THE FIRST PASSIVHAUS IN QATAR: INITIAL MONITORING AND MODELLING ENERGY PERFORMANCE

May Khalfan	University of Liverpool	m.khalfan@liverpool.ac.uk
Prof Steve Sharples	University of Liverpool	Steve.Sharples@liverpool.ac.uk
Dr. Alexander Amato	Qatar Green Building Council	aamato@qf.org.qa
Dr. Cynthia Skelhorn	Qatar Green Building Council	cskelhorn@qf.org.qa
Dr. John A. Bryant	Texas A&M university in Qatar	jbryant@arch.tamu.edu

Fig 1: Passivhaus villa (PHV) (right) and standard villa (STV) (left)

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

Buildings, by virtue of the energy they consume, have the biggest impact on the natural environment, and the price, availability and by-products of energy create societal and economic challenges in areas such as health and fuel poverty. Consequently, the key architectural solution to these challenges is to create buildings that are just as energy-efficient as possible. This message is especially important for parts of the world, such as countries of the Middle East, which have previously not embraced sustainable, low energy building standards. This paper describes an initiative to demonstrate the viability of such an energy standard (Passivhaus) in the Middle East. The Passivhaus standard was initially developed in Germany in 1990, with the main aims of reducing energy consumption and maintaining a comfortable indoor temperature all year round. The success of Passivhaus has stretched beyond Germany, although only around 100 Passivhaus projects have been realised outside of Europe. Qatar, a country in the Arabian Peninsula, launched its first Passivhaus Project in 2013. The estimated energy performance and comfort levels obtained through the IES dynamic simulation tool indicated that the building would successfully operate under the hot and arid climate of Qatar, and in accordance with the Passivhaus standards. To validate results obtained through modelling, the Qatar Passivhaus has undergone monitoring since its completion. This paper presents the initial findings of the Passivhaus project in Qatar, exploring the actual energy consumption and comfort levels achieved to date. Comparison between the modelled and monitored data have been made, revealing the actual performance of this Passivhaus standard dwelling in a hot and arid climate.

Keywords: Passivhaus standard/ Energy efficiency/Hot and arid climate

1. Introduction

Energy consumption in the built environment has gained an increased level of attention in the last decade; it has even become a measure of how well a building performs. Building regulations, assessment procedures and energy performance standards are now a familiar part of the sustainable design process. The Passivhaus standard is one of the most widely used energy standards in buildings. It was initially developed in Central European countries 25 years ago (Passepedia, 2014) and has gained a wide acceptance, initially in Europe, and more recently in other parts of the world. The success of the Passivhaus standard is related to its reduced energy consumption. In a best case scenario the Passivhaus standard can reduce energy usage by around 90% of that required in a conventional design, utilizing internally generated heat from occupants, equipment and activities to maintain a comfortable heated indoor environment, and a radical reduction in energy consumption. This study was conducted to measure the performance of a Passivhaus model in a hot and arid climate zone. Qatar, a country in the Arabian Peninsula, and a member of the Gulf Cooperation Council (GCC) countries, has recently launched its own Passivhaus pilot project. Two single storey villas were constructed, one following the Passivhaus standard, and the other constructed according to the conventional standards in the country. IES, a dynamic building simulation tool, was used to predict and compare the performance of the two villas. In addition, measured energy consumption and environmental data are being collected to monitor performance and compare against the simulation outputs. Initial findings indicate that the Passivhaus villa operates well under the hot and arid conditions.

2. Research Background

2.1 The Passivhaus standard in hot climates

The Passivhaus standard, in comparison to other energy benchmarks, is one of the most promising and stringent measures in terms of achieving the least amount of consumed energy (Passepedia, 2014). The key elements for the success of a Passivhaus project include a super insulated structure, an air tight envelope with minimal thermal bridges, high performance windows and doors and an effective mechanical ventilation heat recovery system. Table 1 summaries the Passivhaus standard mandatory requirements.

Climate considerations play a major role in redefining the outer fabric standards. Projects carried out under the European Passive-On project concluded that both the insulation and air-tightness levels could be relaxed in comparison with the levels found in projects located in Central Europe (Passive-On Project, 2007). Similarly, studies conducted in South America resulted in a relaxation of the outer fabric standard, not only due to climatic consideration but also because of cultural considerations (Tubelo, Rodrigues, & Gillott, 2014).

Table 1: Passivhaus Standard Requirements

Criteria	Requirement
Heating Demand	Specific space heating demand ≤ 15 kWh/(m^2a) Or alternatively: heating load ≤ 10 W/m^2
Cooling Demand (including dehumidification)	Total cooling demand ≤ 15 kWh/(m^2a) + 0.3 W/(m^2aK).DDH Or alternatively: cooling load ≤ 10 W/m^2 AND cooling demand ≤4/(kWh/m^2aK)x ϑe + 2 x 0.3 W/(m^2aK) x DDH – 75 kWh/(m^2a) but not greater than: 45 kWh(m^2a) + 0.3 W/(m^2aK) x DDH
Total Primary Energy	Energy demand ≤ 120 kWh/(m^2a)
Air tightness	Pressure test result, n50 ≤ 0.6 h-1
Thermal Comfort	Thermal comfort must for all living areas year-round with not more than 10% of the hours in any given year over 25°C

Design considerations in hot climates are based on the exact geographic location, specific climate conditions, construction practices and cultural considerations of the region. Examples of design approaches include orientation, ratio of transparent to opaque surfaces, thermal mass and shading elements. The Passivhaus standard encourages the adaptation of local practices provided that Passivhaus's crucial energy demands are fulfilled.

2.2 Energy Efficiency in the GCC

The Gulf Cooperation Council (GCC) countries have enjoyed an abundance of cheap energy from oil and gas. This has, historically, led GCC countries to not adopt energy reduction procedures. Nevertheless, with the growing global awareness and need to mitigate greenhouse gas emissions GCC policy makers have recently started to consider energy standards and policies.

A number of strategies and pilot projects have emerged in recent years. The UAE, Saudi Arabia and Qatar are leading at present, with mandatory rating systems for new buildings. Assessment systems in Kuwait, Bahrain and Oman are still under development (Meltzer, Hultman & Langle, 2014). However, building envelope standards are mandatory for new build in all GCC countries, and contribute to a reasonable degree of reduction in energy consumption (Radhi, 2009).

In an attempt to spread the awareness of energy efficient buildings the Qatar Green Building Council (QGBC), sponsored by BARWA, has launched the first Passivhaus project in the region. The selection of the Passivhaus standard was a result of the widespread reputation for successful performance that the standard has gained in Europe.

2.3 Thermal Comfort

According to ANSI/ASHRAE Standard 55-2013 (2013), thermal comfort can be defined as, *"the condition of mind which expresses satisfaction with the thermal environment"*. Factors that affect thermal comfort include air and mean radiant temperature, airspeed, relative humidity, clothing insulation and metabolic rate. Thermal comfort can be assessed through two main approaches - the heat balance method and the adaptive approach. The heat balance method is advocated to be more suitable for steady state conditions, i.e. occupants having limited control over the factors affecting thermal comfort (Peeters, Dear, Hensen, & D'haeseleer 2009). The adaptive approach, on the other hand, is mostly associated with passive, free-running buildings, where occupants are in control of many of the thermal comfort factors, such as window opening or heating controls. Charts and scales are used to express thermal comfort. Frequently, indoor comfort can be expressed as a function of temperature and relative humidity (Fuchs, Hegger, Stark & Zeumer, 2008). Commonly, a central shaded area defines the comfort zone area and an extended peripheral area defines the acceptable zone. Just such a graphical chart has been used by Schnieders, Feist, Schultz and Krick (2011) in their report, '*Passive House in Different Climate Zones*', where interior conditions of case studies were measured in terms of the operative temperature and the relative humidity (Fig 2).

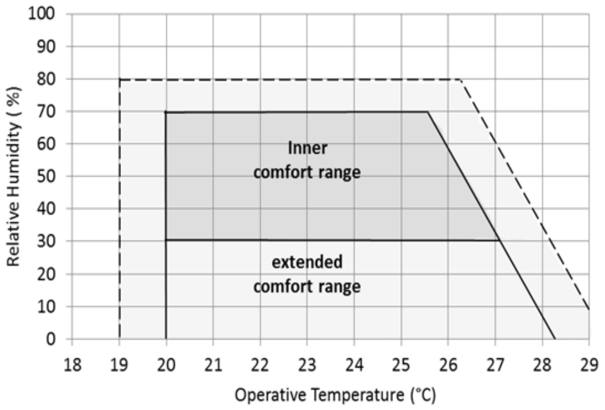

Fig 2: Schnieders et al.(2011) thermal comfort chart

3. Research Methodology

The aim of this research was to examine the performance of the Passivhaus standard in a climatic context that is beyond its already predefined zones. This study was executed by analyzing the pilot Passivhaus project in Qatar. Two computer models were created using IES dynamic simulation software - a base model and a Passivhaus model. IES is an innovative 3D sustainable analysis software used to measure the energy performance of buildings. Dynamic simulation through the IES module Apache-sim is based on first principles of mathematical modelling of heat transfer processes. IES has been validated and tested against a number of standards, such as ASHRAE 1.4, BESTest and USGBC (Crawley, Hand, Kummert & Griffith,2005). IES was chosen over numerous other building simulation tools because of its interoperability, user-friendly interface and proven validity. The study focused on three main aspect: the building envelope, thermal comfort and energy consumption. The effectiveness of the building envelope was analysed by comparing the air temperatures of both house models while cooling was switched off. The indoor environment comfort level was evaluated using Schnieders graphical comfort chart by plotting the annual hourly operative temperature against the relative humidity in the living (LIV) and bedroom space (BR) for both models. The electrical loads obtained from the simulations were compared against the actual energy measurements obtained from monitoring the project. Three sets of meter readings over variable periods were available at the current time. Measured data included lighting, small power and HVAC loads. Statistical analysis was used to acquire an annual energy consumption pattern. HVAC loads, being the most dominant load, was chosen for a detailed comparison between the actual and simulated models. Regression analysis was used to extrapolate the monthly HVAC load. Cooling Degree Days (CDD) were used as the independent variable and the HVAC consumption as the dependent variable. The regression analysis confirmed a strong correlation between the two variables, and an equation was developed to predict the HVAC monthly usage values. Though this method may not give highly accurate results at this time (due to the limited measured data currently available), it did provide satisfactory outputs to preliminarily assess the project. Further monitoring data will provide a better evaluation of the performance of the Qatar Passivhaus model. It should also be noted that the two villas were not occupied at the time this study took place.

4. Project Description

4.1 General Description

The project is located in Barwa City, 18 km from Doha, the capital of Qatar (Fig 3). The project represents a physical experiment that incorporates two villas standing adjacent to each other. The first is constructed according to the Passivhaus standard, while the other is constructed according to conventional construction practices in Qatar.

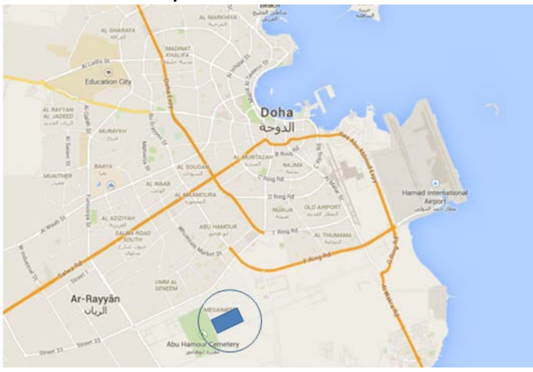

Fig 3: Project Location

Both villas are around 200 m^2 in floor area and are designed for a family of four members. The villas are composed of three bedrooms, an open living/kitchen space and a central atrium. They follow the architectural features found in the vernacular architecture of the region. This is evident through the use of a central atrium and an external colonnade. The private and public zones are separated by providing two entrances to the villa, one for each zone. In addition, the zones are further visually obscured by movable mashrabiya panels (wooden panels with geometric motifs) that allow users to manually maintain their privacy level while guests are present in the public zone (Fig 1). The construction was completed in March 2013, and both villas are currently undergoing monitoring to examine the prevailing comfort levels and actual energy performance.

4.2 Weather

Qatar and all GCC countries according to the Köppen climate classification fall within the hot arid climate zones. This zone is characterized with a prolonged period of sunshine through the year, and with a humble annual precipitation. Two distinct seasons could be classified - hot summers and mild winters. According to Qatar's Metrology Department the average annual temperature is around 27°C. The monthly average maximum temperature is 41.9°C in July, and the monthly minimum temperature is 13.5°C in January. The hot season expands from May to September, when average annual temperatures are between 31°C - 35°C. November through March are considered the mild winter months, when the average monthly temperatures range from 17°C- 24 °C. April and October could be classified as the transitional months. The average annual relative humidity RH is 61%, with a high average monthly RH of 74% occurring in January. The minimum average monthly RH is around 45% in May and June (see Figure 4). Rainfall is light and occasional, with an annual monthly average of around 6.3mm

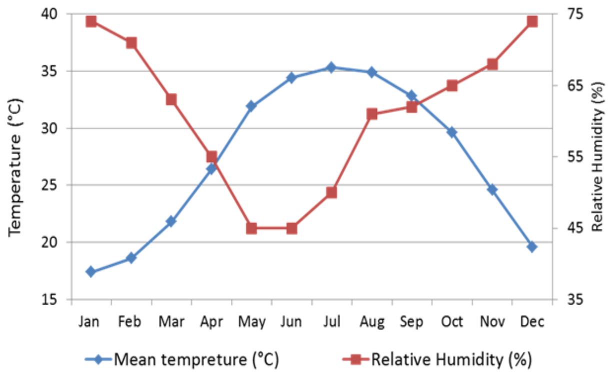

Fig 4: Mean monthly outdoor temperatures and relative humidities for Doha, Qatar

4.3 Outer Fabric Materials

The Qatar Passivhaus villa (PHV) and the standard villa (STV) are identical in their layout, orientation, electrical fittings and appliances. They differ in construction materials, lighting and the HVAC system. In addition, the PHV is equipped with a 220m^2 photovoltaic (PV) array that generates energy to satisfy the full load of the Passivhaus villa. Table 2 illustrates the U-values for both villas and compares them against the Passivhaus standard, and Tables 3 summarizes the construction materials of the PHV and STV.

Table 2 : PHV and STV U-values

Construction	PHV U-values (W/m^{2}K)	STV U-values (W/m^{2}K)	Passivhaus Requirement (W/m^{2}K)
Walls	0.084	1.31	0.15
Roof	0.084	0.30	0.15
Floor	0.11	0.50	0.15
Glazed surfaces	1.11	2.61	0.85

4.4 Technical Features

The Qatar Passivhaus Project has implemented a number of features to qualify for Passivhaus Institute certification. These include a super insulated envelope with no thermal bridges, mechanical ventilation with heat recovery, low air leakage rates, solar water heating, photovoltaic panels, high performance glazing and high efficiency A/C and lights.

5. Results and discussion

5.1 Building Envelope Analysis:

The PHV is characterized by a continuous insulation layer that wraps around its wall, roof and floor. The exposed walls and roof are covered with a 400mm thick layer of polystyrene, while the floor has a 200mm thick layer of the same layer. The STV, on the other hand, based on conventional practices, is insulated with a 100mm polystyrene layer on its roof. In addition, triple glazing is used in the PHV, and double glazing in the STV (see Table 3). The effect of the excessive insulation layer on the PHV model was analysed against the STV model. The models were simulated without air conditioning to measure the peak indoor temperatures. The selected spaces for analysis were the bedroom (BR) and living room (LIV). Results (Figure 5) indicated that the PHV indoor air temperatures were maintained below the high mean outdoor air temperatures all the time during the hottest months (May-Sept), and for most of the times during the rest of the year. The STV indoor temperatures, on the other hand, were close to or above the mean outdoor temperatures all year round.

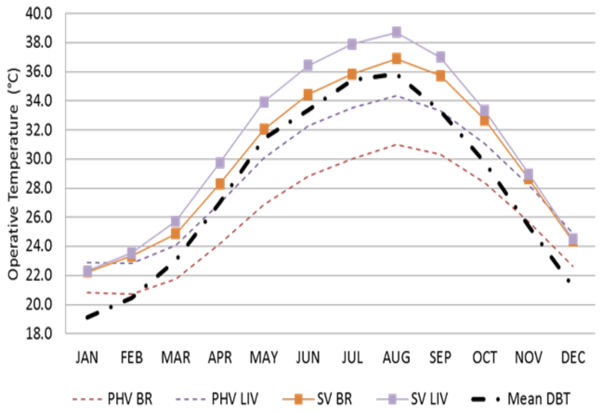

Fig 5: PHV and STV occupied spaces indoor temperatures without air-conditioning on

5.2 Thermal Comfort:

The comfort zone charts for the PHV and the

Table 3 : STV and PHV construction materials

Construction	PHV	STV
Wall	200mm Block work - 380mm Polystyrene layer	300 mm Block work - 50mm cavity in between
Roof	200mm Cast concrete - 380mm Polystyrene layer	200mm Cast concrete - 100mm Polystyrene layer
Floor	250mm Cast concrete - 200mm Polyfoam layer	250mm Cast concrete
Glazed Surfaces	Triple glazing - 6mm clear and coated glass - double 12mm cavity	Double glazing - 6mm clear float glass - single 12mm cavity

STV (Figures 6 and 7) indicated that the operative temperatures in the PHV were mostly within the inner comfort zone area for both the LIV and BR spaces. Conversely, the temperatures in the STV often spread beyond the inner comfort zone for certain periods.

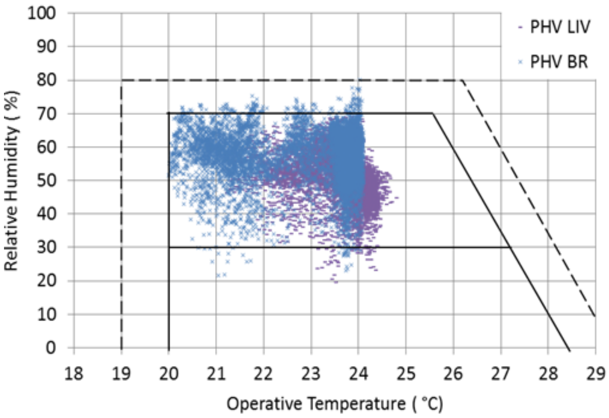

Fig 6: PHV comfort chart

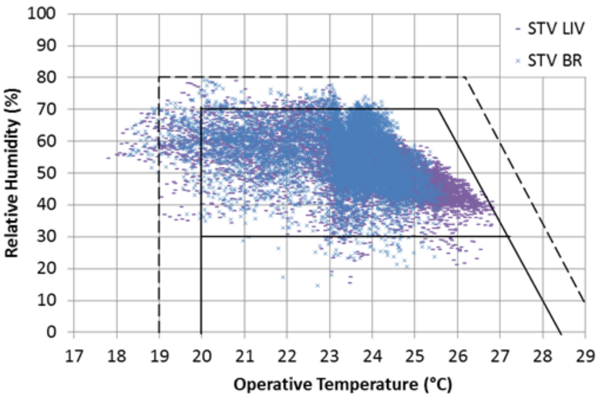

Fig 7: STV comfort chart

5.3 Energy Consumption:

The initial measured annual energy consumption data for the PHV showed values lower than those predicted by the IES modelling, whilst the measure STV results were higher than the IES predictions (Figure 8). This could reflect the fact that the villas were not occupied during the current monitoring phase, instrumentation problems or IES data input/modelling issues. The measured and modelled HVAC consumptions indicated that measured loads were higher than the modelled loads (Figure 9) – again, this could be due to the issues mentioned previously.

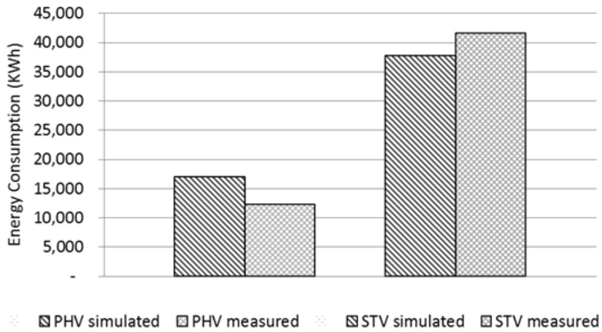

Fig 8: PHV & STV annual energy consumption

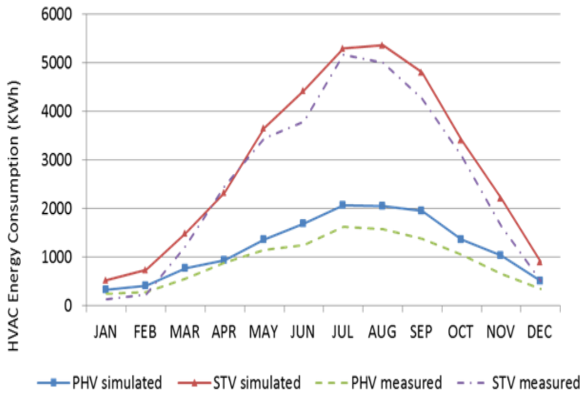

Fig 9 :PHV & STV simulated and measured HVAC consumption

6. Conclusion

The performance of a Passivhaus in a hot and arid climate was examined in this study. Two recently constructed villas in Qatar were investigated - a Passivhaus villa and a standard base viila. Analytical comparisons were carried out using dynamic simulation and statistical analysis. Three aspects were preliminarly covered in this study - the outer fabric, comfort levels and energy consumption. The outer fabric analysis verified that the highly insulated PHV envelope maintained indoor temperatures below the extreme hot outdoor summer temperatures without the need for mechanical cooling. In order to achieve the Passivhaus thermal comfort target a mechanical cooling sytem was added to ensure that the air temperatures in all living spaces did not exceed 25°C for more than 10% of occupied hours in a given year. The thermal comfort charts illustrated that the target was being met, as 0% of occupied hours annualy in the living spaces were above 25°C in the PHV. In the STV, on the other hand, 38% of occupied hours annnualy were above 25°C. Dynamic simulation suggested that the PHV's energy consumption would be less than one-half that of the STV. Initial empirical data suggest that the PHV is actually currently using around one-third as much energy as the STV. Furthermore, the whole load of the PHV is met by the PV panels so that any surplus electricity could be transfered back into the local grid. Despite the limitations of this study, which relate to the current lack of occupants and the limited amount of initial measured data, preliminary analysis indicates that the the Passsivhaus model operates well in Qatar's hot and arid climate and in accordance with the Passivhaus standard.

7. Acknowledgments

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