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# Optimization of materials to improve energy consumption performance within thermal comfort for residential schools in Egypt.

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**ABSTRACT**

The research paper presents an optimized model for optimal design solutions to provide the best thermal comfort within residential school buildings, using Innovative materials with a specific criterion of Thermal Transmittance (U-value), to achieve the best thermal comfort between 23.5oC and 25.5OC, with humidity of 30-60% respectively according to ASHREE-55 [1], while achieving the highest possible reduction in energy consumption. To achieve the research objectives, a building was chosen for one of the residential schools in Obour City, Cairo, the building consists of two floors only, the ground and the first floor, for adult users. The research dealt with the building's first "last level floor" as a case in which the developed model is applied.
The research results showed that four factors directly impact the amount of energy consumed needed to achieve appropriate thermal comfort. These factors are represented in the degree of optimization "heat transfer coefficient of the roof representing 28.5 % - the solar heat gain coefficient of the external windows representing 4.80% - the heat transfer coefficient of the exterior walls representing 23.3 % - the lowest percentage of energy efficiency is for (Floor materials 4.3% and wall paints representing 1.1%) and the percentage of energy efficiency resulting from the four factors combined is 62% of energy.
The research study's results provide information that contributes to finding optimal solutions for choosing building materials and finishes that achieve the best thermal comfort inside buildings while achieving the best energy efficiency.

## 1. Introduction

The main goal of architectural researchers is to achieve the best living conditions for people in their buildings, especially in places of permanent residence such as residential schools, and thermal comfort is considered one of the most important factors that affect people's mental and physical comfort, so the designer seeks to achieve the best degree of thermal comfort inside the building. Research indicates that the energy consumption rates of buildings reach 40% of global energy consumption, and contribute to more than 30% of carbon emissions, and most of the consumption goes to provide thermal comfort inside buildings.[2]

The research seeks to provide the maximum degree of thermal comfort within residential school buildings while raising the efficiency of the required energy consumption rate, by using or replacing

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innovative materials with specifications that work to raise the thermal comfort efficiency of the spaces for the components of the building elements (walls `- floors - ceilings – opening, To achieve the goal, practical simulations are conducted on the last level floor of the building, (which was chosen from two floors in Obour City, Cairo), by using simulation programs (Design Builder), to reach the solutions and choose the best materials that give the best results to optimize the factors affecting the degree of thermal comfort .efficiency inside buildings. "Temperature - Humidity - Ventilation - Carbon Emissions" thus optimizing the rate of energy consumption required to reach the target thermal comfort degree.

This building works as a residential school building for adults " 15 - 48 years" who are full residents, which requires continuous energy consumption throughout the day, and the rate of consumption increases in summer, especially in the months The peak, and the last level floor was chosen for direct exposure to sunlight most hours of the day to stores heat and transmits it inside the building, causing thermal stress for users.

## 2. Material and Methodology

In its methodology, the research sequence is divided into several steps, the first of which is the theoretical definition and presentation of the scientific concept of the terms used in the research, followed by the analytical work of defining the building (LAST FLOOR) and its description (floors - walls - ceilings - openings) and study the properties of materials in their current condition and obtain the results of thermal comfort and energy consumption throughout the year Using the (DESIGN BUILD). Moving on to applied work and selecting types of innovative materials for elements of the spaces (based on the criterion Thermal Transmittance (U VALUE) to choose the optimal type functionally for each element of the spaces, and making comparisons between the results of the current situation and the proposed optimization for a year, and also an analytical study comparing the results on the month of July because it has the highest temperature The proposed innovated materials are replaced with the previous ones to improve the thermal comfort and energy consumption optimization inside the space and access to conclusions and recommendations.

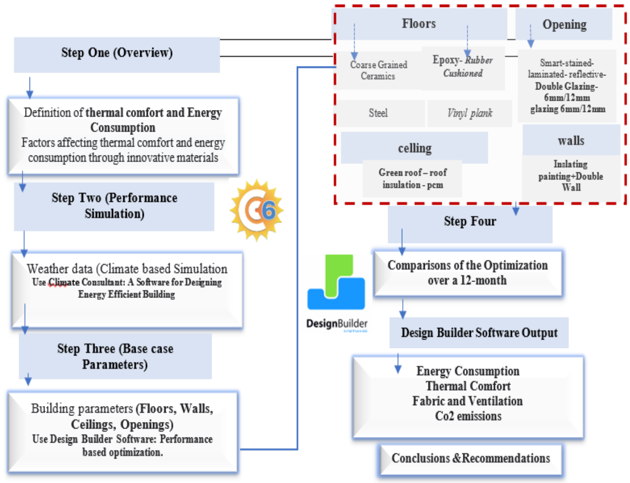



Fig. 1. Research Methodology Framework for the Optimization, source: Researchers

## 3. Research scope

The main purpose of this research is to optimize thermal comfort and raise the efficiency of energy consumption rates in different spaces by replacing innovative materials that raise the thermal comfort efficiency of the components of the building elements to improve the factors affecting the degree of thermal comfort (PMV & PPD), fabric, ventilation, carbon dioxide emissions, internal gains and totals fuel for the whole year. Thus, you will be able to develop and improve the energy efficiency and thermal comfort target for residential school buildings in Egypt.

### *3.1. Thermal energy of buildings:*

In general, people spend more than 90% of their waking hours in enclosed spaces like homes and residential schools. Thermal comfort is therefore essential for their well-being as well as for their capacity to work efficiently [3]. The mental state of satisfaction with a building's thermal environment is known as thermal comfort. Because it differs between users, this happiness cannot be expressed in terms of temperatures or ranges, According to Fanger [4], Users' sensitivity to thermal comfort is significantly influenced by several factors, including relative humidity, mean radiant temperature, air velocity, personal clothing, and activity level, in addition to the indoor air temperature (dry air-bulb temperature). [4] This statement indicates the building components affect the thermal comfort and energy consumption indoors as indicated by the so-called "operative temperature." It represents the mean value of fabric and ventilation, CO2 emissions, and the average value of indoor air temperature Ta (°C).

The factors' values that affect the PMV index might be decided upon during the design phase or assessed through testing or monitoring of the building's environmental and energy performance, that enable the achievement of the appropriate level of environmental quality [5].

*3.2. Thermal load reduction techniques*

To create energy-efficient buildings in both hot and cold regions, it is crucial to reduce the energy needed for heating and cooling. In 2050, the cooling demand is predicted to increase by roughly 150% globally and by between 300% and 600% in developing nations, The use of inexpensive reflecting materials for walls, roofs, floors, and ceilings, as well as the use of low-emissivity coatings for walls, windows, and glazing systems, are just a few of the solutions that are advised to reduce energy consumption in hot regions [6].

*3.3. Thermal effects of innovative materials for building components elements.*

One of the most important of these Criteria is the standard of thermal comfort, which may be directly affected by the materials for innovative floors, walls, ceilings, and openings. This is due to the thermophysical properties of the materials used, in particular the heat absorption coefficient for each material, Thermal Transmittance (U value) “the degree of heat and moisture absorption, storage and radiation.” This also affects the energy consumption required to adjust the temperature of the space industrially [7].

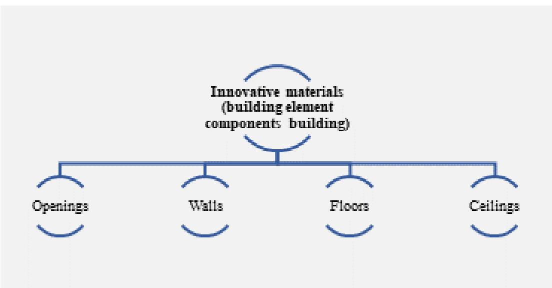



Fig. 2. Innovative materials of buildings elements components, source: Researchers

*3.3.1. Openings*

It is known that the Glazing material is made of silica, which is the sand from which many electronic products are made. Therefore, many types of glazes serve a variety of purposes, especially in the urban field, not only for windows, but the house can be designed externally and internally entirely from various glass in its characteristics, shapes, and sizes, and we review the most prominent glazing types [8]

The two main variables that influence the quantity of heat absorption into the interior and consequently affect thermal comfort and energy usage are the area of the hole and the type of glass employed.

As a result, the 20% glass area will be researched and established as a standard for measurement and the precision of the findings.

- Transparent glazing: It is one of the most popular and widely used types of glazing, as it is characterized by low price and a high degree of purity that allows clear vision through it. It also transmits 80% of natural daylight, thus helping to reduce energy consumption, three types of transparent glazing will be used for windows and doors

1- Single layer transparent glazing

2- Double transparent glazing consisting of two layers separated by an insulating layer of air and characterized by its ability to isolate dust, sound, and heat

3- Three-layer transparent glazing separated by two insulating layers of air. It has higher advantages than double glazing, but the disadvantage is the high cost [9].

- stained glazing: It is a glass of transparency; the required colors have been added to it so that a glass panel acquires another color to add the aesthetic shape of the place. It is usually used in the internal partitions of the spaces [10].
- Reflective glazing: For the surface of the glass to reflect the light as we see it in the mirror, the surface of this type is treated with a thin metal layer that makes the other surface reflect light and sunlight, and it also obscures the view from the outside to the inside, it is also considered environmentally friendly as it is a type of insulating glass, and it is one of the best types of glass for the facades of residential buildings [11].
- Laminated glazing: It is a glass consisting of two or more layers of glass. Each layer is separated from the other by a layer of

transparent vinyl. Some decorations can be added in the middle layers to be used in the interior decoration of spaces. This type of glass is characterized by high durability, as it is one of the strongest glazing types, so it is used in Building balconies, facades، and stairs where the safety factor is achieved, it is also used to divide internal spaces instead of fixed walls [12].

- Smart glazing: It is a high-tech glass that can automatically switch from a state of transparency to a state of darkness electronically, due to the presence of a crystal layer that can control the amount of transparency according to the intensity of the lighting, this type is used in buildings on a small scale due to its high cost [13].

Table 1. Showing the percentage of reflection for types of glass and Thermal Transmittance U value, source: [14].

| Glazing Materials | Reflection% | U value |
|---|---|---|
| **Transparent glazing 6mm** | 6% | 5.9 W/m2K |
| **stained glazing6mm** | 6% | 5.2 W/m2K |
| **Reflective glazing6mm** | 47% | 2.8 W/m2K |
| **Laminated glazing10mm** | 52% | 0.47 W/m2K |
| **Smart glazing (Clayton glass) 6mm** | 85% | 1.0 W/m2K |
| **Double glazing16mm** | 75% | 1.323 W /m2K |

*3.3.2. exterior walls and interior paints with innovative materials on residential school buildings:*

- External wall with thermal and energy:

When considering construction materials, there are many different design factors for traditional walls(single), which respond quickly to heat, that is absorbed during the day. In highly humid and hot climates, traditional wall construction is not recommended because of their limited diurnal range. Double-wall buildings are preferred due to their effectiveness in passive cooling, the optimal choice, recent research showed that innovative, well-insulated, thermal wall designs can lower day and night temperatures by 3–6 °C in hot regions [15].

- wall paints in residential school buildings:

- Water-based paints: characterized by ease of use and resistance to fungus with quick drying and ease of cleaning with color stability and resistance to cracking, but it is defective in that it is short-lived and has a poor texture in addition to their lack of resistance to moisture or exposure to water, which leads to cracking and fading. [16].

- Oil paints: are distinguished by their multi-colours and solidity for all surfaces. It gives glossy surfaces that are resistant to moisture. One of its disadvantages is the emission of strong toxic fumes from it during painting, which causes health damage when inhaled. It is also difficult to clean [17].

- Plastic paints: It is characterized by many characteristics, so it is the most common type of paint at present, due to its suitable prices for everyone, its ease of painting, and the multiplicity of types of “glossy, semi-glossy, and matte” in addition to the possibility of installing the required color with the ease of cleaning it with soap and water, one of its disadvantages is that it is not resistant to the moisture of the walls, and it does not use paint and wooden surfaces.

- Epoxy paints: One of its advantages is that it gives a surface of strong cohesion, quick drying, and hardening, as it hardens within a period of no more than an hour, although some consider this a defect, and one of the most important defects is that its colour does not tolerate light, colours changes from white to yellow when exposed to continuous light, as a result of chemical reactions of its components [18].

Table 2. Showing U value for types of paints, source: [19].

| Paints wall Materials | thickness (mm) | U value |
|---|---|---|
| **Oil paints** | 4 | 2.13 W/m2K |
| **Plastic paints** | 2 | 1.71 W/m2K |
| **Water-based paints** | 2 | 0.45 W/m2K |
| **Epoxy paints** | 3 | 0.145 W/m2K |
| **Velour paints** | 4 | W/m2K |

3.3.3. *Floors Materials [20].*

- Epoxy Floor Materials: Once used, it is a liquid that is spread on level floor surfaces and allowed to dry slowly over several days.
- Vinyl planks resembling wood chips are attached to flat floors, covering a gleaming, parquet-like surface. Small spaces are dispersed.
- Rubber Tiles: Rubber is defined as a material that absorbs shocks and protects individuals who fall on it from major damage.

- Coarse-Grained Ceramic: Ceramic tiles of various sizes and colours are suitable for furnishing all voids of residential and service buildings, but when furnishing spaces for people with mobility disabilities, the advantages and disadvantages must be measured from the point of view of users with motor disabilities.
- Steel Materials: Steel is iron metal combined with various materials such as "carbon - nickel - chromium - tungsten" to produce steel with varying specifications depending on the additions that meet the desired purpose.

#### *3.3.4. Roofs (ceilings Materials)*

Due to their exposure to solar radiation and other environmental elements, particularly last-floor influences, roofs dictate the inside conditions of buildings and have an impact on the circumstances for occupants. According to the weather, composite roofing systems are typically preferred to generate the needed roof characteristics. Insulation is employed in nations with high incidence sun radiation because it is a practical and affordable method of reducing solar heat transmission. There are numerous varieties of roof insulation materials, including low thermal emittance reflecting forms (such as foil aluminium) [21]. As a static building energy-consumption option, the green roof system has gained popularity over time because it effects the transfer of heat from outside to inside and thus affects energy consumption on the last floor. [22]

Table 3. Showing U value for types of flooring, wall, opening, ceiling, source: [23].

| Elements | Type1 | Type2 | Type3 | Type4 | Type5 |
|---|---|---|---|---|---|
| **floor** **U value** **w/m2-k** **Thermal Transmittance** | Epoxy | Vinyl planks | Rubber | Grained ceramic | Marble |
| | **U value 0.25** | U value 1.032 | U value = 0.41 | U value = 0.55 | U value =1.23 |
| **walls** | Traditional wall(25cm) | Double wall | Insulation wall (foil aluminium 5cm) | | |
| | U value 1.92 | **U value 0.29** | U value 0.502 | | |
| | Water-based paints | Oil paints | Plastic paints | Velour paints | Epoxy paints |
| | U value 0.45 | U value 2.13 | U value1.71 | U value 1.52 | **U value 0.145** |
| **Openings (20% aperture ratio)** | Laminated glazing | stained glazing | Double glazing: | Reflective glazing | Smart glazing: |
| | U value 1.323 | U value 5.2 | **U value 0.47** | U value 2.8 | U value 1.0 |
| **ceilings** | Green roof | Roof Insulation | PCM | | |
| | **U value 0.370** R 2.75(M2-K/W) | U value = 0.65 W/m2k, R 1.525 | U value 0.373 R 2.70 (M2-K/W | | |

### *3.4. Optimization*

Optimization is an attempt to obtain new results that are better than the current results by raising the efficiency of the current elements by adding some materials or replacing some current materials with others with technical, natural, or chemical specifications suitable for the purpose required for optimization to obtain the best results at the lowest costs.

The research seeks to optimize the internal spaces' thermal comfort and energy consumption by selecting the most suitable materials for innovative ceilings, floors, walls, and openings to provide the best thermal comfort for the space at reasonable costs [24].

## 4. Building Analysis with Simulation (Case Study)

Basic of Case Study, Selection، and Analysis: a study of the residential school in Obour City- Egypt.

- The research will deal with the analytical part in two successive phases as shown in Fig 3.

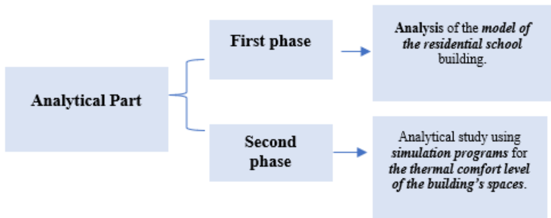



Fig. 3. shows the steps of the analytical study of residential school building Source: Researchers

### *4.1. First phase:*

Analytical the building that was chosen in Obour City as a model for the residential school, as shown in Table 4, a detailed description of the as building as shown in Table 5, its interior elements "celling-floors - walls - openings" and the innovative materials used for these elements.

Building Description: A residential school for adults, the "horizontal plan of the first floors", which is the last floor is shown in Table 4,5. The building has two floors, with the ground floor having an area of 840 square meters.

comprises living quarters, lecture halls, activities, services, and dining rooms, as well as a recreational space and outside yards.

The first floor, measuring 530 square meters, comprises residential quarters, lecture halls, and appropriate activities for residents.

To quantify the degrees of thermal comfort and energy consumption ratios using the (design-builder-simulation program), five points are determined, as shown in Table 4 (the horizontal floor-first plan).

Because of its exposure to sunlight directly, the last floor was selected.

### *4.2. the second phase:(Design Builder)- Analysis of the model of the residential school building*

The results of measuring the level of thermal comfort for spaces and the extent to which they achieve users' satisfaction and physical, psychological، and mental comfort in terms of (temperature - electric energy consumption - carbon dioxide emissions) and the suitability of these materials used to achieve appropriate thermal comfort, as shown in Table 6,7,8.

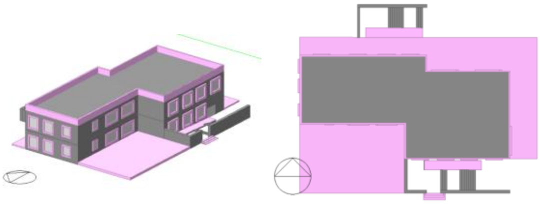


Fig. 4. Layout and 3D of the building (Design Builder Source)

Table 4. Horizontal plans of the ground & first floors of the residential school, Source: Researchers

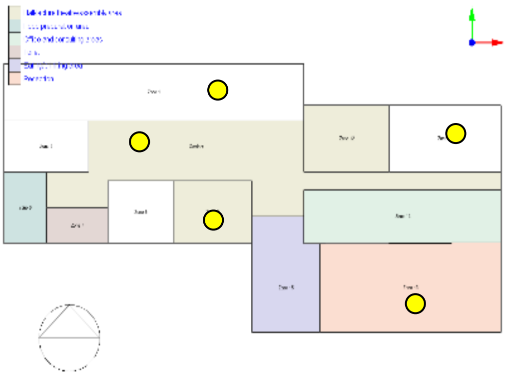
| First Floor plan<br>5-point measure | First Floor (Second Level) -Plan |
|---|---|
|  |  |

Table 5. Analytical study of the materials used for the basic construction of the building for the internal spaces on the ground floor and the first floor, the residential school, Source: Researchers

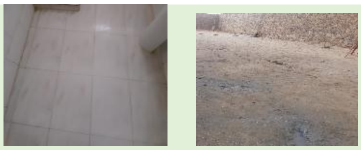
| Materials | Spaces | The material used inside the spaces | photo |
|---|---|---|---|
| Floor Materials | Entrance - ramps | The floors of the entrance space and the ramp are of marble type (Bocchino), and it is difficult to use with a wheelchair due to the ease of sliding. |  |
| | Corridors - rooms | -The floors of the corridors and rooms are made of mosaic tiles, size 30 * 30, and it is used on the first floors |  |
| | Bath – external spaces | -Soft ceramic tiles for bathrooms and kitchens, size 30 * 40<br>-The entire area of the garden is made of sand and has small and uneven stones |  |
| The opening materials | Windows –doors | - first floor, all windows, and doors are made of aluminium and single transparent single-glazing materials |  |
| Walls materials | Internal wall (paints) | -The interior walls of the first floor are painted with oil paints.<br>- The external walls surrounding the building are made of bricks, 25 cm thick, without painting. |  |

Table 6. Traditional External Walls & Roof (Base Case)

| Walls | Roof |
|---|---|
| **Brickwork Outer (25 cm)** | Ceramic tile (2 cm) |
| **Plaster (0.13 cm)** | Cement/Plaster/Mortar (2 cm) |
| | Sand and gravel (4 c m) -Bitumen (2 cm) |
| | Concrete, cast-dense (7 cm) |
| | Concrete, Reinforced (15 cm) |
| **Internal Partition** | Openings |
| **Brickwork Outer (12 cm) Plaster (0.13 cm)** | U-Value =5.77 W/m2-k |

Table 7. The materials used in the floors of the building's spaces for Base Case

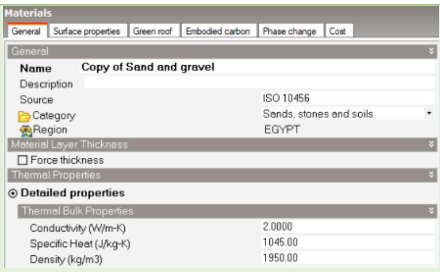
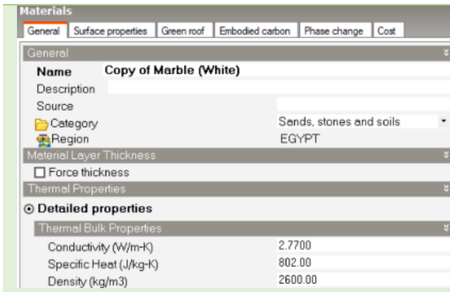
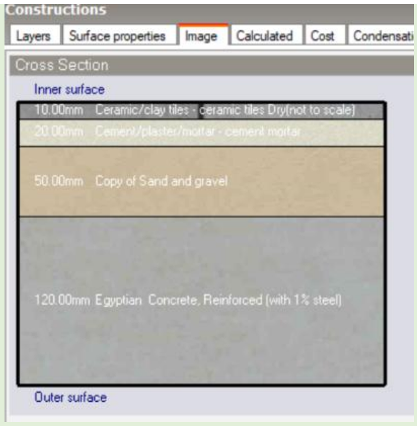
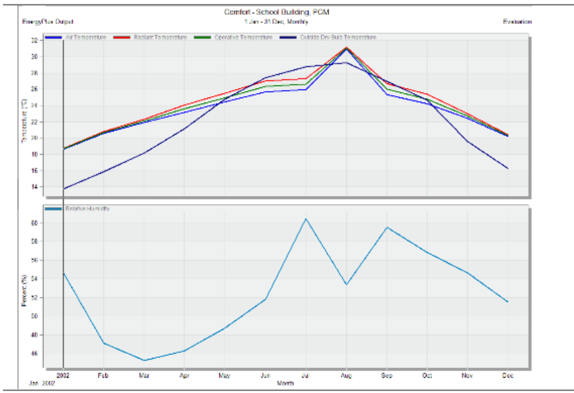
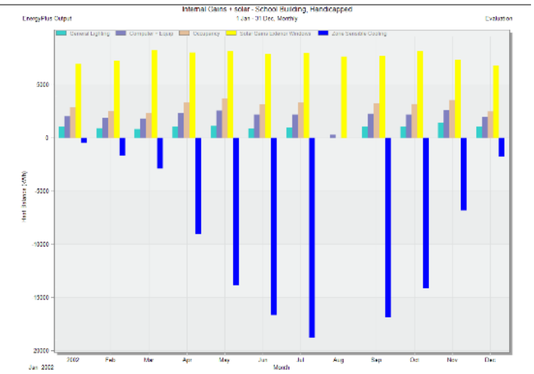
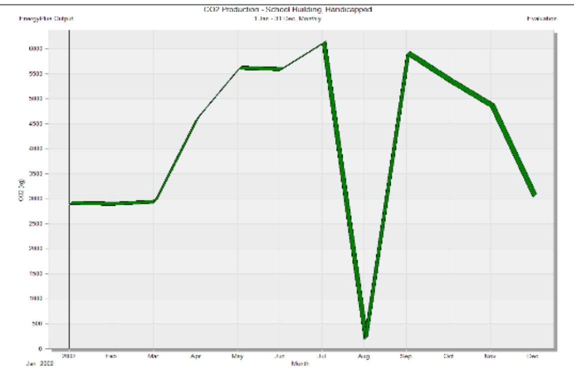
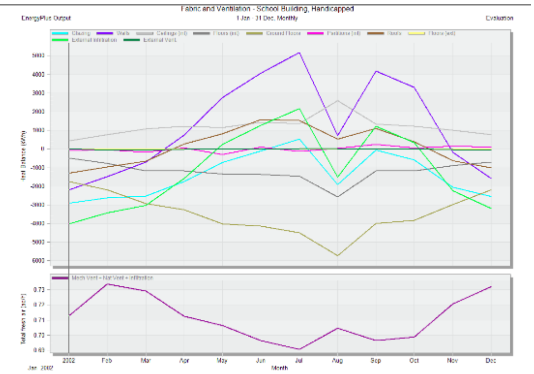
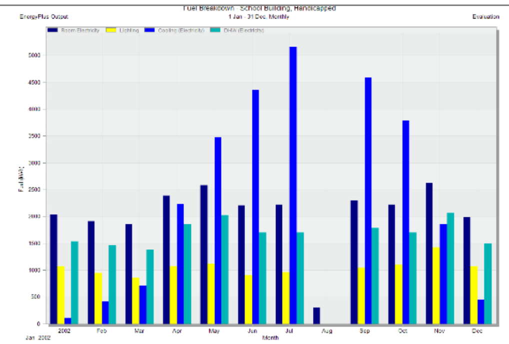
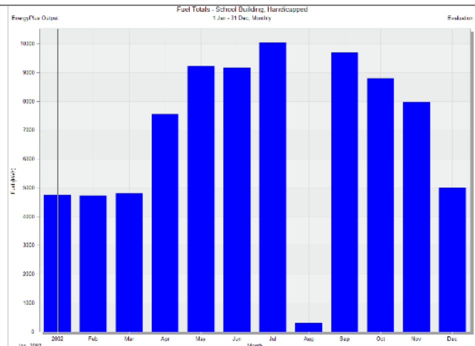
<table>
<tr><th></th><th>Sand</th><th></th><th>Marble</th></tr>
<tr><td>Garden</td><td>
</td><td>Ramp/ Entrance</td><td>
</td></tr>
<tr><td></td><td>Ceramic</td><td></td><td>Traditional plate</td></tr>
<tr><td>Bathroom</td><td>
</td><td>Corridor, Classroom</td><td>
</td></tr>
</table>

Table 8. The Results of the Simulation program analysis of the Base case of the building for thermal comfort: To quantify the degrees of thermal comfort and energy consumption values using the (design-builder) simulation program, five points are determined, as shown in Figure 4 (the horizontal floor-first plan).

| | | | |
|---|---|---|---|
| **Thermal Comfort** **(Monthly results of Building Thermal Comfort range)** |  Analysis for Thermal Comfort Range: (**Highest values achieved).** Operative air temperature: 31.7 $^{0}$C Relative Humidity: 60.46% Fanger PPD: 81.63%, Fanger PMV: +2.87 | **Internal Gain** **(Monthly results of Building Energy consumption (kWh))** |  Analysis for Internal Gain (Highest / Annual Average values achieved). Solar Gains Exterior Windows: 7691 kWh Zone Sensible Cooling: 8571 kWh |
| **$Co_2$ Emissions** **(Monthly results of Building CO2 emission)** |  Analysis for $CO_2$ Emissions: Average Annual achieved: 4141 kg | **Fabric and Ventilation** **(Floor, Ceilings, Floors, Roofs, & Natural Ven )** |  Analysis for Fabric and Ventilation Annual Average: Glazing: 1527 (kWh), Walls: 2257 (kWh) Ceilings: 1193 (kWh), floors: 1192 (kWh) Roof: 901 (kWh) |
| **Fuel breaks down** |  Analysis for Fuel break down: Heating: 15.7 (kWh), Cooling: 2262 (kWh) Lighting: 962 (kWh) | **Fuel Totals** **Electricity** |  Analysis for Fuel Totals: Annual Electricity: 6834 (kWh) |

## 5. a comparison of the innovative materials and systems that have been suggested for optimization to building-components elements:

We use comparative analysis to identify the best systems and materials, apply them to residential school buildings, test and measure them using a simulation program (design-builder), and then analyze the results to determine the materials' best thermal transfer absorption coefficient (U-value), thermal comfort, and consumption of energy.

### *5.1. Comparison Results on openings (U-VALUE)*

The results showed that the best heat transfer coefficient result is for double glazing, where the u value is 0.47w/m2-k, and the worst is the heat transfer coefficient result for stained glazing, where the u value is 5.2 w/m2-k, as shown in figure 5

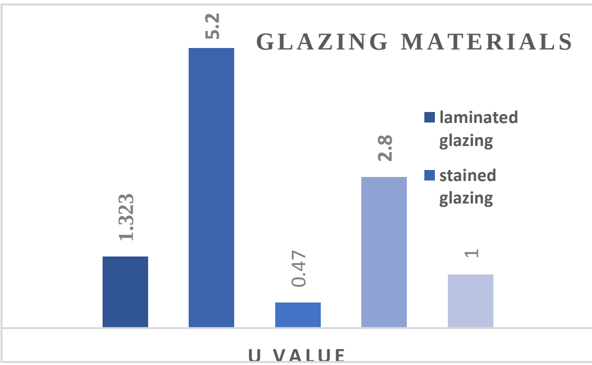



Fig.5 shows the results of the Thermal Transmittance (U value) for glazing materials, source: Researcher

### *5.2. Comparison Results on Exterior Wall (U-VALUE)*

The results showed that the best heat transfer coefficient result is for a Double wall, where the u value is 0.29 w/m2-k, and the worst is the heat transfer coefficient result for a traditional wall, where the u value is 1.92 w/m2-k, as shown in figure 6.

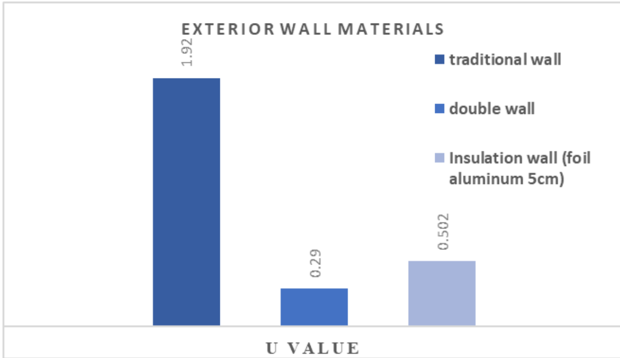



Fig.6 shows the results of the Thermal Transmittance (U value) for Exterior wall materials

### *5.3. Comparison Results on the Ceiling (Roof) (U-VALUE)*

The results showed that the best heat transfer coefficient result is for a Green Roof, where the u value is 0.370w/m2-k, and the worst is the heat transfer coefficient result for a Roof Insulation, where the u value is 0.65w/m2-k, as shown in figure7

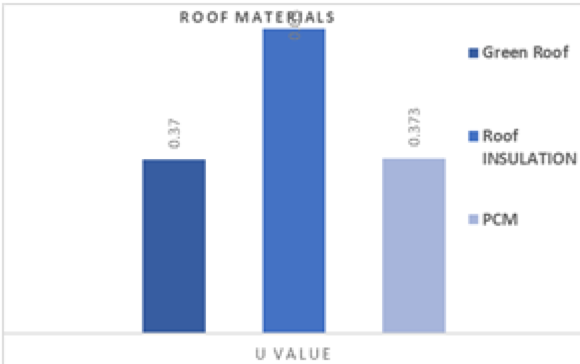



Fig.7 shows the results of the Thermal Transmittance (U value) for the Ceiling (Roof material).

### *5.4. comparison Results on Floor & wall paints* Materials *(U-VALUE)*

The results showed that the best heat transfer coefficient result is for epoxy floors, where the u value is 0.25 w/m2-k, and the lowest is the heat transfer coefficient result for marble, where the u value is 1.23 w/m2-k, as shown in Figure 8.

The results showed that the best heat transfer coefficient result is for epoxy floors, where the u value is 0.25 w/m2-k, and the lowest is the heat transfer coefficient result for marble, where the u value is 1.23 w/m2-k, as shown in Figure 9.

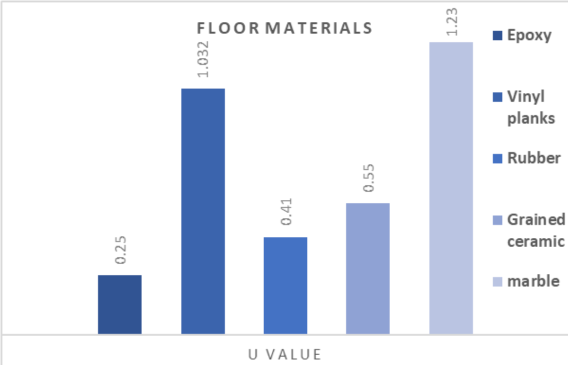



Fig.8 shows the results of the Thermal Transmittance (U value) for the floor material, source: Researcher

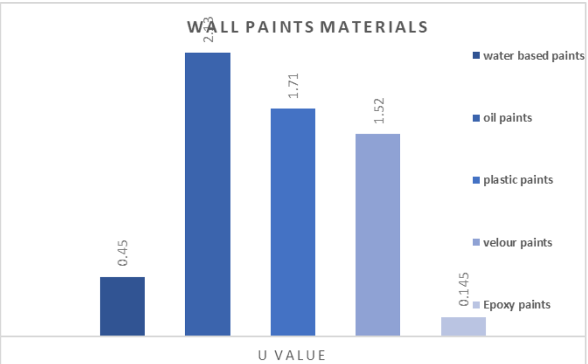



Fig.9 shows the results of the Thermal Transmittance (U value) for the wall paints material, source: Researcher.

## 6. Second step: The Optimization Step:

Practical implementation of the results of the materials for the building elements' components that yield the best (U value) was chosen through comparative analysis, and the next phase will be tested using a design simulation program, (DESIGN BUILDER). by replacing the existing base case building materials (which were previously analyzed and their results recorded) with innovative materials

Input the new material data into the simulation software to obtain optimal thermal comfort measurement results and electrical energy consumption rate.

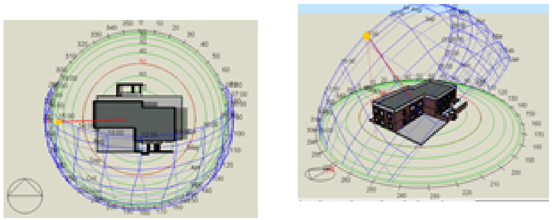
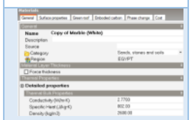
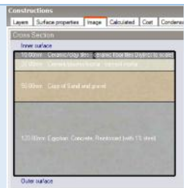


Fig 10. Sun Path View of the building (Design Builder Source)

Table 9. Optimized Materials in the floors of the building's spaces for optimization process (proposal from the questionnaire)

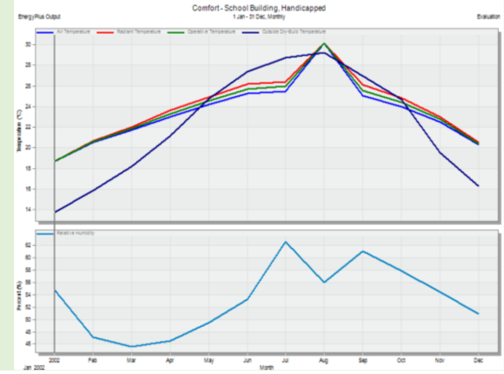
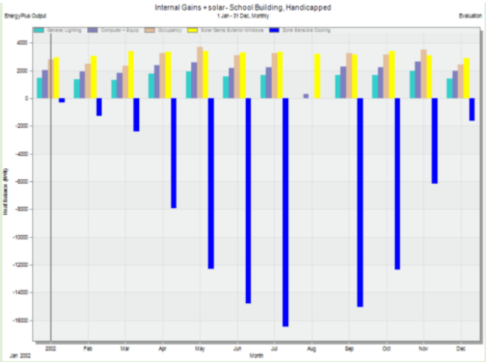
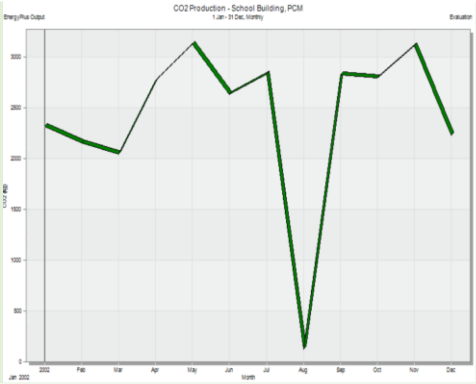
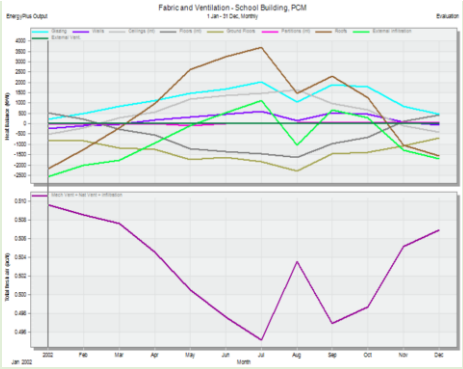
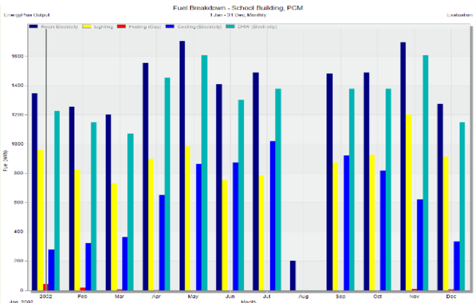
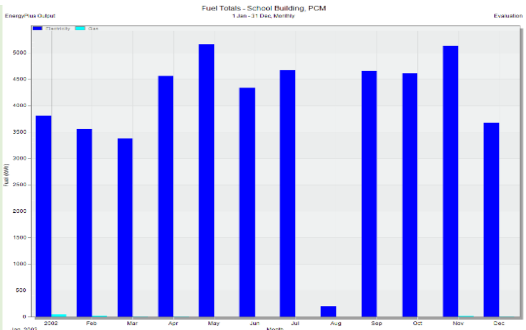
| Epoxy | | | Steel |
|---|---|---|---|
| ***Corridor /External*** |  | **Ramp** |  |
| ***Coarse-grained Ceramics*** | | | **Vinyl plank** |
| ***Bathroom*** |  | **Entrance Lobby** |  |

It is noticed during the analytical reading that there are sharp changes in the measurements of the results for the month of August, and the research shows that the building is empty of occupants in this month of each year because of no occupancy, they are on annual Spaces.

Table 10. Input parameters of Design-Builder simulation tools

| Element | | Data |
|---|---|---|
| **Activities** | **Occupancy pattern** | • 1.12 person/m² on normal school days<br>• For June and July, in summer courses, the occupancy rate is about<br>0.5person/m²<br>• Considering the one day-simulation 22nd of June: the real occupancy pattern was 0.35 person/m |
| | **Working time** | • Sunday to Thursday day, between 7:30 am - 3:0 pm<br>• For June and July, in summer courses, the residential school days are from 10:00 am until 1:00 pm<br>• For the day- simulation whole month of the year, the school day started from 10:00 am until 1:00 pm |
| | **Annual Vacation** | August |
| | **Metabolic rate** | 0.75 |
| | **Clothing** | 0.3 clo. |
| **HVAC template** | **Cooling Systems** | Split Unit + Natural Ventilation (Mixed Mode Ventilation) |
| **Constructions** | **External Wall** | |
| | **Model Infiltrations** | 0.700 (ac/h) |
| **Openings** | **External window** | Single glazing window |
| | **Layout** | Preferred height 1.5 m, 40% glazed |
| **Lighting** | **LED with Linear control** | Suspended Luminaire type |

Table 11. The Results of the Simulation program analysis of the optimization process for thermal comfort of the building (Floor-wall-glazing-ceiling) materials, source: design builder program

| | | | |
|---|---|---|---|
| **Thermal Comfort**<br>**(Monthly results of Building Thermal Comfort range)** | <br><br>Analysis for Thermal Comfort Range:<br>Highest values achieved.<br>Operative air temperature: 26.1 $^{0}$C<br>Relative Humidity: 65.46%<br>Fanger PPD: 55,2%, Fanger PMV: +1.23 | Internal Gain<br>(Monthly results of Building Energy consumption (kWh)) | <br><br>Analysis for Internal Gain:<br>Highest / Annual Average values achieved.<br>Solar Gains Exterior Windows 569.2 kWh<br>Zone Sensible Cooling: 6429 kWh |
| **$Co_2$ Emissions**<br>**(Monthly results of Building CO2 emission)** | <br><br>Analysis for $CO_2$ Emissions:<br>Average Annual achieved: 2025 kg | Fabric and Ventilation<br>(Floor, Ceilings, Floors, Roofs, & Natural Ven ) | <br><br>Analysis for Fabric and Ventilation Annual Average:<br>Glazing: 946 (kW), Walls: 165 (kWh)<br>Ceilings: 760 (kW), Floors: 456.4 (kW)<br>Roof: 455 (kW) |
| **Fuel breaks down** | <br><br>Analysis for Fuel break down:<br>Heating: 3.7 (kWh)<br>Cooling: 433.26 (kWh), Lighting: 718.8 | Fuel Totals<br>Electricity | <br><br>Analysis for Fuel Totals:<br>Electricity: 2690 (kWh) |

### *6.1. Third step: The stage of comparisons between the base case building & the optimization building:*

Comparison of the results achieved by the materials in their ability to create good ventilation and reduce the consumption of electrical energy and their impact on the quality of the internal space (for five months of summer), A comparison between the effect of all materials on the space before and after Optimization for fabric and ventilation.

Table 12. Fabric and Ventilation Chart for the Base Case

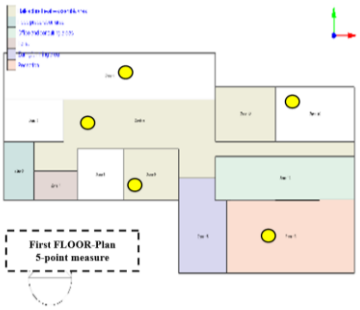
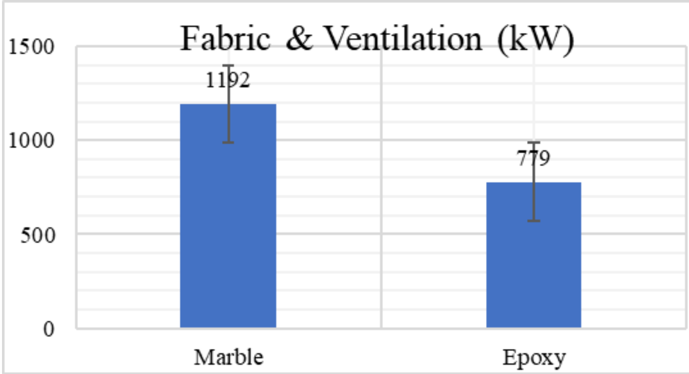
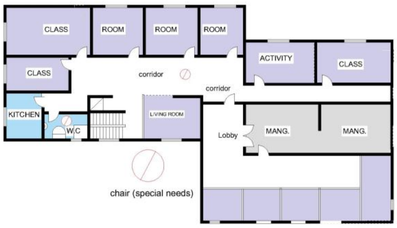
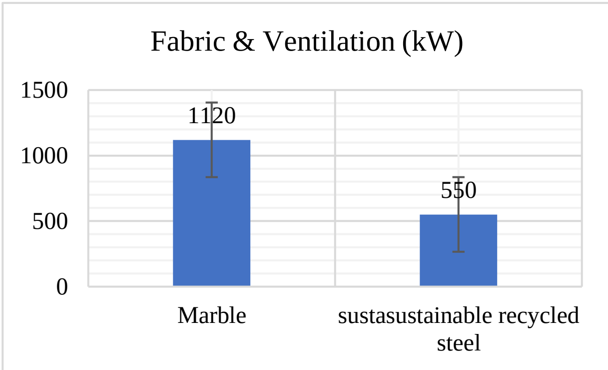
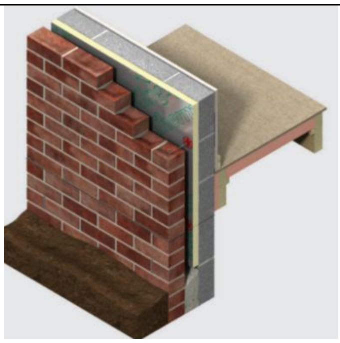
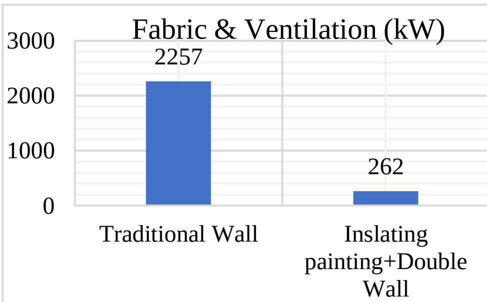
| | Glazing kWh | Walls kWh | Ceilings (int) kWh | Floors (int) kWh | Ground Floors kWh | Partitions (int) kWh | Roofs kWh | Mech Vent + Nat Vent +Infiltration ac/h | External Infiltration kWh |
|---|---|---|---|---|---|---|---|---|---|
| **June** | 1682 | 444.7 | 1359.4 | 1358.4 | 1640.1 | 13.6 | 3256.1 | 0.4 | 522.5 |
| **July** | 2038 | 586.0 | 1470.5 | 1471.8 | 1843.1 | 14.28 | 3709.5 | 0.4 | 1106.5 |
| **August** | 1919.1 | 717.6 | 2596.5 | 2573.7 | 5717.0 | 31.6 | 540.6 | 0.7 | 1502.4 |
| **September** | 55.01 | 4175.4 | 1341.4 | 1179.9 | 4001.2 | 239.9 | 1104.4 | 0.6 | 1209.2 |
| **October** | 582.15 | 3304.9 | 1216.5 | 1173.2 | 3836.4 | 55.0 | 377.2 | 0.6 | 338.2 |

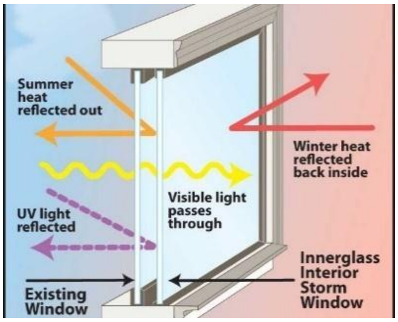
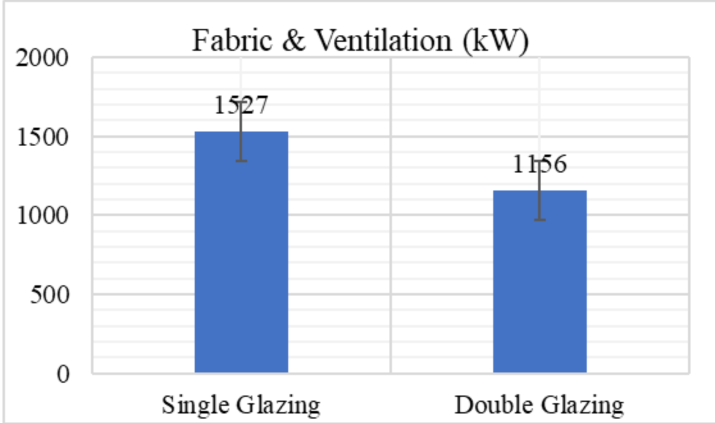
Table 13. Fabric and Ventilation Chart for the Optimization process

| | Glazing kWh | Walls kWh | Ceilings (int) kWh | Floors (int) kWh | Ground Floors kWh | Partitions (int) kWh | Roofs kWh | Mech Vent + Nat Vent +Infiltration ac/h | External Infiltration kWh |
|---|---|---|---|---|---|---|---|---|---|
| **June** | 1682.0 | 444.7 | 1359.4 | 1358.4 | 1640.1 | 13.6 | 3256.1 | 0.49 | 522.5 |
| **July** | 2038.0 | 586.0 | 1470.5 | 1471.8 | 1843.1 | 14.2 | 3709.5 | 0.49 | 1106.5 |
| **August** | 1047.6 | 155.7 | 1640.4 | 1638.5 | 2292.2 | 20.4 | 1466.8 | 0.50 | 1042.1 |
| **September** | 1880.3 | 512.6 | 972.2 | 967.1 | 1457.9 | 58.6 | 2291.9 | 0.49 | 654.5 |
| **October** | 1792.1 | 448.9 | 661.1 | 659.0 | 1405.6 | 20.0 | 1256.8 | 0.49 | 271.8 |

- Comparison of the Results achieved by the materials, in this part, we review a comparison between the results of the materials before and after the Optimization process (each material separately).

Table 14. A comparison between the effect of all materials on the space before and after Optimization

| Corridor & Rooms & classes | | |
|---|---|---|
| | Marble | Epoxy |
| Base case and after optimization | Marble=1192 kWh | Epoxy= 779 kWh |
|   |   | |
| Ramp & Rooms | | |
|   | Marble=1120 KW | sustainable recycled steel= 550 KW |
| |   | |
| External Wall | | |
|  | Traditional Wall<br>= 2257 kw | Insulating painting<br>= 262 kw |
| |   | |
| Double Glazing-6mm/12mm | | |

<table>
<tr>
<td>Single glazing= 1527 kw<br>Double glazing = 1156 kw<br>
</td>
<td>
</td>
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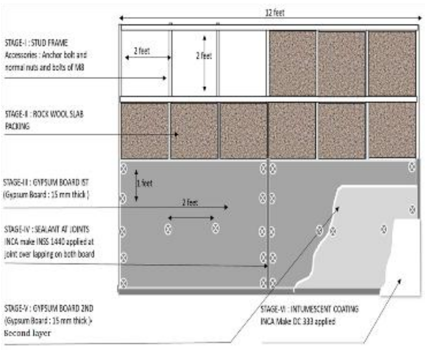
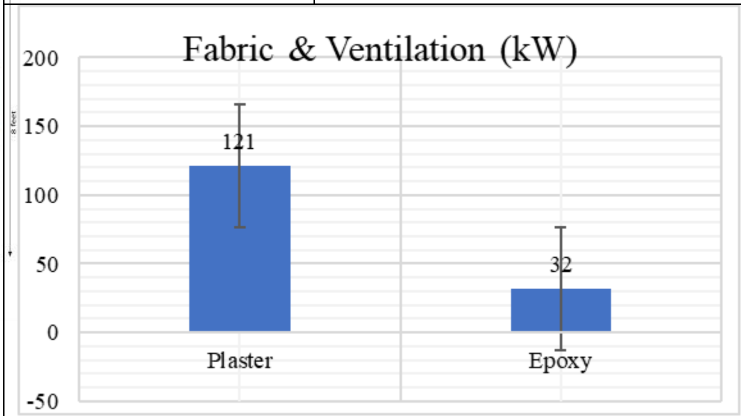
<tr>
<td>Internal Partition<br></td>
<td>Oil paints=121kw | Epoxy=32kw<br>
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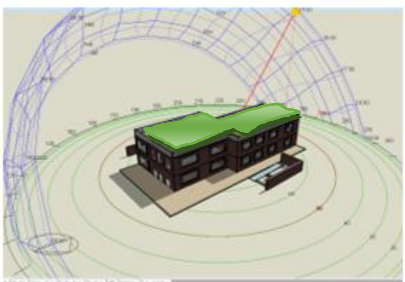
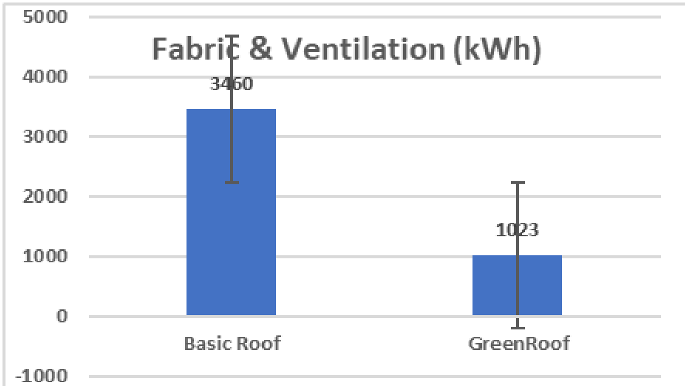
<td></td>
<td>
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### *6.2. comparison of simulation program Results, Base case, and optimization in July month*

One of the months of the year was chosen to compare the results during it, the month of July was chosen when the weather temperature reaches its maximum height, the thermal comfort value of the external and internal spaces reaches its lowest level in July month, before and after optimization

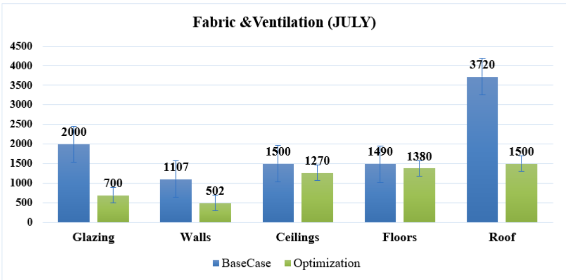


Fig 11. Comparison of fabric and ventilation degrees in July month, before and after optimization

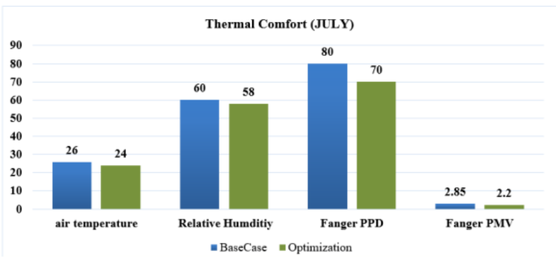


Fig 12. Comparison of thermal comfort degrees, temperature, and humidity, before and after optimization in July month

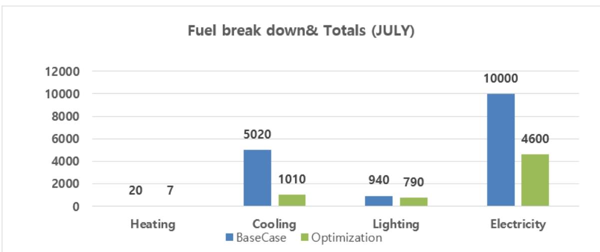


Fig 13. Comparison of fuel breakdown degrees, before and after optimization in July month

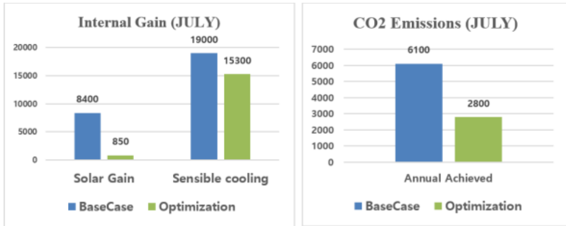


Fig 14. Comparison of internal gain (solar gain & sensible cooling) degrees, co2 emissions (annual achieved), before and after optimization in July month

## 7. Result and Discussions

### *7.1. Thermal Comfort Results:*

Using a metric scale called the Expected Average Value (PMV), it determines the level of thermal comfort for a specific indoor space, the PMV measurement value for areas with satisfactory thermal comfort ranges between 1 to -1, according to the Egyptian Energy Code, from the **Base Case** simulation results for the average months of the year, it was shown, Table 8 that the Air temperature index was 31.7□c, the Relative humidity 60.46%, the thermal comfort **2.87**, Fanger PPD 81.63%, while the simulation results, after performing the **optimization process** for the Air temperature index, were 26.1□C, relative humidity 65.46%, Thermal comfort temperature **1.23**, PPD 55.2%, as shown in Table 10, and the simulation results express a clear optimization in the thermal comfort index.

### *7.2. Internal Gain Results:*

Internal gains including equipment, lighting, occupancy, solar heating/cooling delivery, and air conditioning, the simulation results through the HVAC system showed a clear positive effect when optimization processes were performed, as the solar gain exterior windows decreased from **7691 kW** before the optimization to **569.2 kW** after the optimization, as shown table 11.

### *7.3. Fuel Total Results:*

Fuel consumption is directly proportional to electricity consumption. Table 8 shows that the average electricity consumption for a building decreased from **6834 kW** Base case before the optimization to **2690 kW** after the optimization process as shown in Table 11.

### 7.4. CO2 Emissions Results:

Performs a carbon dioxide analysis, based on the building's fuel consumption for mixed ventilation (natural and mechanical) and other activities such as lights and computers. Table 8,11 shows that the average value of emissions for a building decreased from **4141 kg** before the improvement to **2025 kg** after the Optimization.

Table 15. Summary of the research study for the Sustainable Building (base case & optimization process), Source: Researchers

| Results of the simulation | the Base Case simulation results | After optimization process |
|---|---|---|
| **Thermal Comfort Results:** | 2.87 | 1.23 |
| **Internal Gain Results:** | 7691kw | 569.2 kW |
| **Fuel Total Results** | 6834 kW | 2690 kW |
| **Co2 Emissions Results** | 4141 kg | 2025 kg |

## 8. conclusions

Through the research, the following results were reached:

A significant Optimization in the thermal comfort PMV values of the building's spaces after replacing the Base Case innovative materials with Optimized materials with good specifications.

The goal of the research was achieved by raising the efficiency of the internal spaces of the building through the use of high-quality materials for advanced flooring, walls, and openings, ceiling.

The possibility of reducing electrical energy consumption by optimized innovative materials.

The rate of optimization in the comfort and temperature of the building after the development process

Table 16. Shows the Degree of Optimization in the building before and after development and the degree of energy savings on the building, Source: Researchers

| *Items* | **Energy Efficiency Ratios** |
|---|---|
| ***Thermal Comfort Results*** | 57.1% |
| ***Internal Gain Results*** | 92.9% |
| ***Fuel Total Results*** | 60.6% |
| ***Co2 Emissions Results*** | 51.1% |

- When making decisions for materials in the spaces of buildings, a good choice that achieves good thermal comfort and reduces electrical energy consumption should be taken.

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