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Comparative Evaluation of Thermal Comfort Levels in Passivhaus Under the Impact of Climate Change

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ABSTRACT

As the climate change casts its shadow on our future, while temperatures are rising in a noticeable pace, thermal comfort in buildings are subjected to that effect in terms of future levels. This paper aims at evaluating thermal comfort levels in a pilot Passivhaus building, while integrating building simulation software, implementing new tools alongside the Passivhaus Planning Package, to produce multiple parameters as a detailed output for assessing the building indoor thermal status of users, during current and different future timelines and CO_2 emission scenarios. Findings have predicted a set of PPD values for different timeline-CO_2 emissions combinations, including recording a jump in PPD from 35% at the historical recent timeline of 2003-2017, to 94% at the timeline of 2080s of high CO_2 emission scenario, during summer peaks at each timeline. Results have also identified a set of descriptive outputs regarding psychrometry, thermal sensation, and effective temperatures.

Keywords: Passivhaus; PHPP; Natural Ventilation; Thermal Comfort; Building Simulations; Climate Change.

1. INTRODUCTION

The International Energy Agency [1] promotes how important energy efficiency is in achieving a low-carbon future, while the potential for significant health and well-being benefits exists. While being widely acknowledged, the energy efficiency measures might have potential negative impacts on IEQ.

As well as being highly energy efficient, the Passivhaus building concept claims to have a high level of indoor environmental quality (IEQ), including the aspect of thermal comfort (TC), where it is an equivalent aim beside energy efficiency. Overheating percentages tend to be increasing each year due to climate change, where the increase in temperatures is pushing these percentages towards the Passivhaus standard overheating limit of 10%, affecting the thermal comfort status in a negative way.

Research trends of Passivhaus buildings have several orientations, where the focal point differs accordingly, as shown in Figure 1.

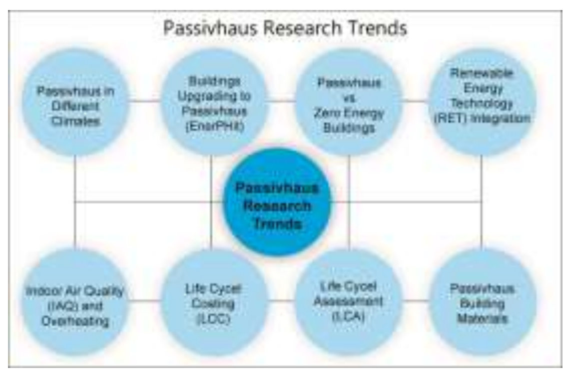

Fig 1 Passivhaus Fields of Research

In the literature review of Indoor Air Quality (IAQ) in Passivhaus dwellings, Moreno-Rangel et al. [2] have indicated that IAQ in Passivhaus-certified dwellings is generally better than in conventional homes, but both occupant behaviour and pollution from outdoor sources play a significant role in indoor concentrations. Located in Sicily, Italy, a certified Passivhaus building have been investigated by Erba et al. [3] in terms of energy

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efficiency and thermal comfort, where the thermal comfort analysis show the achievement of adaptive thermal comfort in summer thanks to the passive features of the building and passive techniques for heat removal.

For a study of another IEQ aspect, Fletcher M.J. et al. [4] have conducted an empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. This study used 21 months of in-use monitored data to consider the overheating risk in a UK Passivhaus dwelling with vulnerable occupants using both static and adaptive thermal comfort assessment methods, revealing apparent overheating during colder months, in addition to substantial night-time overheating.

Moreover, in a large-scale study of a Passivhaus social housing scheme, Botti A. [5] have built upon a post-occupancy study for a Passivhaus-certified large-scale affordable housing development, specifically focusing on summer thermal comfort. The analyses showed a high frequency of overheating, diverging significantly from the estimates made using the PHPP tool. This is due to a combination of factors, such as higher internal heat gains arising from higher occupant density and usage of internal appliances and, in some cases, insufficient reliance on natural ventilation to purge excess heat.

This paper aims at conducting a comparative evaluation of thermal comfort status in a pilot Passivhaus building in Chelmsford, England, under the predicted effect of climate change impact, for recent/future timelines and CO_2 emission scenarios.

2. METHODOLOGY

As for the main objectives, this study takes the opportunity of implementing EnergyPlus for thermal modelling, and ANSYS CFD for ventilation simulations, to extract the required parameters for investigating the thermal comfort levels, through a thermal comfort tool, sourcing the building information from the PHPP, while the Passivhaus relies on it as the main software for design and certification. The work process suggests implementing the dynamic simulations, apart from the PHPP steady-state calculations, in an approach that aims to add a more flexible description of the building's indoor status.

The methodological approach for acquiring the levels of thermal comfort in this study depends on four software packages eventually, where input and output parameters for the Predicted Mean Vote (PMV) method of thermal comfort levels calculations are extracted.

The Passive House Planning Package (PHPP) was the source of building construction details and the natural ventilation plan applied in EnergyPlus for energy modelling, to extract the parameters of air temperature, Mean Radiant Temperature (MRT), and relative humidity percentages (RH), with simulating the mechanical ventilation (MVHR) summer bypass of heat of heat recovery. The base weather file (EPW) for the simulations has been taken for the 2003-2017 timeline, which was inserted in the online platform of WeatherMorph [6] that uses the Morphing Method for producing weather files of predicted climate change impact, simulating multiple CO_2 emission scenarios, according to the Intergovernmental Panel on Climate Change (IPCC) [7], for the timelines of 2050s and 2080s.

Figure 2 shows the EnergyPlus model.

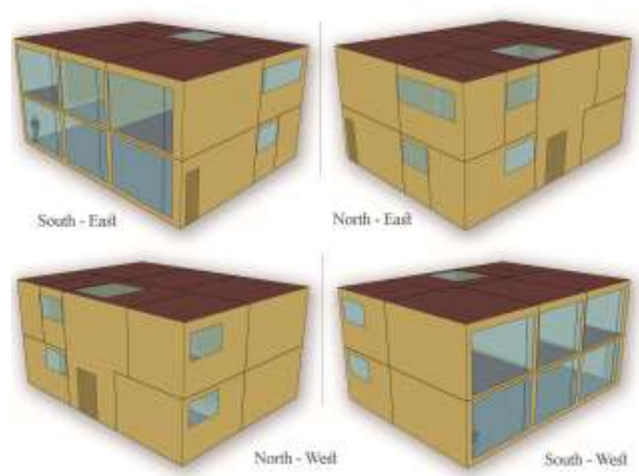

Figure 2 EnergyPlus Model

On the other hand, ANSYS software was used for Computational Fluid Dynamic (CFD) simulations, to extract airspeeds of the indoor spaces of the Passivhaus building. Figure 3 illustrates the Passivhaus model in ANSYS.

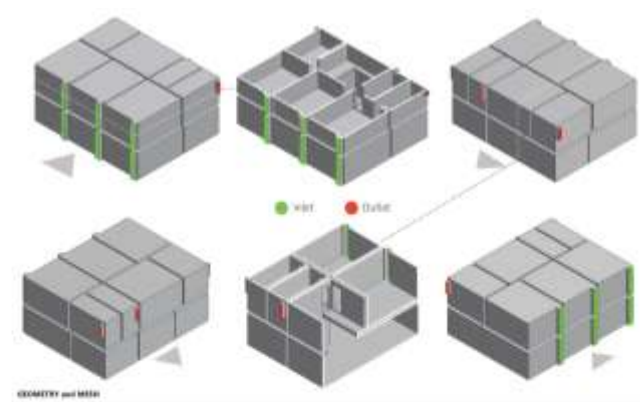

Figure 3 ANSYS Model

Having three steps, this phase starts with modelling the Passivhaus through ANSYS GEOMETRY, with respect to the ventilation plan from the PHPP, regarding openings dimensions and shapes. The second step, with ANSYS MESH, comprises identifying these openings as air velocity inlets and air pressure outlets. The final step in goes through ANSYS FLUENT, where the solution includes simulating the airflow behaviour in the Passivhaus indoor environment. Figure 4 explains.

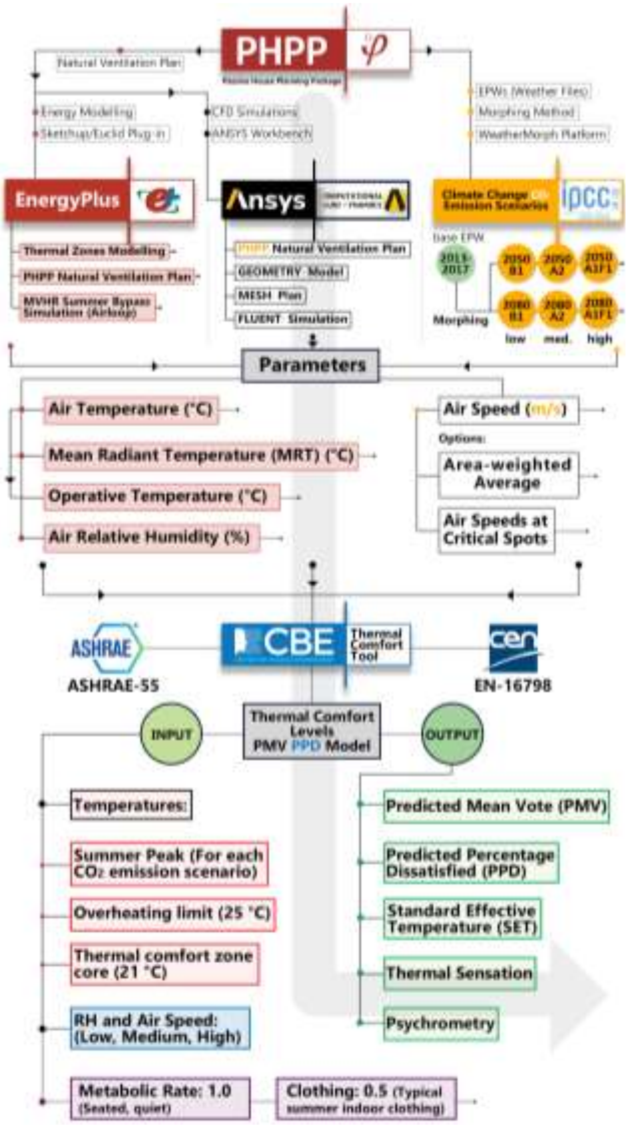

Fig 4 Workflow Diagram

As the diagram in Figure 4 shows, temperatures selected for calculations were chosen for Indoor summer peaks (May-September) at each timeline/emission scenario combination, overheating limit (25 °C), and thermal comfort core of 21 °C, where these parameters are tested with every low, medium, and high values of RH and airspeeds, and fixed parameters of Clothing (typical summer indoor clothing level of 0.5), and Metabolic rate of a seated, quiet user (1.0).

Finally, these parameters are grouped for thermal comfort calculations through the CBE Thermal Comfort Tool [8], calculated with the standards of ASHRAE-55 and EN-16798, outputting results for PMV, Predicted Percentage Dissatisfied (PPD), Standard Effective Temperature (SET), and Psychrometry charting.

3. RESULTS & DISCUSSION

As table 1 shows, the results of the CBE Tool have shown a pattern of parameters, having a specific behaviour of performance for the indoor space. While all the tested operative temperatures for the simulation example shown in Table 1 have been extracted from EnergyPlus for the summer peaks of all the timelines; all the PPD values were not complying with ASHRAE-55-2017 standard, showing the predicted climate change impact on thermal comfort levels.

	PPD (%)	PMV	SET (°C)	Cooling Effect (°C)
2003-2017	35	-1.2	21.8	2.1
2050s B1	13	0.6	26.9	2.3
2050s A2	70	1.86	30	2.6
2050s A1FI	35	1.18	28.4	2.5
2080s B1	27	1.03	28	2.4
2080s A2	72	1.89	30.1	2.6
2080s A1FI	94	2.51	31.4	2.7

Table 1 CBE Tool Outputs example-ASHRAE-55 Standard

2003-2017 Base EPW Simulation

The base simulation EPW of 2003-2017 has recorded a summer peak hourly operative temperature (OT) of 25 °C with 48% of relative humidity (RH), resulting in a PPD of 35%.

3.1 2050s CO_2 Emission Scenarios

The 2050s B1 simulation have resulted a PPD of 13% from an OT of 30.2 °C and 44% RH, while the A2 emission scenario simulation have recorded a 70% of PPD with 34 °C OT and 44% RH. The highest CO_2 emission scenario (A1FI) have marked a peak summer OT of 32 °C and 40% RH.

3.2 2080s CO_2 Emission Scenarios

The low CO_2 emission scenario of B1 simulation has shown a PPD of 27%, from an OT of 31.5 °C and 41.8% RH. Going through the medium scenario of A2, a PPD of 72% was recorded of a 34 °C OT and 39% RH input. The

A1FI have recorded a remarkable PPD of 94% by marking a peak OT of 34 °C and 33% RH.

While shown in Figure 5, as the chosen summer peak OT were selected on an hourly basis; the variation in PPD was not as regular as expected, as the peak OT does not necessarily come with an out of comfort RH, so on another hour of an extreme RH, and a slightly lower OT than the peak (which is still above 25 (°C), the PPD could have a much higher value than the one with the peak OT of the previous results example, and this is where the extended probabilistic potential parameters combinations investigation comes in important, showing other TC status possibilities.

Fig 5 Thermal Comfort-Overheating Hours Correlations

Furthermore, noticing how the 2050s-A2 PPD of 72% was much higher than the highest emission scenario of A1FI of the same timeline (35%), the unexpected result is explained by the fact that the occurrence of these uncomfortable hours is the most important issue, not the bare verdict by the highest OT. The reason why is translated by the overheating number of hours of the mentioned timelines, while the A2 recorded a more severe PPD value, the A1FI recorded 103 more overheated hours, meaning that the occurrence of the uncomfortable hours is more intense than the very high PPD value of the A2 simulation, meaning that the building could have a low number of hours where the occurrence of a 72% PPD exists, while the A1FI could have double the hours of a lower PPD value, but still, both do not comply with the ASHRAE-55 standard.

Nevertheless, the climate change impact on thermal comfort levels is predicted to be obvious and of a negative effect on the building indoor environment, and the behaviour of the variation has a specific pattern of predicted performance.

On the other hand, the low CO_2 emission scenario of B1 simulations for the 2050s and 2080s have predicted how the commitment to a low CO_2 emissions process could remarkably impact buildings performance in a positive way in the future, where the building indoor environment has been predicted to record lower PPD values than the current ones, even in the 2080s, if the mitigation measures have taken place in an effective way, globally.

Moreover, the pattern of overheated hours throughout the tested timeline-CO_2 emissions scenario combinations has given a more comprehensive evaluation of the simulated Passivhaus indoor thermal status, alongside multiple output parameters from the CBE Tool, where further results groups are available for analysis through the SET and the Cooling Effect parameters, that has a strong relation with the simulated natural ventilation plan, and the summer period of a cooling demand, signified by the effective temperature.

4. CONCLUSION

While some building design processes include compliance test procedures for thermal comfort levels, as in the Passivhaus concept of building, accounting for building future performance is one essential measure that could create a longer life-span for buildings in terms of coping up with climate change impact.

Integration of multiple software packages alongside the PHPP have provided a wider range of parameters extraction, while supporting the design indoor performance output with a variety of aspects, the software combination have offered a more detailed description of the parameters that are used to calculate thermal comfort through the CBE Tool, producing a detailed report that includes even more parameters to help with working out a proper building design that can still operate within the design goals even during a climate change negative impact scenario.

Results have focused on an example that takes the worst case scenario of a summer peak operative temperature, to simulate all the possibilities that could come up in the future, in terms of CO_2 emission scenarios, which are expanded in a longer version of this evaluation study, taking more parameters under the analysis and comparison processes, comprising the other thermal comfort standard of EN-16798, alongside the tested ASHRAE-55-2017 standard, to show the contrast between the two standards in terms of applying on the same building.

concluding what the previously shown results have demonstrated, focusing on an example that has the peak operative temperatures during summer as a main outline of indoor environment performance evaluation, the PPD-overheating hours correlation have shown how a pattern of outputs can explain each other, in terms of dealing with unexpected values that usually take the path of gradual increase. The simulations have predicted that it is not the severity of the issue that should have all the attention regarding results, but the occurrence does, in terms of repetition and existence for more hours per day, putting both severity (highest parameters) and occurrence (repetition of the phenomena) within the same framework.

Furthermore, the parameters that are extracted from the CBE Tool calculations like the SET and the Cooling Effect give a more comprehensive way of description to the passive cooling processes in the building, specifically natural ventilation that have been simulated in both EnergyPlus and ANSYS Fluent, concluding that the SET-Cooling effect combination offers a prediction approach to investigate the cooling periods of demand during summer days and show the potential of passive cooling in terms of passive cooling zone limits of effect, through specific methods.

Limitations of the study exist, while revolving around the evaluation of the simulations results accuracy, nevertheless, the simulation building results were audited to confirm corroboration of results with building physics principles, computational fluids dynamic mechanisms and widely-followed procedures. With acknowledging the complications of a validation process, in real life, and as this study went as far as it could reach regarding resources and implications, recapitulating the aim of it have its own inference, while highlighting the digital process through the tools of the workflow, that forms a methodological approach for predicting some performance aspects, with the fact that a complicated monitoring campaign that includes the aspects of thermal performance, airflow patterns behaviour, and post occupancy evaluation is a proper validation method to evaluate the accuracy, especially when looking at specific performance descriptions of aspects like natural ventilation, and seeking to acquire parameters similar to the ones provided by the CBE Tool calculations. Yet, the computer software used in this methodology has its approaches that are, to a certain level, implemented in a decent range in the building sector.

Finally, such methodological approach of having integrated supportive software packages beside the certification PHPP, could provide the wider perspective to look at the design performance for a multi-disciplinary approach, to achieve a more durable building, and attain a current/future prediction measures of performance.

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