THERMAL COMFORT ANALYSIS FOR THE FIRST PASSIVHAUS PROJECT IN QATAR

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Abstract

The Passivhaus standard is a well-established energy efficient standard, initially developed for central European countries, where heating is the dominant building requirement. The success of the Passivhaus standard has attracted the attention of architects and engineers around the world, including Qatar. Qatar has recently announced the first Passivhaus project in the MENA region. The project is experimental in nature - two villas have been constructed side-by-side, one according to the Passivhaus standard and the other according to conventional construction practices in the country. The objective of the study is to test the environmental performance of the Passivhaus standard in a hot and arid climate. The performance of the two villas has been analysed using the IES-VE building performance simulation tool, with the focus on the thermal comfort of the indoor environment. The indoor temperature and relative humidity were the main indicators of occupant comfort levels. Annual hourly data were analysed and, in addition, a detailed analysis of the occupied spaces in both villas on the typically hottest and coldest days of the year was undertaken. The findings indicated a consistent and more uniform level of comfort in the Passivhaus model compared to the standard base model; additionally, the cooling energy requirements to achieve comfort in the Passivhaus villa could frequently be met by the villa's own on-site renewable energy system. Initial findings suggest that the Passivhaus standard is potentially viable in a hot and arid climate.

Keywords: Passivhaus / thermal comfort / hot and arid climate

1 INTRODUCTION

Humans spend the majority of their time indoors, either in private or public buildings. This has provoked scientists and engineers in the last decade to extensively invest in research related to the area of indoor thermal environment. Not only for the purpose of achieving thermal comfort as an essential contemporary human need, but also as a measure to moderate energy use through the optimum control of the indoor environment [1,2]. Consequently, codes and standards have set out guidelines to achieve the least energy demand commensurate with the desirable indoor thermal satisfaction. One of the most promising and stringent standards is the Passivhaus standard. The Passivhaus standard was initially developed as a construction concept for residential buildings in Central Europe, but in the past 25 years it has spread to various parts of the world, and has been applied in different types of buildings [3]. Table 1 gives a summary of the requirements of the Passivhaus standard, which primarily include the energy demands and thermal comfort criteria to acquire a Passivhaus certification.

Table 1. Passivhaus standard

Criteria	Requirement
Heating Demand	Specific space heating demand ≤ 15 kWh/(m^{2}a) Or alternatively: heating load ≤ 10 W/m^2
Cooling Demand (including dehumidification)	Total cooling demand ≤ 15 kWh/(m^{2}a) + 0.3 W/(m^{2}aK).DDH Or alternatively: cooling load ≤ 10 W/m^2 AND cooling demand ≤4/(kWh/m^{2}aK)x ϑe + 2 x 0.3 W/(m^{2}aK) x DDH – 75 kWh/(m^{2}a) but not greater than: 45 kWh(m^{2}a) + 0.3 W/(m^{2}aK) x DDH
Total Primary Energy	Energy demand ≤ 120 kWh/(m^{2}a)
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

The aim of this research is to investigate the thermal comfort in a Passivhaus residential building situated in a hot and arid zone. Qatar, a member of the Gulf Cooperation Council countries, has launched the first Passivhaus project in the MENA region. Two identical villas were constructed in 2013, one built according to the Passivhaus standard and the other according to local construction practices in the country. Integrated Environment Solutions Virtual Environment (IES-VE), a building energy simulation tool, was used to evaluate virtually the performance of the villas. On-site measurements have also been recorded to validate the results obtained through IES-VE and to further evaluate the thermal comfort of the Passivhaus villa (PHV) against the standard villa (STV) and in accordance with the Passivhaus standard. The simulations indicated that the PHV thermal comfort levels were more consistently within the comfort rage specified by the Passivhaus standard, compared with the STV values.

2 THERMAL COMFORT

Thermal comfort could be defined as ‘the condition of mind that expresses satisfaction with the thermal environment.’[4]. Factors affecting thermal comfort are categorized in three main groups: (i) environmental factors; which include air temperature, air movement, humidity and radiation; (ii) personal factors which comprise of metabolic rate, clothing, state of health and acclimatisation, and finally (iii) other contributing factors that consist of food and drink, body shape, subcutaneous fat and age and gender [5]. Given the various number of factors affecting thermal comfort, a universal thermal comfort index is not easily attained. A number of studies and researches since 1900 were carried out to predict the thermal satisfaction. Fanger’s heat balance thermal model is a widely used measure; it is based on the thermal sensation of individuals in a controlled climatic chamber. The Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) are two scales obtained from Fanger’s experimental chamber. The two measures are applied in building simulation tools to measure thermal comfort in buildings [6]. Recent research advocates that steady state conditions, which were used to derive the PMV and PPD scales, are not applicable in residential building, as occupants freely adapt to reach thermal sensation by changing the environmental or personal factors [7]. Thus, adaptive thermal comfort models have been introduced in recent years [8].

2.1 Adaptive thermal comfort

Adaptive thermal comfort models are mainly used for naturally ventilated buildings. Occupants’ adapt to achieve thermal comfort through the opening of windows, operating of fans and by changing clothing or drink and food [8]. A number of surveys have been carried out to measure the adaptive thermal comfort [9, 10], but since the thermal comfort is a function of the outdoor temperature it has been found that the adaptive comfort is variable, being based on location. The adaptive thermal comfort model in ASHRAE 55-2010 standard (Figure 1) suggested a wide range for the acceptable operative temperature (18°C-29°C) [11]. A wider range of temperatures are considered to accommodate for acclimatization based on the specific climate and culture.

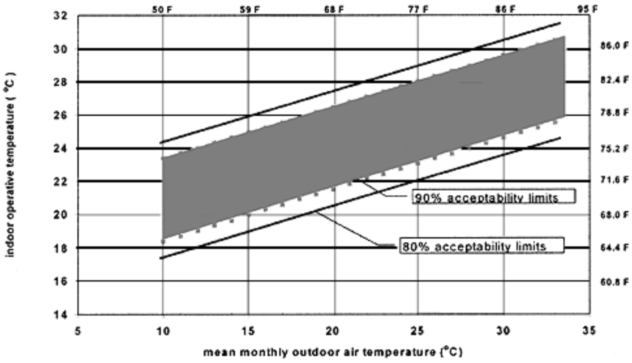

Figure 1. Acceptable operative temperature ranges for naturally conditioned spaces

2.2 Schnieders’s comfort chart

The Passivhaus Institute, in an attempt to promote and further evaluate the Passivhaus standard in various climates, has issued a number of performance related studies. The ‘*Passive House in Different Climate Zones;* [12] is a study carried out by the institute to assess the performance of the standard in extreme climates. A graphical representation (Figure 2) was used to measure thermal comfort in the projects. Annual hourly operative temperatures and the concurrent relative humidity are plotted against each other. A central shaded area represents the inner comfort zone, covering a wide range of temperatures (20°C to 27°C) and relative humidity levels (30% to70%). The outer peripheral area represented the extended comfort zone.

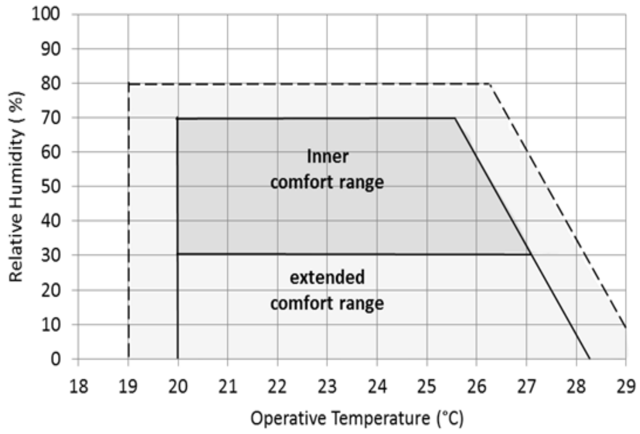

Figure 2. Schnieders's thermal comfort chart

3 RESEARCH METHODOLGY

The evaluation of the PHV comfort level was assessed in four parts. The first part was to acquire Qatar's weather Data by using Meteonorm 7. Meteonorm is a tool used to generate hourly weather data for a vast number of locations around the world [13]. The second part of the research was done by using Climate Consultant 6.0 [14], where the obtained hourly weather data were further analysed and the indoor comfort strategies were examined. Climate Consultant is a graphic-based computer program developed by UCLA energy design tools group and is meant to aid designers understand the specific climate and provide design strategies that best deliver indoor comfort. The third part was conducted by using IES-VE. IES-VE is a building simulation energy tool, which has been validated against a number of standards, such as ASHRAE 140, USGBC and BEST TEST [15]. The indoor temperatures of the PHV and STV model were analysed, and the annual hourly data (operative temperatures and relative humidity levels) were obtained to be plotted on the Schneider comfort chart. The last part of the study included a comparative analysis between the simulated and measured indoor temperatures for both villas. Data loggers, which recorded air temperatures, were placed in the living room (LIV) and the bedroom (BR) in both the PHV and the STV during the hottest month to measure the actual performance of the two villas.

4 PROJECT DESCRIPTION

4.1 General description

The project is composed of two identical single storey residential buildings set out in a new Development 20 km away from the capital Doha, called Barwa Development (Figure 3).

Figure 3. Barwa City location

Both villas are around 200m^2 in floor area and are composed of an open living/dining area, two single bedrooms, a master bedroom and a central atrium in addition to supporting facilities (Figure 4). The architectural features of the region were respected through the implementation of a central courtyard and an external colonnade. Furthermore, privacy aspects were addressed by introducing a movable wooden screen that obscures that view to the private quarters. (Figure 5a, 5b)

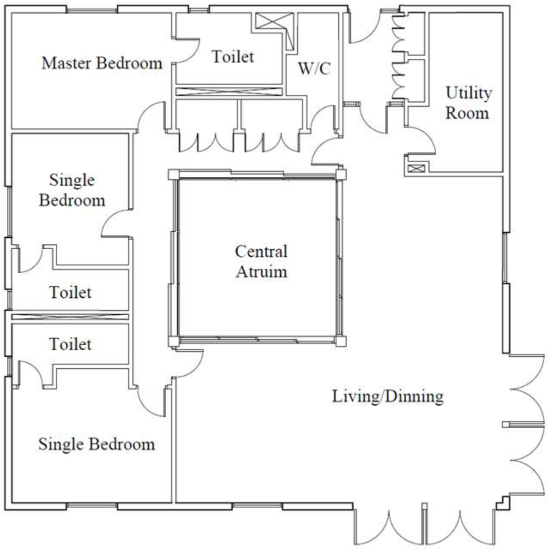

Figure 4. Villa typical Layout

The construction of the villas was completed in March 2013. The two villas are currently unoccupied, and are the subject of research by a number of interested bodies. Qatar Green

Building Council (QGBC) is the organization directly responsible for the project. Its responsibilities include, but are not limited to, organizing visits, authorizing access and providing related information about the villas [17].

Figure 5a. Colonnade and atrium STV & PHV
Figure 5b. Privacy screen in STV

4.2 Weather

The weather in Qatar is characterized by long hot summers and short mild winters. The average monthly temperatures range from 19°C in January to 37°C in July and August, with a maximum temperature of 47°C in July and a minimum of 12°C in January (Figure 6). The average annual relative humidity is around 57%, with a minimum of 39%, in June and a maximum 71% in December.

4.3 Building materials

Although the two villas are similar in their layout, the construction materials and electrical fixtures are different. The PHV is equipped with high efficiency fixtures and systems, while the STV is built and equipped according to normal practices in the country. Table 2 summaries the building materials and systems used in the villas.

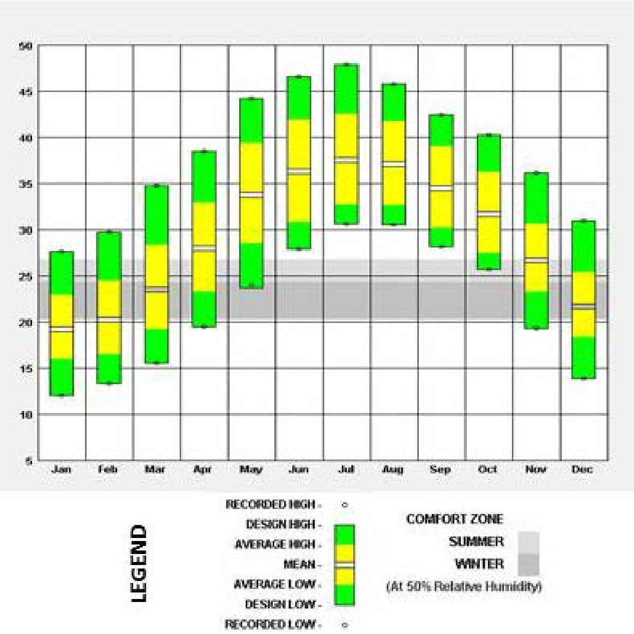

Figure 6.Tempreture Range (Climate Consultant)

Table 2: Summary of PHV and STV building materials and fixtures

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
Cooling systems	High efficiency ducted split cooling system with heat recovery ventilation unit	Ducted split cooling system
Added features	-Solar water heater -220m^2 photovoltaics array mounted on roof -High efficiency lighting	None

5 THERMAL COMFORT ANALYSIS AND DISCUSSION

A number of methods have been addressed in this research to configure the thermal comfort of the Passivhaus project in Qatar. The steady state thermal comfort model has been used, as both villas are air conditioned and unoccupied at the moment. In addition, the use of passive cooling measures has proven to fail to satisfy both the thermal comfort demands in this specific region and the Passivhaus comfort criteria (Table 1).

5.1 The PMV thermal comfort model

ASHRAE's thermal sensation 7 point scale (Table 3), which was derived from Fanger's PMV equations, was used to predict the thermal comfort in the villas. The PMV results obtained were directly acquired through IES-VE vista pro workspace.

Table 3: ASHRAE thermal sensation scale

+3.0	Hot
+2.0	Warm
+1.0	Slightly Warm
0.0	Neutral
-1.0	Slightly Cool
-2.0	Cool
-3.0	Cold

IES-VE inputs included the nominal design air speed, clothing level and activity level. The following design assumptions have been made. The nominal design speed was limited to 0.15m/s, even though a Passivhaus building, due to its sealed envelope may even reach a lower level. Summer clothing insulation was estimated as (0.5 Clo.) with an activity level of (90 W/m^2), and the winter clothing insulation was increased to (1.0 Clo.), with the same activity level. Figure 7 illustrates the minimum PMV for the coolest month, which was January according to the weather data set used, and Figure 8 shows the maximum PMV for the hottest month, which was July based on the weather data set. For the purpose of presentation the LIV and one BR space in both the PHV and STV were considered, and the thermal sensation scale showed values from (-1.5 to 1.5) only to clearly mark the differences between the spaces.

By using the PMV thermal sensation scale it was evident that the PHV maintained a better thermal comfort sensation than the STV. The maximum daily thermal comfort in the STV was slightly warm during the hottest month and slightly cool during the coolest month, whereas the PHV maximum and minimum PMV in both months were within the neutral score.

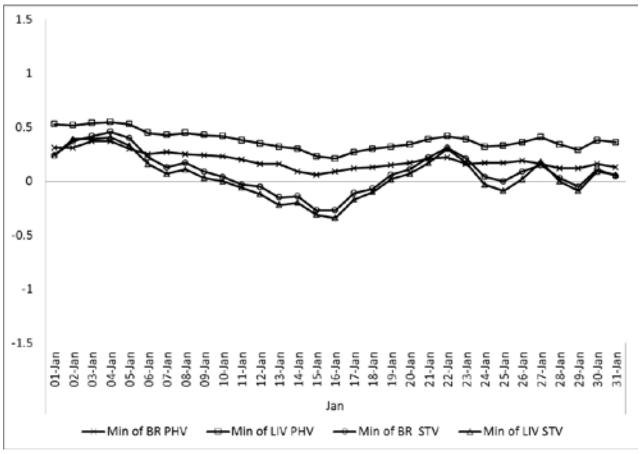

Figure 7: Minimum PMV in the LIV & BR during the coolest month

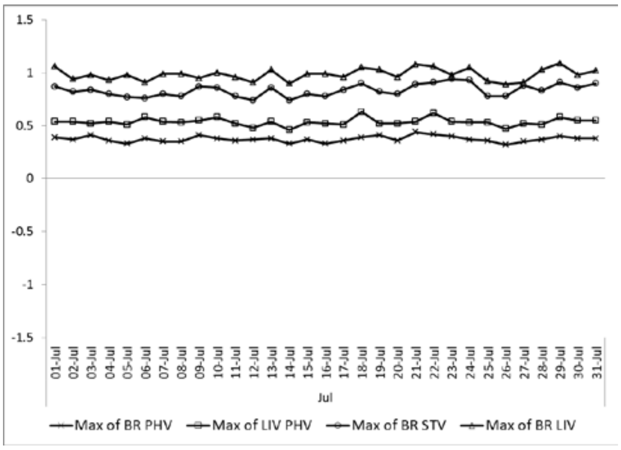

Figure 8: Maximum PMV in the LIV & BR during the hottest month

5.2 Schnieders's comfort chart

The annual comfort was analysed using Schnieders's comfort chart. The annual hourly relative humidity levels and the concurrent operative temperatures were plotted against each other. The data were obtained through modelling using IES-VE. Figures 9 and 10 represent the comfort levels in the LIV and BR spaces in STV and the PHV respectively. Schnieders's comfort chart showed a similar observation to the PMV thermal sensation scale. The PHV comfort levels were consistently within the inner thermal comfort zone, whilst the STV comfort levels expanded beyond the inner thermal comfort zone, reaching the extended comfort zones and further - indicating a consistent level of comfort in the PHV in comparison to the STV.

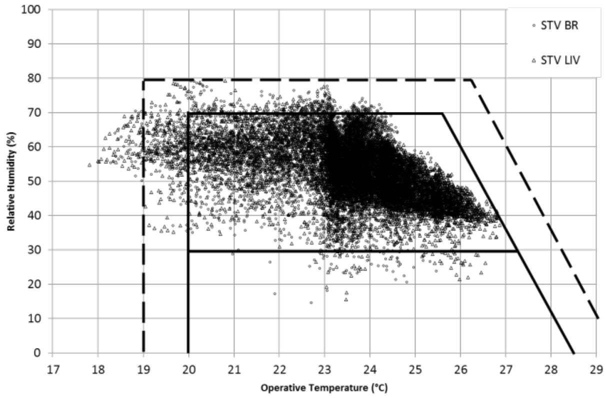

Figure 9: The STV comfort levels

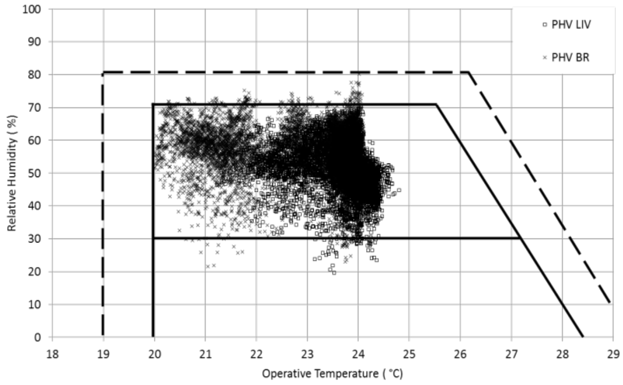

Figure 10: The PHV comfort levels

5.3 Measured vs. Simulated indoor temperatures

To validate the results obtained through modelling the Passivhaus project in Qatar had undergone a monitoring period of five consecutive weeks during June /July (the hottest month). HOBO data loggers were used to record the indoor temperature of the living spaces and bedrooms in both villas at 10 minute intervals. Figures 11 and 12 compare the maximum daily indoor air temperature of the BR and LIV in the villas. The comparative analysis showed variable outcomes between the LIV and BR spaces. The variance between the modelled and recorded average temperatures in the BR was less than 6% in both houses. On the other hand a bigger difference was noticed in the LIV spaces. The average indoor air temperatures differences reached up to 30% in the STV and around 10% in the PHV.

The reasons behind this wider range could be related to a number of causes. Firstly, the loggers were placed closer to the ceiling in the LIV rooms, in comparison to a lower location, at height level, in the bedrooms. The stack effect and ceiling temperature could have caused the difference in temperatures. Another factor that may have contributed to this difference could be attributed to the fact that the living space is the main portal to the villas. The project is considered experimental, where a number of visits are organized throughout the year to carry out field work and measurements, resulting in a non-uniform occupant and user patterns. Lastly, as part of the villa layout, the living room areas are surrounded with large amounts of glazing. Two fully glazed double entrance doors to the north-east and south-east, in addition to the exposure to the solar radiation transmitted through the fully glazed courtyard walls in the interior of the villas, may have contributed to differences in predicted and monitored temperature values (Figure 4).

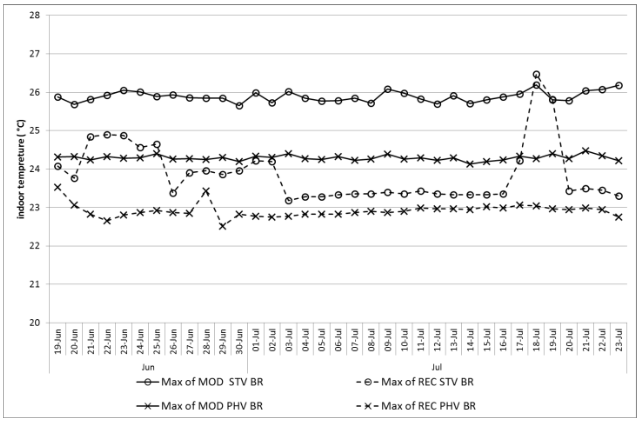

Figure 11: The daily maximum (modelled and recorded) indoor air temperatures in the PHV and STV bedrooms

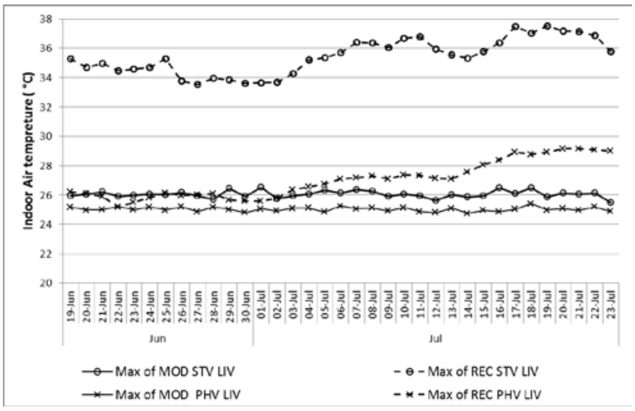

Figure 12: The daily maximum (modelled and recorded) indoor temperatures in the PHV and STV Living rooms

6 CONCLUSION

The Passivhaus standard promises to deliver a comfortable indoor environment. This hypothesis was put to the test in the newly constructed experimental Passivhaus project in Qatar. Thermal comfort in the two villas in Qatar's project was the main subject of this research. A number of thermal comfort measurements have been applied to investigate thoroughly the thermal comfort of the houses. The main tools used for this research were the IES-VE building energy software and on-site indoor temperature measurements. Three thermal comfort measures were undertaken, the widely used PMV thermal scale, Schnieders's thermal comfort chart (developed by the Passivhaus Institute) and a comparative analysis between the actual indoor temperatures in both villas in comparison to the predicted indoor temperatures acquired through modelling.

The outputs indicated that the PHV thermal performance was consistent throughout the year and especially in the hottest month. The average PMV was 0.2 and 0.3 in the BR and LIV respectively. In comparison, the STV recorded a slightly warmer sensation; the average PMV in the STV was 37% and 49% higher than the PHV PMV in the BR and the LIV respectively. According to the Passivhaus thermal comfort criteria the operative indoor temperature should not rise above 25°C for more than 10% of the time during the year. Based on simulation, this criterion is met in the PHV, where 0% hours were above 25°C, in comparison to 38% of the annual hours above 25°C in the STV in all BRs and LIV spaces.

The monitored indoor air temperatures, on the other hand had shown varying results. The actual temperature recorded in the BRs spaces proved similar result in the PHV, where 0 hours during the monitored period were above 25°C. The LIV space in the PHV, due to the reasons of improper logger positioning and other possible reasons, as mentioned in Section 5.3, has revealed that the indoor temperature was above 25°C for 80% of the total monitored hours, but above 27°C for 20% of the time. The recorded temperatures in the STV were found to be above 25°C 32% of the total monitored hours in the bedroom spaces, and above 27°C 15% of the time. The recorded temperature has even exceeded 29°C 12% of the monitored time, mainly during the afternoon hours in the M BR. The STV living space, due to similar reasons as mentioned above, was found to be above 27°C for 100% of the monitored hours.

Another remark is that the actual indoor temperatures in the bedroom spaces were mostly below the predicted indoor temperature through IES-VE. In comparison, the actual indoor temperature was found to be higher than the predicted in the living spaces.

Despite the shortcomings of the LIV spaces monitored indoor temperature, the bedrooms showed a close proximity with the results obtained through monitoring. Accordingly, based on the thermal measurements, it could be argued that a more consistent overall thermal performance was achieved in the PHV, in comparison to the STV slightly variable results. Additionally, the PHV has achieved the Passivhaus comfort criteria, where indoor temperatures were maintained below the 25°C limit. Further field studies would be recommended to assess the thermal comfort aspect in both villas comprehensively, once the occupancy period of the villas begins.

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