# Impact of Outer Shell Design on peformance of Educational Buildings.pdf

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| WORD COUNT | 5789 | TIME SUBMITTED | 24-MAY-2019 01:50AM |
| | | PAPER ID | 47318775 |

## Impact of Outer Shell Design on Energy Performance of Educational Buildings

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**Abstract:** Sustainability has become a dominant theme in the debate on architecture and building in the last decade. 50% of the total global electric energy consumed by buildings with their different functions. Buildings as they are designed and used today, contribute to serious environmental problem because of their excessive consumption of energy and other natural resources. The is a close connection between energy and buildings. Buildings demands for heating, cooling, ventilation, and lighting cause sever depletion of invaluable environmental resources.
The research aims to investigate the green retrofit aspects of existing educational buildings within Mediterranean climate area as part of sustainable buildings approach. To achieve its objectives, the research follows a comparative analytical approach through investigating the important strategies that achieve sustainability, environmental efficiency. Through the study regional models that have applied sustainability retrofit strategies and maintaining the use of natural resources in deign to conserve energy consumption were analysed and discussed. Retrofitting a private university existing building in Cairo of Egypt was investigated as applied case study. A thermal model was built using Design Builder to investigate the building thermal performance. Through the model, impact of different building material strategies, alternatives and modifications of outer shell were tested and analysed. Both economic and technical aspects in improving the overall performance of the building and its energy consumption were studied. The research concluded with the best suggestions alternative for green retrofitting of existing buildings through modifying its outer shell to reduce its energy consumption as part of achieving more sustainable and environmental friendly building stock.

**Key words:** Environmental Design, Educational Buildings, Energy efficiency, Building materials.

### Research Problem and Questions:

The research is directed to answer the following questions; (i) What are sustainable strategies for retrofit existing buildings? (ii) How far thermal performance of existing buildings can be improved through architectural renovation? (iii) how far outer shell enhancement can contribute to existing buildings thermal performance?

### Aim and Objectives:

This paper aims to explore the potentials of retrofit of existing educational buildings in cities within Mediterranean climate area, in terms of improving their energy consumption through enhancing their outer-shell. This is achieved through a combination of objectives includes; (i) Explore sustainable approaches to improve existing buildings. (ii) Study the impact of buildings outer-shell on their thermal performance. (iii) Identify walls local materials thermal characteristics. (iv) Investigate the feasibility of enhancing existing buildings thermal performance through architectural retrofitting.

### Methodological Approach:

The methodology is based on three different approaches; theoretical, analytical and applied approach. (i) Through the theoretical study, identification of concepts and strategies to achieve to sustainability through retrofit of existing buildings. (ii) This is followed by an analytical study of benchmark case studies of retrofitted existing buildings to evaluate the applied strategies in achieving sustainable educational buildings. (iii) Testing the concluded results on one case study building at El-Sherouk University in Cairo, Egypt. This is done through analysing building existing energy consumption, internal environment control system, outer-shell materials and their thermal characteristics. Manipulating outer-shell materials as one of these factors affecting thermal performance to test its impact on reducing energy consumption. Defining the most feasible retrofit approaches, both environmentally and economically to enhance its thermal performance of existing educational buildings. The study concludes with the recommended outer-shell retrofit for existing educational buildings in Egypt that would reduce the energy consumption and improve thermal performance as part of building sustainability approach.

**Theoretical Framework:**

***Global efforts on green retrofit:*** Almost half of the produced energy worldwide is consumed by residential, commercial, and public service buildings. Commercial and public-sector buildings alone consume up to 23 % of the total produced energy worldwide. (World Energy Council, 2016). Most of this energy is consumed by existing buildings. Annual replacement rate of existing buildings by the new-build is only around 3.0% (El-Darwish2017). In the 2030 challenge, the American Institute of Architects (AIA) along with U.S. Green Building Council advocated that new construction of residential and commercial buildings should use half the fossil fuel of average existing buildings and a gradual increase in performance of the existing buildings so that by 2030 new buildings are carbon-neutral. Meanwhile, achieving the gradual increase in energy performance of existing residential buildings would require leading-edge energy retrofits. (Oluwafemi, 2016). Therefore, rapid enhancement of energy efficiency in existing buildings is essential for a fast reduction in global energy use and promotion of environmental sustainability. Therefore, sustainable retrofit was subject for thoroughly investigations by researchers to improve existing buildings thermal performance. Bin et al., indicated that energy performance of existing buildings can be improved significantly through sustainable retrofit. (Bin, 2012) Moreover, Flourentzou also argued that significant reduction in energy use of existing buildings can be achieved through proper retrofit. He also defined renovation as the work that require upgrading an existing old building and renovate its systems. (Flourentzou and Roulet, 2002)

***Sustainable retrofit:*** Sustainable retrofits involve the renovation of an existing buildings to enhance its environmental performance, reduce water use, and improve the comfort and quality of its internal environment. This could be achieved through either simple treatment like replacing old heating or air-cooling old parts, or sophisticated like adding new photovoltaic system to the roof. (Ma et al., 2012). Several approaches and strategies were developed through the last decades for a successful green retrofit. (Dascalaki et al. 2011) argued that building typology can be adopted as an indicator of energy performance of buildings. This can be utilized in initial energy performance assessment. Caccavelli and Gugerli presented a decision-support tool that, contains a diagnostic package to evaluate the general state of office buildings in terms of deterioration, energy consumption and indoor environmental quality. (Caccavelli 2002)

***Building performance assessment:*** Richalet suggested three approaches to evaluating building energy performance, including:

- Computational-based approach relying on data collected through energy audits.
- Performance-based approach where input data comes from building utility bills.
- Measurement-based approach with in situ measurement procedures. (Richalet et al., 2011)

For certain building, the proper performance assessment technique should consider user requirements, accurate energy consumption, main retrofit scope, etc. Reliable estimation of energy consumption enhancements is essential for any sustainable retrofit decision-support system. Performance of different retrofit measures is commonly evaluated through energy simulation and modelling packages. There are a number of these packages, such as Energy-Plus, e-QUEST, etc., that is used to simulate the thermodynamic characteristics and thermal performance of different retrofit alternatives.

***Sustainable Retrofit Phases:*** Sustainable building retrofit is to determine and implement the most cost-effective technologies to enhance energy performance while maintaining indoor thermal comfort, under a given set of operating constraints. The overall process of a building retrofit can be divided into the following five phases

- Project setup, data gathering and pre-renovation survey.
- Energy audit and performance assessment.
- Identification of retrofit options. This can be achieved through using energy simulation model, economic analysis and risk assessment tools.
- Retrofit plan implementation.
- Audit and verification of energy savings.

***Building envelope in focus of retrofit study:*** Building envelope includes roof, walls including windows, and foundations. Air leakage considered as one of the primary elements that affect building HVAC loads. Air-conditioning systems consume one-third of the global energy used in public buildings. Good building envelopes are the key element for any energy consumption reduction plans. Building envelope is critical in determining the energy required to heat and cool a building. Building envelope design needs to be optimized to minimize heating and cooling loads as a critical part of any long-term energy reduction strategy.

- Passive heating and cooling technologies are important design considerations. In hot climates, low-cost solutions, such as reflective roofs and walls, low-emissivity (low-e) window coatings and films, and exterior shades, can curtail expected sharp increases in cooling loads. In cold climates, passive heating contributions can be increased with improved building design and from windows with dynamic solar control.
- Integrated facade systems need to be pursued for office buildings to optimize performance of day lighting while minimizing heating and cooling, artificial light and peak loading.
- Greater focus on air sealing with validated results is critical during new construction and is also important for deep envelope retrofits.

***Envelope Components and their impact on energy consumption:*** Energy losses through different building envelope components vary significantly based on building type, configuration, climate, vintage, level of construction sophistication, etc. Several studies illustrate that roofing representing 14% of heating and cooling loads in the United States while in European the percentage is about 32%. As for windows, the United States heating and cooling impact represents 31%, while Europe showing 15% (Winbuild, 2012 and SEI, 2007). Building materials with different properties respond differently to climatic conditions. The thermal properties of building outer shell such as types of walls, curtain walls and roofs dictate building's energy consumption and comfort conditions of its users. (Soofia 2006 and Liu, 2008)

**Analysed Case Studies:**

***Case study 1: Improvement of the sustainability of existing school buildings, Italy:*** This project aimed to verify in the field, and in actual buildings, the technical and economic feasibility of sustainable retrofitting of existing school buildings to improve its energy efficiency and sustainability to match the international protocols. Trough the study an economic evaluation was conducted considering cost of retrofits main items. Cost items were considered in the economic evaluation compromises; building envelope retrofit, heating systems upgrade, ventilation systems, solar PV, water efficiency cost. All costs were then proportioned according to the gross floor area and expressed in (€/m2).

***Study lessons:*** It is important to strategic vision regarding, having comfort educational buildings with a high indoor air quality will contributes to improving the learning environment. The economic issue will always have a greater value when operating inside the public market. The real estate market can apply greater value to more sustainable building. The availability of a standard like LEED®, which has an international matrix, is a good thing taking into account the consistency between rules contained in LEED® and Local Building Codes. (Giuliano, et al, 2013)

***Case study 2: Retrofitting existing university campus buildings:*** This study was part of the efforts of turning the University of Applied Sciences Stuttgart (UAS) into a CO2 neutral university and implement key principles of sustainability. Air conditioning and lighting systems was examined and compared with other available alternatives. Following a detailed performance analysis, the best applicable options were identified and the study concluded with following lessons:

- Retrofitting measurements combined with continuous monitoring are essential to sustain a high energy efficiency and comfort level.
- User awareness or automated systems help saving energy.
- Using effective evaporative cooling system could save up to 60% of required energy and GHG. (DILAY, 2016)

***Case Study 3: Energy and sustainable strategies in the renovation of existing buildings: An Italian case study:*** The project investigates the rehabilitation of the former San Salvatore hospital in L'Aquila and illustrates how best-practice strategies can be implemented in the rehabilitation of an existing building. The project considered two different approaches; firstly, the adaptive re-use of existing building with great impact in the urban core of the city; secondly, the implementation of green retrofit strategies when upgrading the building envelope and its systems. The most leaned lessons through the project are:

- A comprehensive functional and performance behavior of building elements can be achieved through comprehensive analyses of thermographic, thermo-hygrometric and heat-flux analysis.
- Most effective solution is to investigate the available alternatives. Invent the best technical-executive procedure that suit existing building context and its specific features.
- Climatic analysis within the retrofit conceptual phase is essential to support strategic decisions regarding upgrading and improving environmental comfort.
- Technological innovation facilitates contemporary living requirements without compromising architectural values of existing traditional buildings. (Pierluigi et al., 2016)

**Analytical study: Retrofitting Egyptian Education Building:**

***Location and climatic context:*** University building located in Cairo city. The weather summary of the region shown Table 1 have the following climatic information of the case study location, latitude/longitude, radiation (direct/diffuse), dry bulb temp, relative humidity, wind direction, and wind speed. From Table a, it can be found that max wind speed is 4 meters during April and March with 30 to 50 degrees direction. From the table, it can be noticed that maximum average monthly temperature is 26 degrees in August while the minimum is 16 degrees in February.

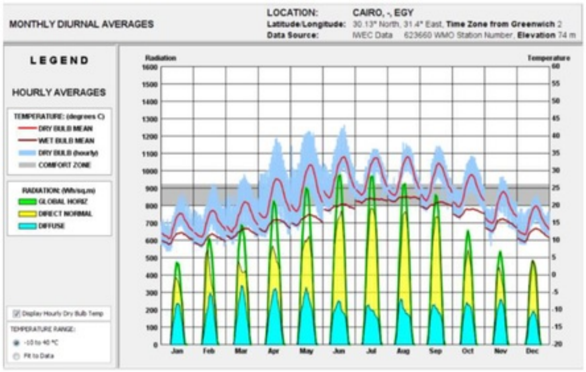
Table 1. Climatic analysis of Cairo region

WEATHER DATA SUMMARY

LOCATION: CAIRO, -, EGY
Latitude/Longitude: 30.13° North, 31.4° East, Time Zone from Greenwich 2
Data Source: IWEC Data 623660 WMO Station Number, Elevation 74 m

| MONTHLY MEANS | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Global Horiz Radiation (Avg Hourly) | 318 | 426 | 487 | 542 | 617 | 670 | 661 | 601 | 562 | 442 | 349 | 311 | Wh/sq.m |
| Direct Normal Radiation (Avg Hourly) | 304 | 392 | 393 | 437 | 497 | 593 | 597 | 524 | 525 | 390 | 309 | 361 | Wh/sq.m |
| Diffuse Radiation (Avg Hourly) | 166 | 200 | 230 | 222 | 229 | 194 | 181 | 187 | 178 | 185 | 182 | 137 | Wh/sq.m |
| Global Horiz Radiation (Max Hourly) | 707 | 842 | 932 | 1003 | 1029 | 1025 | 1007 | 987 | 930 | 839 | 646 | 611 | Wh/sq.m |
| Direct Normal Radiation (Max Hourly) | 932 | 954 | 935 | 957 | 938 | 899 | 896 | 884 | 867 | 874 | 843 | 891 | Wh/sq.m |
| Diffuse Radiation (Max Hourly) | 932 | 954 | 935 | 957 | 938 | 899 | 896 | 884 | 867 | 874 | 843 | 891 | Wh/sq.m |
| Global Horiz Radiation (Avg Daily Total) | 2926 | 3976 | 4908 | 6085 | 7014 | 7614 | 7452 | 6718 | 5989 | 4201 | 3283 | 2865 | Wh/sq.m |
| Direct Normal Radiation (Avg Daily Total) | 2853 | 3816 | 4045 | 4987 | 5696 | 6737 | 6712 | 5825 | 5565 | 3714 | 2961 | 3354 | Wh/sq.m |
| Diffuse Radiation (Avg Daily Total) | 1542 | 1890 | 2370 | 2531 | 2678 | 2316 | 2138 | 2158 | 1964 | 1825 | 1742 | 1288 | Wh/sq.m |
| Global Horiz Illumination (Avg Hourly) | 34607 | 46113 | 52979 | 58762 | 66892 | 73257 | 72879 | 66236 | 61551 | 48498 | 38098 | 33727 | lux |
| Direct Normal Illumination (Avg Hourly) | 28727 | 38012 | 38410 | 42998 | 48956 | 58560 | 58770 | 51297 | 50792 | 37729 | 29086 | 34012 | lux |
| Dry Bulb Temperature (Avg Monthly) | 14 | 14 | 16 | 21 | 24 | 28 | 28 | 28 | 26 | 23 | 19 | 15 | degrees C |
| Dew Point Temperature (Avg Monthly) | 7 | 6 | 8 | 9 | 10 | 14 | 18 | 19 | 17 | 14 | 11 | 8 | degrees C |
| Relative Humidity (Avg Monthly) | 68 | 60 | 61 | 48 | 44 | 48 | 58 | 62 | 58 | 59 | 63 | 66 | percent |
| Wind Direction (Monthly Mode) | 0 | 190 | 20 | 30 | 50 | 40 | 350 | 0 | 20 | 30 | 340 | 350 | degrees |
| Wind Speed (Avg Monthly) | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | m/s |
| Ground Temperature (Avg Monthly of 3 Depths) | 17 | 16 | 17 | 17 | 20 | 23 | 25 | 26 | 25 | 24 | 21 | 19 | degrees C |

Figure 1 illustrates Dry blub temp, radiation monthly relative to thermal comfort zone for Cairo region. It can be concluded form the chart in Figure 2 that Cairo whether is dominated by hot weather and humidity during the summer causing high thermal stress on individuals, while weather prevails warm in winter.



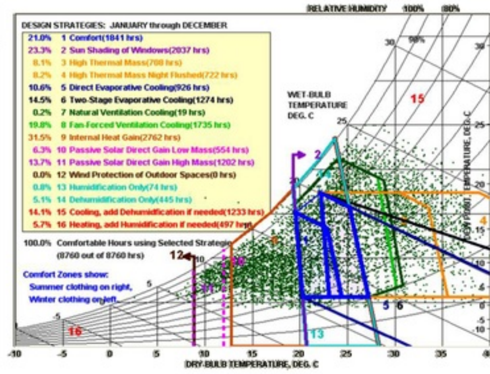




Figure 1. Dry blub temp, radiation monthly relative to thermal comfort zone.

Figure 2. Bio-climatic analysis for Cairo city

The introduced psychometric map of the area shown in Figure 21 developed as per ASHREA 55 - 2005. The bio-climatic analysis of this psychometric map shows buildings users requirements (cooling - heating - cooling evaporation - work window shading - ventilation - natural ventilation. etc) during the summer and winter in Cairo city.

***Case study Architecture Description:*** The case study of this paper is a four-storey educational building at a private university. Figures 3 and 4 shows the main floor plans, while Figure 5 illustrate the existing building and its surrounding. Figure 6 shows a 3D model of the study building. Figure 7 shows the air-conditioning system within the building where most of classrooms and offices are air conditioned using split units with no ventilation or fresh air. Only main spaces such as library and auditoriums have central HVAC system. Corridors are not conditioned at all.

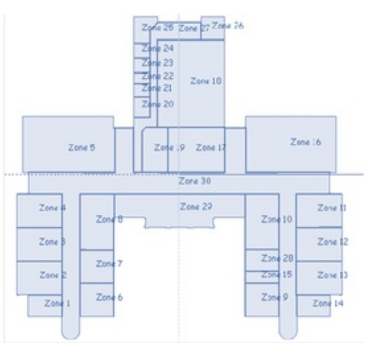



Figure 3. Ground floor plan

Figure 4. Third floor plan

Figure 5. Photo of main Building elevation

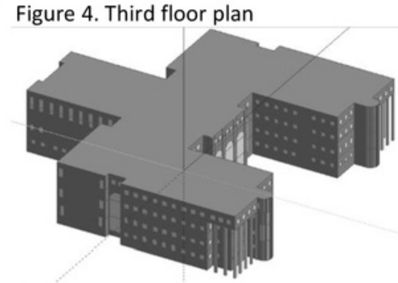


Figure 6. Perspective shot in front elevation

***Building envelop thermal properties:*** Existing building roof, walls and glass areas were defined, and their thermal properties were calculated. The flowing sections will investigate the alternatives for materials and their layers on the thermal performance and the possible reduction energy consumption.

***Outside walls characteristics:*** Walls are constructed of cement brick with a 2000 kg/m$^3$ density and a 2000 kg / m$^3$ mortar cement density. Total thermal resistance of wall layers is 0.398 m$^2$.c°/Watt. Figure 8 shows the wall construction layers while Table 2 presents the characteristics of external wall layers components.

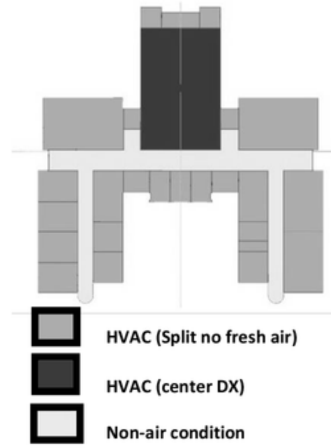



Figure 7. Space select for air condition, type of air condition and non-air conditioned

Table 2. Physical characteristics wall components

| Component | layer L (cm) | Conductivity K (Watt/m. c°) | Density P (kg/m$^3$) | Specific C (jol/kg.c°) | Resistance R (m$^2$. c°/Watt) |
|---|---|---|---|---|---|
| 1-Cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| 2-Solid Cement brick | 25 | 1.4 | 2000 | 840 | 0.178 |
| 3-cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| U-value | 2.51 (W/m$^2$.K) | | | | |
| R | 0.398 (m$^2$.K/ W) | | | | |

*Curtain walls*: 28% of the outer walls are glass areas and curtain walls. It is made up of system structural glazed which is a double-glazed with thermal transition of 6.12 W/m$^2$.c, with solar heat gain coefficient factor of 0.81 and visible transmission of 0.88. Table 4 shows the optical properties of the glass used in the case study building. Table 3 presents the thermal and optical properties of the used glass in the case study.

Table 3. Thermal and optical properties of the glass used in the case study.

| Type of glass | SHGC | U-value | VT |
|---|---|---|---|
| Single glass 6 mm | 0.81 | 6.12 | 0.88 |

*Note:*

- Thermal resistance for outdoor surface = 0.055 (m$^2$.K/ W)
- Thermal resistance for indoor surface = 0.123 (m$^2$.K/ W)

*Roof characteristics:* Roof is composed of six different layers the overall value of its thermal resistance is 2.083 m$^2$. c ° / Watt. Figure 8 illustrates a cross section in the roof layers and Table 4 presents a detailed characteristics of roof layers components.

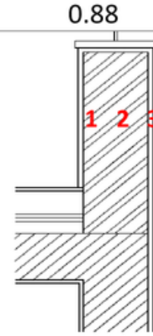



Figure 8. Cross section in the main wall.

Table 4. Physical characteristics roof components

| Component | layer L (cm) | Conductivity K (watt/m. c°) | Density P (kg/m³) | Specific C (jol/kg.c°) | Resistance R (m². c°/watt) |
|---|---|---|---|---|---|
| Gypsum Plastering | 2 | 0.4 | 1000 | 1000 | 0.05 |
| Reinforced concrete | 26 | 2.3 | 2300 | 1000 | 0.11 |
| Expanded polystyrene | 5 | 0.035 | 35 | 1400 | 1.42 |
| Preference Concrete | 7 | 0.72 | 1850 | 840 | 0.096 |
| Sand | 5 | 0.3 | 1500 | 800 | 0.167 |
| Cement tile & mortar | 5 | 1 | 1900 | 840 | 0.05 |
| U-value | 0.47(W/m².K) | | | | |
| R | 2.083(m².K/ W) | | | | |

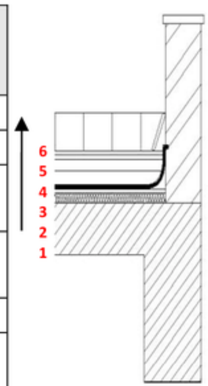



Figure 9. Cross section in the roof.

***Time schedule of building spaces operations:***

1. Weekly working hours of administrative rooms are running Sunday to Thursday between 9 am and 4 pm, and the whole building is off Fridays and Saturdays.
2. Set working hours for the Class rooms inside the building from 9 am to 4 pm during the day except the holidays (15 July -15 September). Setting set-point temperature for cooling and heating shown in Figure 10.

***Building cooling and heating monthly consumption:*** As shown in Figure 10, The study building consumes 440,670 Kwh every year; 84% of this consumption goes for cooling while the rest used in heating. The heating is required starting from December to February. Cooling is needed for seven months. This period extends between April and October. It can be noticed also that the maximum consumed energy recorded at June with 108,549 Kwh.

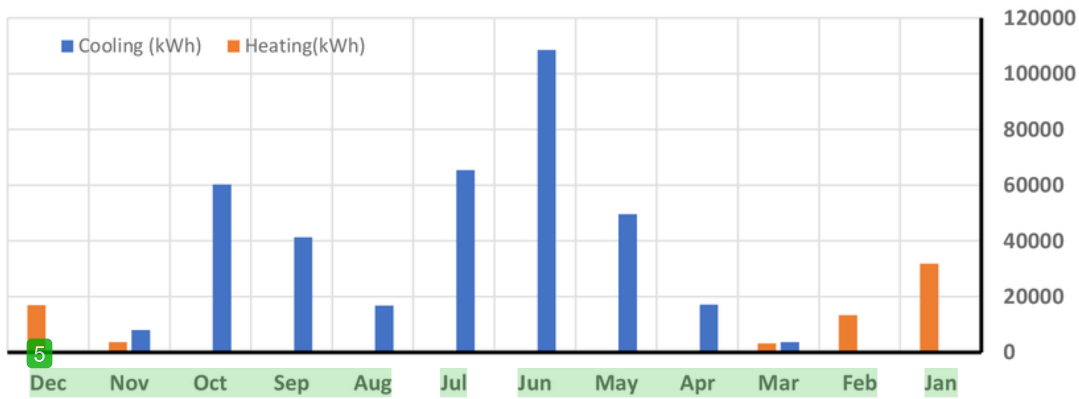



Figure 10. Monthly consumption for the base case.

***Bioclimatic Analyses:*** Thermal simulation package Design Builder was used to analyze how different outer shell materials, layers and construction perform under outdoor weather conditions. This tool can simulate the performance of the building using different climate conditions and different building indoor setup as well. In this study, all sources of internal casual gains were ignored for running the simulation. Accordingly, no occupants or appliance were considered in the model as a source of internal heat gains. This approach was to make a clear evaluation of the impact of the building's materials and their construction on the building thermal performance.

**Discussion: Assessment of the Improvement Levels Predicted to Be Achieved:**

Simulation Model input data includes climate data, envelope components, materials of these components and the thermal characteristics of each of these materials, working schedule and set point temperature. Entry data were analyzed, and energy consumption was estimated. Calculated consumption was compared to collected data from building bills. The annual consumption of electric power, as well as monthly consumption shown in Table 5, and Figure 17.

***Impact of applying different types of wall bricks:*** Different type of bricks were tested to replace existing one (base sample). Four different types of bricks were tested. The used thermal conductivity of each type is shown in Table 5. Figure 11 shows the cross section of the proposed outer wall layers. The impact of four types of bricks on the energy consumption was tested.

Table 5. Physical characteristics different types of bricks.

| Brick type | layer L (cm) | Conductivity K (watt/m. c°) | Density P (kg/m$^3$) | Specific C (jol/kg.c°) | Resistance R (m$^2$. c°/watt) |
|---|---|---|---|---|---|
| 1- Solid Cement brick | 25 | 1.4 | 2000 | 840 | 0.178 |
| 2-hollow cement brick | 25 | 1 | 1100 | 880 | 0.25 |
| 3-clay brick | 25 | 0.6 | 1790 | 840 | 0.416 |
| 4- light sand brick | 25 | 0.13 | 650 | 1000 | 1.92 |

Figure 12a shows the total consumption during cooling and heating periods where light sand bricks proved to enhance thermal performance and reducing the energy consumption during both periods. Figure 12b shows the percentage of the reduction in the energy consumption as a result of using each of the four tested brick types. It can be noticed from the figure that using light sand brick decrease the energy consumption by 15.6%.

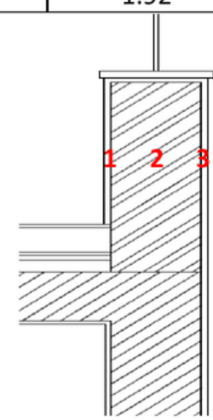



Figure 11. Cross section in the wall after replacement of Solid cement brick (layer 2) by hollow cement brick, clay brick and light sand brick

***Impact of adding insulation layer to walls:*** Different types and thicknesses of insulation materials were tested. It was found that using expanded polystyrene with different thicknesses increases the total thermal resistance of the walls. Table 6 presents the physical characteristics of the different wall components. It can be noticed from the table that expanded polystyrene has the best physical characteristics. In Table 7 the effect of using expanded polystyrene with different thicknesses on the total thermal resistance of the wall was presented.

Table 6. Physical characteristics of wall components

| Component | layer L (cm) | Conductivity K (watt/m. c°) | Density P (kg/m$^3$) | Specific C (jol/kg.c°) | Resistance R (m$^2$. c°/watt) |
|---|---|---|---|---|---|
| 1-Cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| 2-Solid Cement brick | 12 | 1.4 | 2000 | 840 | 0.089 |
| - expanded polystyrene | 2 | 0.035 | 35 | 1400 | 0.571 |
| 4-Solid Cement brick | 12 | 1.4 | 2000 | 840 | 0.089 |
| 5-Cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| U-value | 1 (W/m$^2$.K) | | | | |
| R | 1 (m$^2$.K/ W) | | | | |

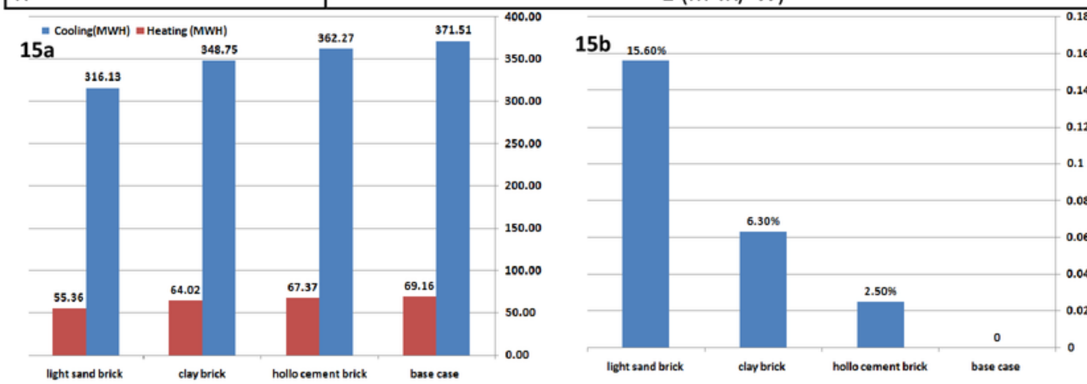



Figure 12. Effect of different types of bricks on the energy consumption

Table 7. Effect of using expanded polystyrene with different thicknesses on the total thermal resistance of the wall.

| Insulation layer thickness | Total thermal resistance wall |
|---|---|
| Base case (no insulation) | 0.398 (m$^2$.K/ W) |
| 2cm | 1 (m$^2$.K/ W) |
| 3cm | 1.25(m$^2$.K/ W) |
| 5cm | 1.82(m$^2$.K/ W) |

The building has an insulted roof with 5 cm expanded polystyrene. Any extra thickness did not make meaningful difference. Insulating walls contribute to buildings' users comfort in hot zones (A.S. Dili, 2011). Figure 13 illustrates a cross section of the outer wall with internal insulation (layer 2). Figures 14a and 14b illustrates the effect of using expanded polystyrene with different thicknesses on the overall energy consumption of the building. Figure 14a shows the total consumption during cooling and heating period, where 5 cm proved to have the least consumption during both periods. Figure 14b shows the percentage of the reduction in the energy consumption as a result of using each thickness. It can be noticed from the figure that insulating the outer walls with

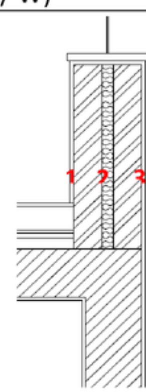
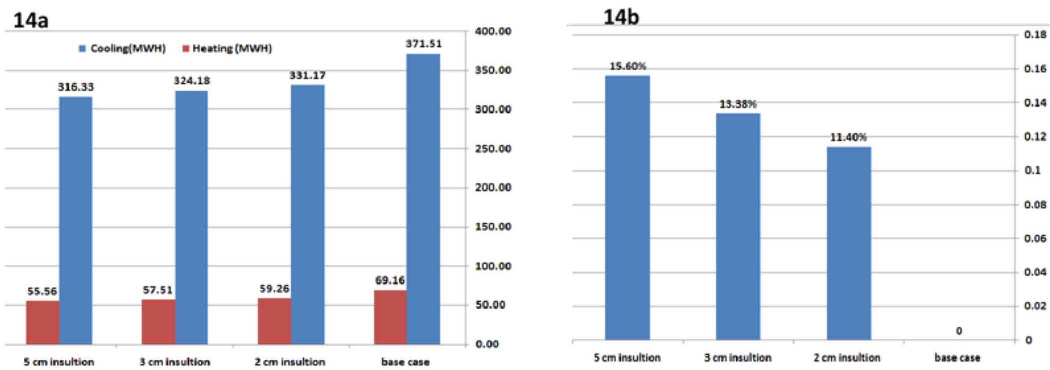


Figure 13. Cross section in the wall reveals the insulation layer (layer 3)




5 cm thickness of expanded polystyrene decrease the overall building energy consumption by 15.6%.

Figure 14. Effect of using expanded polystyrene with different thicknesses on the energy consumption.

***Impact of changing elevation finishing to artificial stone cladding:*** In addition to the previous alternatives of wall types and insulation thicknesses, artificial stone cladding with different thicknesses of insulation were tested. Table 8 presents the total thermal resistance for wall layers with different Insulation layer thickness. Table 9 shows the Thermal characteristics of insulation layer with different thicknesses behind artificial stone.

Table 8. Physical characteristics of wall components

| wall layers with different Insulation thickness | Total thermal resistance |
|---|---|
| Base case | 0.398 ($m^2$.K/ W) |
| artificial stone+ expanded polystyrene 2cm | 0.98 (m2.K/ W) |
| artificial stone+ expanded polystyrene 3cm | 1.26 (m2.K/ W) |
| artificial stone+ expanded polystyrene 5cm | 1.8 (m2.K/ W) |

Table 9. Thermal characteristics of insulation layer with different thicknesses behind artificial stone.

| Component | layer L cm | Conductivity K watt/m. c° | Density P kg/$m^3$ | Specific C (jol/kg.c° ) | Resistance R ($m^2$. c°/watt) |
|---|---|---|---|---|---|
| 1- Artificial stone | 2 | 1.3 | 1750 | 1000 | 0.015 |
| 2- Expanded polystyrene | 2 | 0.035 | 35 | 1400 | 0.57 |
| 1-Cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| 2-Solid Cement brick | 25 | 1.4 | 2000 | 840 | 0.178 |
| 5-Cement mortar | 2 | 0.93 | 2000 | 750 | 0.021 |
| U-value | 1 (W/$m^2$.K) | | | | |
| R | 0.98 ($m^2$.K/ W) | | | | |

Simulation results proved that using expanded polystyrene insulation layer with different thicknesses behind artificial stone as an external cladding decrease the overall energy consumption of the building. Figure 15 illustrates a cross section of the outer wall with 2 cm artificial stone cladding and expanded polystyrene insulation behind it (layer 2). Figures 19a and

19b illustrates the effect of using this wall configurations with different thicknesses of insulations on the overall energy consumption of the building.

Figure 16a shows the total consumption during cooling and heating period, where 5 cm proved to have the least consumption during both periods. Figure 16b shows the percentage of the reduction in the energy consumption as a result of using each thickness. It can be noticed from the figure that insulating the outer walls with 5 cm thickness of expanded polystyrene decrease the overall building energy consumption by 16.78%.

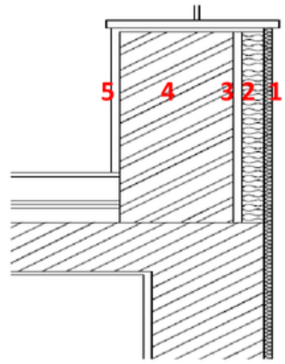



Figure 15. Cross section in the wall reveals the insulation layer (layer 2) behind artificial stone.

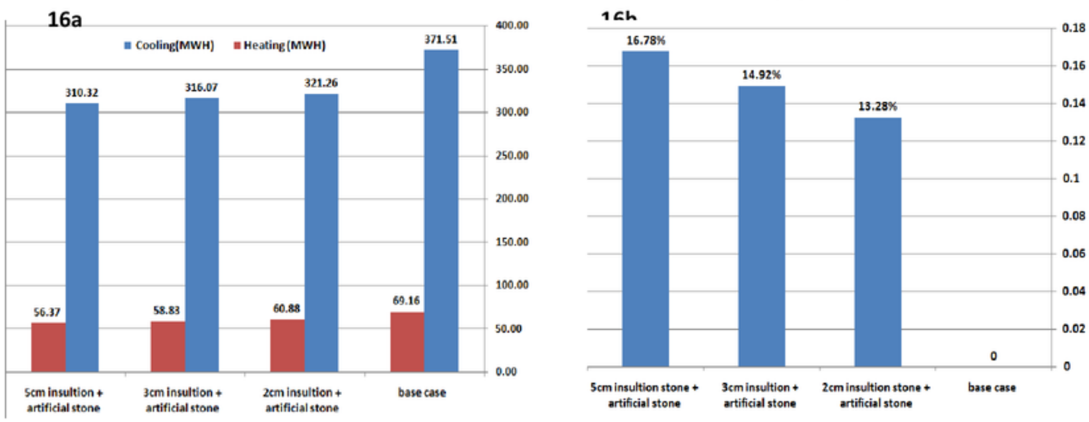



Figure 16. Effect of using insulation layer with different thicknesses behind artificial stone on the energy consumption.

***Double layered blue glass curtain walls:*** As shown in Figures 5 and 6, building elevations have large glass areas. Different configurations of these walls were tested. Table 10 presents the physical Characteristics of different types of glass.

Table 10. Physical characteristics of different types of glass.

| Characteristics | 6mm SGG REFLECTASOL Blue (#2) 12mm Air Space 6mm Clear | 6mm SGG COOL-LITE ST 767 (#2) 12mm Air Space 6mm Clear | 6mm SGG PLANITHERM T Blue (#2) 12mm Air Space 6mm Clear | 6mm SGG COOL-LITE KNT 764 (#2) 12mm Air Space 6mm Clear |
|---|---|---|---|---|
| **VISIBLE LIGHT** | | | | |
| Transmission (%) | **19** | **38** | **49** | **37** |
| Reflection Out (%) | 22 | 12 | 8 | 8 |
| Reflection In (%) | 52 | 22 | 11 | 9 |
| **SOLAR ENERGY** | | | | |
| Transmission (%) | 18 | 28 | 30 | 23 |
| Reflection Out (%) | 15 | 9 | 8 | 8 |
| **U-VALUE (W/m2.K)** | **2.80** | **2.80** | **1.80** | **1.90** |
| **G Value** | **0.28** | **0.37** | **0.36** | **0.30** |
| **Shading Coefficient** | **0.32** | **0.43** | **0.42** | **0.34** |
| 1st Lite Price (L.E./sqm) | **105** | **140** | **165** | **220** |
| 2nd Lite Price (L.E./sqm) | **35** | **35** | **35** | **35** |
| **Both Lites Price (L.E./sqm)** | **140** | **175** | **200** | **255** |

Using double glass panels with air gab can increase curtain walls thermal performance. Several types of glass and several gab distances were tested (Tavares, 2011). Results are shown in the following figures. Figure 17 shows the effect of using double blue glass (production of SAINT-GOBIN) in the transparent parts of the building on the energy consumption.

Figure 17a shows the total consumption during cooling and heating period, where different types and combinations of glazing were applied. Blue glass proved to have the best impact on the energy consumption during both periods. Figure 17b shows the percentage of the reduction in the energy consumptions as a result of using each one. It was found that using double blue glass in the Transparent part of the building decrease the energy consumption by 10.5% .

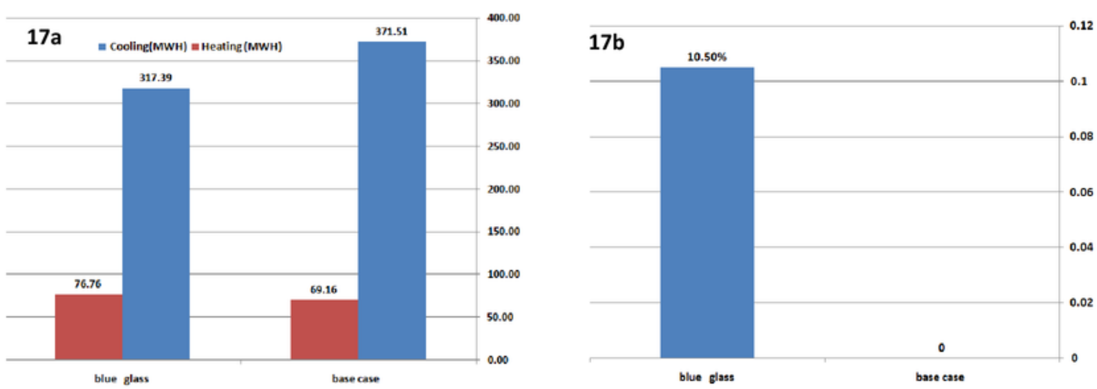



Figure 17. Effect of using double blue glass in the transparent part of the building on the energy consumption.

Changing outer shell of the building can contribute to the energy saving of any existing educational building. (Norbert, 2016) Combined treatments were tested for energy consumption saving. Table 11 shows the selected treatments for external walls. Figure 18 illustrates the impact of different treatments on the total energy consumption. From the figure, it can be concluded that using double blue glass and expanded polystyrene 3cm behind artificial stone decrease the total energy consumption by about 27%.

Table 11. Selected treatments for energy saving consumption

| Treatment | Energy saving |
|---|---|
| Blue glass | 10.5% |
| Artificial stone+ expanded polystyrene 3cm | 14.92% |

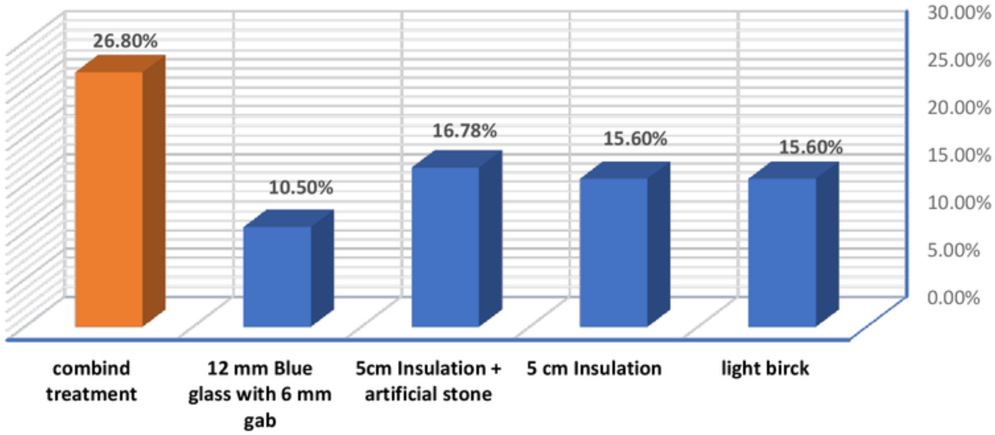



Figure 18. Impact of different treatments on the total energy consumption.

**Conclusion:**

This paper presented a systematic methodology for appropriate retrofits of existing buildings for energy efficiency and sustainability. An overview of previous studies related to the investigation and evaluation of energy performance and economic feasibility of different retrofit technologies utilized in several cases is introduced. There is a large body of research on building retrofits available in the public domain. However, existing buildings continue to be upgraded at a very low rate. For instance, existing commercial building stock is currently being retrofitted at 2.2% rate per year only (Olgyay 2010).

Previous studies have demonstrated that energy and environmental performance of existing buildings can be improved significantly through appropriate retrofits. Most of these studies were carried out using numerical simulations. Actual energy savings due to the implementation of retrofit measures in real buildings may be different from those estimated. More research with practical case studies is needed to help increase the level of confidence in potential retrofit benefits. Obtaining better data for existing building stock; materials and systems within local market will allow for better building envelope programmed development and enable policy makers to address the most important elements for the particular climate, building characteristic and market.

Most effective solution is to investigate the available alternatives. Invent the best technical-executive procedure that suit existing building context and its specific features. Comprehensive detailed data for energy performance by building envelope components are hard to obtain, consequently, saving opportunities are even more difficult to predict because they are highly dependent upon base loads. This study utilized one of the thermal performance assessment pakages “Design Builder” to analyze the effect of envelope components and their design on reducing energy consumption. Factors include exterior walls construction materials, thermal insulation as well as Glass type. Simulation proved that the total consumed energy can be reduced through green retrofit process. This process includes changing the external walls materials and layers of any existing educational building. Reconstructing envelope with carefully selected materials of external walls can have great impact on energy consumption and internal space comfort.

Analyzing results of the tested case, it can be concluded that using light sand brick as a construction material decrease the energy AC system electric consumption by 15.6%. Results also showed that insulating external walls with 5 cm thickness of extended polystyrene decreases the Air conditioning system energy consumption by 15.6%. Moreover, results proved that using 2 cm thickness artificial stone cladding with 5 cm thickness insulation can decrese the consumed energy by 16.78%. Studying Glass types showed that using double layered 12 mm blue glass with 6 mm air space can reduce energy consumption by 10.50%. The study finally suggests green retrofit with a comprehensive approach that consider the both economic and environmental. This approach will facilitate user comfort with 26.8 reduction of consumed energy. Appropriate selection criteria and weighting factor assignments are essential in the formulation of multi-objective optimization problems to select the most cost effective retrofit strategies. Major concerns of building owners in regard to retrofits should be carefully considered during the development of the optimization problem.

To sum up, there is still a long way for building scientists and professionals to go in order to make existing building stock be more energy efficient and environmentally sustainable. To achieve building resilience due to the effects of climate change, more research on low energy adaptive strategies for building applications is needed. Further research work and investigation in this regard are needed to facilitate cost effective building retrofits.

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