Improving Energy Efficiency performance utilizing building envelope design in High standard housing in Egypt

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Abstract

Nowadays Climate change is the main dilemma urging the world actions to mitigate it, mainly through fossil fuel independency and energy consumption management. Energy deficient performance of the building envelope in residential buildings is a major driver increasing energy consumption rates. Since the cooling loads and lighting are on top of the electric consumption rates in housing, then a key mitigator to improve the energy efficiency performance of a building envelope is the adequate management of energy flow through the household by the passive strategy (cooling and daylighting) techniques to acquire the best advantage of the local climate. Selecting the high standard housing segment represented in new Gated communities, spotting the gap between the formal and new market criteria and how it is widely spreading with no considerations to their building envelope energy deficiency performance and accumulation of energy consumption loads urges the need to take the High standard housing into an actual high standard not only per income level, but also in its energy high performance aligning with global aspect. Cases studied were analyzed to observe their passive cooling techniques implemented in the Building Envelope to improve the energy efficiency performance. Then one base case study (SODIC EAST-MVvilla) is selected and adapted with previously induced eight passive cooling techniques then simulated with DesignBuilder software to assess the energy consumption, thermal performance, and CO2 production of the building. The study resulted in significant electric consumption annual decrease by 41% thermal comfort annual improvement by 66% that lead to a decrease in CO2 production by 41% annually and that is when a building improves its energy efficiency utilizing the building envelope using passive cooling strategies.

Key Words: Climate mitigation, Energy Efficiency, Building Envelope, High standard housing, Passive cooling strategies.

1.Introduction

1.1 Background

The world is nowadays living a time where climate mitigation and energy crisis issue is no more a luxurious case. Improving energy efficiency through the building envelope components is a key mitigation to decrease energy consumption rates through the building in which its importance has exceeded even the role of renewables. It is found that approximately 66% energy savings can be achieved in the household annual energy usage by focusing on maximizing the energy efficiency (mainly thermal performance) of building envelope, minimizing the energy loads, and incorporating solar energy technologies (passive strategies are recommended) (Yuanming Kwan, Lisa Guan, 2015). The importance of improving the energy efficient performance in the building envelope components (wall, roof, fenestrations) assures the adequate energy management of the whole building energy performance, occupant comfort, environment health adding the real estate value investment.

A Well-designed energy efficient envelope enhances its energy performance, maximizes cooling movement of air, and exclude the sun (heat gain) in the summer season as its performance is dependent on the climate and available resources. There are many types of passive cooling strategies that can be recommended for use in cooling dominant climate such as Egypt. Nowadays, High standard housing segment in Egypt should align with high standard criteria not only through high income life standards but also through high global architecture standards addressing occupant comfort, economic and environmental high standard aspect. Addressing the high standard housing building envelope energy performance efficiency and the study hypothesized outcomes shall support the government for big actions, real estate investors and occupant attention to its implementation benefits value in environment, investments value and occupants` aspects.

1.2 Statement of problem:

The problem addressed by this study is the deficient energy performance of building envelope design affecting residential consumption rates of non-renewable energies adding more accumulations to energy situation in Egypt, economic loads, occupant discomfort and climate change disorders. Promoting the residential building sector as a main contributor in increasing the energy consumption rates due to its building envelope design deficiencies. Selecting the high standard housing segment in Egypt represented in Gated communities' trends which has a promising wide spreading growth seeking more luxurious facilities and new lifestyle standards that subsequently adds more energy loads accumulations with its energy deficiency status. This study is clearing the risk of the widely spreading high standard housing investments with its energy consumption loads aligning with neglecting the on ground actual energy deficiency performance accumulation through its building envelope design that needs to be adequately monitored and improved.

1.3 Aim of the paper:

The aim of this study is to declare the importance of improving the energy efficient performance of building envelope at the design process to help in decreasing the energy consumption rates in high standard housing segment represented in GC[1] at GCR[2], Egypt.

[1] **GC: Gated Communities**
[2] **GCR: Greater Cairo Region**

The energy efficient performance of the building envelope shall enhance thermal comfort decrease total electric consumptions loads thus, lowering CO2 production shares by residential buildings. The improvement in energy efficiency performance is tested when applying eight passive cooling strategies through the building envelope main components (wall, roof, fenestrations, finishes) that will lead to improvement in thermal comfort, less energy consumption and CO2 production, thus leading to more climate mitigations, environmental health, occupant comfort and real estate high value investment growth aligning with global high standard aspects.

2. Research methodology

This study adapts an inductive method followed by a simulation method.

<u>2.1 The inductive method:</u> The inductive method started with a **theoretical approach** stating the climate change status and its mitigation methods related to energy consumption rates dilemma thus observing the energy efficiency importance as a key driver energy consumption reduction with its significance in climate mitigation. Followed by the importance of building envelope energy performance as an energy flow manager controller. Depending on the climate, about 33-50% of the global final energy use in the residential building sector is used for space heating/cooling thus optimizing building envelope design performance to take advantage of the building's local climate is important in achieving reduced energy use in the building sector. Discussing the building envelope high performance design importance, properties, design considerations and technologies used through the building to achieve energy efficient levels.

As Egypt has a cooling dominant climate then superiority of Passive cooling design techniques is highly recommended to be utilized in improving the energy efficiency performance of building through the building envelope components.

Then the study went through a theoretical discussion on Housing in Egypt, its classification, standards, and the gap happening in formal and market aspect as per new private segment investments. Putting an overview on the importance of high standard housing segment investments represented in gated communities and its wide spreading trends. Stating the high standard housing energy performance and the governmental steps towards solving the energy deficiency problems. Highlighting the importance of energy efficiency investments in that tier and how important to improve the energy efficiency performance of that segment utilizing the building envelope with passive design approaches.

Then an analytical approach is set analyzing the passive cooling strategies techniques applied in residential building envelope main components and observing their application consequences in the cases studied which supports its importance in improving the performance of energy efficiency leading to an energy efficient high standard household.

2.2 <u>Simulation method:</u> The simulation approach uses the inductive method concluded criteria to improve the energy efficient performance of the building utilizing the building envelope. Where it promotes an adapted residential case selected from a high standard GC (SODIC East) that will be assessed by the application of eight passive cooling strategies through the building envelope components that is proved by three analyzed cases to improve the energy efficiency performance of the building envelope leading to energy efficient high standard household with less energy consumption loads, more occupant thermal comfort and less CO2 production loads on the environment. The aiding simulation tool is the DesignBuilder software with Energyplus (plug in)

3.Climate and Energy

3.1 Climate change and energy consumption:

Our Earth climate is undergoing a dramatic change due to the anthropogenic activities. WMO[3] has stated the CO2 production as a main physical driver of climate to change[4] in which our overall energy consumption sources (fossil fuels) subsequently triggers the CO2 emissions rise and puts it at the heart of the climate change debate. The EIA has defined the amount of GHG in total emission of CO2 by the Fossil fuels is 56.6% and increasing[5]while the IEO 2019 Reference case stated the world energy consumption rises nearly 50% by 2050. That puts the energy consumption rates from fossil fuels as a main driver of climate change disorders. Adding a major source of rising energy use and emissions by the global building sector is the **electric consumption**. The emissions (direct and indirect) from electricity and commercial heat used in buildings rose to 10 GtCO2 in 2019 (the highest level ever recorded) that makes the residential building energy consumption a high priority in mitigating the climate by its energy consumption decrease.

4.Housing and high standard segment energy performance

4.1 Housing classification in Egypt and formal- market gap criteria:

Egypt as many other countries has its own legislations for housing setting its own categories and level standards of housing sector. Income has been the most common factor in the classification of housing categories. In the 1960s, housing levels in Egypt were classified according to class gradation and family income as follows: low, middle, and high-income levels. This also reflected on the classification of housing units according to housing unit location, area and finishing level.

Emam Hassan (Emam, 2011) study has alleged (through a market aspect analysis) that the high-income sector was to be considerably low investment and not recommended to invest in this segment. **Well, this phase is changing now** and the investment in the real estate market by the private sector has been lately playing the **Pull approach** role, which means that the firm (*state and the housing investors*) produces the products and services (*housing units, compounds, new cities*) according to the customers need. This market approach is customer oriented; this orientation increases the added value for the customer by eliminating the product or service features that are not needed by the customer, and if other features are added to the product the customer pays even though they are not required (Adding lifestyle and luxurious facilities upgrades).

That new market approach has significantly increased the investment in high standard housing segment mostly represented in Gated communities` trend resulting in new formed High standard housing criteria seeking more luxurious facilities and new high standard lifestyle. That new market criteria have created a gap between formal and new real estate criteria for example: the high standard housing as per formal standard shall have a high standard finishing level and a minimum floor area of 160m², while this is not found on the new real estate market for the same segment as the household may be delivered with no finishing and the floor area may be found with 64m² , but still labelled

[3] WMO: World Meteorological Organization.
[4] WMO-No. 1233 © World Meteorological Organization, 2019
[5] https://www.eia.gov/energyexplained/energy-and-the-environment/where-greenhouse-gases-come-from.php. Visited on: 5/2/2021.

as a high standard household for real estate criteria as the Gated community criterion with its new lifestyle and luxurious facilities promoted. Gated communities are the new representative face of the high standard housing segment feeding the occupants` needs that is widely spreading.

4.2High standard housing energy performance and energy deficiency:

The total investment in the High-standard segment (Public and private) exceeded 7 million with a total number of housing units 8743 in 2018-2019 (CAPMAS 2019)[6]. Comparing 2019 total investment in the high standard segment with that in 2010 with 3 million - adding the current with potential future investments, too, shows how rapid this investment is growing and on demand. The high standard segment household consumption has increased neglecting the energy deficiency in building envelope design that leads to more energy consumption rates, thermal discomfort and more CO2 production. There are a total of 19.46 million residential meters and 70% of the consumers consume 1000 kWh and more in the high standard housing tier where lighting has the biggest share in energy consumption 31% followed by cooling loads. Figure (3)

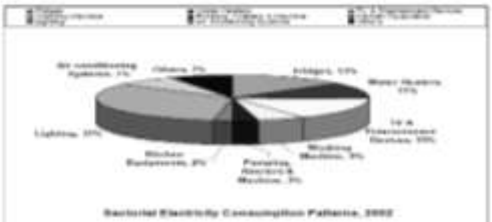

Figure 1 shows Electricity consumed in residential sector by type subsidies where lighting (31% of total electricity consumption),(13%) make up the largest components of residential electricity consumption. Source: (Sustainable Energy Potential in the Egyptian Residential, 2013)

4.3 Energy efficiency and building envelope performance:

A major source of rising energy use and emissions by the building sector is the **electric consumption**. The emissions from electricity used in buildings rose to 10 Gt CO2 in 2019 (the highest level ever recorded). Improving energy efficiency measures through the high standard housing segment is a main road to decrease energy consumption rates and climate mitigation. One of the main drivers of energy use in buildings is the building envelope as it plays the role of energy flow manager in the whole building energy use so that makes the building envelope a key driver when improving the energy efficiency performance through of the whole building. The most influencing drivers contributing to higher or lower energy demands are improvements in the energy efficiencies of the **building envelopes** (e.g., better insulation and windows) and in the high performance of building energy systems (e.g., heating, cooling, and ventilation) and components (e.g., cooking equipment) have helped to offset energy demand growth. The more efficient performance of the building envelope components taking best advantage of surrounding climate, the more energy efficient standard it accomplishes.

Energy efficiency improvements in high standard housing segment has a big potential to adequately manage the energy consumption of the household while improving the level of comfort in the building where it can be achieved through:

a) Reducing cooling demand.
b) Reducing energy requirements for ventilation.
c) Reducing energy used for lighting.
d) Reducing the electric consumption for household appliances.

[6] https://www.capmas.gov.eg/Pages/StaticPages.aspx?page_id=5035

- The Energy efficiency measures has an investing potential that results in reducing energy costs for owners and tenants, lowering maintenance requirement and improve thermal comfort and life quality and enhances the property value. (Table 1)

EE importance in High standard Housing	EE investment benefits in Housing sector
▪ **Reducing cooling demand.** (Thus, decreasing cooling loads and energy consumption) ▪ **Reducing the energy requirements for ventilation.** (Increasing indoor air quality and decreasing cooling loads) ▪ **Reducing energy use for lighting.** (Enhancing Daylighting and decreasing electric consumption loads) ▪ **Reducing energy used for heating water.** (Thus, reducing energy consumption loads) ▪ **Reducing electricity consumption of household appliances.** (Using energy efficient appliance)	▪ **Reducing energy costs for households' owners and tenants.** ▪ **Reducing energy use for space heating/cooling and water heating.** ▪ **Reduced electricity uses for lighting and household appliances.** ▪ **Lower maintenance requirements.** ▪ **Improved comfort and productivity.** ▪ **Enhanced property value.**

Table 1 stating the Energy Efficiency importance and investment benefits in High standard housing sector. (Adapted by researcher)

4.4 <u>Importance of Energy Efficiency measures applications in high standard housing segment:</u>

Applying the E.E[7] measures is recommended for high standard housing to enhance energy consumption reduction loads, improve thermal comfort, and decrease CO_2 emissions by the following methods:

a) **Application of the Passive cooling methods.** (Thus, reducing cooling demand)
b) **Enhancing Natural ventilation methods.** (Thus, Reducing the energy requirements for ventilation.)
c) **Enhancing Daylighting methods.** (Thus, reducing energy use for lighting)
d) **Passive water heating application methods.** (Thus, reducing energy used for heating water)
e) **Using energy efficient appliance. (**Thus, reducing electricity consumption of household appliances.)

- It is concluded that energy consumption rates are a direct influencer on climate mitigation and as the building envelope performance is the key driver of energy consumption of the whole building energy flow, then it comes in priority when approaching to improve the energy efficient performance of the building to assure an adequate energy consumption, thermal comfort and CO_2 decrease through the building envelope performance.

[7] E.E: Energy Efficiency

4.5 The building envelope energy performance is efficiently maximized by:

a) Adequate skin construction material synchronizing with the environment.
b) Climatic requirements.
c) Enhanced daylight features to promote efficient comfort light with no glaring.
d) Maximizing efficiency of heat loss/gain prevention system.
e) Maximizing efficiency of airtight envelope.

4.6 Passive cooling strategies triggering the energy efficiency performance in building envelope:

A high performance and energy efficient building envelopes are highly dependent on climate zone as well as building function, occupancy pattern, orientation and equipment loads as well as envelope type. (Aksamija, 2019). The high-performance building envelope design considerations that should be followed to enhance a significant energy consumption reduction are: orientation and sizing, thermal comfort measures with shading devices, daylighting enhancement, adequate natural ventilation, glazing performance and efficient finishing.

Passive cooling strategies are a non- mechanical approach based on climatic considerations that supports and enhances the high-performance building envelope design considerations. This approach works by 2 ways, either by preventing heat from entering the interior (heat gain prevention) or by removing heat from the building (natural cooling). Passive design techniques are either cooling, heating or daylighting techniques.

As per our study scope with cooling dominant climate, Passive cooling system is analyzed through cases studied where eight passive cooling techniques are implemented in the building envelope main components (wall, roof fenestrations, finishes) resulting in an important result in energy efficiency performance with a decrease in energy consumption rates, more thermal comfort that led to a decrease in CO_2 production.

5. Analytical study:

The purpose of the application study is to test the significant improvement in energy efficiency performance when using the building envelope design.

First step before the application is by analyzing three cases that did have significant results in E.E improvement when applying passive cooling design techniques to the building envelope of a residential building.

Second step the application approach by simulating the previously induced eight passive design techniques on a base case, implementation on the building envelope to test how much improvement will occur on energy consumption rates (electricity), thermal performance and amount of CO_2 production in the high standard housing segment.

5.1 Case studies summary:

Criteria of case study selection comes from having cooling dominant climate, the household is a high standard housing segment, the need of implementing passive cooling strategy techniques as a gateway for the energy efficiency performance improvement and the utilization of building envelope main components design in the improvement method.

5.1.1 Case study 1: SEMMER VILLAS (DSO), Dubai, U.A.E

Figure 2 Showing location of the gated community DSO in UAE, source by google earth

Figure 3 showing main entarnace -south façade of the Semmer villa case study- source: *(M.Taleb, 2014)*

Figure 4 showing ground floor and first floor plan of the Semmer villa case study- source: *(M.Taleb, 2014)*

Lead Consultant	Archgroup
Location	Dubai Silicon oasis, Dubai, UAE
Date	2014
Type	Residential villas in a gated community
Owner	Dubai Silicon Oasis (DSO)
Climate	Cooling dominant climate

5.1.1 1 Project description overview: Semmer villa is a prototype standalone residential villa built by the DSO authorities in the UAE as a part of the Dubai Silicon Oasis. DSO contains two villa development compounds one of them is the (Semmer Villas) with its own community facilities and amenities. (figure2)

Despite the massive potential for energy savings in buildings of UAE still the country has been identified as one of the highest carbon emitters per capita that needs to indulge in the energy efficiency high performance aspects aligning with global criteria. (M.Taleb, 2014). (figure3,4)

Hanan M. Taleb has introduced a simulated case study on the DSO Semmer villa using eight passive cooling strategies implemented on the building envelope of the household to achieve an energy efficiency improvement leading to a reduction in energy consumption and thermal performance improvement. (Figure 5)

- **The eight passive techniques are:**

1- **Louver Shading devices:** implemented on southeast façade horizontally with 45̊ tilt for sun protection in summer while allowing breeze in winter.

2- **Double glazing:** implemented and gapped with argon gas with a solar control film on all fenestrations.

3- **Wind catcher and cross ventilation**: to harness cool breeze into the indoor and enhance air quality.

4- **Green roofing**: Increases roof insulation and decrease indoor temperature by 30C̊ and reduces energy demands by 6%.[8]

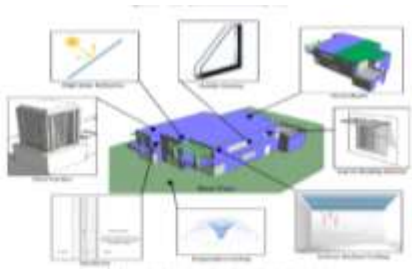

Figure 5 showing the villa study case with application of 8 passive strategies . credits to Taleb, Hanan. (2014).

5- **Insulations**: act as a barrier to heat flow reducing heat gain in summer. A reflective bubble white poly insulation applied in walls, floor and ceiling.

6- **Evaporative cooling:** two fountains are needed in this house as per NDM[9]

[8] https://www.sciencedirect.com/science/article/abs/pii/S0960148111006604

7- **Radiant cooling:** Also known as nocturnal cooling which can only be applied to the last floor (roof) It contains a specialized radiator that is made of a metallic plate with air space above it. The air cooled by the long wave radiation under the metallic radiator is used to cool the indoor space of the second floor.
8- **High reflective coatings (light colored):** Applied on exterior walls to enhance solar reflection and reduce indoor temperature**.**

5.1.1.2 Simulation results: As a result of the passive cooling strategies applied, the simulation proofed that all temperatures on the hottest day to the coolest day achieved comfort zone inside the house from using these mentioned passive strategies. The study (M.Taleb, 2014) assures that there is a potential reduction of cooling loads by 9% after applying the passive cooling strategies and that the total annual energy consumption could also be reduced by 23.6% in buildings implementing passive cooling strategies.[10]

5.1.2 Case study 2: Barwa City Passivhaus (QATAR)

Figure 6 map showing the location of Barwa city in Doha, Qatar

Figure 7 shows a perspective view of the Passivhaus and BAU villas

Figure 8 shows Eye bird view of the Passivhaus and BAU villas

Lead Consultant	Partnership (QGBC, Kahramaa, BRE, MMUP)11
Location	Barwa city, west Doha, Qatar
Date	2014
Type	Residential villas in a gated community
Owner	Barwa Real Estate Group (BRE)
Climate	Cooling dominant climate

Project description: The Barwa real estate entered the Passivhaus (passive house) approach by building two prototype villas, one acting as a base case with conventional building construction called BAU[12] villa and the other with passive cooling strategies named Qatar first Passivhaus villa. The two villas are completed and located in BARWA City Southwest of Doha, Qatar. The villas are to be inhabited by two similar families. Applying six passive cooling strategies to improve energy efficiency performance using the building envelope as follows:

Figure 9 showing the PV cells array playing as a shading device, the light-colored coatings, and the west façade green walls.

1- **Louver shading devices:** implemented in the form of interior blind shades manually adjusted.
2- **Triple glazing:** Is implemented on all building envelope fenestrations with air gapping.

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[9] Novel design and modelling of an evaporative cooling system for building) https://onlinelibrary.wiley.com/doi/epdf/10.1002/er.1199, visited 17/05/2021.
[10] https://core.ac.uk/download/pdf/82430518.pdf- visited: 17/05/2021.
[11] QGBC: Qatar Green Building Council, (MMUP): Ministry of Municipalities and Urban Planning, (BRE): Barwa Real Estate Group
[12] BAU: Business as Usual

3- **Roof shades:** a total shading offset of the roof perimeter is added with Photovoltaic cells arrangements, works as roof shading and solar harvesting. (figure9)
4- **Insulations:** wall insulations on all building envelope, insulated airtight with 370mm extruded polystyrene.
5- **Green walls:** installing green walls vegetation on the west façade of the house that harvest most solar gain with Green Deciduous trees to create more shades on the west façade thus more thermal comfort indoor.
6- **High reflective coatings:** high reflective light coloring external paints over the whole building envelope to ensure maximum solar reflection.

5.1.1.2 Simulation results: The two model houses (BAU- Passivehaus) were assessed and energy modeled by using IES-VE. A six-month period of testing and commissioning then comparing the villas' base line performance without occupants resulted in 50% reduction in annual operational energy consumption, improvement in thermal comfort and reduction in CO_2 emissions rates. (Dr. Alex Amato, Dr. Cynthia Skelhorn, 2014)

5.1.3 Case study 3: Bunyesc Passive house, Spain

Figure 10 perspective view of the house from south façade.

Figure 11 showing patio and adjustable shading device.

Figure 12 shows location of Lleida, Spain

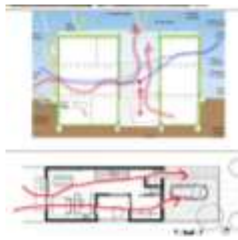


Figure 13 showing the natural ventilation process through plan and patio section. (Palacín, 2012)

Architect	Josep Bunyesc
Location	Lleida, Spain
Date	2015
Type	Residential, detached house
Client	Josep Bunyesc
Climate	Cooling dominant climate

Project description: This case study differs from the previous two as it is previously designed as a whole design strategy involving the building envelope design components with energy efficient criteria in which its results show how important it is to plan for the E.E in the design stage. A single-family detached house in Lleida, Spain with a dominant cooling climate is comprised of a ground floor, first floor and basement for office and housing. The 241.5 m² detached house is a Passive House certified which achieved its Green building awards2015[13] by applying 10 passive strategy techniques to create energy efficient building envelope have compensated the house with 80% of its energy consumption[14] . (Palacín, 2012) (Figure10, 12)

The ten passive cooling techniques are:

1- **Orientation:** Orientation of the house façade along with South to capture Solar energy on the PV façade while using the PV façade panels as a protector from Sun gain in summer. *(Insulation device)*

[13] https://www.construction21.org/case-studies/es/passive-house-bunyesc.html
[14] https://www.construction21.org/case-studies/es/passive-house-bunyesc.html

2- **Insulation:** The building envelope wooden frame structure all is insulated with local sheep wool.
3- **Natural ventilation:** An optimization of cross, stack and night flush nocturnal ventilation systems are applied together through a created patio that offers a stack and cross ventilation through the house, also night flushing by opening windows at night, letting wind-driven or buoyancy-driven airflow cool the space, and then closing windows during the day. that directly helps in decreasing cooling loads. (Figure13)
4- **Solar gain harvest:** adding PV cell units on roof and south façade to harvest solar energy and works as an insulation on wall.
5- **Glazing:** Double glazing implementation on windows.
6- **Patio- movable shading device:** Creation patio oriented along the south façade increases the area with shaded walls, enhances the natural ventilation (stack- cross) around the house in summer while in winter with removing the adjustable shade helps in letting in more solar energy into the indoors.
7- **Radiant cooling:** Radiant ceiling emits and absorb radiant energy. An object will cool by radiation if the net flow is outward, which is the case during the night. Since the roof provides the greatest surface visible to the night sky, designing the roof to act as a radiator is an effective passive strategy.
8- **Ground coupled heat/cool exchange:** An underground heat exchanger that can capture heat from and/or dissipate heat to the ground. They use the Earth's near constant subterranean temperature to warm or cool air or other fluids for residential.[15]
9- **High reflection coating:** High reflective external color of materials on roof like in the movable shade, polycarbonate sheets and the louvers help in more solar heat reflection in summer and reducing heat gain through the building envelope.

10- Shading devices: Three types of shading are implemented, the Louver shadings (exterior) that are installed on the south façade, Blind shades (interior) that helps in reflecting solar gain, diffuse sunlight and Movable roof awning shading adjustable on patio to enhance day light and solar gain in winter.

5.1.1.3 Simulation results: As a result of Passive cooling strategies applied utilizing the building envelope efficient components in the design stage, the energy consumption has been decreased to 80% of the total annual energy consumption for the home and electricity has been generated from the PV cells grid. The house office and carload come from the photovoltaic generation of the roof itself.[17]Also Roof helped in rainwater harvesting to garden and water closets use[18] as well as decreasing cooling loads in summer improving thermal comfort and decreasing CO2production. **The building is certified as energy efficient building rate A, which is one of the study objectives in high standard segment promoting to elevate the high standard housing into aligning with the global high standard energy efficient level**. (figure14)

Figure14 showing energy consumption pledge status of the building scoring A source: [16]

[15] https://en.wikipedia.org/wiki/Ground-coupled_heat_exchanger
[16] https://www.construction21.org/case-studies/es/passive-house-bunyesc.html- visited on: 18/05/2021- 10:00 pm
[17] https://www.buildup.eu/en/practices/cases/casa-bunyesc-passive-house-lleida-spain
[18] https://passivehouse-database.org/index.php#d_2116

5.2 Summary of the analyzed cases:

As per the three previous case studies selected and analyzed, applying the passive strategies approaches utilizing the building envelope components triggers its high performance resulting in efficient energy consumption with a decrease rates by a range from 23.6% as in Dubai villa (case1), 50% in Barwa city Qatar (case2) and 80% reduction as in Bunyesc Spain (case3). It is Important to state that the big difference that made the cases (2) and (3) hits high levels in energy consumption decrease more than that in case (1) is the addition of PV cells for electric generation as an additive approach over passive cooling strategies for energy efficiency of the building envelope. Case (1) and (2) had no privilege to design for orientation in first stages as they were already constructed in compounds that did not approach for passive strategies, thus they had to follow the urban design of the clusters in the compound while trying to overcome it with another passive approach.

As a result of the analytical study, applying the common eight passive cooling techniques had achieved important results in improving E.E performance in the residential units utilizing the building envelope main components (wall, roof, fenestrations, finishes, foundations).

Common 8 Passive cooling techniques for improving E.E performance utilizing the building envelope	Orientation and sitting (Applied in the design stage)
	Shading devices
	Natural ventilations
	Glazing (double-triple)
	Green Roof
	Insulations
	Evaporative cooling
	High reflective coating (light colored)

PS: Solar Gain harvest (PV cell arrays) Photovoltaic cell units are not considered passive techniques as it involves actives means to convert the solar energy to electric one. Still, it is highly considered in triggering the high performance of a building envelope when it comes to decreasing energy consumption rates and supporting the household with clean energy.

6. Application approach: (simulation study)

The purpose of the application study is to test the significant improvement in energy efficiency performance when using the building envelope main design. A simulation study uses the previously induced eight passive design techniques implemented on the building envelope to observe how much improvement will occur on energy consumption rates (electricity), thermal performance and amount of CO2 production in the high standard housing segment.

6.1 Criteria of sample selection:

Selecting the sample study (SODIC East) Gated Community at the East of GCR[19] as it represents the high standard housing trends in Egypt, promoting new lifestyle standard and luxurious facilities with a cooling dominant climate requirement that needs an improvement in energy efficiency through its building envelope performance. Selecting the MV villa type as it acquires the average floor area and average number of rooms as per many other high standard housing segment samples in Egypt.

[19] GCR: stands for Greater Cairo Region

6.2 Case study: SODIC East (Gated Community), Egypt:

Figure 15 showing location of SODIC East GC, Egypt.

Figure 16 showing an arial prespective view of the GC

5.2.1 MV villa description:

The villa type selected to be assessed in the case study has common average number of rooms and total area that most of the other gated community acquires. The villa total area is 340m², consisting of a ground floor area of 133m² containing a guest room, a kitchen and a reception (Figure20). The first-floor area is 157m² containing 3 bedrooms, bathroom and a living area (figure 21). The penthouse area has a 50m² and a terrace area of 85m² (figure 22).

Figure 15-1 Elevation- South Façade- (Entrance) source SODIC.com

Figure15-2 Elevation- North Façade- source SODIC.com

5.2.2 Site overview:

Egypt's climate is a cooling dominant climate, semi-desert characterized by hot dry summers, moderate winters, and extraordinarily little rainfall. The country is characterized by particularly good wind regimes with excellent sites along the shores.[20]The site is located East of GCR[21] with a prevailing preferrable wind of Northeast, an annually average temperature of 22.25℃ with an acute rise in temperature through summer months peaking in (July- August) with approximately 30℃ and sometimes reaches 40℃. (figure 5,6,7)

Figure 17 showing the Sun path diagram in 15 july on the north facade - simulated by designbuilder

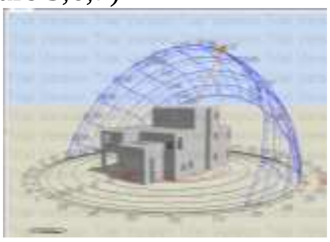


Figure 18 showing the Sun path diagram in 15july on south facade. simulated by design builder

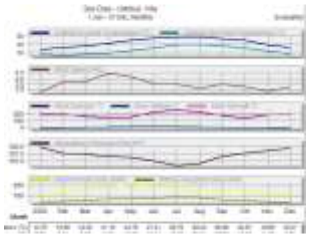


Figure 19 chart analysis stating site temperature monthly evaluating the temperature rises high in August reasching approximatly 30 degrees

[20] https://www.adaptation-undp.org/explore/northern-africa/egypt#:~:text=Egypt's%20climate%20is%20semi%2Ddesert,Red%20Sea%20and%20Mediterranean%20coasts.&text=The%20Nile%20waters%20originate%20outside%20Egypt%2C%20flowing%20through%20nine%20countries.- visited: 03/05/2021- 2:45am

[21] GCR: Greater Cairo Region

5.2.3 Base case status overview:

Figure 20 Ground floor plan of the MVvilla

Figure 21 First floor plan

Figure 22 Penthouse floor plan

5.2.3.1. The building envelope construction overview:

The building envelope is oriented with short sides along the North and South, walls are typically constructed from single wall light weight concrete blocks, fenestrations with single glaze, roof is concrete construction with traditional single heat and single moist insulation and the façade finish is with a typical exterior coating. The household building envelope indicates a household that is highly dependent on air-conditioning during Summer and heating during winter which leads to more energy consumption demands (lighting and cooling) to acquire thermal comfort. (Table 2)

5.2.4 Adapted case overview:

By taking best advantages of the climate, eight passive cooling strategy techniques were implemented aiming to improve energy performance by thermal comfort improvement, energy consumption reduction (mainly electricity) and CO2 production as follows:

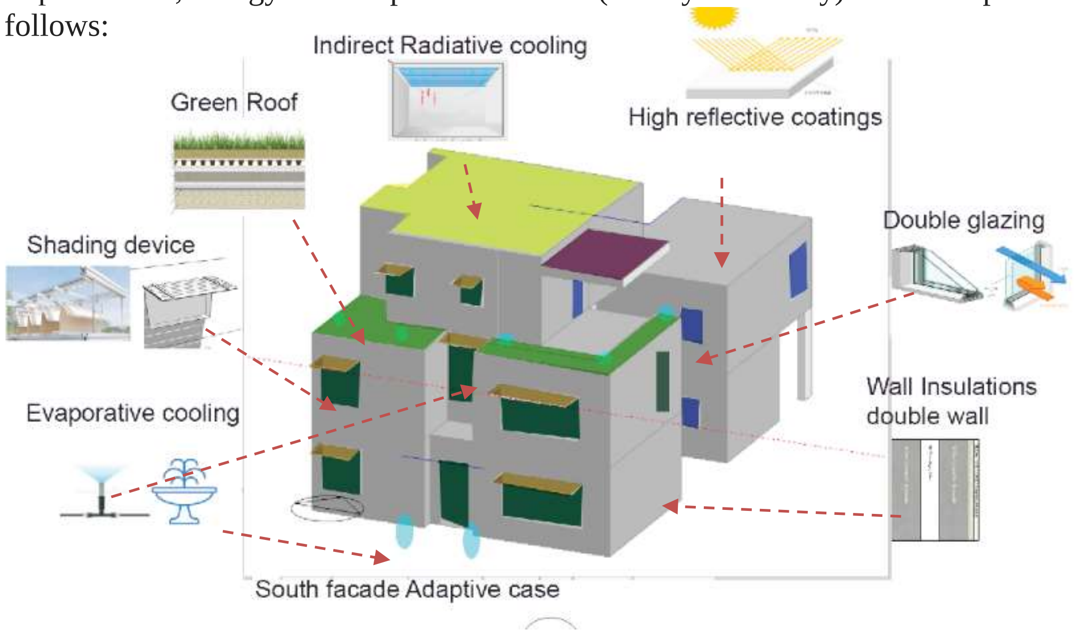


Figure23 Showing the eight implemetented passive techniques on the base case after adaptation. (adapted by researcher , simulation -Design builder)

5.2.4.1 Shading devices:

Louvered shading devices were implemented horizontally on South facades windows and an adaptive moveable one is implemented on roof (south area) to block Sun gain and add more shading areas on the envelope. The shading is designed in such a way that it blocks the sun in summer yet allows it to enter in the winter. (figure24, 25)

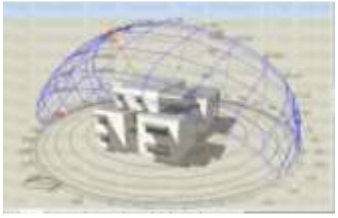


Figure24 showing the shading areas spreading widely on south façade at 2:00pm on 21st August with the high reflective light coating added. (Adapted by researcher with DesignBuilder)

Figure 25 showing the shading areas on the southeast façade and on the roof south shaded area at 2:00 pm on 21st August. (Adapted by researcher with DesignBuilder)

5.2.4.2 Glazing:

As windows are the main element in the transfer of huge amounts of heat between a building and exterior environment, thus all building envelope fenestrations were implemented with 40% double blue glazing gapped with air, except for the south façade fenestrations have implemented with 40% double blue glazing 6mm/13mm gaped with argon gas to enhance more insulation effect and maintain indoor thermal comfort.

5.2.4.3 Natural ventilation:

A cross natural ventilation is enhanced by adding a window opening in the east south façade to add adequate ventilation to the room letting preferable wind from the east to introduce cool air to the room temperature. (figure29)

5.2.4.4 Green roof

Green roofing is regarded as the best method of insulation for a roof. Studies show that the roof is one of the main solar heat gain points in a building, so by using a high level of insulation it can reduce heat conduction to the interior of the building. (Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in UAE, 2014) Green roof areas are implemented on south area of the roof to add more insulation effect to the building, reduce heat gain from building roof with a 20.00mm green roof soil layer above the heat and moisture isolation layers, R-value of 18.92 m²-k/w and U-value 0.53w/m²k.

Figure 26 showing layers of green roof with isolations in simulation process

Figure 27 showing the wall insulatione with 50mm isolating substance in the inner surface.

5.2.4.5 Insulations

Insulation acts as a barrier to heat flow, reducing heat loss in winter to keep the house warm and reducing heat gain in summer to keep the house cool. Insulations in this case is implemented through the building envelope walls. All walls double with insulations achieving U-Value of 0.41(w/m²- k), except the south façade that needed more insulations thus a simulation with double gap wall gapped with insulation substance resulted in a U-Value of 0.288 (w/m²- k) which was not sufficient in this case to achieve fewer cooling loads. Then a final simulated implementation with a doubled wall filled with air gap achieved a U-Value of 0.49 w/m²- k and enhance thermal comfort inside the building leading to less cooling loads. (figure27,28)

Figure 28 showing the 100.0 mm air gap between two 150mm concrete block light weight walls

Figure 0-3 showing the double wall with inner insolation that didint achieve fewer cooling loads in the case simulation

5.2.4.6 Evaporative Cooling:

Water Features are added in the shape of water fountain in front of the south façade area and as a water sprinkler feature serving the green roof area. These water features help in cooling the air facing the south façade in Summer thus decreasing the heat gain on the building envelope, decreasing cooling loads and improving thermal comfort. The water features not only cools the air, but also cleans it adding value to the environment aspect improvement. This technique is not considered into the simulation results as it is out of the building envelope, but it is highly recommended to add thermal comfort effect on the building envelope thus, elevating the simulation results.

5.2.4.7 Indirect Radiant Cooling:

A radiant cooling method was utilized to add more cooling effect. Radiant cooling takes place through the net emission of electromagnetic waves from warm objects to cool ones. The process then continues until both objects reach the same temperature. (Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in UAE, 2014) The process promoted for this case study is known as nocturnal cooling, which is only applicable to the second floor of the villa due to its proximity to the roof area. It involves radiant cooling of a specialized radiator that is made of a metallic plate with an air space above it (figure 30). The air cooled by the long-wave radiation under the metallic radiator is used to cool the indoor space of the penthouse area.

5.2.4.8 High Reflective Coating:

Exterior walls exposed to solar radiation can transfer a huge amount of heat to a building interior, then using a high reflective light-colored coating with a 61%reflection of the spectrum can have a beneficial effect on energy saving.

Figure 29 first floor plan with added opening window on the east south facade to enahnce cross ventialtion and

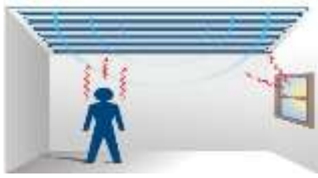


Figure 30 penthouse floor with added indierect radiant cooling feature to the ceiling

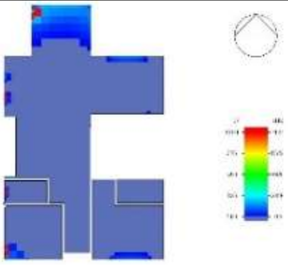
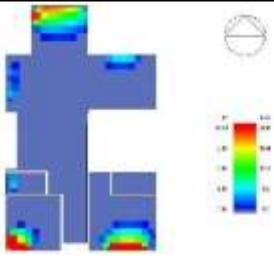
5.2.5 Building envelope performance analysis of the Adapted case:

Through the simulation process the cooling setpoint temperature to achieve was set to comfort at 24C̊ according to ASHRAE standards. And the simulation was concluded monthly on 21st August as it has the peak in temperatures, then annually.

5.2.5.1 Thermal performance and Daylighting analysis:

The monthly heat gain of the adaptive case is indicating a significant rise in comfortable temperatures and solar gain in summer period (July- August) leading to decrease in Solar gain from exterior windows value 13085.60kwh annually, less sensible cooling needs with moderate fresh air and total cooling loads with 70% and less need of ventilation types to get fresh air by 50%

The daylighting and thermal performance after adapting the passive strategies indicates improvement in the thermal performance with daylighting enhancement through the building envelope parameter while the previously addressed areas in base case have improved with thermal insulations and protection techniques (red-colored points have significantly decreased) through the south façade and the glazed area in the north façade. (figures31,32)

THERMAL PERFORMANCE AFTER ADAPTATION	THERMAL PERFORMANCE BEFORE ADAPTATION
 **Figure31 shows ground floor plan adapted case with thermal and daylight improvement.**	 **Figure 32 shows ground floor plan base case with thermal performance and daylighting deficiency indicated with red color zones.**

5.2.5.2 Electric consumption performance analysis and CO2 production state:

The analysis of the adapted building envelope for the electric consumption performance has indicated a significant decrease in consumption rates with lighting consumption of 3091.13 kwh annually, cooling loads 9228.0 kwh annually and total electric consumption 16620.46 annually that led to a CO_2 production with 41% annual decrease.

5.2.6 Results:

As a result of adapting eight passive cooling techniques on Sodic East residential MVvilla base case, significant improvement in energy efficiency performance is achieved when utilizing the building envelope. Implementation of louvered shading devices horizontally on the south façade windows created more shaded areas on south walls that is needed on summer while in winter where the angle of the Sun is lower, the horizontal implementation let Sun rays in feeding the south wall with needed solar energy. Also, adding another adaptive moveable shading device implemented on the south area roof where it is adjusted as needed to create more shaded areas on the roof on Summer and works as a roof extra insulator increasing thermal comfort and decreasing cooling loads through the first-floor south area, while in Winter the shade can be closed leading to preferable solar energy harvesting on the south roof area. Double glazing was added with 40% double blue glazing 6mm/13mm gapped with air, except for the south façade fenestrations air gapping was substituted with argon gas to enhance more insulation effect and maintain indoor thermal comfort in summer season as it needs more solar insulations where it all resulted in a decrease in solar gain through exterior windows annually by 46%. Natural cross ventilation was enhanced by adding a window on the southeast façade through the first floor(southeast) bedroom leading to more natural cross ventilation thus enhancing thermal comfort and indoor air quality. Green roof addition with a 20.00mm green roof soil layer above the heat and moisture isolation layers, R-value of 18.92 (m^2-k/w) and U-value 0.53(w/m^2k) worked as an additive insulation decreasing heat conduction through the roof surface especially on the south area over the two south bedrooms and increases thermal comfort on the south area in hot summer days. Setting wall insulations was implemented by two types, first implemented on all façade walls as a single insulation layer on the inner side on a 150mm concrete block (lightweight) that resulted in a U-Value of 0.41(w/m^2- k), then a second type implemented on the south façade which needed more insulations with double concrete block (lightweight) gapped with air achieving a U-Value of 0.49 w/m^2- k that enhanced thermal comfort inside the building leading to less cooling loads. Evaporative cooling was created through two fixtures, a fountain feature along the entrance (south façade) and the water sprinklers implemented on the south green roof acting as outdoor air-cooling features as water cools the hot air changing it into a cooled breeze entering the building in summer season, while in winter it can be disabled. The indirect radiant cooling implementation in the penthouse roof worked as an additive roof insulation achieving thermal comfort indoor in the space and decreasing cooling loads needed in summer. A prevention passive step to protect the building envelope from Egypt well-known Sun (solar energy) in peak hot summer days, finish materials needed the implementation of a high reflective light color coating material with a 61% reflection spectrum that indeed had an important effect in solar energy reflection. Finally, as a result of previous eight passive techniques implementation on the SODIC MVvilla, a new adapted residential case with an impressive energy efficient improvement is produced with a building improvement in thermal comfort performance by improvements in solar gain(through fenestration) by 53% monthly and 46% annually, sensible cooling improvement by 70% monthly, total cooling loads improvement by 69% monthly and 66%annually.The energy consumption improvement was clear in lighting (electricity) reduction by 13% monthly and annually as well, cooling loads (electricity) were reduced by 69% monthly and 66% annually, while total electric consumption was decreased by 53% monthly and 41%annually. Checking (Table 2) for more detailed improving results.

ing Energy Efficiency Utilizing Building Envelope Design in High standard housing in Egypt

Energy efficiency improvement aspects						
Thermal Performance	**Solar gain Exterior windows** (KWH)		**Sensible cooling** (KWH)		**Total cooling loads** (KWH)	
	M	A	M	A	M	A
BASE CASE	2400.7	27907	- 3433.2	-18781.8	-4818.9	-23462.6
ADAPTED CASE	1292.3	13085.6	-2408.3	-12708.5	-3337.2	-15503
Improvement Achieved	53%	46%	70%	64%	69%	66%
Energy consumption	**Lighting (electricity)** (KWH)		**Cooling (electricity)** (KWH)		**Total electric consumption** (KWH)	
	M	A	M	A	M	A
BASE CASE	1911.85	22387	2868.42	13965.8	4896.0	39960.5
Adapted case	262.80	22387.9	986.4	228.0	2606.6	16620.4
Improvement achieved	13%	13%	69%	66%	53%	41%

Table 2 stating the thermal performance and energy consumption improvement achieved through the implementation of the 8 passive techniques utilizing the building envelope. The Monthly simulation was recorded on the 21st of August as it is considered peak records. (Adapted by researcher).

7. Conclusion:

This study tried to clarify the importance of improving the energy efficiency performance of the high standard housing represented in gated communities through utilizing the building envelope components in the design stage. Implementation eight passive cooling techniques (shading devices, double glazing, wall insulations, green roof, indirect radiant cooling, evaporative cooling, natural cross ventilation, high reflective light coatings) in Egypt cooling dominant climate was a gateway to improve energy efficiency performance of the high standard housing segment utilizing the building envelope resulting in significant energy consumption (electricity) reduction by 41% annually, improvement of thermal performance by 66% annually leading to a CO_2 production reduction by 41% annually. High standard housing segment with the energy efficient improvement high potential will is aligning with global high standard aspects concerning energy efficiency, energy consumption, climate mitigation, thermal comfort and enhanced real estate value investment.

8. Recommendations:

The study recommends that:

- Adapting Energy Efficiency considerations and measures through the design process is recommended to promote its positive consequences in energy consumption rates, thermal performance, and CO2 productions.
- Building envelope performance shall be taken into a whole design strategy consideration to take best advantage of climate to enhance its energy performance consequences.
- Passive cooling design strategies implementation is a big opportunity in Egypt to take best advantage of climate and enhance energy efficient performance of housing industry.
- High standard housing in Egypt should be elevated into high standard measures not only per income level and life standards, but also per household energy efficient level aligning with global market with energy efficiency codes levels, thus codes should be implemented and taken into actions to rise the real estate housing value in Egypt.

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