

# Passive Cooling Strategies in Greening Existing Residential Building in Hot Dry Climate: Case Study in Bahrain

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**Abstract:** This paper will present several passive-cooling technologies and design features that can be adopted to reduce building heat gain without the need of excess energy consumption. A typical residential unit will be selected as case study and a three basic passive cooling strategies were selected to enhance the building envelop, as well as using appropriate shading devices and green roofing system that prove to be a good environment quality improver. IES energy simulation software will be used to evaluate the performance of the building. The study revealed a number of significant findings in reducing the energy consumption and enhancing the tenants' thermal comfort. American Society of Heating Refrigerating and Airconditioning Engineer (ASHRAE) standards specially via improving the performance of building envelop because it is the interface between internal and external environment. Moreover, improving the building envelope has recorded that overall energy and chiller energy consumption can be reduced up to 10.8% and 21.6% respectively. Therefore, it is anticipated that further reductions can be achieved via applying more passive cooling strategies. Finally, it could argue that the results of this paper will not only be applicable to Bahrain but also many countries that have similar climatic and environmental context.

**Key words:** Passive cooling, thermal comfort, energy efficiency, IES software, Bahrain, residential building, hot dry climate.

## 1. Introduction

Bahrain is a country that depends on combusted fossil fuels namely coal to run its power generation. The value for electricity production (Kwh) has increased almost 32% between 1971 and 2010 [1]. Moreover, it is anticipated to increase further to match the growing demand of both market and population, which will lead the government to increase inefficient production capacity. In addition, Bahrain was identified among the top 10 unsustainable and wasteful nations in the Middle East per capita [2]. According to Tibi [3], it has been noted that residential sectors consume about 47% of the total produced energy. Similarly, residential sector in Bahrain accounts for 54% [4]. Several reasons have contributed to the current situation in Bahrain. The

main reason is that the government subsidizing to electricity, ignorance and lack of awareness about sustainable building practices. Therefore, any possible saving in this sector will improve the national economy and enhance the local environment conditions as well as offering the tenants better quality of life. Therefore, incorporation of passive cooling strategies in residential units is crucial.

Passive house is a low energy house that accounts for its energy performance throughout its overall life cycle starting at preliminary design stage, followed by construction and operation period until its demolition. In general, the studies in greening existing residential buildings are very limited. However, most of the conducted studies in Bahrain focused on post construction evaluation of several building envelops, then implemented active systems such as building integrated photovoltaic (BIPV) and building integrated wind energy (BIWE). Yet most of the

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studies focused on commercial buildings only and there is not enough research in the residential buildings and units. The studies highlighted the main constraints of discouraging the implementation of such modern strategies. The reason behind that is the low energy cost, difficulty in applying taxes and the community ignorance of life cycle cost analysis of both photovoltaic's and wind turbines [5]. Moreover, it has been noted that the current energy and envelope codes for commercial buildings in Bahrain is not sufficient to reduce the energy consumption and its mandatory to move in the direction of more passive approach [4]. Therefore, studying this category of buildings is very important to evaluate the effectiveness of applying several passive-cooling strategies to enhance the thermal performance and reduce the overall energy consumption in hot dry climate conditions, particularly in Bahrain.

Accordingly, a typical detached social house was selected as a case study to assess and evaluate the selected passive cooling strategies in a very holistic way with reference to the building parameters such as geometry, orientation and building materials. This case study was selected because the majority of housing units in Bahrain have similar size and building construction materials. Every passive cooling strategy will be studied and optimized individually and then the best strategies will be combined in one optimized model to be studied and compared to the existing case study. Accordingly, the paper aims to look into the potential of applying the selected cooling passive strategies to enhance thermal performance and reduce overall energy consumption.

### *1.1 Factors Impacting Thermal Performance and Cooling in Buildings*

Generally, achieving thermal comfort in hot arid climate particularly in the summer should use the three-tier design approach namely: the first level is heat avoidance, second level is passive cooling and the third level is mechanical cooling. The first level is

to minimize the heat gain via several strategies such as shading and daylight, orientation, color, vegetation, insulation and control of internal heat sources. The second level is to lower the temperature via several strategies such as cooling with ventilation, radiant cooling and evaporative cooling. While, the third tier is mandatory when the above two tiers are not sufficient to maintain thermal comfort mechanical cooling which is the case of residential units in Bahrain and all the other buildings.

Furthermore, it has been noted that design with climate is one of the most important criteria to be considered with sense of place [6]. Therefore, this section will discuss two types of factors that affect the design and thermal comfort. The first factor is climatic conditions and the second factor is design parameters that are strongly affected and controlled by the climate and architect.

### *1.2 Climatic Condition Affecting the Internal Thermal Comfort*

Generally, the local climatic conditions have a significant impact on the indoor environment quality. Architects and builders have no control to override this factor but yet they can reduce their impacts by incorporating some special design treatment that acts smartly with the outdoor environment. The climate conditions are presented by numbers of elements such as outdoor air temperature, relative humidity, wind speed and direction and solar radiation. Based on the Directorate of Meteorology of Bahrain, the annual average temperature was 26.5 °C and monthly average maximum temperature was 41 °C on August and monthly average minimum temperature was 14.4 °C on January.

### *1.3 Design Parameters: Strongly Affected and Controlled by the Climate and Architect*

With reference to the first tier namely "heat avoidance", orientation, shading and day lighting, color and building design and building envelope.

Accordingly, other passive cooling strategies can be maintained to serve the second tier such as different ventilation moods and solar gains control.

## 2. Materials

This study used computer simulation tool via the Integrated Building Analysis Software System namely IES (Integrated Environmental Solution). This software is mainly to examine the impact of passive cooling strategies on the overall building thermal performance and energy consumption. Moreover, it is capable to assess the impact of efficiency measures, specifically passive cooling strategies that are added to the existing building such as external thermal insulation, glazing type and shading devices etc. on

the overall energy performance.

### 2.1 Base Case Description, Modeling and Performance

Late in 1984, Madinat Hamad was set up in northern Bahrain as a new affordable housing city for those residents who cannot afford to own a house in the city centre. This city has a high percentage of social housing when compared to the private housing units in the city and expected to grow more and more with the current progressive developments. Therefore, a typical 2 storey-housing unit located in Madinat Hamad among a new development of 48 standard housing units over a total plot area of 2.5 hectares (Fig. 1) has been selected as a case study for this research.



Fig. 1 Case study location in Bahrain.

The total built up area of the selected housing unit is 209 m<sup>2</sup> that spreads over 2 floors of 3.17 m height. This unit has 2 bedrooms and a 2 master bedroom, living room, family living, kitchen and two bathrooms, in addition to the garage and small garden (Fig. 2). The total external wall area is 421.6 m<sup>2</sup> and the total opening area is 104.02 m<sup>2</sup>. Therefore, the window to wall ratio is 40%.

The envelope of the house is made of typically used building materials, mostly from the Bahraini local building material market and it has 0.25 Air exchange per Hour (ACH). Moreover, the envelope thermal properties are characterized by U-value for wall, roof and glazing is equal to 2.746 W/m<sup>2</sup>·K, 0.53 W/m<sup>2</sup>·K and 3.26 W/m<sup>2</sup>·K. The walls are composed of 12 mm plaster, 200 mm concrete blocks and 20 mm gypsum

rendering without insulation. The roof is insulated and composed of 70 mm screed, bitumen sheet, EPS polystyrene and 200 mm reinforced concrete slab. The windows are made of aluminium frames with double coated glazing of 6 mm glass pans and 8 mm of air gap.

The internal loads, including occupants, lighting and other appliances are approximated to be 5 W/m<sup>2</sup> of sensible load and 3 W/m<sup>2</sup> of latent load. The thermal comfort zone is between 18 °C and 26 °C. The house was set to a daily profile associated with mix mode mechanical system that is used to provide cooling system but not heating as illustrated in Fig. 3. The weather file used to simulate the weather of Bahrain is that of Kuwait since it is the nearest to Bahrain in both location and weather conditions.



**Fig. 2** Case study floor plans.

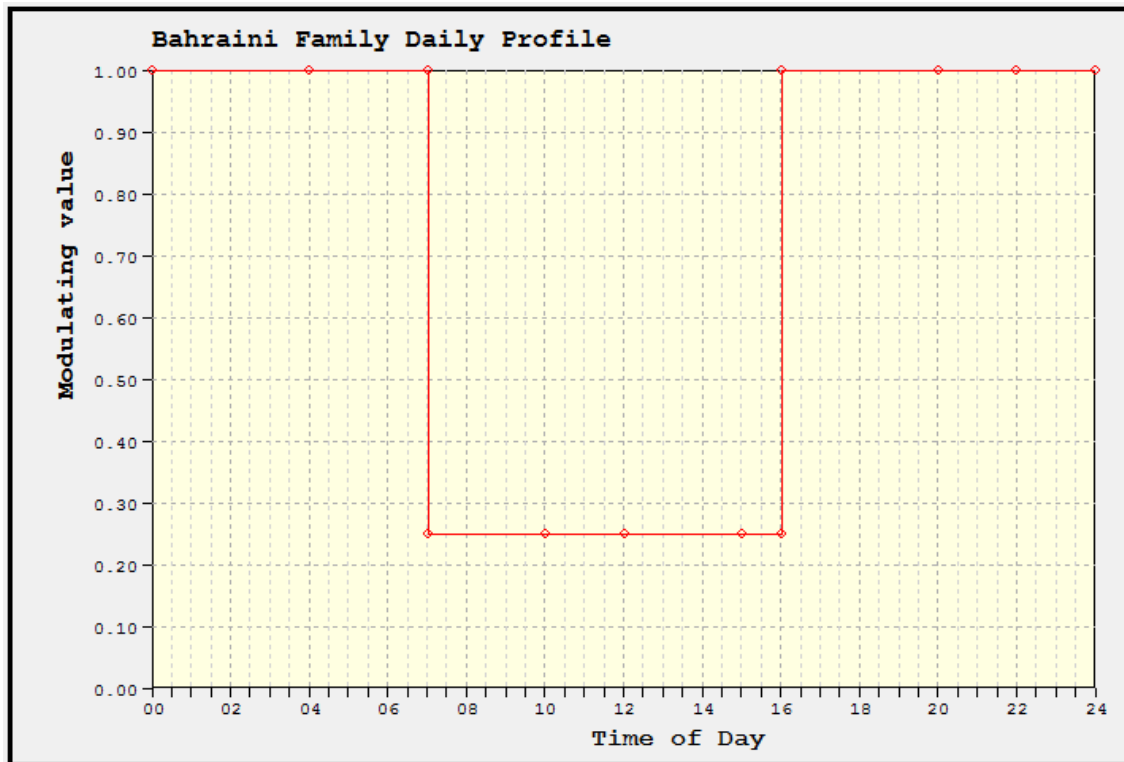


Fig. 3 Typical Bahrain family daily profile and HVAC cooling system.

## 2.2 Base Case Validation

To validate the case study a straight forward comparison must be done between computer simulation results and real occupied housing units that have similar size and construction materials. Therefore, the author studied 3 existing typical housing units that are similar to the case study in both size and construction materials. The average total energy consumption is equal to 166 MWh as per Electricity and Water Authorities of Bahrain 2013. On the other hand, the simulation result for the same unit is equal to 178.4 MWh. The difference between the model results and those recorded by the authorities was 7%. The differences between the two records are resulting from the variation between the tenants behaviour that will directly affect the overall energy consumption. Furthermore, the changes in cooling loads and energy consumption trends due to local climatic changes. However, a deviation of less than 10% is always acceptable between experimental and simulation models and can be ignored as highlighted

by Nikpour [7].

## 2.3 Theoretical Background: Review of Previous Research Work

Number of studies and research papers compared several passive-cooling strategies by using the IES software. Al-Sallal and Rais [8] indicated that using green roof system in Abu Dhabi-UAE performed as separation layer between the indoor and outdoor environment to protect the building from the excess solar radiation and consequently will reduce the heat gain. Furthermore, it was suggested that green roofing could reduce the need of the roof thermal insulation. Moreover, Passive cool roof is another strategy introduced by Dabaieh [9] which can reduce the cooling energy up to 53% in discomfort hours in residential housing units in Egypt by using designed algorithmic hybrid matrix. This paper specifically highlights that using vault roof with high albedo coating combined with natural ventilation will reduce the cooling energy and increase the human comfort.



Toe and Kubota [10] indicated that cross ventilation through small courtyards is very effective for high thermal mass construction through nocturnal ventilative and radiative cooling. The paper draws attention that cross ventilation can reduce the temperature of the outside before entering the house that will reduce the energy required for cooling purposes. Furthermore, Benhammou [11] stated that the vernacular wind tower and wet surfaces is one of the most effective passive cooling strategies in hot climate. However, this paper point out that combining Earth Air to Heat Exchanger (EAHE) and wind tower will result a better cooling energy reduction when compared to the conventional wind tower.

Yassine and Abu-Hijleh [12] found out the most effective shading device in Dubai is the horizontal louvers that can reduce up to 33% when applied on all facades. However, the maximum reduction can be achieved by implementing horizontal louvers on the South followed by both West and East orientation.

Similarly in Spain, a study conducted by Ralegoankar and Gupta [13] concluded that passive solar design and altering of solar contribution of solar

to total cooling of buildings directly related to ratio of wall to window, orientation of the building, window details and proper sunshade to control the amount of solar radiation.

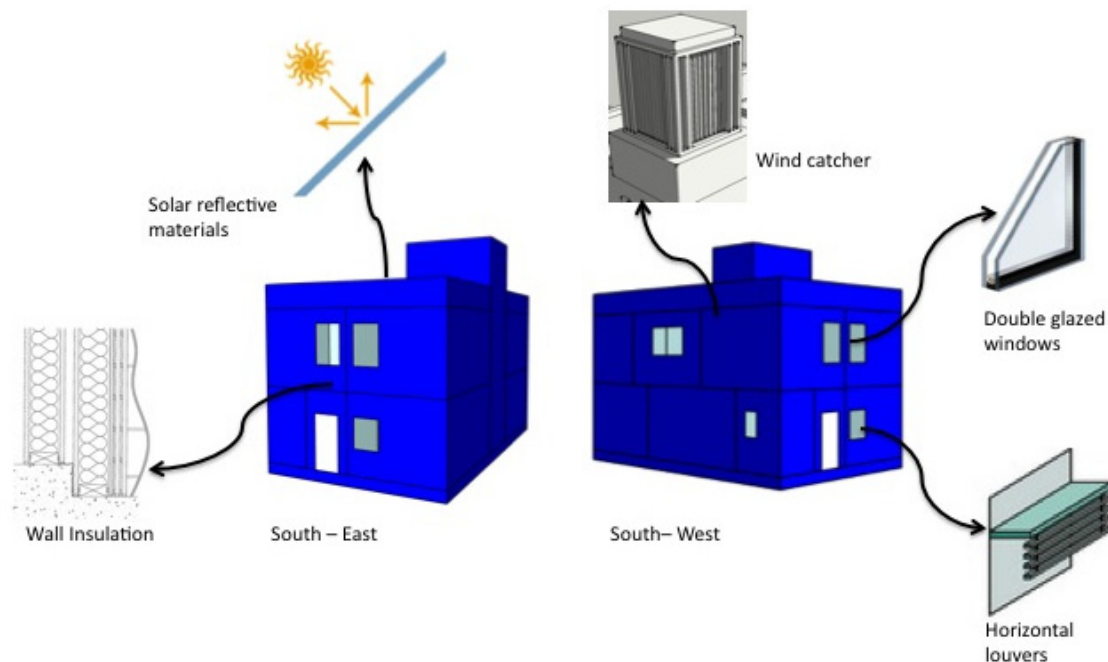
Finally, it was concluded from many papers that passive design strategies based on both internal temperature and solar irradiation set points is more efficient than implementing strategies separately.

#### *2.4 Applicable Passive Cooling Strategies*

Several passive cooling strategies are applicable to the case study as shown in Fig. 4 followed by a brief description of each strategy and justification of use based on the sun path diagram and local climatic condition.

#### *2.5 Insulation*

The insulation of wall and roof is one of the most effective ways to reduce the heat loss or gain via the building envelope. Therefore, enhance the indoor environment and the thermal comfort because wall and roof are the largest exposable surfaces to the solar irradiation. Based on the available insulation materials in Bahrain, an external thermal insulation composite



**Fig. 4** Schematic of the adopted passive cooling design strategies.

system was used with a U-value of  $0.21 \text{ W/m}^2\cdot\text{K}$ . While the insulated roofing polymeric membrane is lacquer coated waterproofing and it is characterised by resisting UV irradiation with a U-value of  $0.44 \text{ W/m}^2\cdot\text{K}$ .

### 2.6 Double Glazed Windows

Generally, in building most heat gain or losses comes from windows and openings. However, in the case study, the total opening area is  $104 \text{ m}^2$  and total external wall is  $421 \text{ m}^2$ . Therefore, the window to wall ratio is 24.7% that is relatively low and will not achieve dramatic changes in energy reduction. Moreover, it was highlighted by High Performance building Organisation [14] that fenestration having lower than 15%-20% of floor area is found to be inadequate for both ventilation and lighting in hot dry climate while in the selected case study it is 49.7%. Therefore, the single glazing was replaced by double glazing with 12 mm cavity containing Argon gas.

### 2.7 Natural Ventilation

Natural ventilation is vernacular architecture which is always found as wind catcher or cross ventilation that are efficient in reducing energy consumption and providing a fresh and healthy indoor environment. Based on the air flow and site analysis, in the case study, the best to locate the wind catcher on the north-west direction in order to catch the cool and fresh air and cross ventilation can be encouraged in the kitchen to assure the freshness and hygiene of the air circulation.

### 2.8 Shading Devices: Louvers

Based on several studies, the horizontal louvered shading device was implemented on the West and East façade in order to block the sun gain during the summer. Taleb [15] suggested that horizontal louvers are more efficient when tilted to  $45^\circ$  because when the sun is high, the louvers will allow transmit light and neglect the heat.

### 2.9 High Reflective Colors Coatings

High reflective colours coating for walls and roof is very effective in minimising radiation losses. This strategy will affect the temperature of the indoor spaces via reducing the heat transmission and will consequently reduce the cooling loads. Taleb [15] stated that several studies showed that temperature was reduced up to  $4^\circ\text{C}$  by using shades of grey or darker colours. Therefore, it is anticipated to have more reduction in temperature. In addition to that, it was noted that using a paint with 61% reflection of the spectrum can have more effect on energy saving.

Furthermore, there are more passive cooling strategies such as green roofing and evaporative cooling that are not applied on the selected case study. However, green roofs are known as energy conservation tool and it acts as powerful insulation material. However, it needs a lot of care and irrigation to survive and perform well. Therefore, it will not be a smart and efficient idea to have green roof in hot climate with the presents of water scarcity.

## 3. Results and Discussion

To evaluate the passive design strategies, different tools and softwares are required but due to the time limitation, the study focused on enhancing the building envelop namely walls, roof and fenestration as well as the usage of high reflective colors coatings. Therefore, it was noted that overall energy consumption could be reduced up to 10% and the chiller energy up to 21.6% when compared to the base case. This significant result can be achieved by applying external thermal insulation composite system with a U-value of  $0.21 \text{ W/m}^2\cdot\text{K}$ . At the same time, the insulated roof is characterised by resisting UV irradiation with a U-value of  $0.44 \text{ W/m}^2\cdot\text{K}$ . While the windows are composed of double glazing with a 12 mm cavity filled by Argon gas with a U-value of  $1.69 \text{ W/m}^2$  and SHGF of 36%.

Furthermore, it is anticipated that applying more

passive strategies such as horizontal louvers shading devices, natural ventilation and specifically cross ventilation and wind catcher that based on the vernacular design strategies learned from the past will reveal more reduction in cooling energy and will enhance the human thermal comfort.

#### 4. Conclusion

Passive cooling design techniques in hot arid climate are only successful if all the design elements are able to block the heat during the summer season. In the case of Bahrain, the aim of passive design strategies is to reduce the mechanical cooling energy consumption and to keep the indoor environment within the comfort thresholds as per ASHRAE standards. This paper shows that upgrading the building envelop can reduce the energy dramatically up to 21.6% via using the external insulation system, insulated roof and double-glazing. The study used a typical existing social housing unit in Bahrain. The case study has been validated by comparing the energy records given by Electricity and Water Authorities in Bahrain and a simulation model created in IES software that is the main simulation tool used in this study. Last but not the least, it can be argued that the results of this study is not limited to Bahrain but can be applied in any location that has similar local and climatic conditions.

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