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Performance of a Passive House under subtropical climatic conditions

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ABSTRACT

The principle of Passive Houses is an important milestone in the evolutionary development towards environmental friendly and energy efficient buildings. The concept as such was developed in central Europe tackling primarily the issue of heating. However, as the goal of sustainability has become a common one throughout Europe and beyond, it is now established that the energy performance of Passive Houses has to satisfy thermal comfort under diverse climatic conditions, in order to enable its adequate global applicability. This study presents the monitored performance of the first Passive House designed and constructed in Cyprus, a south-eastern Mediterranean European country with subtropical climatic conditions. This study aims to provide useful insights to improve the performance of Passive Houses in subtropical climates. The "as built" performance of the investigated building is compared to its asset design, revealing design gaps and possibilities for improvement. Different zones of the building were selected for investigation and the percentage of overheating in the examined zones was specified. The thermal performance of the examined building was also numerically investigated, by means of dynamic simulation in order to consider improvement options. The simulation model was validated for a cooling design day. The performance of a single zone was further investigated using CFD simulation for a specific summer day and the effect of potential measures for the improvement of its thermal performance was evaluated. An average reduction of 1.4 °C of the indoor air temperature was achieved by applying an optimized strategy for night ventilation, while the increase of the cooling capacity of the HVAC was found to significantly improve the thermal performance of the zone. The effect of external thermal coating application was also examined.

1. Introduction

Passive Houses are amongst the world's leading concepts for the design and construction of energy efficient buildings. As of late 2015, there are approximately 25,000 Passive Houses certified in Europe [46]. The vast majority of passive structures have been built in German-speaking countries and Scandinavia [42]. This fact has the opportunity for some doubts about the successful applicability of the passive-house-concept in warmer climates. There is therefore a significant demand for research and development targeted to the adaptation of Passive Houses under diverse climatic conditions, especially for Mediterranean and Sub-tropical ones.

Passive Houses need very little energy for heating, ventilation and air-conditioning (HVAC) purposes, in order to achieve indoor thermal comfort conditions. This is mainly based on their efficient design, by means of high levels of thermal insulation and airtightness. Furthermore, particular attention is being paid to avoiding thermal bridges. In this way Passive Houses allow for significant savings in heating and cooling energy requirement, compared with typical contemporary buildings. Specifically, Passive Houses require less than 15 kWh/m^{2}a for heating or cooling and the heating or cooling peak load is limited to a maximum of 10 W/m^2. In order for a building to be considered as a Passive House, its conventional primary energy use must not exceed 120 kWh/m^{2}a. The standard allows excessive temperatures for 10% of the cooling period in warmer climates [34].

Abbreviations: CFD, computational fluid dynamics; CIBSE, chartered institution of building services engineers; FVM, finite volume methods; HVAC, heating ventilation and air-conditioning; IC, inequality coefficient; iPHA, International Passive House Association; LCA, life cycle assessment; LCC, life cycle costing; PCM, phase change materials; PHI, passive house institute; PHPP, passive house planning package; PPD, predicted percentage dissatisfied; RES, renewable energy sources; RET, renewable energy technologies.

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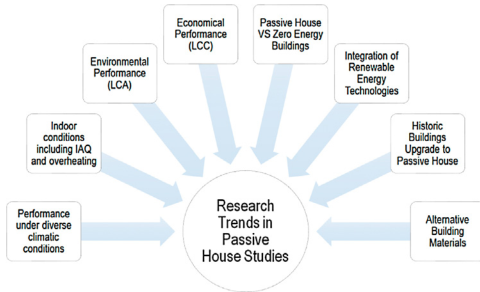

Fig. 1. Research Trends in Passive House Studies.

The aim of this study is to monitor and evaluate the performance of the "Tseri Passive House", a residential unit, built according to the passive-house-concept, and operating under subtropical climatic conditions in Nicosia, Cyprus. The "as designed" performance of the house is discussed in section 3. Section 4 presents the methodological approach applied and in section are presented and discussed 5 the findings of the monitored performance, together with possible improvements and also the validation of the numerical model used for the evaluation of the building' thermal performance, which was done by using the Energy Plus software and the Design Builder interface. The main findings of this work are synopsised in Section 6.

2. Research trends in passive houses studies

Passive Houses' performance has been one of the very popular research subjects of building physicists since the late '90s. Fig. 1 presents the current research trends in the field of Passive Houses. The vast majority of the passive-house-related studies currently focus on the following topics:

- Passive Houses thermal performance under diverse climatic conditions [39–41,44]
- Indoor environment of Passive Houses [30,21,25]
- Passive Houses life cycle assessment (LCA) [6,37]
- Passive Houses life cycle costing (LCC) [1,13]
- Comparative assessment of Passive Houses with zero energy buildings [27,4,24]
- Integration of renewable energy technologies (RET) into Passive Houses [14,38]
- Upgrade of historic buildings to Passive Houses [32,26]
- Investigation of building materials performance in Passive Houses [43,33].

2.1. passive houses under diverse climatic conditions

Several studies have been recently conducted regarding the performance of Passive Houses in various climates. The main finding is that under extreme climatic conditions Passive Houses fail to meet the design limits. Ridley et al. [39] analysed the data from the first monitored heating season of the Camden Passive House, which is the first new London dwelling certified to the Passive House standard. Problems with the installation and control of the DHW and heating system were identified and rectified, resulting in sub optimal performance. The dwelling failed to meet the total primary energy target < 120 kWh/m^2 (124 kWh/m^2), and the level of internal gains was 3.65 W/m^2, 43% more than the standard value of 2.1 W/m^2 assumed for a Passive House. Summertime overheating was also observed, as the house failed to comply with the Chartered Institution of Building Services Engineers (CIBSE), Passive House Planning Package (PHPP) [34] and EN 15251 [5] thermal comfort criteria. Ridley et al. [40] reported on the monitored thermal performance of two Welsh Passive Houses, completed in 2010 and occupied with tenants in April 2011. It is important to notice, that the occupants' electricity consumption behaviour and appliance choices were found to have a great impact on the energy performance of the houses. Similarly to the Camden Passive House, both Welsh dwellings were found to have internal gains which are much greater than those assumed in the PHPP design calculations. It was also shown that under the Welsh environment, a Passive House with a highly glazed south façade may achieve its passive space heating targets, even during a very harsh 3570 ◦ day winter; however it will exhibit a higher risk of summer time overheating. Georges et al. [15,16] investigated the air heating utilized as space heating for Passive Houses using dynamic simulations, by employing the Type 31 component of TRNSYS, for four cities in Norway. This study showed that under cold climatic conditions the required air change rate to achieve the 10 W/m^2 heating demand limit was 0.3-0.4 air changes per hour. This analysis also revealed the significance of thermal losses from ventilation ducts in cold climates. It further showed that centralized heating coil simulation lead to an uneven temperature distribution in space, and that a multi-zonal analysis was required. Rhodin et al. [41] reported on the experiences from nine Passive Houses built in Linköping (Sweden), concerning the indoor thermal comfort and the use of energy. According to the findings of this study, the post-occupancy evaluation revealed complaints of the users, including cold floors in winter and overheating in summer. Schnieders et al. [44] showed by hygrothermal dynamic simulation that it is possible to realize residential Passive Houses in all of the world's relevant climate zones, represented in their study by Yekaterinburg, Tokyo, Shanghai, Las Vegas, Abu Dhabi, and Singapore. In humid climates like Shanghai or Singapore, it was concluded that special attention must be paid to humidity aspects, whereas in climates which were hot and humid all year long, the total useful energy demand for sensible and latent cooling exceeded 70 kWh/m^{2}a.

2.2. Passive houses' indoor environment

Regarding the indoor environmental conditions of Passive Houses, selected studies showed that although the indoor conditions are in line with the requirements set by the relevant standards, the occupants' behaviour plays a decisive role in order to achieve this. Mlakar and Štrancar [30] reported on the living comfort in Passive Houses, by employing a model of energy flux, and by parameterizing the general response of Passive Houses' indoor thermal comfort to the environmental conditions. The results in this study showed that simple strategies in real Passive Houses, like strict shading during the day, and generous ventilation through opened windows during the night could keep the internal temperatures within the comfort level. Kaklauskas et al. [21] employed simulation tools to analyse the comfort, the micro-climate and the quality of life aspects of Passive Houses in Lithuania, within the frame of the NorthPass (Promotion of the Passive House Concept to the North European Building Market) and IDES-EDU (Master and Post Graduate education and training in multidisciplinary teams implementing EPBD and beyond) projects, two Intelligent Energy Europe research initiatives. To this end, a model for the quantitative and qualitative analysis of Passive Houses was developed. Langer et al. [25] evaluated the indoor environment in 20 new Passive Houses and 21 conventional houses, with the implementation of indoor air quality measurements. In this study it was revealed that Passive Houses have significantly lower relative humidity and formaldehyde concentrations compared to the conventionally built houses. The absence of mycoflora related to mould growth or water-damage in the Passive Houses, as opposed to several such occurrences in the newly built conventional houses, was a further interesting finding. The concentrations of NO2 were similar in the