BIM-Based Model of Energy Analysis Heating and Cooling Loads for Residential Building in Egypt

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Abstract:

Sustainable construction is the most important requirement of the modern era in all the different fields that the world needs today. Previous studies began to improve the work of BIM technology in energy analysis, as these programs were not limited to drawing the building in three dimensions, but rather to studying and predicting the building's behavior in heat, lighting, and natural ventilation. Therefore, using BIM technology in the building and construction process is recommended by experts and researchers to save time, and costs to improve energy efficiency that affects buildings and users. BIM is one of the most important technology requirements of projects in general and all engineering disciplines, as the world was affected by Covid-19, which led to the deterioration in the global economy; therefore, governments and institutions resorted to using technology for Online communication. Projects are affected by time and cost as a result of the various factors facing the world today in rapid changes, this led to resorting to the use of BIM in projects to reduce the environmental impact of pollutants and increase the proportion of carbon dioxide (CO_2). The research presents using of BIM technology from simulation programs in social housing that was implemented in Egypt, which was built in traditional materials such as steel and concrete, without using appropriate solutions that reduce energy consumption. Also, it presents BIM technology from simulation programs in social housing that was implemented in Egypt, which was built with traditional materials such as iron and concrete without using appropriate solutions that reduce energy consumption. The study presents the selection of residential projects implemented in Egypt at one of the housing levels, which is social housing, which suffers from a lack of efficiency and sustainability in the building. Therefore, BIM programs such as Revit Architects were used to create a 3D housing model, then use the simulation software Insight 360 for Revit to run and analyze simulations such as sun trajectory, and solar analysis, and calculate heating and cooling loads through appropriate solutions. Therefore, the use of BIM technology helps in developing suitable solutions or alternatives such as; insulating materials and the quality of glass that allows accessing natural light only to achieve thermal comfort to achieve heat efficiency and reduce thermal loads, cost, and time.

Keywords:

Building Information Modelling; Energy Efficiency; Energy Simulation; Sustainable Design

المستخلص:

يعتبر البناء المستدام من أهم متطلبات العصر الحديث في جميع المجالات المختلفة التي يحتاجها العالم اليوم. بدأت الدراسات السابقة في تحسين عمل تقنية BIM في تحليل الطاقة، حيث لم تقتصر هذه البرامج على رسم المبنى بثلاثة أبعاد فحسب بل

بدراسة وتوقع سلوك المبنى في الحرارة والإضاءة والتهوية الطبيعية. لذلك، يوصى الخبراء والباحثون من خلال الأبحاث والدراسات المختلفة باستخدام تقنية البيم في عملية البناء والتشييد لتوفير الوقت والتكاليف لتحسين كفاءة الطاقة التي تؤثر على المباني والمستخدمين.

يستخدم البيم أحد وأهم المتطلبات التقنية للمشاريع بشكل عام وجميع التخصصات الهندسية، حيث تأثر العالم بـ Covid-19 مما أدى إلى تدهور الاقتصاد العالمي. لذلك، لجأت الحكومات والمؤسسات إلى استخدام التكنولوجيا للاتصال عبر الإنترنت. تتأثر المشاريع بالوقت والتكلفة نتيجة العوامل المختلفة التي تواجه العالم اليوم في التغيرات السريعة، مما أدى إلى اللجوء إلى استخدام البيم في المشاريع للحد من الأثر البيئي للملوثات وزيادة نسبة ثاني أكسيد الكربون (CO2). يعرض البحث استخدام تقنية البيم من برامج المحاكاة في الإسكان الاجتماعي الذي تم تنفيذه في مصر، والذي تم بناؤه بمواد تقليدية مثل الحديد والخرسانة دون استخدام الحلول المناسبة التي تقلل من استهلاك الطاقة. تعرض الدراسة اختيار المشاريع السكنية المنفذة في مصر بأحد مستويات الإسكان وهو الإسكان الاجتماعي التي تعاني من قلة كفاءة واستدامة المبنى. لذا تم استخدام برامج البيم مثل الريفيت المعماري لإنشاء نموذج إسكان ثلاثية الأبعاد؛ ثم استخدم برنامج المحاكاة Insight 360 لبرنامج Revit لتشغيل وتحليل المحاكاة مثل مسار الشمس والتحليل الشمسي وحساب أحمال التدفئة والتبريد من خلال الحلول المناسبة. لذا فإن استخدام تقنية البيم يساعد في تطوير حلول أو بدائل مناسبة مثل المواد العازلة وجودة الزجاج التي تسمح بالوصول إلى الضوء الطبيعي فقط لتحقيق الراحة الحرارية وتحقيق الكفاءة الحرارية وتقليل الأحمال الحرارية والتكلفة والوقت.

الكلمات المفتاحية:

نمذجة معلومات البناء؛ كفاءة الطاقة؛ محاكاة الطاقة؛ التصميم المستدام

Nomenclature

CO_2	Carbon dioxide
L/S	
Liters per Second (Air Conditioning)	
KWh/m^2	Kilo watt per meter square
W	Watt
W/m^2	Watt per meter square
w/m^2-k	Watt per meter square per kelvin

Acronyms

3D	Three-Dimensional
BIM	Building Information Modelling
IEA	International Energy Agency
LCA	Life cycle Assessment
NZEB	Net-zero-energy building
SHGC	The Solar Heat Gain Coefficient

1. Introduction

Society and new technology have affected major changes in the construction sector to facilitate tasks in the least time and cost, the introduction of new building materials and new concepts of information and communication technology, and the development of traditional methods better through the introduction of the concept of sustainable construction (Sorensen, et al., 2015). Sustainable building in the construction process is one of the most important requirements for the use of appropriate environmental methods and solutions to control the consumption of materials and follow the life cycle of the building during the design, implementation, and operation process (Kibert, 2016). In the twentieth century, the increase in population numbers and the requirements of living led to the emergence of a shortage of consumable materials, an increase in pollutants, and the emergence of various disease symptoms, which affected the world during the epidemic of Covid-19. This epidemic affected the world greatly regarding the economy and the deterioration of various fields, which led to a significant increase in prices and the disruption of projects due to the high calculated budget deficit and the emergence of risks in projects. In Egypt, projects implemented through the government and the private sector have been greatly affected by the health and economic crises that the world is witnessing in the recent period, which increased the deficit rate, the disruption of project implementation, and an increase in the prices of building materials. Egypt began to improve energy consumption, use renewable materials and produce them continuously, use technology, and increase investments to improve electricity efficiency, increase productivity, and reduce the percentage of pollutants to reach stability. Egypt is also seeking to increase the production of renewable energy like natural Gas instead of Oil sources to reach 43% of electricity production by 2035, (International Energy Agency, 2022). In Key energy statistics, 2019 according to the International Energy Agency's impact index.

The energy consumption indicators as shown in Figure 1

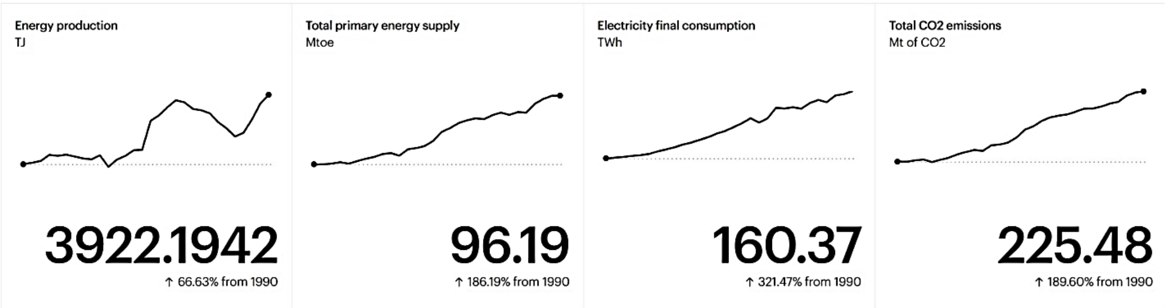

Figure 1: Key energy statistics in Egypt, 2019 according to the International Energy Agency's impact index.
Source: International Energy Agency, 2022

Therefore, the countries of the world have taken care of climate change every year, reducing energy and materials consumption, reducing pollutants resulting from industries, and using technology and environmental materials for projects, all to improve energy efficiency and reach zero energy as much as possible, (Ascione et al., 2019). The research problem is the lack of interest in simulation programs and the reduction of the specific productivity of these programs, which are related to BIM technology, which helps reduce energy consumption, time, and cost. The problem is 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. The potential of smart systems in building facades has not been utilized to reduce thermal loads.

The research aims to use BIM technology to reduce the impact of high temperatures in buildings, and thus it is possible to reduce the use of active cooling devices and increase the benefit of appropriate solutions and treatments from using insulating materials and types of glasses to achieve thermal comfort and reduce loads of cooling and heating energy. So, it is applied in social housing projects implemented in Egypt by using some parameters of the facades from finishing materials and choosing the appropriate quality of glass to improve the environmental efficiency of the building by making different variables or parameters by choosing the layers of building materials and the appropriate type of glass to reduce the values of high cooling and heating loads.

2. Background of BIM technology

BIM technology has appeared recently, which has helped in solving many problems in projects for architects and engineers in design building and construction (Ajayi SO, et al., 2015; Chen et al., 2019). It helps to make a decision-making process in each project phase (Najjar M, et al., 2017) to organize all contributions in the project and follow the building life cycle assessment (Morsi, D.M.A, et al., 2022). The companies have produced simulation programs as they have started designing these programs, such as BIM, to help designers and engineers to facilitate in implementing projects to find appropriate solutions and reduce time and cost (Santos R, et al., 2019; Caetano. I and Leitão, A., 2019). Therefore, many studies had started developing these programs and making the necessary improvements to reach the accounts as accurately and clearly as possible. (Bonenberg and Wei, 2015). BIM helps in solving many of the problems faced by buildings from energy consumption, which harm the environment, to reach a "Net-zero-energy building" (NZEB) (Samer El Sayary and Osama Omar 2021; Mohanta, A. and Das, S. 2022). BIM also helps in converting 2D into different dimensions such as; (3D, 4D, 5D, 6D & 7D), which can analyze and evaluate environmental performance through simulation programs. (Scott Beazley, et al., 2017).

3. The Benefit of using BIM for Energy Analysis

Previous studies began to improve the work of BIM technology in energy analysis, as these programs were not only satisfied with drawing the building in three dimensions but also studying and predicting the behavior of the building in heat, lighting, and natural ventilation (L. Tuomas, 2007; Sampaio, A. Zita, 2022). So, BIM can use to enter the inputs to make the simulation and show the results for analysis, and also different parameters can be entered to compare these results to reach the best possible result (Kim. S. et al, 2016; S. Kalavagunta, 2015).

4. Methodology

Many residential buildings suffer from the lack of thermal comfort due to using of materials in buildings, which absorb large amounts of solar radiation all day, and therefore users resort to using cooling devices to reduce these harmful effects, and thus energy consumption increases by using active cooling than passive cooling. Therefore, the use of active cooling means, represented by the use of cooling devices, consumes 40% of the total energy, and this percentage is dangerous to the environment and users, (Zervos A., 2018).

The Project is drawn after collecting information and data about the project to research and develop appropriate solutions to improve the environmental efficiency of the building, by drawing the building in the simulation program and analyzing the cooling and heating energy loads and making calculations for them, then making different variables or parameters by

choosing the layers of building materials and the appropriate type of glass to reduce the values of high cooling and heating loads.
So, the study presents one of the housing projects implemented in Egypt, which is called social housing, due to the largest community group that suffers from the use of traditional materials and the lack of insulation materials that help reduce high temperatures.
Also, the use of transparent glass and an increase in the percentage of openings increase the transmission of heat and sunlight significantly, which increases the heat and illumination of the place significantly. BIM programs such as Revit are used to create three-dimensional housing modeling; then use simulation software plug-in Insight 360 for Revit to run simulation analysis like sun path, solar analysis, and calculation of heating and cooling loads. After the process of simulation, the results were compared and evaluated when using parameters such as; Insulation Materials and types of glasses to reach the appropriate results as shown in Figure 2.

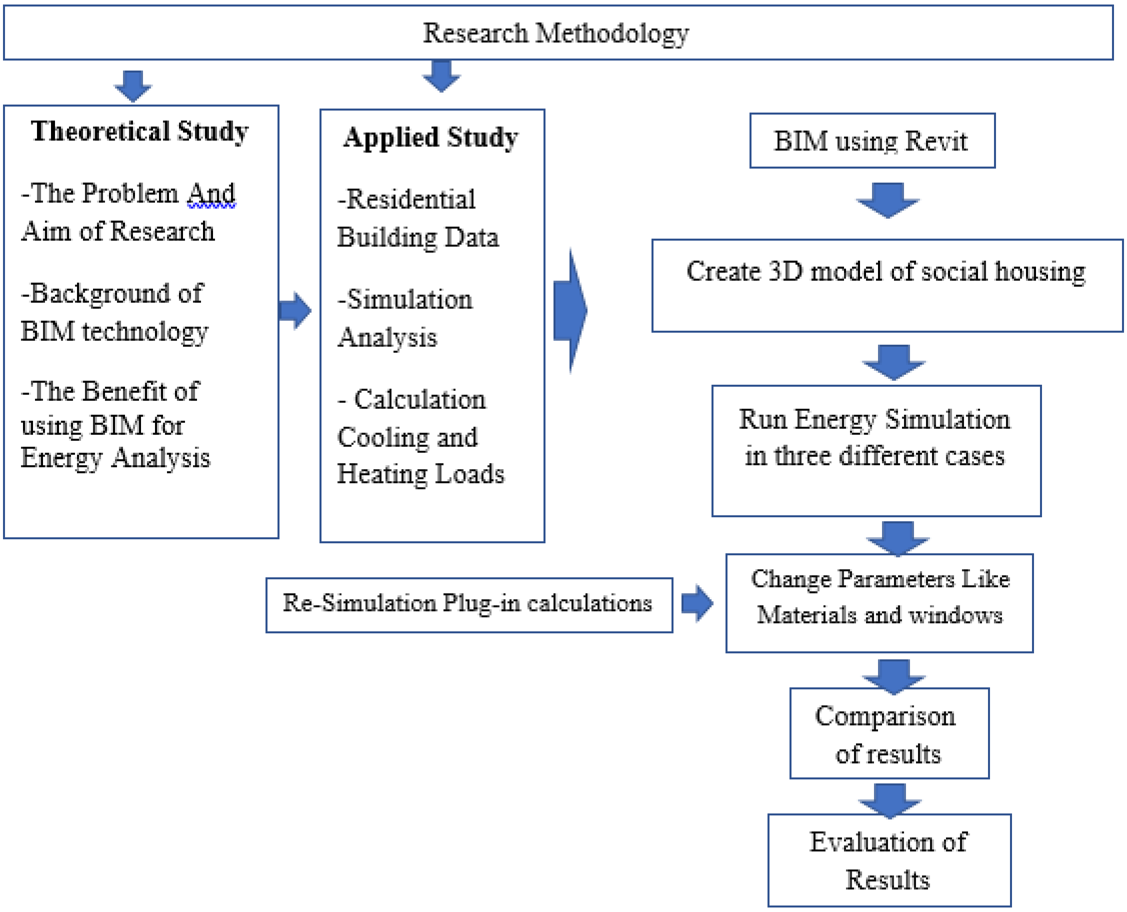

Figure 2: Chart of Research Methodology
Source: The Author

5. Create a 3D model and Inputs

Existing buildings around the world represent one of the most global energy-consuming sectors, and this requires controlling the consumption of materials and reducing the use of cooling and heating devices using alternative methods and renewable energy sources (Leal Filho W, 2018; Bapat, H., Sarkar, D. and Gujar, R., 2022).

5.1. Base Case

The Residential model was chosen and implemented, which is called social housing in Egypt with an area of 90 m^2, and the location was chosen in Cairo Governorate. The building consists of a ground floor and five floors and each floor consists of four apartments. The 3D model was created in the Revit program inputs data (walls, floors, roof, windows, etc.) without any changes in materials and using a simple type of glass as shown in Figure 3.

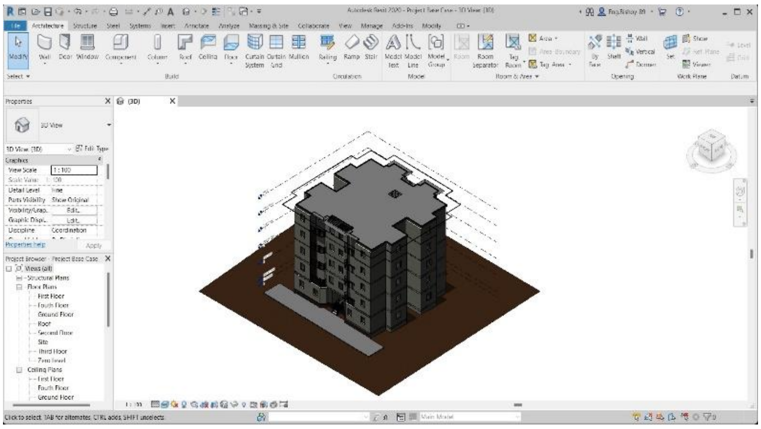

Figure 3: Create a 3D Residential model
Source: The Author

So, Project data such as; (location, building type, building area, number of floors, materials, and type of Glasses used can be summarized as shown in Table 1.

Table 1: Project data Inputs
Source: The Author

Location	**Cairo**
Building Type	Residential Building
Total floor area	90 m^2
Number of floors	Ground floor and five floors and each floor consists of four apartments
Materials in Base case	External walls: Brick, Common 25 cm and Plaster Internal walls: Brick, Common 12 cm
Type of Glasses in Base case	Single window 6 mm

5.1.1. Sun Path and solar radiation analysis of Base Case

At this stage, after determining the location, weather data file, date, the movement of the sun, and its impact on the building is studied for the facades exposed to the sun need appropriate solutions to reduce the negative impact of high temperatures inside the building and shaded places. The location of the sun was determined in the program and set at 12 P.M, considering this time is the peak hour in which the sun shines and affects the building as shown in Figure 4.

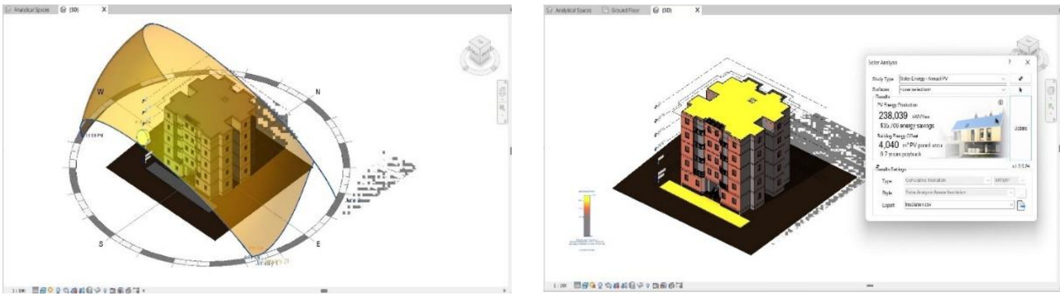

Figure 4: Left: Sun Path analysis, right: solar radiation analysis
Source: The Author

The previous figure shows the high solar energy after simulation was 703 (KWh/m^2), which affects the building on the southern facade of high solar radiation, which requires the installation of architectural solutions of materials insulation for facades and roofs, as well as controlling the proportion of glass openings and using the appropriate quality of glass that only allows access of natural light.

5.1.2. Calculation of Heating and Cooling Loads of Base Case

At this stage, the heating and cooling loads for the building were calculated in the simulation program as in Figure 5 and table 2 where the inputs are also specified such as (location, type of building, materials used in the building from walls, floors, roof, and type of glass).

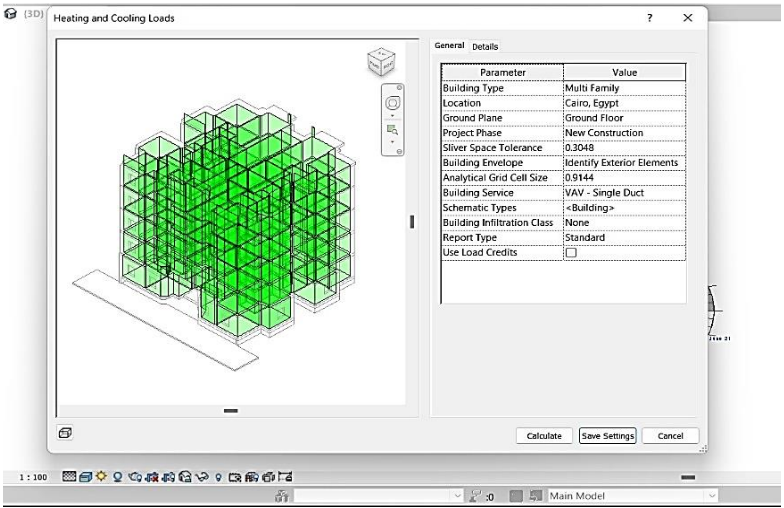

Figure 5: Calculation of Heating and Cooling Loads
Source: The Author

Table 2: Calculation of Heating and Cooling Loads
Source: The Author

Calculated Results	
Peak Cooling Total Load (W)	**89.878**
Peak Cooling Sensible Load (W)	85.975
Peak Cooling Latent Load (W)	3.903
Maximum Cooling Capacity (W)	84.371
Peak Cooling Airflow (L/s)	10.040.9
Peak Heating Load (W)	**18.520**
Peak Heating Airflow (L/s)	6.720.5

Checksums	
Cooling Load Density (W/m²)	**55.99**
Cooling Flow Density (L/(s·m²))	8.25
Cooling Flow / Load (L/(s·kW))	52.88
Cooling Area / Load (m²/kW)	6.41
Heating Load Density (W/m²)	**17**
Heating Flow Density (L/(s·m²))	5.52

At this stage, it is shown that the cooling and heating loads have increased in the reference case, which is considered the worst case due to the absence of any environmental treatments for the building, which has increased the cooling load values to 89.878 watt and heating loads to 18.520 watt as shown in Figure 6.

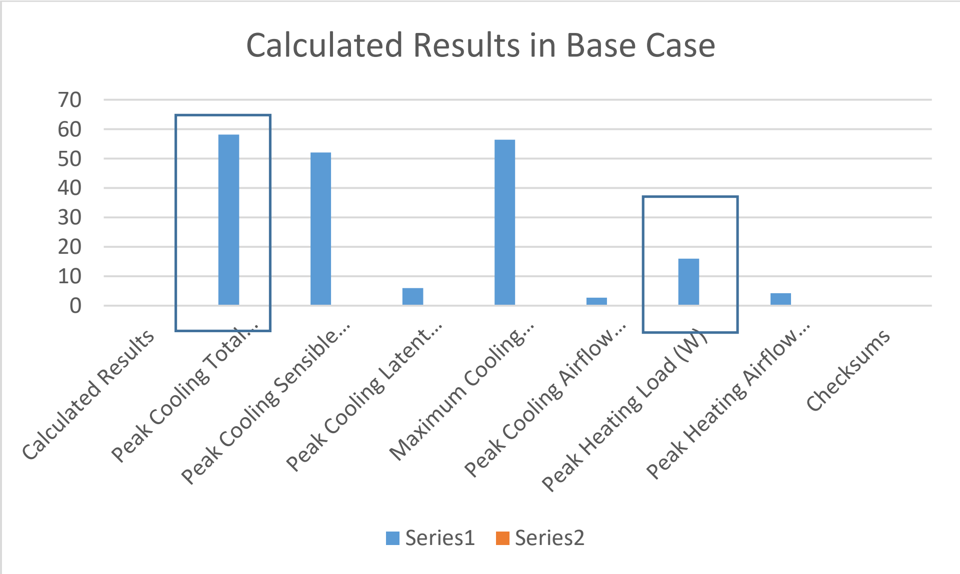

Figure 6: Calculation of Heating and Cooling Loads in Base Case
Source: The Author

Also at this stage, it is shown that Checksums in Base Case for cooling and heating loads have increased in the reference case, which is considered the worst case due to the absence of any environmental treatments for the building, which has increased the cooling load Density values to 55.99 watt/m^2 and heating loads to 17 watt/m^2 as shown in Figure 7.

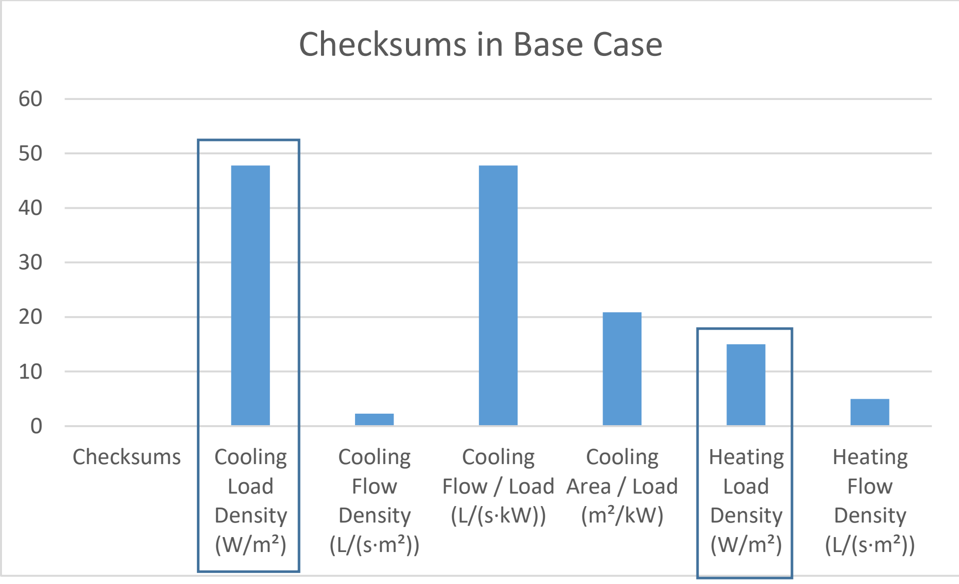

Figure 7: Checksums in Base Case
Source: The Author

5.2. Simulation Model by Inputs solutions in the First Case

Project data was created such as; materials in layers, and type of Glass used as shown in Table 3 and Figure 8.

Table 3: Project materials and type of Glasses Inputs
Source: The Author

Materials Insulation layers Inputs **in five layers**	Layer1: Finishing of External walls: Brick, Common 25cm Layer2: Insulation material: Polystyrene 2cm Layer3: Air Layer4: Insulation material: Polystyrene 2cm Layer5: Internal walls: Brick, Common 12 cm
Type of Glasses in Inputs	Double Glazing Window 6 mm

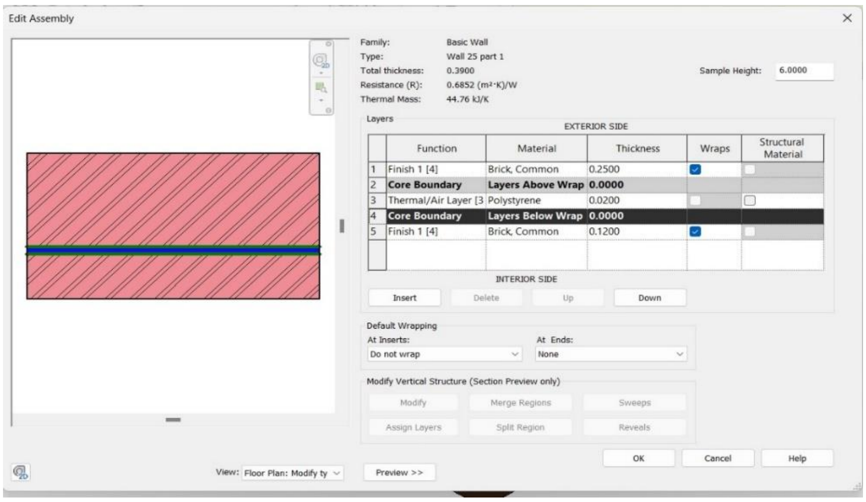

Figure 8: Project materials insulation and glasses type Inputs
Source: The Author

5.2.1. Sun Path and solar radiation analysis in the first case

The location of the sun was determined in the program and set at 12 P.M, considering this time the peak hour in which the sun shines and affects the building as shown in Figure 9.

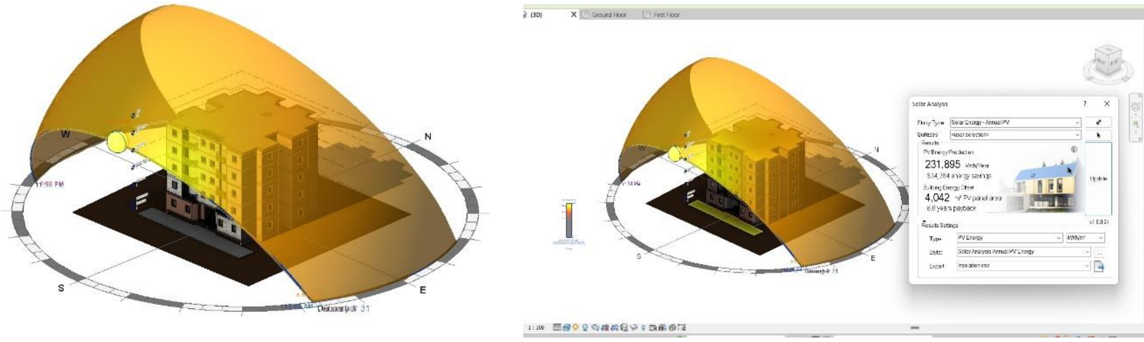

Figure 9: Left: Sun Path analysis, Right: solar radiation analysis
Source: The Author

The previous figure shows the reduction of solar energy after simulation was 273 (KWh/m^2), as the temperatures decreased in the building as a result of the use of appropriate treatments on the facades and surfaces exposed to the sun.

5.2.2. Calculation of Heating and Cooling Loads in the first case

At this stage, the heating and cooling loads for the building are calculated in the simulation program as shown in Figure 10 and Table 4.

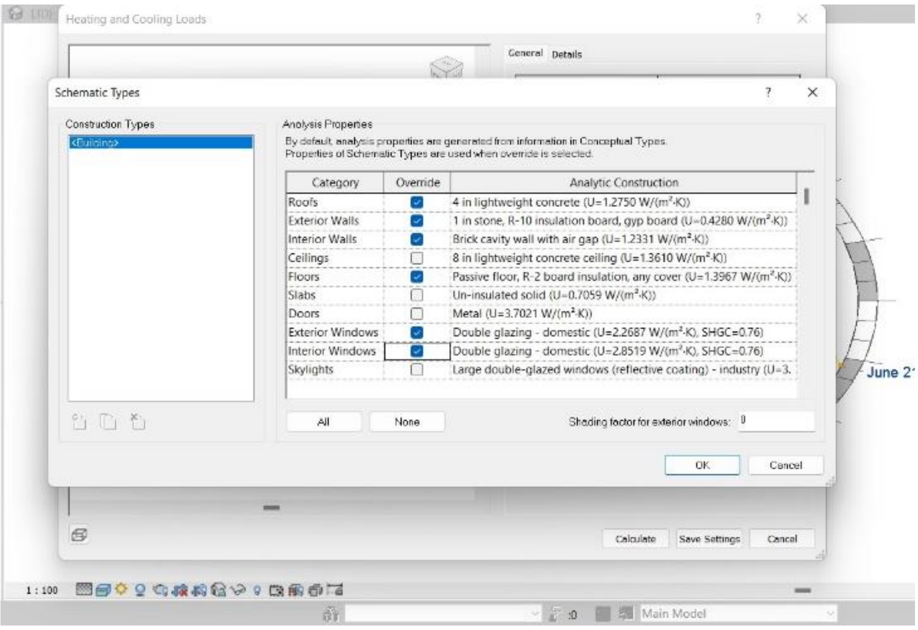

Figure 10: Project materials insulation type and type of Glasses Inputs for Calculation of Heating and Cooling Loads
Source: The Author

Table 4: Calculation of Heating and Cooling Loads
Source: The Author

Calculated Results	
Peak Cooling Total Load (W)	**58.211**
Peak Cooling Sensible Load (W)	52.126
Peak Cooling Latent Load (W)	6.085
Maximum Cooling Capacity (W)	56.473

Peak Cooling Airflow (L/s)	2.782
Peak Heating Load (W)	**16.035**
Peak Heating Airflow (L/s)	4.3
Checksums	
Cooling Load Density (W/m²)	**47.82**
Cooling Flow Density (L/(s·m²))	2.29
Cooling Flow / Load (L/(s·kW))	47.8
Cooling Area / Load (m²/kW)	20.9
Heating Load Density (W/m²)	**15**
Heating Flow Density (L/(s·m²))	5

At this stage, it is shown that the cooling and heating loads have decreased in the first case after adding variables of layers of materials and the chosen type of Glass, which the result after simulation of the cooling load values is 58.211watt and heating loads to 16.035watt as shown in Figure 11.

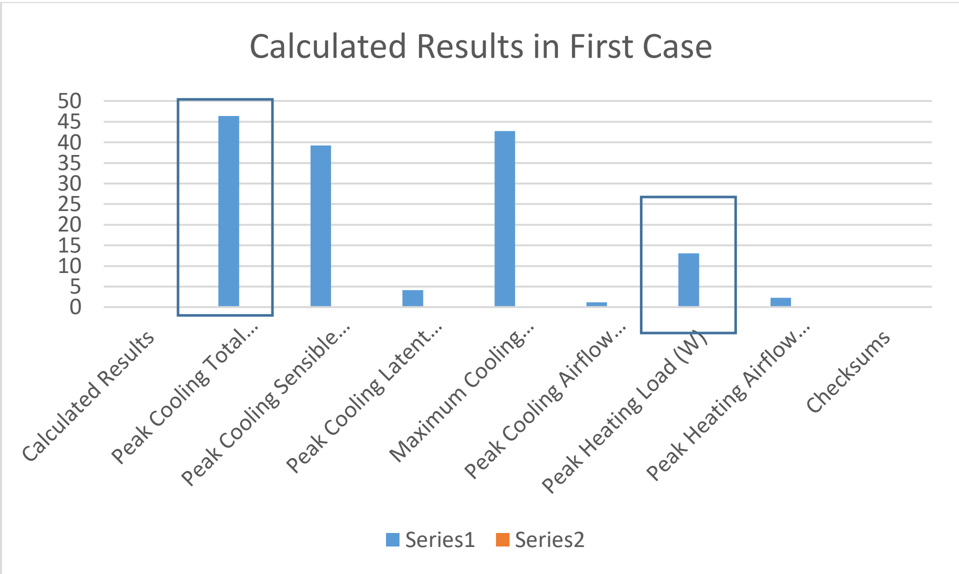

Figure 11: Calculation of Heating and Cooling Loads in the First Case
Source: The Author

Also at this stage, it is shown that Checksums in First Case for cooling and heating loads have decreased in this case, after adding variables of layers of materials and the chosen type of Glass, so the result of the cooling load Density values is 47.82watt/m^2 and heating loads to 15 watt/m^2 as shown in Figure 12.

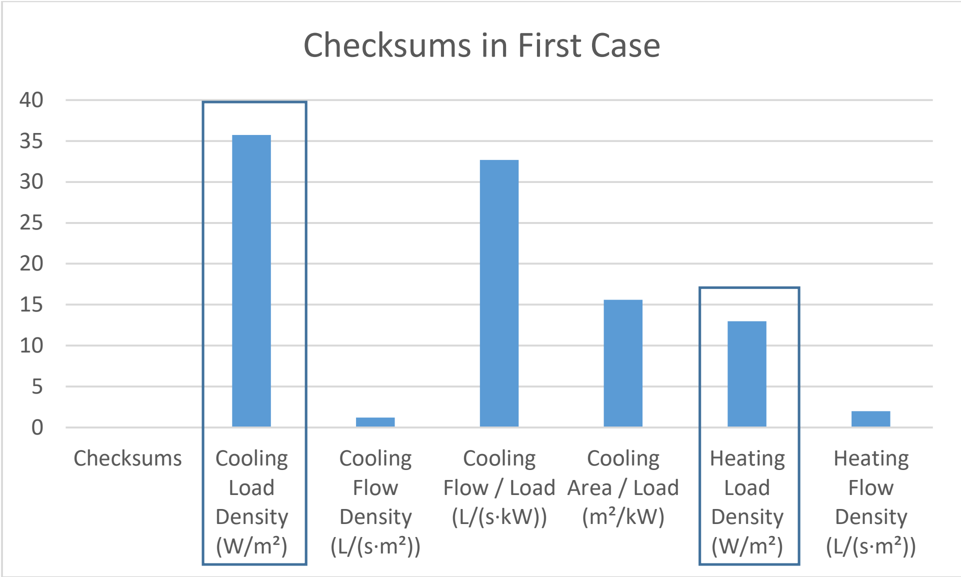

Figure 12: Checksums in the First Case
Source: The Author

5.3. Simulation Model by Inputs solutions in the second case

In this case, solutions were added and developed to improve Project data such as; materials in layers, and type of Glass used as shown in Table 5 and Figure 13.

Table 5: Project materials and type of Glasses Inputs
Source: The Author

Materials Insulation layers Inputs **in five layers**	Layer1: Finishing of External walls: Brick, Common 25cm Layer2: Insulation material: Polystyrene 2cm Layer3: Insulation material: Air Layer4: Gypsum wall board 5cm Layer5: Internal walls: Brick, Common 12 cm
Type of Glasses in Inputs	Double Glazing Window 12 mm

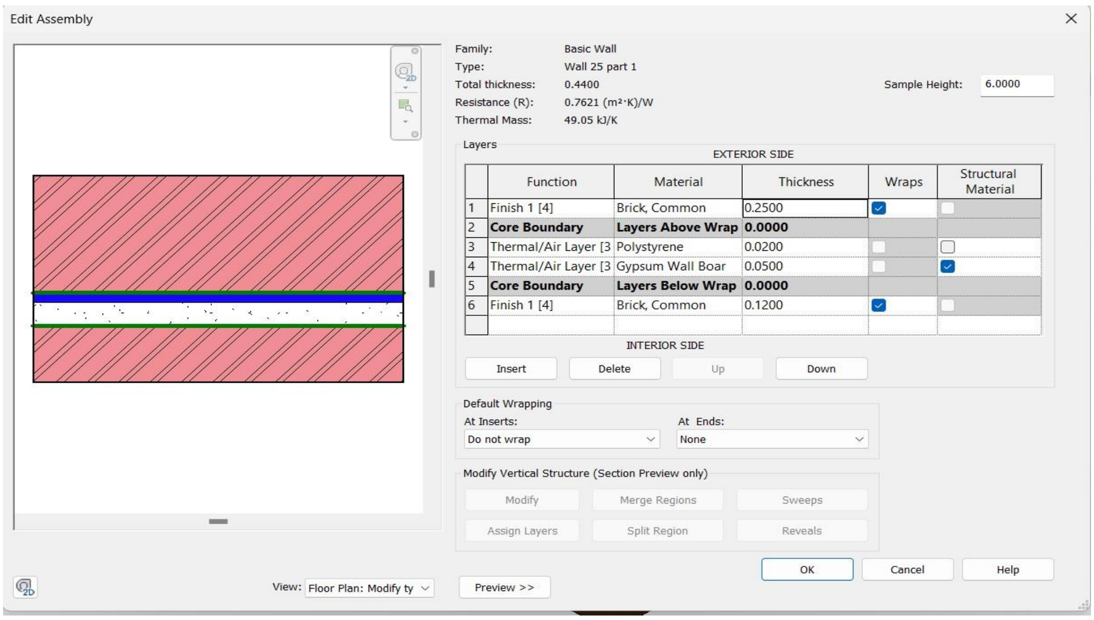

Figure 13: Project materials insulation and glasses type Inputs
Source: The Author

5.3.1. Sun Path and solar radiation analysis in the second case

The location of the sun was determined in the program and set at 12 P.M, considering this time the peak hour in which the sun shines and affects the building as shown in Figure 14

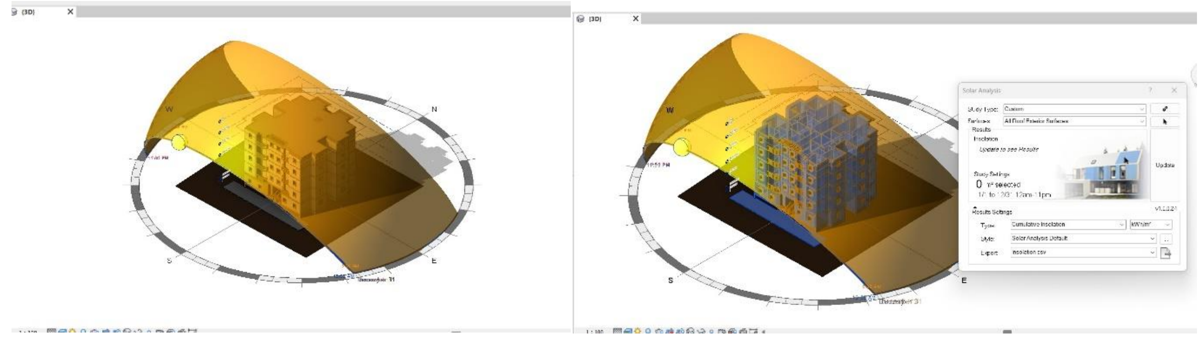

Figure 14: Left: Sun Path analysis, Right: solar radiation analysis
Source: The Author

The previous figure shows the reduction of solar energy after simulation was 251 (KWh/m^2), as the temperatures decreased in the building as a result of the use of appropriate treatments on the facades and surfaces exposed to the sun.

5.3.2. Calculation of Heating and Cooling Loads in the second case

At this stage, the heating and cooling loads for the building are calculated in the simulation program as shown in Figure 15 and Table 6.

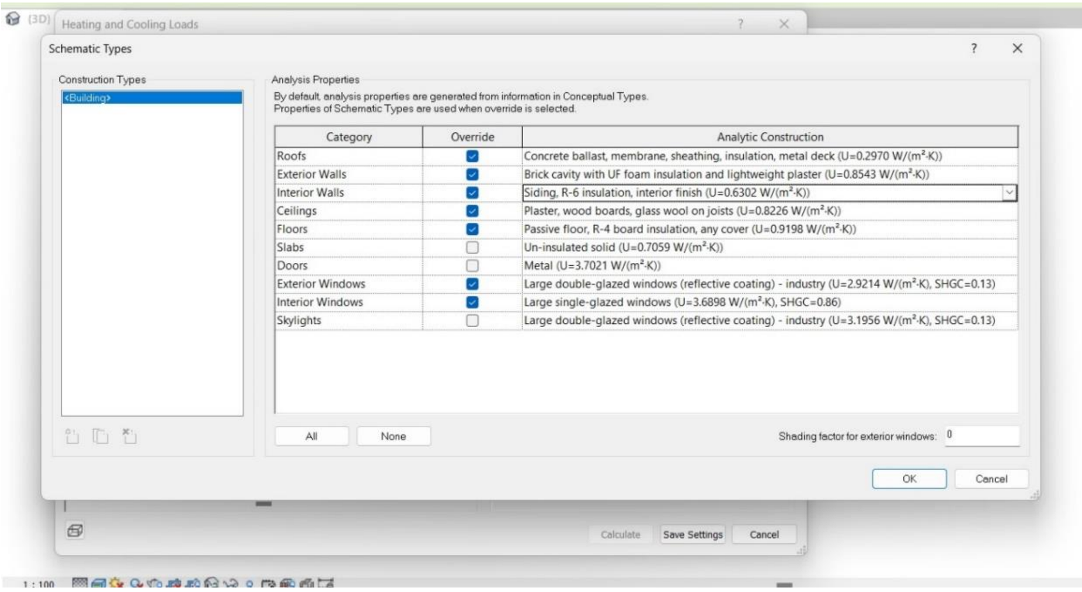

Figure 15: Project materials insulation type and type of Glasses Inputs for Calculation of Heating and Cooling Loads
Source: The Author

Table 6: Calculation of Heating and Cooling Loads
Source: The Author

Calculated Results	
Peak Cooling Total Load (W)	**46.361**
Peak Cooling Sensible Load (W)	39.254
Peak Cooling Latent Load (W)	4.126
Maximum Cooling Capacity (W)	42.768

Peak Cooling Airflow (L/s)	1.234
Peak Heating Load (W)	**13.048**
Peak Heating Airflow (L/s)	2.3
Checksums	
Cooling Load Density (W/m²)	**35.74**
Cooling Flow Density (L/(s·m²))	1.20
Cooling Flow / Load (L/(s·kW))	32.7
Cooling Area / Load (m²/kW)	15.6
Heating Load Density (W/m²)	**13**
Heating Flow Density (L/(s·m²))	2

At this stage, it is shown that the cooling and heating loads have decreased better in the second case after adding more variables of layers of materials and the chosen type of Glass, which the result after simulation of the cooling load values is 46.361watt and heating loads to 13.048 watt as shown in Figure 16.

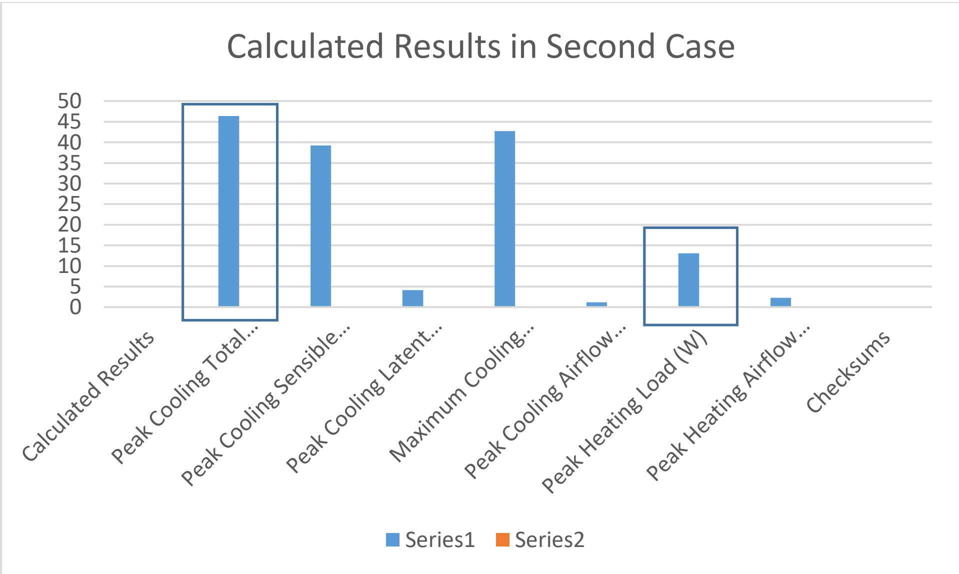

Figure 16: Calculation of Heating and Cooling Loads in the Second Case
Source: The Author

Also at this stage, it is shown that Checksums in the second Case for cooling and heating loads have decreased better in this case, after adding more variables of layers of materials and the chosen type of Glass, so the result of the cooling load Density values is 35.74watt/m^2 and heating loads to 13 watt/m^2 as shown in Figure 17.

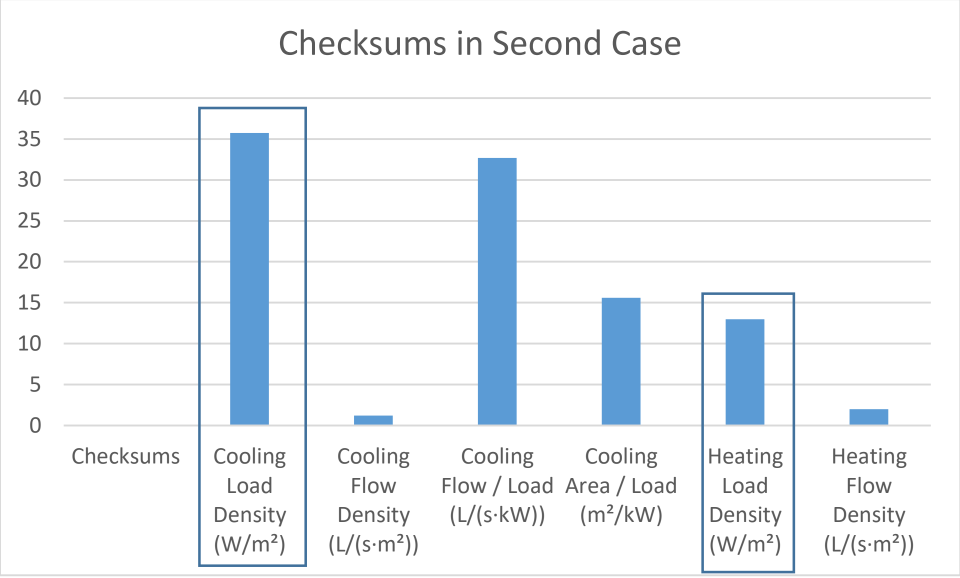

Figure 17: Checksums in the Second Case
Source: The Author

6. Results and Discussion

The previous simulation of the base case shows the increase in the value of cooling loads in the Base case, which reached 89.878 watt, the building was affected by the high sun radiation on the facades of the building, thus increasing the temperature of the building and causing a sense of heat comfort for the building users. Therefore, this study requires the use of appropriate solutions and methods to be applied in the building, such as; (insulating materials for facades exposed to sunlight and choosing the appropriate quality of glass that reflects sunlight and allows to access natural light only). Also, the value of Heating loads reached 18. 520 watt, which means during the winter period, the use of heating machines are required for the place and thus increasing the consumption of electrical energy.

The previous simulation after solutions in the first case (insulating materials for facades and choosing the appropriate quality of glass that reflects sunlight and allows to access natural light), shows decreasing the value of cooling loads, which reached 58.211watt. Thus, achieve thermal comfort and natural lighting in the building, reduces the use of cooling devices and energy consumption saving. Also, the value of Heating loads, which reached 16.035 watt, therefore; reduces using of heating devices and energy consumption at certain times and the possibility of the sun's heat throughout the day as much as possible and storing it for heating at night.

Finally, the previous simulation after solutions; in the second case solutions were added and developed to improve Project data such as; materials in layers, and type of Glass (insulating materials for facades and choosing the appropriate quality of glass that reflects sunlight and allows to access natural light), shows decreasing the value of cooling loads, which reached 46.361 watt, thus, achieve thermal comfort and natural lighting in the building, reduces the use of cooling devices and energy consumption saving. Also, the value of Heating loads, which reached 13.048 watt, therefore; reduces using of heating devices and energy consumption at certain times and the possibility of the sun's heat throughout the day as much as possible and storing it for heating at night.

7. Conclusion

The research discussed the importance of BIM technology in the construction and building industry, and its importance for its use to solve design and implementation problems, especially in studying energy efficiency in buildings that reduce consumption to reach zero energy and the absence of carbon dioxide.

BIM and energy simulation programs were used to test and measure the suitability of the building with the environment, where the residential model was selected and drawn in the Revit program and a simulation of the building was made before introducing treatments or solutions, studying the impact of solar energy on the building and calculating the cooling and heating loads.

After reaching this stage and extracting the results, the parameters such as; materials and windows were added to the building to simulate it, extract the results, and make a comparison in the presence of the difference in values. So, the research found that using BIM is a tool to help designers to take the right decision. Future work will continue to explore and test this tool with the simulation program used more with other variables to reach results that achieve energy efficiency in buildings.

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Declaration of Competing Interest

The author declares that the research has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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