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Lessons Learned from the First Passivhaus Building in Qatar

May Khalfan[1]

[1] *Department of Architecture and Interior Design, University of Bahrain, P.O. Box 32038, Bahrain*

Abstract

Energy efficient models have become the path to reduce energy consumption and Greenhouse gas emissions in the built environment in many developed countries. According to the Energy Performance of Buildings Directive (EPBD), new buildings constructed within the European Union (EU) countries are expected to be nearly zero energy buildings (nZEBs) by 2020, while new public buildings are expected to adhere to this target by 2018. The Passivhaus approach has been identified by several researchers as a possible roadmap to achieve nZEBs. The meticulous engineering and high standards of the Passivhaus building fabric, in addition to the high comfort levels, are the main reasons behind the success and widespread of the standard. Recently, in 2013 the Passivhaus principles have been applied to an experimental residential project in the hot and arid climate of Qatar. The project is composed of two identical buildings, one built according to the Passivhaus standard and the other according to normal practices in the country. The thermal performance and comfort levels of both buildings were assessed through dynamic simulation and on-site measurements. Results indicated that at least 50% reduction in annual operational energy, water consumption, and CO2 emissions were achieved in the Passivhaus model in comparison to the standard model. This paper aims to highlight the lessons learned through the Passivhaus project; first by exhibiting the Passivhaus criteria that have been met, second by showcasing the outcomes of the project, and third by displaying the barriers and difficulties that have been associated with building according to the standard in Qatar. Finally, recommendations and general guidelines are suggested towards a possible adoption of the Passivhaus standard in Qatar and the Gulf Cooperation Council (GCC) countries

Keywords

Passivhaus ***;*** *Hot and Arid Climates****;*** *Energy and Thermal Comfort*

1. Introduction

Buildings have been renowned as the main contributor to energy use globally, almost 40% of energy is consumed within the commercial and residential sectors alone (Laustsen, 2008). The International Energy Agency (IEA) publication, *"Tracking Clean Energy Progress 2017"*, reported that two-thirds of the countries have not yet established or enforced energy codes. Additionally, it was highlighted in the report that the means for reaching the 2° target would be through employing energy efficient measures in the built environment (IEA, 2017).

Currently, with the depletion of energy sources and with the alarming signs of climate change, developed nations are striving to integrate mitigation and adaptation plans in their legislation. Based on the EPBD, buildings in the EU are required to meet nearly-zero energy performance by 2020, while public buildings are expected to meet the target by the end of 2018. Furthermore, the 20-20-20 EU targets include a reduction in greenhouse gas emissions by 20% from the 1990 level, an increase by 20% in energy efficiency within the building sector and a 20% increase in investment in renewable energy sources (European Commission, 2018). Energy efficient models today are recognized by many researchers as the blue-print for future-proofing buildings (Carlucci, Zangheri and Pagliano, 2013; Hopfe and McLeod, 2015; Mlecnik, Kaan and Hodgson, 2008; Schnieders and Hermelink, 2006).

2. Passivhaus standard

Passivhaus buildings are associated within a number of studies as ultra-low energy and nearly zero energy buildings (Carlucci, Zangheri and Pagliano, 2013; Hopfe and McLeod, 2015). The careful engineered German Passivhaus standard accounts for very stringent building systems. It Incorporates five main pillars; (a) highly insulated shell, (b) a well-ventilated building utilizing an effective heat recovery ventilation system, (c) high definition glazing and well-insulated fenestration frames, (d)An air-tight envelope and (d) the absence of thermal bridges (PHI, 2015).The notion behind developing the Passivhaus standard actually incorporated a number of energy efficient measures that have been adopted throughout different times, such as traditional architectural solutions and experimental buildings that appeared after the first oil crisis in the 1970s. A Passivhaus building is defined as "… a building, in which thermal comfort (ISO 7730) can be provided solely by postheating or postcooling of the fresh air flow which is required for good indoor air quality (DIN 1946) - without using recirculated air in addition." (Passepedia, 2017).

The German Passivhaus buildings spread beyond Germany to reach most parts of Europe through a number of profile-raising projects such as the Cost Efficient Passive Houses as European Standards project(CEPHEUS), the Passive-On project, the Pass-Net project, the PEP project and the E-retrofit-kit (Berrutto, Sutherland and Cadima, 2008). The objective of the projects was to study the performance of the buildings in different climatic conditions. In the CEPHEUS project over 200 dwelling units were constructed according to the Passivhaus standard in five different countries across Europe; France, Germany, Austria, Switzerland, and Sweden. The findings were based on monitored data collected from 100 units in three participating countries; Germany, Austria and Switzerland, the results showcased the possibility of adopting Passivhaus technology in various locations other than Germany (Schnieders and Hermelink, 2006).

The Passive-On project similarly was carried out to study the feasibility of applying Passivhaus standards in the warmer parts of Europe. Five countries; France, the United Kingdom, Spain, Portugal, and Italy took part in this study. Virtual residential models were created for each location based on the specific climatic conditions. The results indicated that further considerations would be necessary to achieve Passivhaus criteria, especially in terms of creating a cooling load and thermal comfort benchmarks and a relaxed infiltration rate (Passive-On, 2007). The Pass-Net and the PEP projects promoted the spread of the Passivhaus standard through creating networks and providing necessary information for the public and specialists (Berrutto, Sutherland and Cadima, 2008). The E-retrofit-kit was created to endorse Passivhaus retrofitting and it mainly targeted the retrofit of social housing projects in Europe (The E-Retrofit-Kit, 2007).

Other examples of individual projects were carried out in different parts of Europe where, in most cases, a comparative study was carried out to asses the performance of Passivhaus buildings against other energy efficient building such as low energy buildings, or against a conventional building that followed the building standards in each country. The outcomes of the studies focused on the energy savings and thermal comfort level achieved through applying the Passivhaus standard, furthermore, the risks and challenges were highlighted in some studies such as the risk of overheating and the challenge to build and operate a Passivhaus building (Audenaert, De Cleyn and Vankerckhove, 2008; Badescu and Rotar, 2012; Brunsgaard, Knudstrup and Heiselberg, 2012; Ridley et al., 2013).

The concept was also adopted by other concerned organizations in nations such as the US and Denmark but was further altered to meet the specific climatic requirements based on the geographical location (PHIUS,2018; Mlecnik, Kaan and Hodgson, 2008). Although the standard was initiated in cold or moderate climates, a number of experimental Passivhaus projects were established in hot climates. Examples of Passivhaus buildings in hot regions are found in mainly in the Asia and USA , such Energy+ Building in Dubai, the Passivhaus project in Qatar, the Austrian Embassy in Jakarta, and the Le-Bois house in Louisiana,USA (Brumana, Franchini and Perdichizzi, 2017; Bryant et al., 2013; Oettl, 2014; Saft and Helton, 2012). This Paper aims to highlight the Qatari Passivhaus experience through presenting the outcomes and challenges associated with building according to the Passivhaus standard in hot and arid climates.

2.1. Qatar Passivhaus Experimental project

Qatar Peninsula, according to the Koppen-Geiger climate classification, is located in a hot desert arid zone, where annual temperatures are greater than 18°C and the annual precipitation is lower than 250mm (Peel, Finlayson and McMahon, 2007). Based on Qatar's meteorology department (QMD, 2016), the annual average temperature is around 27.3°C and the annual average relative humidity levels are around 61%, and the annual average rainfall level is around 6.6 mm (see Figure 1).

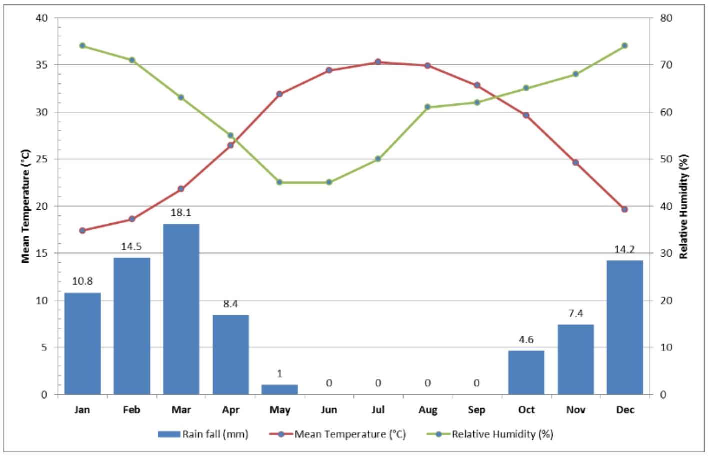


Figure 1. Qatar monthly average rainfall, mean temperature and relative humidity (QMD, 2016)

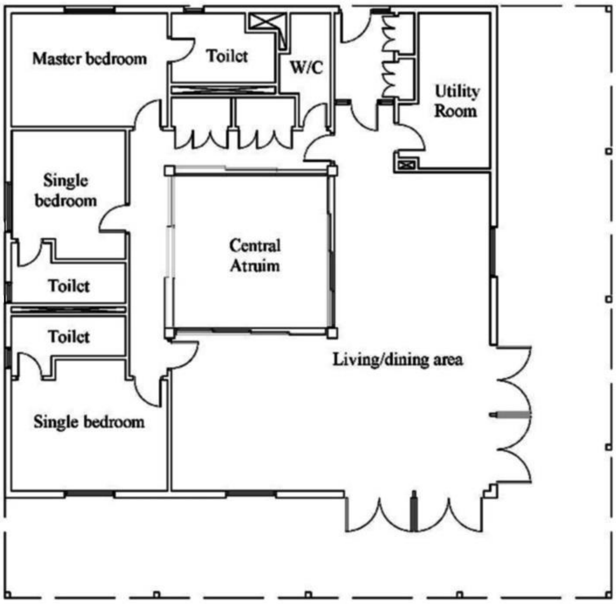
Qatar along with the United Arab Emirates (UAE) are considered the two leading countries in the Gulf Cooperation Council (GCC) countries in adopting energy efficient policies (Willis, 2015). Although Qatar has not finalized a green building code yet, it has shown a number of efforts to enforce green practices, such as founding Qatar Green Building Council (QGBC) and initiating the Global Sustainability Assessment system, in addition to setting sustainability and energy targets for the country (Meltzer, Hultman and Langley, 2014). As well as erecting a number of sustainable projects which include energy efficient measures such as the Passivhaus experimental project.

The Qatar Passivhaus project was initiated in 2013 by Qatar Green Building Council (QGBC) and a real estate developer, BARWA real estate company. The high-performance levels of Passivhaus buildings were the trigger towards experimenting with the feasibility of the standard in the region. A team of experts was assigned to launch the project; QGBC, the AECOM group from London, KAHRAMAA, the Qatar General Electricity and Water Corporation, BARWA real estate and other partners such as ALMCO and Qatar Solar Technologies (Bryant et al., 2013). A site in Barwa development was dedicated to the project where the two identical buildings would be the specimen for the project.

2.2. Project Description

The project was composed of two identical buildings, the Passivhaus villa (PHV), and the business as usual standard villa (STV), and was designed to house a family of 4 members. The villas comprised of the following; a living/dining space, 3 bedrooms, and associated service areas (see Figure 2).

Additionally, the buildings had a central courtyard and a patio which shaded the two main entrances of the villas. The two villas were located in a mixed-use development Barwa city, which was situated 15 km away from the capital



Doha (

Figure 3**Error! Reference source not found.**). The design of the villas respected the traditional architecture of the region through three main aspects; (a) a central courtyard, (b) a colonnaded patio and (c) the provision of motif movable panels around the courtyard that visually restricted the view towards the private section of the villas.

Although the two buildings were identical in their layout, the PHV was upgraded to reach to Passivhaus requirements and included the following sustainable features:

- An intensive 300mm insulation layer around the outer fabric of the building, walls, and roof
- High definition glazing panels with low U –values
- Energy efficient lighting system
- Energy efficient cooling systems
- Heat recovery ventilation system with high efficiency
- Greywater system for irrigation
- Photovoltaic panels mounted on the roof of the building
- Operable shading louvers on the courtyard skylight
- An air-tight building envelope with minimum thermal bridges

Figure 2. Barwa city location (Google Maps, 2016)

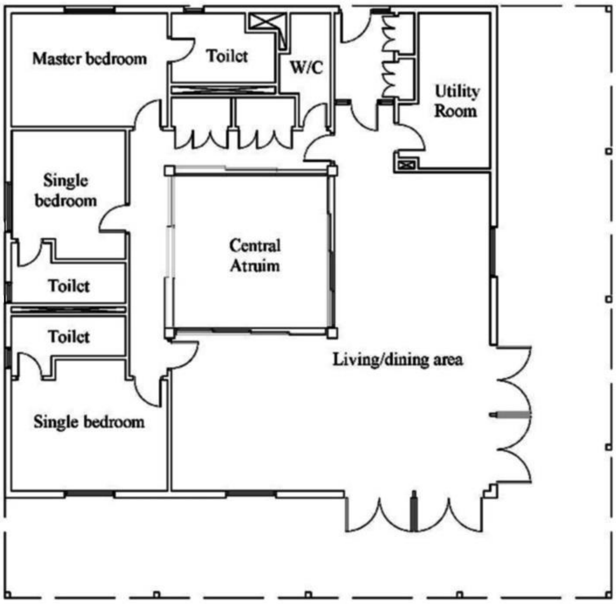


Figure 3. PHV and STV typical layout

2.3. Methodology

The performance of the villas was assessed through real-time measurements and thermal simulations. Two sets of virtual models were created for each villa, one representing the villa with occupancy and the other without. The villa's outer fabric configuration assumed occupancy and assumed household appliances usage were simulated in the software Integrated Environmental Solutions –Virtual Environment (IES-VE). IES-VE is an innovative 3D sustainable analysis software pack used to measure and manage sustainable, efficient and affordable built environments (IES, 2018).

Two weather sets were used, one representing the current climatic conditions and the other representing future climate. As wether files for Qatar were not readily available, Meteonorm a comprehensive meteorological reference weather generator tool was used to acquire the present day weather data (Meteonorm, 2016). For future projections, an excel worksheet based software package developed by the Sustainable Energy Research Group at Southampton University was used. The Climate Change World Weather Generator (CCWorldWeatherGen) is used to generate future weather files according to IPCC scenario A2, for the years 2020, 2050 and 2080 (SERG, 2015). In this paper, the comparisons will be presented for the present time and for 30 years from now, i.e. the 2050 weather data.

Furthermore, to study the performance of the building fabric, IES-VE was used to evaluate the robustness of the building fabric. This was assessed by de-activating the cooling option in IES-VE and evaluating the indoor temperature in both villas while conducting a comparison with the expected outdoor temperature.

Initially, both villas were to undergo an extensive monitoring period of around two years. During the first six months, the villas' performance would be assessed without occupancy. Later on, occupant behavior will be further studied, first by monitoring their behavior without taking an induction on how to operate a Passivhaus building effectively, and the raming period would be assessed after providing the induction to the occupants. Unfoutunalilty, the monitoring process was not completed as originally planned. However, both villas went through a monitoring period of several weeks during the summer and winter of 2016/2017. Internal indoor temperatures and relative humidity levels were recorded in the habitable spaces (living room and bedrooms) using data loggers that captured the indoor environment.

Additionally, three meter readings were used to assess the energy use in the villas, further interpolation was necessary to envisage the annual energy use in the villas.

2.4. Passivhaus criteria met by Qatar Passivhaus project

According to the Passivhaus standards, stringent criteria need to be met to ensure both a reduction in energy use and a high degree of thermal comfort. Based on the simulation results, the Passivhaus in Qatar has met the stringent Passivhaus criteria in all criteria except for primary energy use, however, it is worth mentioning that the energy generated through the PV panels is sufficient to fully meet the load of the PHV.

In addition, Qatar PHV has failed in meeting the requirement for air-tightness. Based on the blower door test carried out at 50 Pas n_{50} in the PHV, the recorded infiltration rates were higher than the Passivhaus standard by around 40%. Other requirements such as the cooling demands, thermal comfort levels and the thermal transmittance of external surfaces were according to the standard (see Table 1).

Table 1.Qatar Passivhaus villa vs. Passivhaus standards based on simulation results

Criteria	Passivhaus standard	Qatar PHV
Specific primary energy	≤120	135/(-186)[1]
Specific cooling demand (kWh/m^2)	≤ 27	23
Overheating frequency (% of time operative temperature above 25°C)	10/0[2]	0

Table 2 continued

Moisture level limit (% of time moisture content above 12 g/kg)	20/10[2]	3
Opaque surfaces' U-value (W/m^2k)	0.25	0.08
Transparent surfaces' U-value (W/m^2k)	1.0-1.20	0.8
Air tightness (@ 50 Pa)	≤ 0.6	0.9
1 Negative energy demand as a result of excess energy generated through PVs 2 Without active cooling/with active cooling		

2.5. The thermal Performance of the PHV and the STV

The PHV and STV thermal performance assessment were carried out though investigating three main performance indicators, (a) energy use, (b) indoor thermal comfort and (c) the thermal performance of the building envelope. Following is a summary of each performance indicator.

a. Energy use: According to the obtained results, it was evident that the PHV had consumed at least 50% less energy than the STV. The PHV predicted energy use through IES was around 21,000 kWh annually, while the STV energy usage was estimated to be around 44,500 kWh annually.

Additionally, with the consideration of the energy generated through the PV panes, the whole loads of the PHV could be met with a surplus load that could also be transferred to the local grid.

Figure 4 and Figure 5 illustrate the energy use in both villas in term of small power, lights and HVAC system usages. It is evident through the figures that most of the loads in both villas are exerted by the HVAC system. Furthermore, the measured HVAC energy use is less than the predicted energy use in the PHV, and vice versa in the STV, as the measured cooling demand is more than the estimated cooling demand through IES.

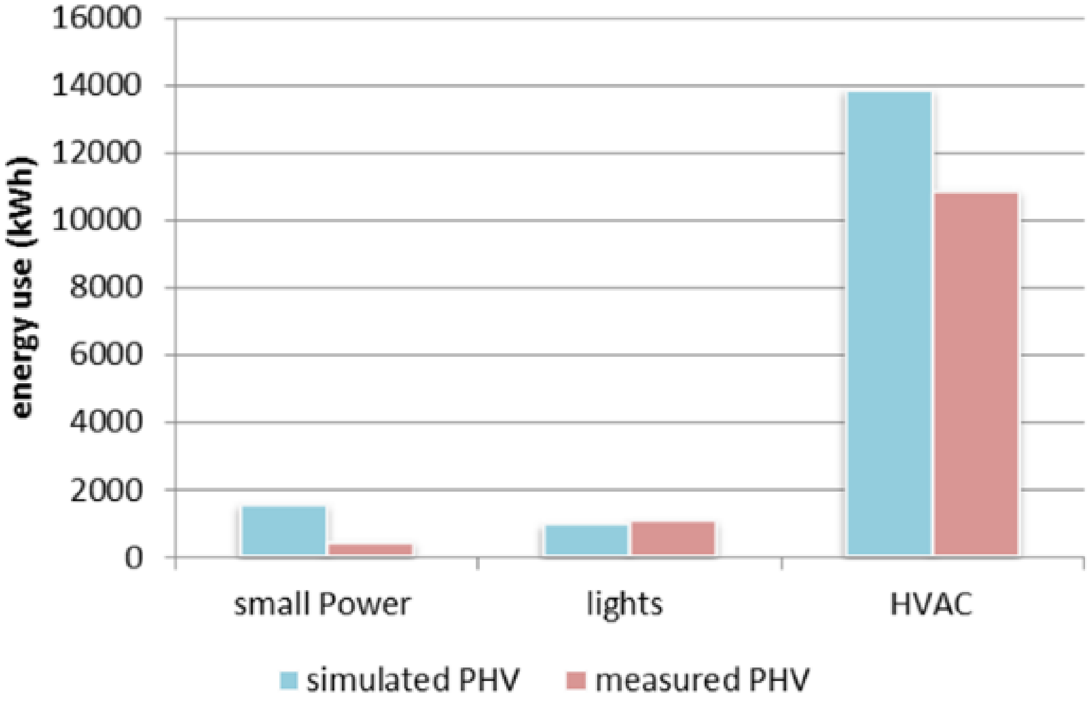


Figure 4. PHV simulated and measured energy use

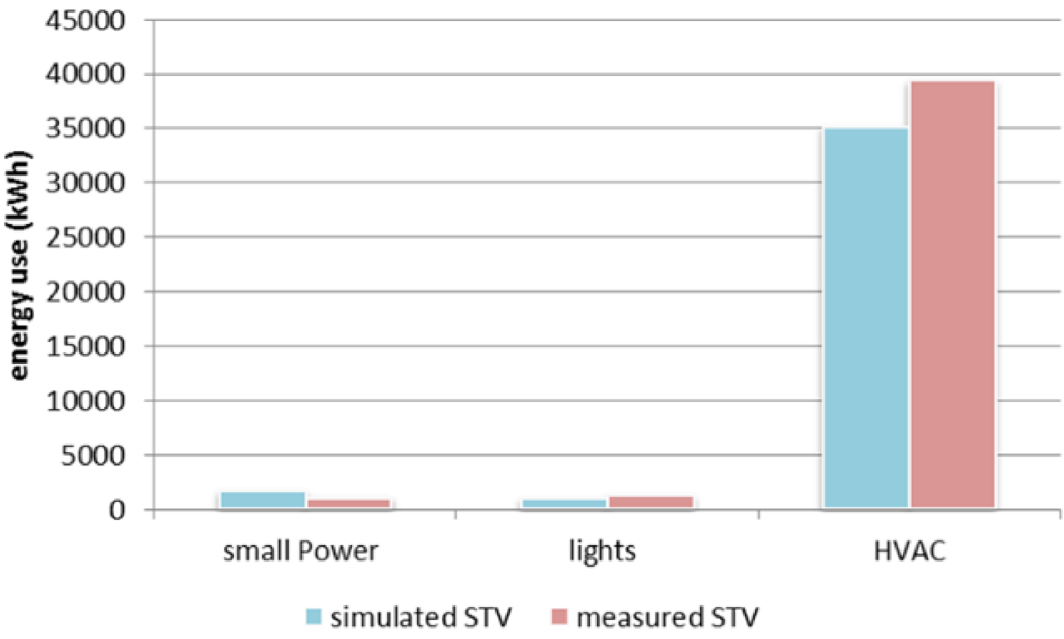


Figure 5. STV simulated and measured energy use

Differences between the measured and recorded data have been found, this may have been caused due to the manipulation of the setpoint temperature, or by the mispositioning of the data loggers or a possible error in simulation and calculations. Figure 6 illustrates the measured and predicted energy use in terms of HVAC use.

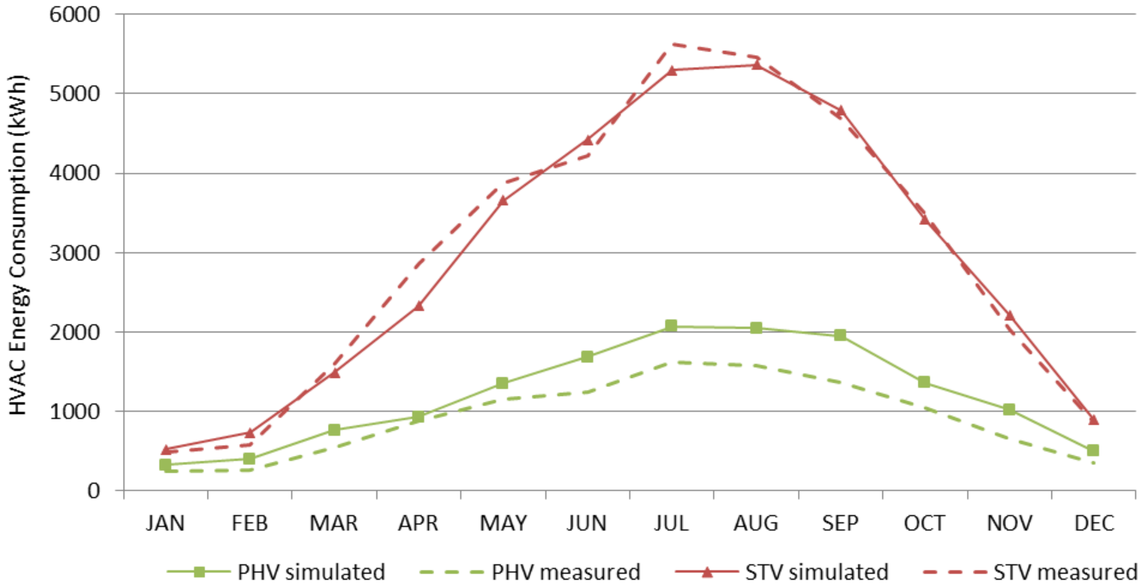


Figure 6. PHV and STV measured and predicted HVAC energy use

The present and future scenario indicate that the PHV will continue to use 50% less energy compared to the STV and that its full loads could still be met by the energy generated through the PV panels (see Figure 7).

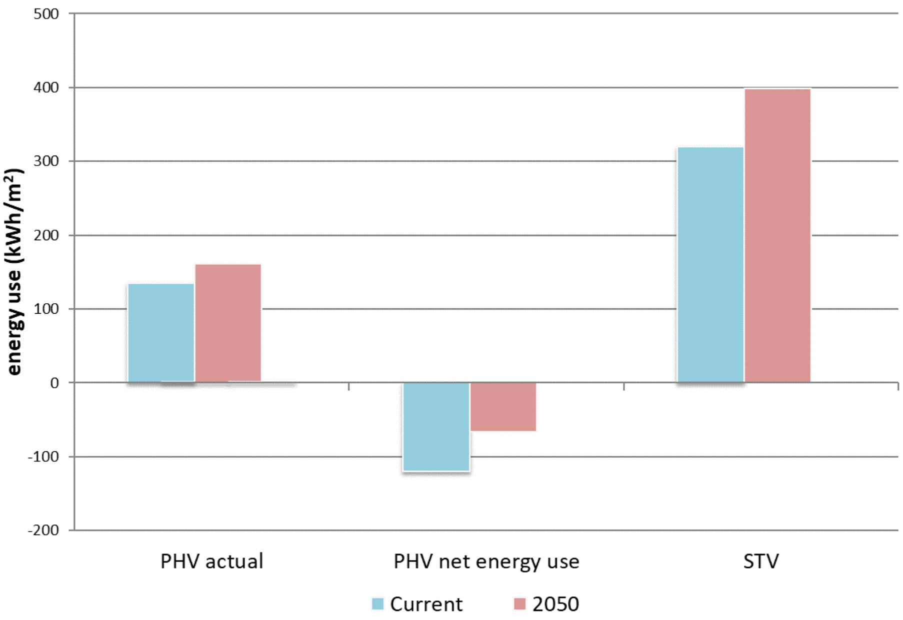


Figure 7. Annual energy use in the PHV and STV in the present time and the future (2050)

b. Indoor thermal comfort: Both villas showed a satisfactory level of thermal comfort, this was assessed through the data loggers installed in both villas and through simulation. Figure 9 illustrates the measured and predicted indoor temperature for the living space, both with and without occupants.

It should be noted that in the PHV a higher level of thermal comfort is expected especially throughout the projected year 2050. As presented in Figure 11, the occupants of the STV are expected to feel slightly warm during the hottest day of the year. This is expressed by the PMV figures of above (+1) during specific times of the day.

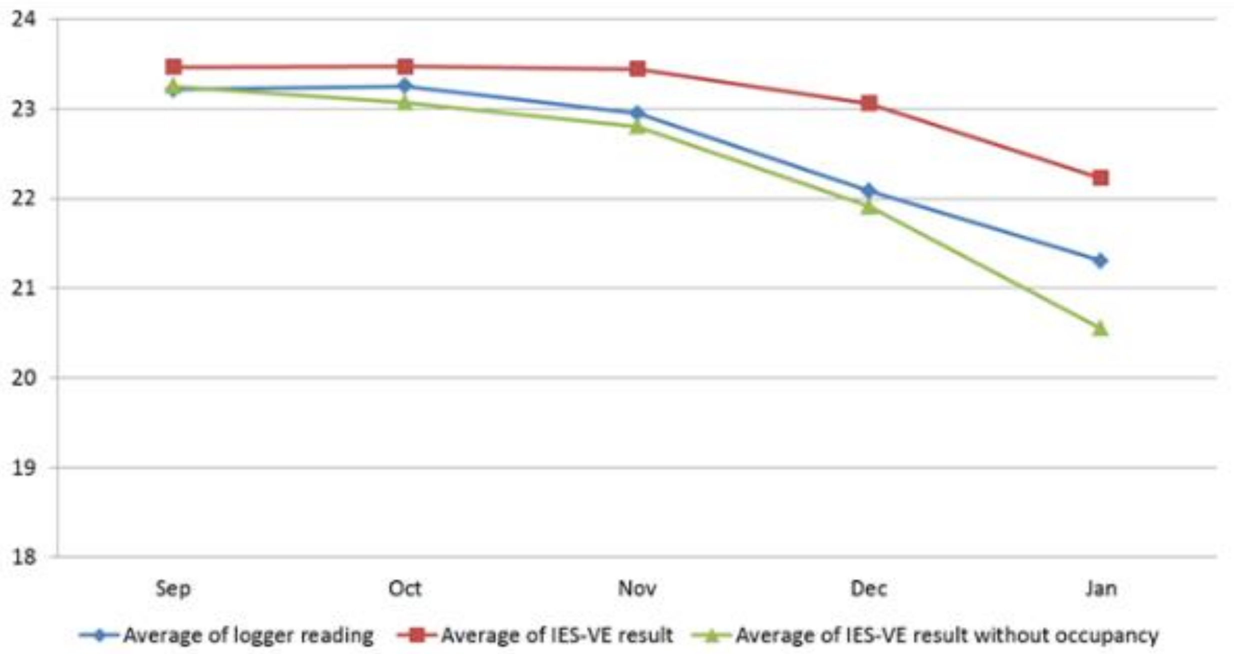


Figure 8a. Average measured and predicted monthly indoor temperature in PHV living room

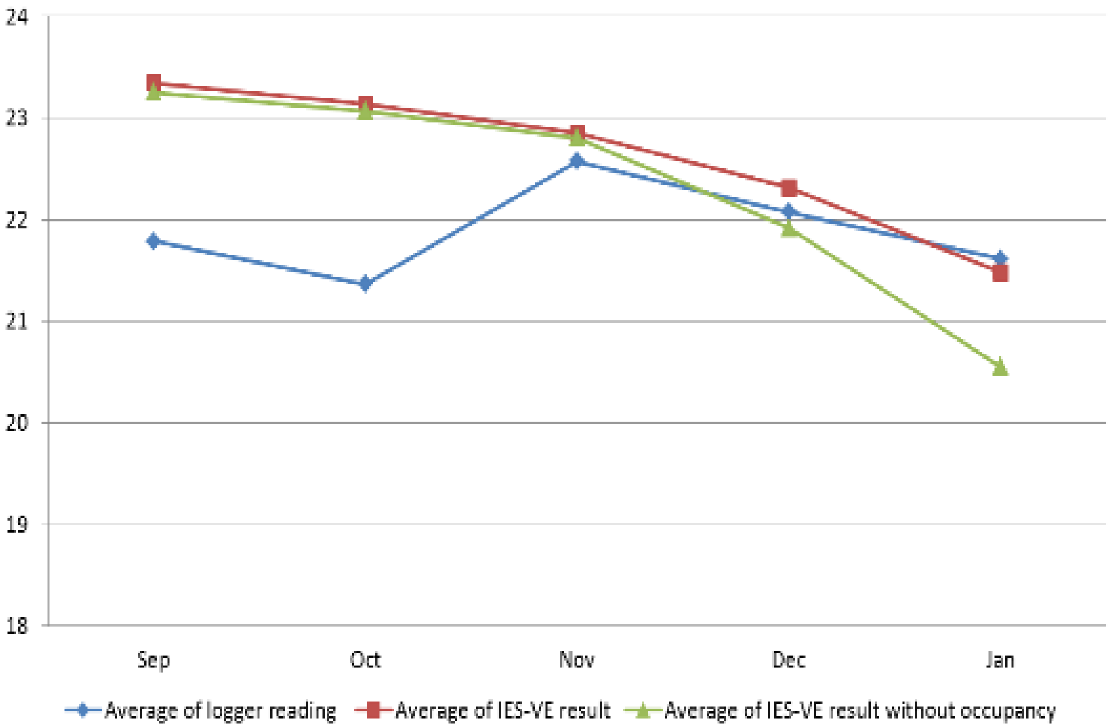


Figure 9b. Average measured and predicted monthly indoor temperature in STV living room

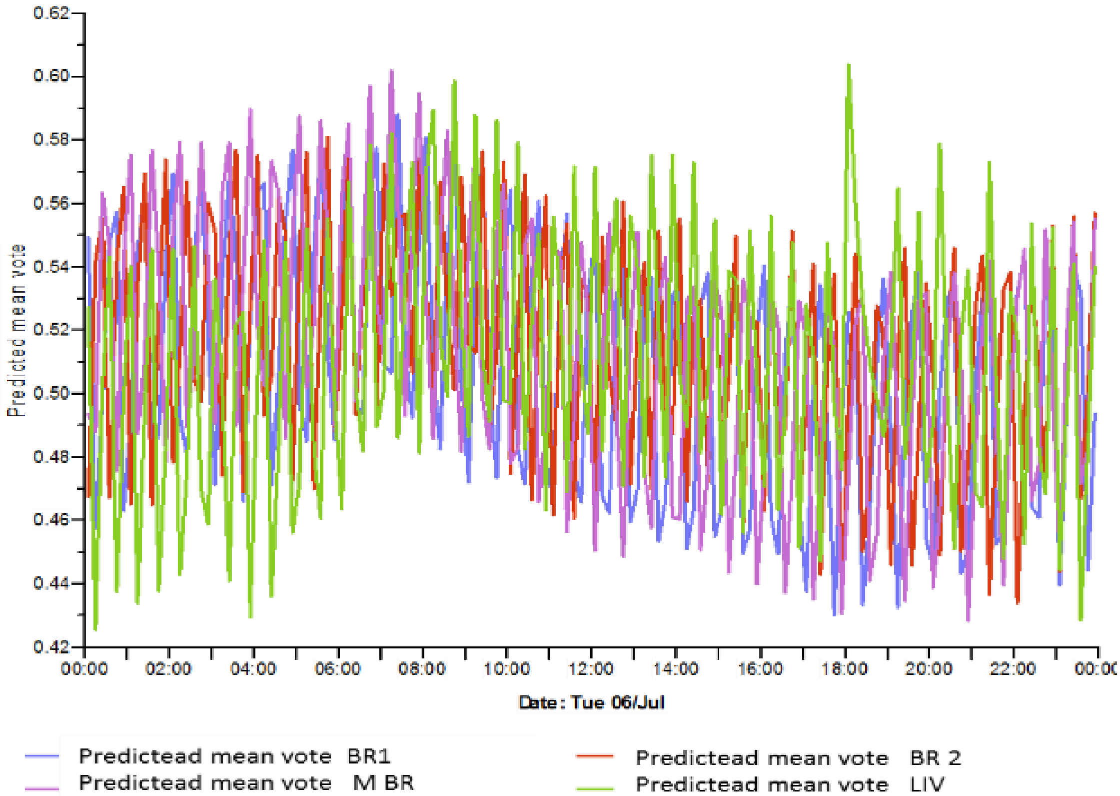


Figure 10a. PMV during the hottest day (PHV)

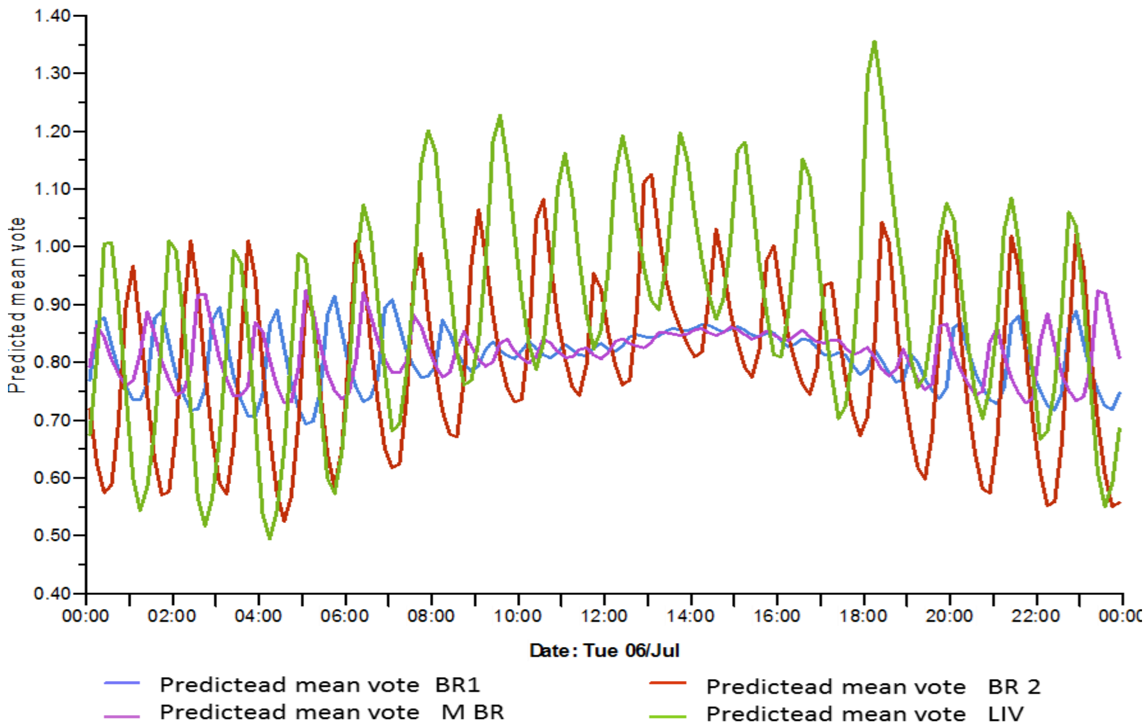


Figure 11b. PMV during the hottest day (STV)

c. Thermal performance of the building envelope: The results obtained through IES-VE while de-activating the cooling system in both villas indicated that the outer fabric of the PHV was much more resistant to thermal conductivity and that the indoor temperatures were maintained well below the extreme outdoor dry bulb temperature during the hot season. However, in the STV the indoor temperatures were above the outdoor dry bulb temperature during the hotter months (see Figure 12 and Figure 13).

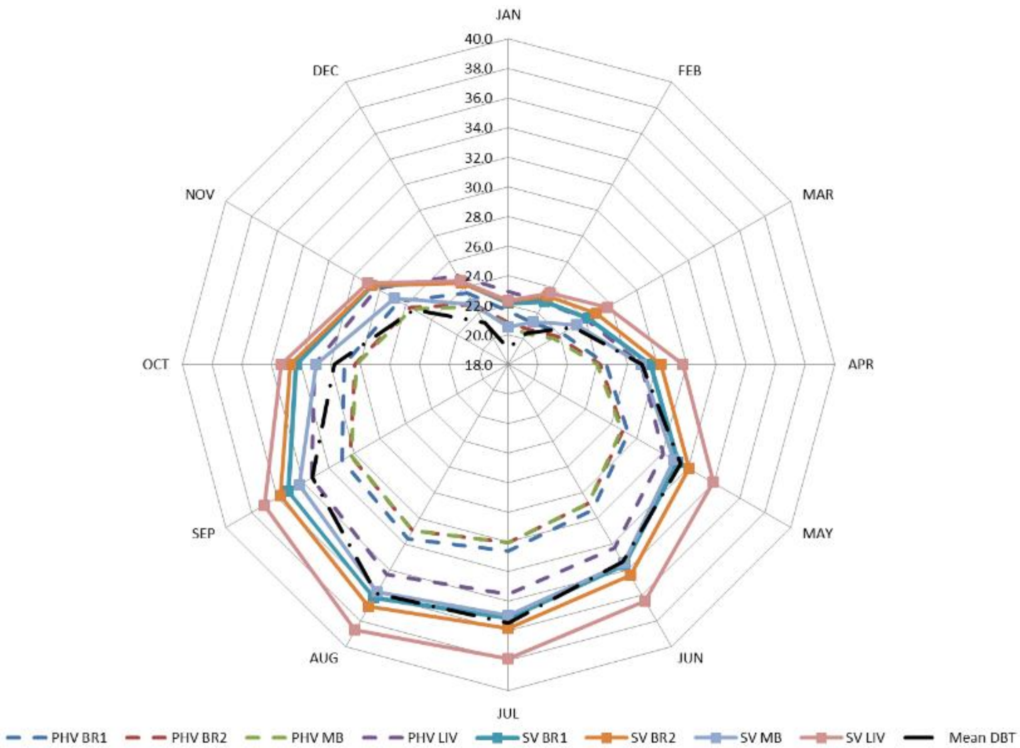


Figure 12. PHV and STV thermal envelope performance in the present time

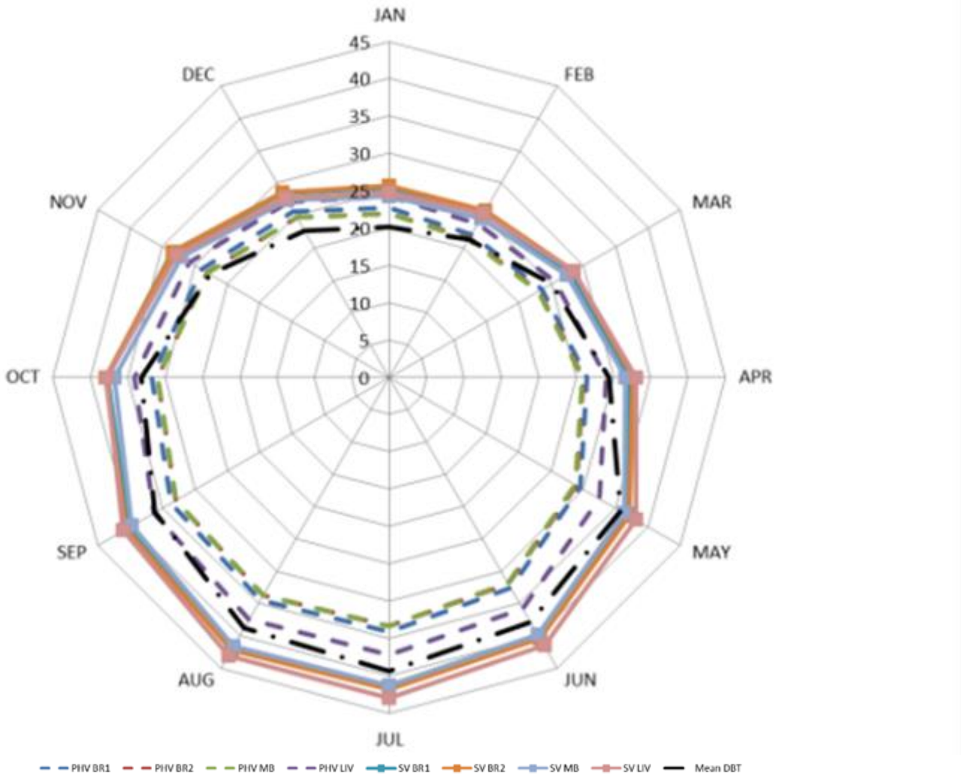


Figure 13. PHV and STV thermal envelope performance in the projected time (2050)

2.6. Challenges in implementing the Passivhaus Standard in Qatar's PHV

Although the PHV did not reach full Passivhaus standards, its design, construction, and commission involved rigorous specifications that were associated with various challenges. Starting from the design stage; with the lack of expertize in Passivhaus design, QGBC had to acquire a team of experts to deliver this project, which included AECOM, KAHRAMAA; the Qatar General Electricity and Water Corporation, BARWA real estate and other partners such as ALUMCO and Qatar Solar Technologies (Alumco, 2014). AECOM group of London were chosen to design the Passivhaus villa, owing to their expertize in Passivhaus design. A virtual dynamic model of both the PHV and the STV were created in IES-VE to study the thermal performance of the buildings under hot climates. Additionally, the Passive House Planning Package (PHPP) was also used to calculate the energy balance and annual energy demand in the villas, and to adhere to the Passivhaus standard certification process.

Upon completion of the drawings, and once commencing the construction, several challenges arose; first, due to the physical allocation of the design firm, continuous supervision by the architect was not feasible. However, QGBC team did not spare any effort to closely monitor the construction process. Second, construction workers were not customized to constructing airtight buildings, this resulted in a number of issues, which eventually affected meeting the airtightness benchmark of the Passivhaus standard. As mentioned in section 1.1, an airtight envelope with minimum thermal bridges is required to achieve Passivhaus standards. During the blower door test, several airgaps were found. the first was between the building envelope and piping and plumbing work, the second was found between the outer envelope and external fenestrations.

Finally, the third air gap was also detected along the ducting work. The PHV team tried to rectify these errors through the application of sealing materials, the airtightness of the envelope was reduced to the minimum, but still not the Passivhaus benchmark. The PHV yet stands as an example, of probably, the most airtight villa in Qatar.

Based on the literature review constructing to reach Passivhaus standard is one of the challenges that have been recorded especially outside of Germany (Müller and Berker, 2013). This is merely due to the fact that the standard was originally nourished in this region and that the workers have gained enough skill to construct buildings to meet the rigorous Passivhaus criteria.

Other challenges associated with the construction phase could also relate to the purchase of the energy efficient building systems, such as the cooling and the ventilation system. The purchase and implementation of a heat recovery ventilation system within buildings in the GCC is not common, this imposes two main issues, the first is related to the availability of such systems in the local markets and the second is associated with the level of knowledge to make a well-informed choice while selecting a high efficiency ventilation system.

Furthermore, with the construction of any energy efficient building, additional costs are inevitable. the inclusion of additional insulation, high-performance glazing, and energy efficient appliance in addition to the ventilation, heating/cooling systems all add up to raise the construction costs of such buildings. In on the studies that compared a Passivhaus to low energy building it was found that the option of a low energy building was much more feasible and practical in terms of the payback period (Audenaert, De Cleyn and Vankerckhove, 2008). In case the case of Qatar the PHV construction cost were 15-20% more in comparison to the STV.

Furthermore, it was reported in a number of studies that one of the major challenges in Passivhaus buildings was related to effectively operating the ventilation system (Brunsgaard, Knudstrup and Heiselberg, 2012; Ridley et al., 2013). Although the PHV has not been occupied during the study period, it could be predicted that such a challenge would be expected. Especially during the cooler months where the cooling system may not be required and the ventilation system might need to be adjusted to ensure a continuous supply of fresh air in the villas.

Another challenge related to post-occupancy studies in Passivhaus buildings was denoted as the overheating problem (Brunsgaard, Knudstrup and Heiselberg, 2012). In the PHV and through the initial monitoring period this problem was not evident, with the use of the cooling system the indoor temperatures were maintained at the set point temperature of 23.5°C, it was also evident that during the winter times the indoor temperature dropped to around 18°C in the PHV and the STV. However, as occupancy patterns are unpredictable, the overheating problem may also rise in the future in the Qatar Passivhaus building or in other Passivhaus building in a hot climate, despite the use of the cooling system, and given the expected projection of future climate change.

3. Discussion

The GCC countries in the last few decades had witnessed an economic, urban and demographic growth. This has resulted in an increase in energy demand, especially in the residential sector (Krarti and Ihm, 2016; Lahn and Preston, 2013). Furthermore, in 2006 a green action has started to be noticed in the GCC, signified by the emergence of a number of green councils and the introduction of building standards (Willis, 2015). Despite the presence of building codes, the enforcement of the codes has been mainly limited to governmental buildings (Alalouch, Saleh, and Al-Saadi, 2016).

The Passivhaus Standard has proven to succeed in reducing energy use to significant levels while maintaining a high level of thermal comfort. This success has been mainly recorded in Europe. In Qatar and the region, the application of the Passivhaus standard or any other energy efficiency standard will be bound by a number of challenges. First, due to the absence of green codes, or the limited enforcement of the existing codes end users may not consider the actual implementation of energy efficient measure in their buildings. Second, due to the highly subsidized energy tariffs in the region, consumers lack concerns that relate to the costs of energy bills. While thermal comfort levels are achieved through the active cooling systems, the reduced energy tariffs overshadow the sustainable aspect of introducing green measures. Third, there is a general absence of awareness in the region, especially within the consumer sector. Energy agencies have provided a number of campaigns to spread the awareness and to embrace the importance of energy conservation. Finally, the Passivhaus exemplifies a stringent buildings code and requires specific skill and systems in order to succeed as have been learned through the PHV challenges that were presented.

To successfully provide a smooth transition towards the adaptation of the Passivhaus standard in the region a number of suggestions could be considered (Khalfan, 2017):

1. Upgrading the building codes and increasing the enforcement levels.
2. The promotion of energy efficient buildings in the region by providing subsidies for such buildings.

3. Reviewing the highly subsidized energy tariffs, and providing higher rates for consumers with higher energy usage.
4. collaboration with the Passivhaus institute or other Passivhaus qualified bodies to provide workshops and training programmes for architects, contractors, and professionals in the region.
5. The creation of a web portal which illustrates Passivhaus buildings in the region and provides best practices that suit the climatic conditions in the area.
6. The inclusion of certified Passivhaus materials and systems which are available in the region to aid designers and architects during the design stage of a Passivhaus building.

4. Conclusion

In this research, the performance of a Passivhaus building in a hot and arid climatic zone was investigated. Qatar, through the QGBC, commisioned the first Passivhaus building in the region. This pilot project was experimental in nature, as two identical villas were under study, one built according to the Passivhaus standards and the other according to the conventional practices in the country. The assessment method was carried out by comparing the performance of the houses in terms of thermal comfort, energy use, and the thermal envelope performance. Physical measurements and simulation results were used during the compersion process. Results indicated that the PHV actually consumed 50% less energy than the STV, both during the present time and in the future, furthermore the energy generated through the PV system was sufficient to cover all loads of the villa. In terms of thermal comfort, both villas had satisfactory levels, however, results indicated that the PHV indoor climate was better for both timelines.

While conducting a comparison of the thermal envelope performance, the PHV intensive insulation layer has proved to maintain the indoor temperature below the extreme outdoor temperatures in the present and future scenarios. On the other hand, the STV indoor temperature closely matched those of the outside temperature, which was more evident in the future scenario. Furthermore, the PHV has closely matched the performance of a Passivhaus building but has mainly failed in meeting the airtightness benchmark. A number of challenges are associated with the application of the Passivhaus standard in the region. This is mainly due to the fact that there are no strict building codes applicable in the area. The design, construction, and operation of these buildings are likely to be the main confrontations.

The achievement of Passivhaus buildings are possible, this has been proved by the construction of the second Passivhaus project in UAE (Brumana, Franchini and Perdichizzi, 2017). Both buildings stand as an example of the applicability of the standard in the area, however, with actual occupancy and the conduction of post-occupancy studies, it will possible to obtain a holistic approach towards assessing the performance of Passivhaus buildings in hot and arid climates.

Numerous future studies could be undertaken in the Passivhaus project such as, as mentioned above, post-occupancy studies. Occupant behavior is known to be one of the unpredictable and subjective aspects within the built environment and can alter predicted energy use and comfort level patterns in buildings. Other possible future studies were listed in QGBC research agenda (Amato and Skelhorn, 2017) which included various measurements; such as the embodied carbon payback, surplus energy generation through PV panels and its connection to the local grid, PV array cleaning, indoor air quality…etc.

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