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Evaluating the performance of an EnerPHit building under different climates in Greece – A Digital Twin approach

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ABSTRACT

This paper presents a critical evaluation of the performance of the first awarded EnerPHit building under the different climate zones of Greece following a digital twin approach. The thermal behavior and the relative humidity of the original building without active strategies have been numerically investigated for the four different climates. The results show that the Passive House design could be applied in all four climate zones in Greece with minimum updates in terms of insulation thickness, providing an avenue for mass prefabrication and application of the Passivhaus concept in Greece.

Keywords: Passivhaus; Digital Twin; Climate; Energyplus; PHPP.

1. INTRODUCTION

The Passive House standard is a way to fulfill the expectations of designing buildings, which reduce the energy use in terms of heating, cooling, domestic hot water and lighting. Passive House buildings are characterized as comfortable, affordable, energy efficient and ecological buildings [1]. However, in order to harness the Passivhaus concept in the way that would lead to the best results, some details that influence the energy performance of a building, should change depending on the climate zone that the building will be constructed.

Regarding the climate in Greece, it is characterized from warm and dry summers and mild and wet winters. The climate of Greece is Mediterranean, a warm and temperate climate [2]. However, Greece is separated into four different regions, depending on the climatic conditions shown in Figure 1 and are listed below:

1. Zone A, in the southern Greece (Heraklion).

Fig 1 Climate zones in Greece

2. Zone B, in the central Greece (Athens).
3. Zone C, in the northern Greece. (Ioannina).
4. Zone D, in two geographic location in the northern Greece, where the winter weather conditions are extreme compared to Zone C (Kozani). [3]

The Passivhaus standard considers overheating as the conditions when the indoor air temperature is above 25 degree centigrade for more than 10 % of the year [4], [5].

The aim of this paper is the investigation of the performance of a free running EnerPHit building in different climates in Greece, in terms of indoor

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temperature and humidity through the development of a digital twin. The novelty of this approach relies on the integration of the Passivhaus Planning Package (PHPP), dynamic building energy simulations and monitoring data to assess and inform the building design and adaptation.

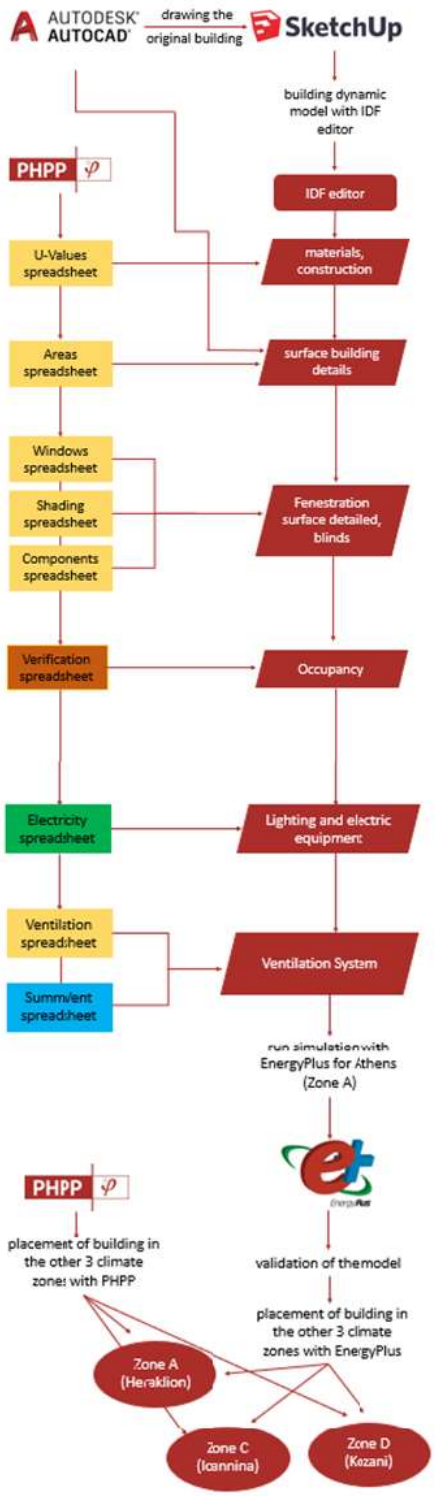

Fig 2 Methodological workflow

2. METHODOLOGY

The building presented in this paper is a detached house with a ground floor and a heated semi-basement located in Papagou, in Athens. This building is the first Passive House by renovation in the Mediterranean and it is awarded as the first EnerPHit Plus building in the world [6]. The refurbishment took place on a building of 142 m^2 of area that was built in 1964 on a 520 m^2 corner plot. The ground floor and the semi-basement are 98.80 m^2 and 43.60 m^2 respectively [7]. Following the retrofit, the ground floor is the dwelling area with a kitchen, a living room, a bathroom and two bedrooms and the semi-basement was converted from a boiler / utility room into an office, and is independent from the ground floor.

The methodological workflow is shown in Figure 2.

Firstly, a climate analysis was performed on the four climates in Greece with weather data obtained from Climate One Building [8] as EPW files.

Secondly, the building was modelled in SketchUp, as shown in Figure 3, following the original retrofitting plans and the geometry and shading were imported into Energyplus. All the simulation parameters for the dynamic building simulation were taken from the original EnerPHit Passive House Planning Package (PHPP) tool as follows:

- U-values for the fabric.
- Occupancy of 4 people in the basement and 3 in the ground floor.
- Glazing with an average U-value of 1.1 W/m^2K and g-value of 0.54.
- Lighting load is 14 W/m^2 (basement) and 5.6 W/m^2 (ground floor).
- Equipment load is 670 W (basement) and 4590 W (ground floor).
- Constant infiltration of 0.56 air changes per hour (acph).
- Summer natural ventilation rate of 0.54 air changes per hour (acph).
- Additional night ventilation rates in summer of 0.17 air changes per hour (acph).
- Free running building, no heating or cooling.
- Simulations run for a full year.

Thirdly, the Energyplus model was validated with in situ monitoring data.

Finally, once validated, the Energyplus model was dynamically simulated in the four climate location for Greece.

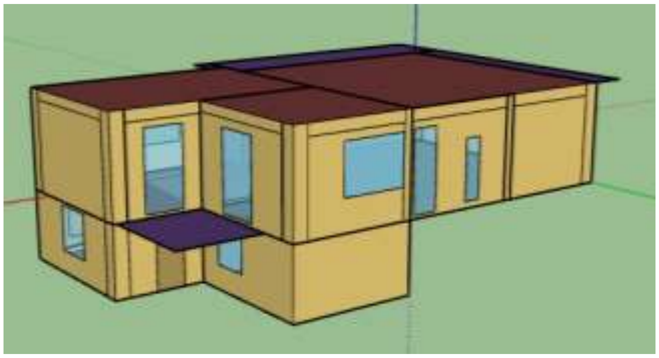

Fig 3 SketchUp model

3. RESULTS & DISCUSSION

3.1 Climate Analysis

The four climate locations presented in this paper were analysis following a frequency bin approach to understand the temperature and relative humidity distributions for the whole year on an hourly basis.

In terms of outdoor temperature, the climate in Zone A (Heraklion) is the hotter of all, while Zones C and D are the coldest reaching temperature below zero.

Considering the effect of relative humidity, Zone C (Ioannina) has an occurrence of more than 45% of the year with a relative humidity above 80%, which added to the cold temperatures, creates a challenging cold and wet conditions for building design.

The climate in Zone B (Athens), the original location for the building modelled in this paper, seem to be the more balance climate with temperatures mostly in the range between 10 and 30 degrees centigrade and relative humidity in the range of 40% to 70%, which are optimum conditions for indoor environments.

3.2 Validation

The EnergyPlus model discussed in the methodology was solved for Athens. The validation of the method has been done with the use of data monitoring measurements of the building and the PHPP results, that have been compared with the EnergyPlus results. The PHPP has been validated, then, from Table 1, it can be seen that the EnergyPlus results, for the thermal behavior of the PH building without active cooling or heating in Athens, are close enough to PHPP results, so the EnergyPlus model is appropriate for the critical evaluation of the thermal behavior of this PH building in the four different climate zones in Greece.

Table 1 Indoor Temperature Difference between PHPP and EnergyPlus

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PHPP	14.67	14.78	16.25	18.72	21.48	25.91	29.02	29.35	26.32	23.02	19.5	16.21
E+	15.59	14.64	16.23	18.9	21.81	26.32	29.58	29.9	26.71	23.22	19.38	15.9
Difference (%)	6.29	0.94	0.1	0.98	1.52	1.58	1.94	1.86	1.47	0.87	0.6	1.9

3.3 Analysis of temperature and relative humidity in different climates

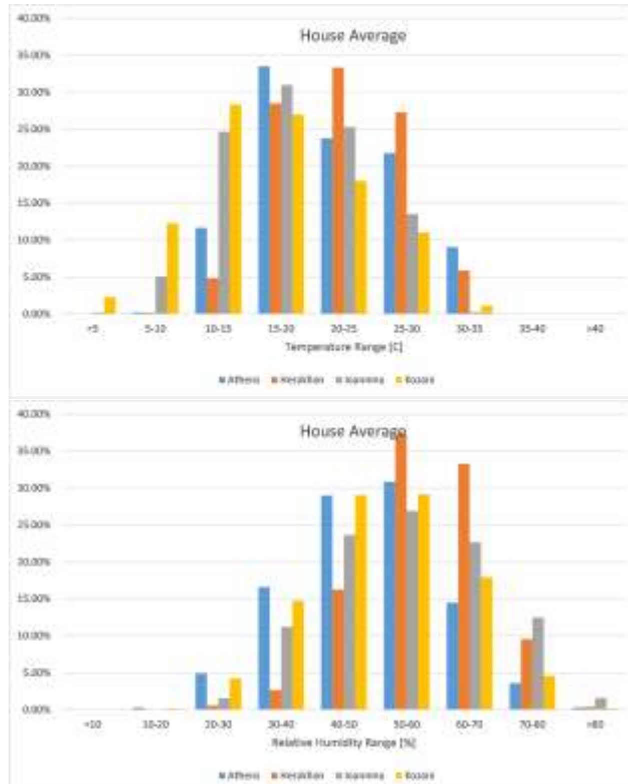

Fig 4 Temperature (top) and relative humidity (bottom)

As it is obvious from the diagrams in Figure 4, the temperature in the other three climate zones in Greece is at satisfactory levels for a passive house without the use of active strategies. More particularly, regarding Heraklion that belongs to Zone A, its thermal behavior is appropriate for ensuring human thermal comfort, as the biggest proportion of temperature range is equal to 20 – 25 ℃. Moreover, by comparing the thermal behavior of Heraklion with Athens, it is easily seen that the thermal insulation could be even slightly thinner. After trials, it has been investigated that a potential thickness of thermal insulation for Zone A could be 15 cm as the insulation of the original building in Athens, so that less active strategies could be used. Regarding Zone C, and specifically, Ioannina, the main temperature range was 15-20 ℃. This means that in order for the PH building to have similar thermal behavior as in Athens, some adaptation should be made. After trials, it has been seen that by adding 5 cm more thickness in thermal insulation, the thermal behavior of the building could be similar to the awarded PH building in Athens. Finally, the main temperature range for Kozani (Zone D) is between two temperature ranges, as shown in the diagram, but with a small difference about 28% of the temperature measurements range from 10 to 15 °C. This means that there should be an increase in the thickness of thermal insulation in Kozani, but with the simultaneously use of active strategies in Northern Greece. Therefore, after trials that have been done in EnergyPlus, in order to reach similar temperature ranges as in Athens, where is the PH building located, it has been determined that the appropriate thermal insulation thickness is approximately 21 cm.

Regarding the relative humidity, the bar chart in Figure 4 shows that for all climate zones in Greece the relative humidity ranges between 50 – 60%, which is an ideally range for human thermal comfort.

4. CONCLUSION

The critical evaluation of the performance of the first awarded EnerPHit building under the different climate zones of Greece has been presented in this study to evaluate its adaptation to all the four climates in Greece. The thermal behavior and the relative humidity of the original building without active strategies have been numerically investigated for the four different climates. From the results, the following conclusions emerge. Firstly, after the placement of the EnerPHit design building in the other three climate zones in Greece, with both EnergyPlus and PHPP, the challenging Passive House criteria between the different climate zones in Greece was the heating demand criterion. Regarding, Zone B (Papagou, Athens), where the original EnerPHit Plus building exists, the exterior insulation thickness that has been chosen, in order to satisfy the heating demand standard is equal to 15 cm, with triple glazing windows, airtight envelope, thermal bridge - free construction and a balanced mechanical ventilation system with heat recovery with efficiency of 98%. In terms of Zone A (Heraklion), it has been proved that no changes are needed as the heating demand criterion and other criterion were fulfilled. Moreover, there is the opportunity to decrease the thickness of the insulation, while maintaining the building with the Passive House design standards. In terms of Zone C (Ioannina), from the placement of the original construction of the building in Ioannina, it has been seen that the heating demand criterion is not fulfilled. Hence, it is suggested an addition at the insulation thickness of 5 cm, in order to satisfy all the Passive House criteria and achieve human thermal comfort. Furthermore, regarding Zone D (Kozani), the same effect as in Zone C (Ioannina) occurs. The Original building construction is adapted with 6 cm more insulation thickness in order to achieve the Passive House standards.

In general, from the research that has been done under this project, the climate conditions in the four climate zones in Greece are not extremely different. The Passive House design could be applied in all climate zones in Greece. It is more obvious that in southern Greece the heating demand is less than in northern Greece, as the weather is warmer. Furthermore, the heating demand criterion is met in the northern Greece, with, just an increase of the insulation thickness. Therefore, it is recommended that in Greece, there could be prefabrications of Passive House buildings with a unique change in the thickness of their insulation. With this as a guide, the total cost of the Passive House building could be less than by constructing a unique building design for every location. Hence, the advent of the Passive House standard could be spread faster than in recent years in Greece.

The research has now expanded to consider the impact of cooling loads due to the increase of insulation thickness. More specifically, in Greece the impact between the different climate zones is not big, as the original building exists already in a warm region (Zone B) as Zone A, and the other 2 zones (Zone C and Zone D) are cooler than Zone A. However, the increase in insulation has an influence on the increase of insulation thickness at the cooling loads of a Passive House. At this project, due to the warm climate of Greece, it is taken for granted that active cooling is used for the building. Undoubtedly, the cooling loads, as it can be seen from both the original building in Athens and the placement of the building in the other climate zones in PHPP, the cooling demand is low because the construction is a Passive House. Regarding the future climate scenarios, about overheating in dwellings, the key to the problem is the construction of buildings that fulfill the Passive House standards, so that not only the achievement of human thermal comfort, but also, the avoidance of too high cooling loads, as the Passive House buildings need less active cooling than the conventional buildings. Hence, active cooling could be used even in cooler climates, due to future climate scenarios. Finally, as regards to the Passive House design in different climates, there is no doubt that future studies, regarding the future climate change and the risk of overheating in dwellings, should take place with a range of possible climate scenarios, in order to investigate the energy performance of Passive House design in the future [9].

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