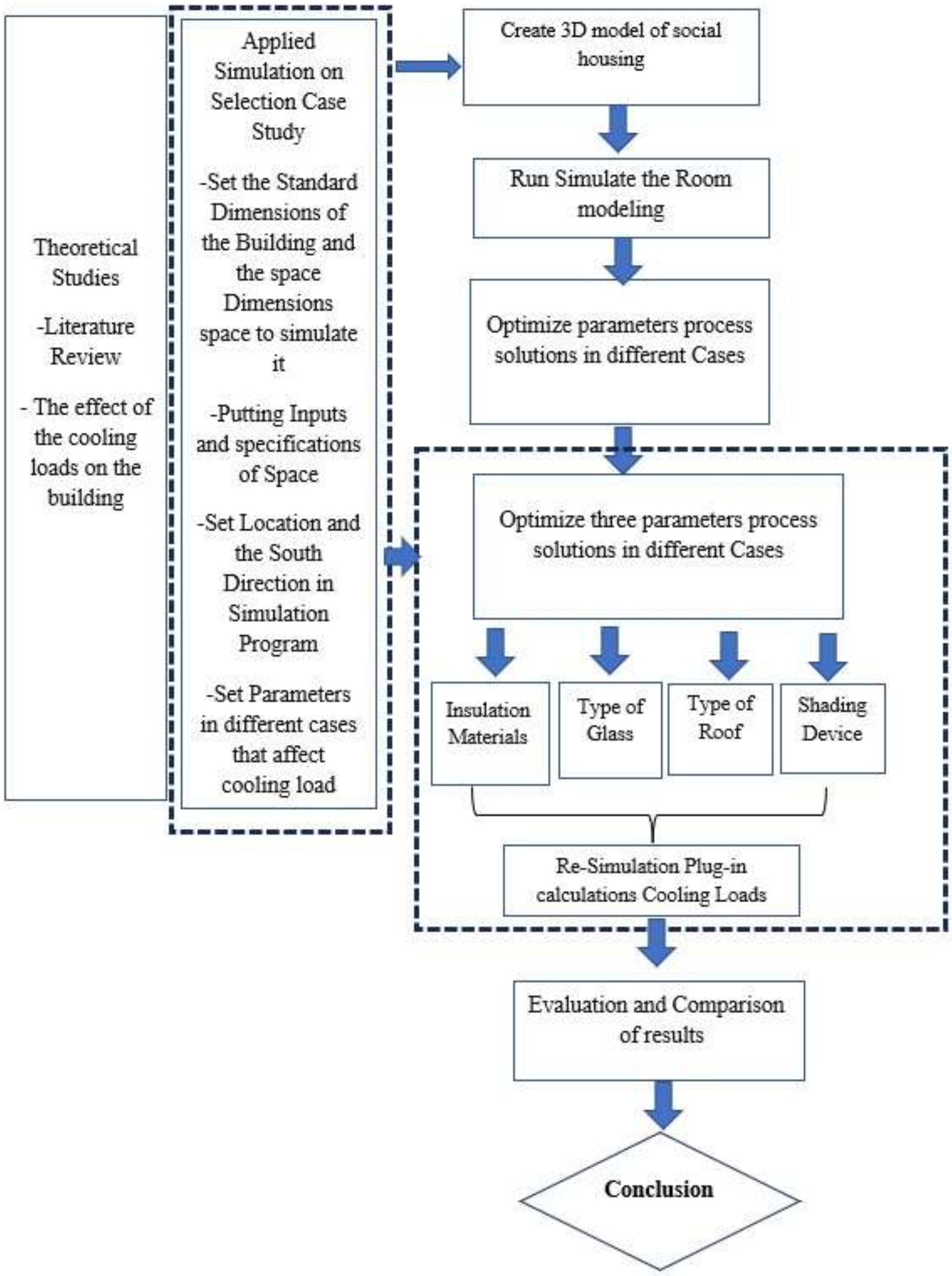


Fig. 3: Chart of Methodology flowchart

Source: The Author

4.1. Building description: Al-Rehab housing project

In 2022, the Egyptian government launched the Al-Rehab Housing project, offering apartments with different specifications and spaces. Al-Rehab Housing project, which was established through the Ministry of Housing, is characterized by the simplicity of design and construction. The apartment areas in Al Rehab City have ranged from 92, 121, 122, 130, and 131 m2 in the Rehab Extension project, the ninth phase, group (125), in New Cairo, offered by the Ministry of Housing, represented by the New Urban Communities Authority [33] as Shown in Fig. 4

The housing units were constructed from first to fourth floors. These units are constructed of cement brick-bearing walls, screed, and cement plaster or mortar as Shown in Fig. 5

Fig. 4: The Urban Design of Al-Rehab Housing project, group (125)

Source: Ministry of Housing Utilities and Urban Communities [33]

Fig. 5: The model of Al-Rehab Housing project

Source: Ministry of Housing Utilities and Urban Communities [33]

Also, apartments in Al Rehab City consist of 2 or 3 bedrooms, a living room, reception, kitchen, and bathroom as Shown in Fig. 6

Fig. 6: Left: Ground Floor of Al-Rehab Housing Model, Right: Typical Floor of Al-Rehab Housing Model from First Floor to Fourth Floor

Source: Ministry of Housing Utilities and Urban Communities [33].

This part focuses on developing appropriate solutions to the problem of energy consumption for residential buildings in Egypt. An existing residential project in Egypt, specifically in New Cairo, was selected and included in one of the simulation programs. Then, some appropriate treatments were added in different cases during in summer period to reach for the most appropriate case when making a comparison between those cases. This also focuses on learning about specialized simulation software for environmental climate design to be used in research. They are the Reasons for choosing this project:

• It represents the selected projects from the types of economic housing and they were designed in small spaces in an area of 92 m^2.

• Not using appropriate treatments in the facades to achieve thermal comfort in the spaces, such as the use of insulation and reflective materials for sunlight, types of glass and shading in the openings exposed to sunlight, appropriate light colors...etc.

4.2. Definition of a simulation program

Many applications and different simulation programs have appeared that help the designer to make a decision, as they are used to predict the behavior of the building with the introduction of any element of the treatment to reach the best solutions suitable for the building environmentally, including achieving better thermal comfort. These programs nowadays rely on digital representation in the computer and reach the results of appropriate design decisions. There are many programs used in the simulation process and the creation of other new programs that help designers conduct tests and experiments to study buildings and help them make appropriate decisions and solutions [34]. In the applied study, the researcher used the Design Builder program to calculate the cooling loads in the building, where several tests are performed on it according to the different treatments and variables on the model, and then the results obtained are reviewed by comparing the results in the building facade suggested by the research in reducing Carrying cooling in the building and thus reducing energy consumption rates. The climatic assessment process for buildings using digital representation to simulate the thermal behavior of buildings, in general, passes through three steps:

• Building a representative model for the proposed alternative.

• Introducing the appropriate treatments and variables and simulating the thermal behavior of the model.

• Evaluating by calculating cooling loads and comparing them with other alternatives to reach the low value of the cooling load.

The program usually consists of three parts:

• The unit for building the analog-digital model.

• Simulation unit.

• Decision-making process through the different results and compare them and choose the best result. The climatic data and location are entered from the Energy Plus program, then data and information are entered for the housing model, and the space that will be faced is determined through the appropriate treatments in different solutions and suggestions in the Design Builder program, as it builds three-dimensional models, and provides various solutions and alternatives from simulations to reach to the best alternative [34].

4.3. Create a 3D model and Inputs

At this stage, the data and information about the location and climatic data of the Al-Rehab Housing project in New Cairo City were entered into the simulation program before starting to draw the model, and the period that exceeds high temperatures and thermal loads during the summer season throughout the year, specifically in the month (April - May - June - July - August - September). These months were chosen because these periods are when temperatures increase in the summer, which increases the heat of the place inside the building and thus cooling loads increase due to the increased energy consumption resulting from the use of cooling devices. This requires the development of appropriate solutions to reduce the values of cooling loads in the summer season as shown in Table 1

Table 1: Entering data and information of the Model into the program

Source: The Author

Location	New Cairo
Regional Climate	The Greater Cairo region is located in a hot climate
Model area	92 m^2
Floor	Fourth Floor
Summer Period	1 of April to 30 of September

The 3D model was created in a simulation program consisting of the Ground Floor and Typical Floors to the Fourth Floor as shown in Fig. 7

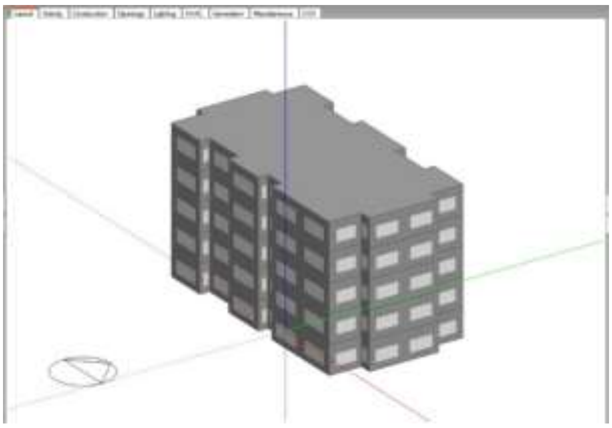


Fig. 7: 3D housing model in the program
Source: The Author

The Fourth floor was determined to develop appropriate solutions and treatments, and then one of the residential spaces the living room was chosen to simulate it as shown in Table 2 and Fig. 8

Table 2: The steps for entering data and information dimensions of selected space to simulate in the program

Source: The Author

Type of space selected	Living room
Area of space	26.4 m^2
The direction of the space	South
Space dimensions	4m x 6.6m x 3m
Door dimensions	0.90m x 2,20m
Windows dimensions	0.90m x 1m

Fig. 8: Plan of the Fourth floor of Al-Rehab Housing project and the space selection in the simulation program

Source: The Author

Data and information for various activities were entered within the space and the type of devices used, which are the most important factors for thermal loads, and how to reduce high cooling loads by appropriate methods, as shown in Table 3 and Fig.9

Table 3: Data of various activities and types of devices used in the space

Source: The Author

Type of Space	living room
Density inside the hall	0.2 person per m^2
Number of family members	Four persons
Activity type	Eating, studying…etc.
Clothing	0.5 clo in summer 1 clo in winter:
Natural Summer outside temperature	35 C°
Indoor temperature to be achieved	26 C°
Equipment used in space such as computers, TV...etc.	Existing

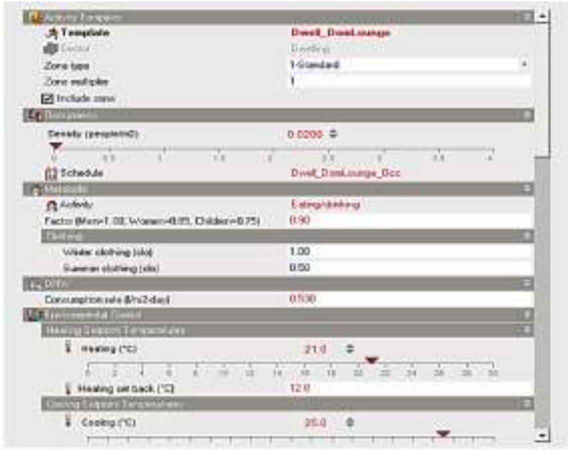


Fig. 9: Screenshot of various activities and types of device data used in the space

Source: The Author

4.4. Simulation of Calculation Cooling Loads analysis by different Techniques in different cases

At this stage comes the application of the residential model in the simulation program to calculate the cooling loads in different cases by adding some variables from modern building materials, that reduce the value of the cooling loads to improve the building's thermal performance and the consumption of cooling devices throughout the summer season.

The thermal performance of the selected housing model is evaluated and improved using simulation software through the following:

• For the building block (Orientation, The height of the floor in the residential model, The area of the residential model, The area of the selected room to simulate).

• For walls (Thickness of the external walls, The colors of finishes, and types of building materials for the exterior facades of the residential model, External facade area such as insulation materials).

• Treatment of window openings (Dimensions of openings, Location, Type of window glass, Different Techniques for different shading methods (vertical, horizontal, compound...etc.).

• Roof (Thickness of the roof layers, materials finishes, and insulation materials).

4.5. Cases of applied studies in the program

The residential model was studied as a base case without any treatments after entering all its data from the reality of nature, and then three other cases were proposed as follows:

1. The first case: The model is entered with the use of some common traditional methods such as; overhang on windows and insulating materials such as; foam boards and polystyrene sheets.

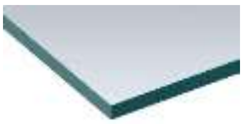
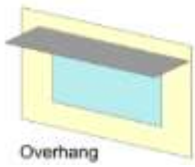
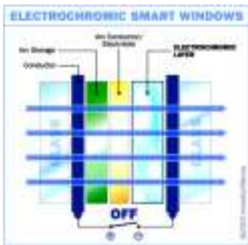
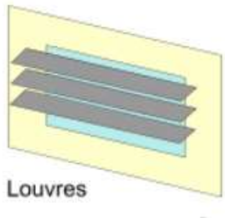
2. The second case: The model is entered using perlite material and electrochromic glass.

3. The third case: The model is entered using PCM material with type BioPCM M182/Q21 and double glass glazing. The results in different cases can be added as shown in Table 4

Table 4: Simulation of cooling loads in different cases

Source: The Author

Location: New Cairo

Phases	**Base Case**	**First Case**	**Second Case**	**Third Case**
Type of External wall materials used in the facade	Cement bricks bearing walls (25cm), screed (2cm), and cement plaster or mortar (1cm) 	Cement bricks (25cm), white foam boards (5cm), polystyrene sheets (3cm) and Screed (1cm) 	Cement bricks (25cm), foam Slag (5cm), perlite (3cm), polystyrene plates (2cm), and plaster (1cm) 	Cement bricks (25cm), PCM material with type BioPCM M182/Q21 (5cm), perlite (2cm), polystyrene plates (2cm) and plaster (1cm) 
Type of windows	Plain clear glass with a thickness of 6 mm 	Plain clear glass, 6 mm thick, with the use of an overhang 0.5 m wide 	6mm thickness Electrochromic Glass 	6mm thickness double glass between argon gas separating other glass thickness 13 mm with 1m projection Louvre 
Shading Device	No Shading	0.5m Blind with high Reflectivity Slats with angle 90^0:Horizontal	1m Overhang with an angle of 30^0	1m projection Louvre with angle 45^0
Roof	Tiles (2cm), sand (5cm), reinforced concrete (30cm), cement mortar (2cm), cement plaster or mortar (1cm)	Tiles (2cm), sand (5cm), insulation like bitumen (2.5cm), reinforced concrete (30cm), air cavity (2cm), roofing felt (3cm)	Ballast (3cm), 2 in polystyrene (5cm), screed (2cm) insulation like bitumen (3cm), concrete (5cm), roofing felt (3cm)	Concrete ballast (3cm), membrane (2cm), Moisture Insulation (2cm), Green roof of plant layers (8cm),
U-value (w/m^2-k)	Walls: 1.823, Openings: 2.789, Roof: 2.23	Walls: 1,035, Openings: 1.646, Roof: 0.964	Walls: 0.848, Openings: 0.660, Roof: 0.653	Walls: 0.677, Openings: 0.511, Roof: 0.478

5. Results and Discussion

In the last stage, the calculation of Cooling loads for Al-Rehab Housing project in four cases was evaluated after the simulation process, created the model 3D and the appropriate treatments for it to choose the lowest cooling loads and the best case of using different Techniques, the result shows that the third case is the best case and the lowest value for the cooling load after the introduction of Different Techniques on Thermal and Cooling Energy Performance for the residential model as shown in Table 5 and Fig.10

Table 5: Results of Simulation of cooling loads in different cases

Source: The Author

Months	**April**	**May**	**June**	**July**	**August**	**September**	**Total Cooling Loads (K.W/h)**
Base Case	210.9	370.5	530.45	610	672	522.3	2916.15
First Case	220	380.04	516.5	600.1	648.81	473.9	2839.35
Second Case	210.57	315.2	433.1	488.9	540.6	430.7	2419.07
Third Case	180.63	289.76	403.3	459.13	489.35	385.76	2207.93

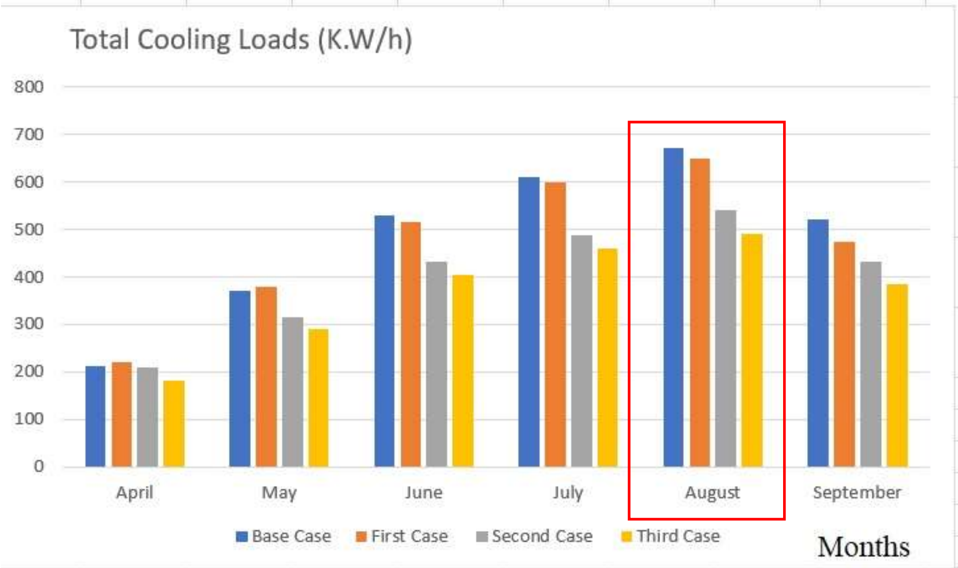


Fig. 10: Chart of Results of Simulation of cooling loads in different cases

Source: The Author

As the previous Table and Figure, the results were reached after the simulation process on the southern facade of the residential unit exposed to high sunlight in the living room, and the highest thermal and Cooling Loads were reached in August, so it should be used different techniques of different techniques in walls, windows, and roof to reduce it. In the Base case, materials were used Cement bricks bearing walls (25cm), screed (2cm), cement plaster or mortar (1cm), and Plain clear glass with a thickness of 6 mm in windows. The specified months reached the highest total cooling load values during the summer months period, reaching the Total Cooling load of 2916.15 k.W/h. This is considered the highest value of the cooling load without any appropriate treatments. In the first case, other treatments were used in walls, such as; Cement bricks (25cm), white foam boards (5cm), polystyrene sheets (3cm), Screed (1cm), and Plain clear glass, 6 mm thick, with the use of an overhang 0.5 m wide in windows. After the simulation process, the total cooling load values during the specified summer months reached the Total Cooling Loads in this case 2839.35 k.W/h. In the second case, it was used some systems such as the use of perlite in walls and electrochromic glass in windows, and after the simulation process, the total cooling load values during the specified summer months reached the Total Cooling Loads 2419.07 k.W/h, and finally in the third case some systems were used, such as the use of PCM with type BioPCM M182/Q21 in walls and using of double glass with 1m projection Louvre as angle 45^0, and after the simulation process, the total values of cooling loads during the months of the specified summer period reached the Total Cooling Loads 2207.93 k.W/h, and therefore after the simulation process, it becomes the third case is the best case and the lowest value of the cooling load after the introduction of using of different techniques and systems for the residential model.

6. Conclusion

The research discussed the problem of thermal loads that many residential buildings depend on mechanical systems to achieve the required levels of thermal comfort inside them, and this results in a continuous increase in energy consumption rates, which represents a great economic burden, so the research aimed to find an alternative or other suitable techniques that reduce Cooling loads by using systems in facades of residential buildings to provide a suitable internal thermal environment for users and reducing of mechanical devices. Some systems represented in materials and glass were selected for the application, as well as one different housing unit existing in Egypt was selected in the study, as the residential sector is considered the highest energy-consuming in Egypt samples for the study, specifically in New Cairo. A simulation program was chosen for the application, which is the (Design Builder) program can create model housing units to simulate and test of thermal behavior of the building by suggesting different alternative techniques for appropriate materials and comparing them to reach the research goal.

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Declaration of Competing Interest

The author has no financial interest to declare in relation to the content of this article.

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