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A Parametric Study of Passive House Design in a Sub-tropical Climate

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Introduction

Passive houses have become synonymous with quality, comfort and ultra-low energy buildings that require little energy for space heating or cooling. In heating dominated climates where there has been substantial improvement of the passive house concept, heating load is no longer a major concern. The passive house concept is based on reducing the heat transfer using design and construction principles such as super-insulation, advanced window technology, air-tightness, thermal bridge free and heat recovery ventilation system. As a result, there is a 90% reduction in the heating energy demand compared to the existing building stock (Schnieders et al., 2015). This achievement positions a unique opportunity for the built environment to become energy neutral or net energy positive along with the integration of renewable energy systems. On the other hand, there is a need for improved understanding of the passive house concept in cooling dominated climates. In a sub-tropical climate such as Cyprus, where the passive house concept has been applied, the issue of overheating has been highlighted (Fokaides et al, 2016). Other studies also show this is the case in other climate zones including regions characterized by hot summers and mild winters (Kylili and Ilic, 2017) (Ridley et al, 2013). Against the above background, a parametric study of a passive house in a sub-tropical climate was carried out.

Methodology

To develop an understanding of the overheating issue, a passive house; the Tseri passive house (figure 1), certified by the Passivhaus Institute was selected as the focus of this study. The building is located in Nicosia, Cyprus, a Subtropical climate, Mediterranean and semi-arid region described as the warmest climate in the European Union. Typical summers last approximately eight months, beginning in April with average temperatures of 21-23°C and ending in November, with average temperatures of 22-23°C. In mid-summer (July and August) the average maximum temperature rises to about 35°C during the day and around 25°C at night.

A performance and lifecycle analysis, previously carried out and analysed by (Fokaides et al, 2016) and (Aylili and Ilic, 2017) was used as a reference point for this study, as it provided more data and information about the building after construction. The building was then modeled with the Integrated Environmental Solution (IES) software package, which is used extensively across the industry for building thermal and energy modelling (figure 2). The building model in IES-VE was built by inserting data gathered from Fokaides et al (2016) based on the building elements used in the construction of the building, see table 1. The airtightness of the building set at 0.6 air changes per hour at 50 Pa. The airflow provided by the mechanical ventilation system is 300 m^3/h, a heat recovery exchanger and ventilation system manufactured by Atrea (DUPLEX 370 EC4.D(CF)), combined with a 2.6 kW Mitsubishi Heavy Industries heat pump are used to maintain the indoor temperature. The heat recovery unit, which is a Passive House certified component, has an efficiency of 82%.

Figure 1: Pictoria view of the Tseri Passive House.

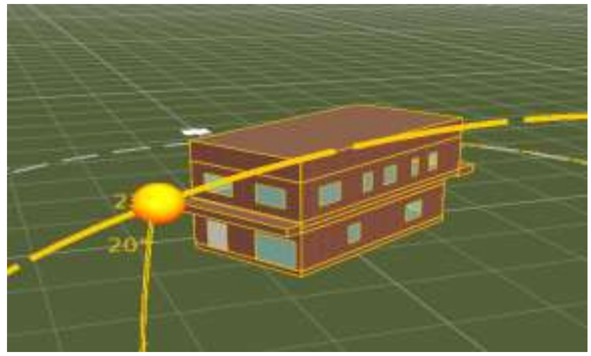

Figure 2 : Overview of the IES Model of the Tseri Passive House .

Table 1: Tseri Passive House, Building Elements Thermal Transmittance (W/m^2 ^oC) according to (Fokaides et al, 2016) ISO 6946:2007

Building Element	Thermal Transmittance (W/m² °C)	Minimum NZEB Requirements (W/m² °C)
External walls	0.18	0.4
Roof	0.15	0.4
Ground floor slab	0.48	N/A
Window frame	1.3	2.25
Glazing	0.8	--

The model was validated by comparing the simulation results against the experimentally measured temperature and humidity of the Tseri Passive house documented in Fokaides et al. (2016) as shown in figure 3. The results showed good agreement between the temperature of the Tseri Passive House simulation in IES and the measured output carried out April 2014 to September 2015.

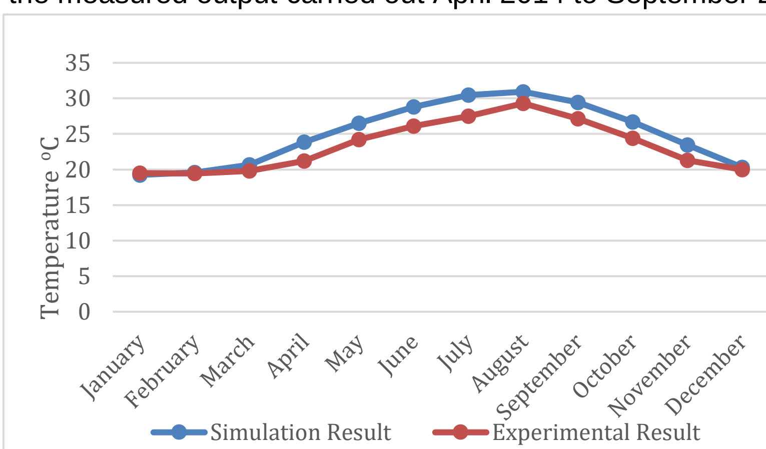

Figure 3: Comparison between Simulation and Measured Temperature (^oC).

Energy analysis of the simulated building in IES was also compared to the Passive House Planning Package (PHPP) (annual heating and cooling demand, heating and cooling load and primary energy used to design the building) (Table 2). The slight disparities observed could be due to factors such as operation of the building and the as constructed details (difference between virtual representation and actual building). Moreover, the typical meteorological year (TMY) weather data for Larnca (Cyprus) was used for the simulation as opposed to Nicosia (Cyprus), as weather data for Nicosia was not available in the IES database. The distance between the location of the Tseri Passive House (Nicosia) is about 36 kilometres to Larnaca. It is expected this could somewhat have affected the observed results, albeit, marginal.

Table 1: The "Tseri Passive House" PHPP and IES Certification Parameters

Passive House Certification Parameter	**PHPP**	**IES**
Annual heating demand (kWh/m^2)	5	4.23
Annual cooling demand (kWh/m^2)	15	7.21
Heating load (W/m^2)	7	6.94
Cooling load (W/m^2)	13	10
Annual total energy (kWh/m^2)	63	45.6

Results and discussion

Having validated the model, a parametric analysis investigated the effect of insulation on thermal transmittance (U-Value) of the building envelope, taking account of other factors such as glazing, airtightness, orientation of the building. In order, to understand the effect of each factor, the model building's variables were varied one at a time, with the indoor temperature and the building energy use analysed.

Initially the thermal transmittance of the original building envelope was reduced by half and also doubled, representing an increase and decrease in insulation of the building envelope. The decrease in the thermal transmittance, shows the average indoor temperature increased particularly during the winter months (figure 4). This is reflected in the energy analysis result as the heating demand is significantly reduced, by almost half, from the original design output. This also delivers a corresponding reduction in the total energy, see table 3. When the thermal transmittance was increased the results show average monthly indoor temperatures reduced in the winter months. A corresponding increase in annual heating demand and total energy is also observed. However in both cases no significant change was observed to the temperature in the summer months (May-October), thus only a slight change in annual cooling demand was found.

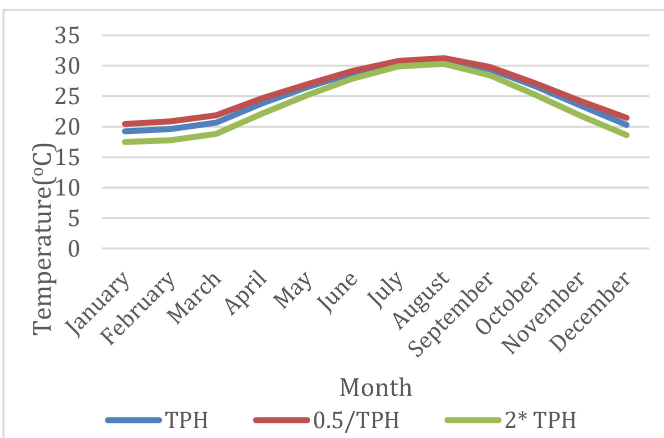

Figure 4: Monthly Temperature (°C) output of the varied thermal transmittance of the model. TPH-Tseri passive house

Table 3: Energy Analysis of the varied thermal transmittance (U-value) of the model Building.

Parameter	**0.5 x**	**Base case**	**2 x**
Annual heating demand (kWh/m^2)	2.34	4.23	7.82

Annual cooling demand (kWh/m²)	7.25	7.21	7.20
Heating load (W/m²)	5.87	6.94	8.37
Cooling load (W/m²)	9.34	9.34	9.34
Annual total energy (kWh/m²)	42	45.60	51.07

When the airtightness was decreased from the original design specification of 0.6 to 5.0 air changes per hour, at 50 Pa, the result showed the average monthly indoor temperature reduced. see figure 5. In the winter months this resulted in a corresponding increase in heating demand and total energy, table 4. However, no significant change was observed in the summer month as the average indoor temperature difference was less than 0.5ºC, and the corresponding annual cooling demand is the same as the original model. These results are in line with the passive house design which focuses on maximizing heat gain and reducing heat loss. What is apparent, is that the heat gained is trapped in the building especialy in summer, when cooling is required. This suggests that varying infiltraion and insulation of the building is not sufficient to faciitate cooling load reduction.

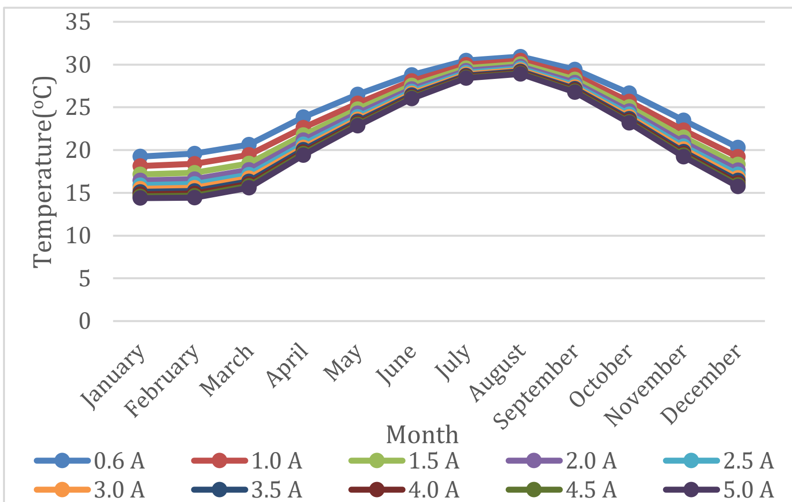

Figure 5: Monthly Temperature (ºC) output of the varied airtightness of the model.

Table 4: Enery analysis of the varied airtightness of the model building.

Parameter	Base case (0.6)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Annual heating demand (kWh/(m²a)	4.2	6.6	8.9	10.8	12.3	13.5	14.5	15.4	16.1	16.8
Annual cooling demand (kWh/(m²a)	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
Heating load (W/m²)	6.9	7.9	8.7	9.4	9.9	10.2	10.5	10.8	11.1	11.2

Cooling load (W/m^2)	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
Total energy (kWh/(m^{2}a)	45.6	48.9	52.9	55.9	58.3	60.3	61.9	63.3	64.5	65.5

In view of the above, only the winter months and its corresponding heating demand varied significantly as the building design factors were varied. The temperature and corresponding cooling demands remained much the same as the original building output for both temperature and energy analysis. Accordingly, the analysis shows that replicating the reference model of the Tseri Passive house with some design adjustment such as airtightness and thermal transmittance would only significantly affect the heating demand of the building.

The reference model is likely to overheat through out the year in a cooling dominated climate, considering the indoor temperature of the building in the summer months. Noting that the thermal comfort criteria for passive house requires that the measured operative temperature should not exceed the Tmax (25 ^{o}C) by 3^{o}C or more at any time. However, Figure 5 shows that the average monthly indoor temperature specifically in July and August (mid-summer) exceeded 28^{o}C. Therefore, reduction of glazing size, shading of all windows, stack ventilation or night cooling may need to be considered for cooling dominated climates if the passive house requirement is to be met.

References

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