The Passive House in a Cooling Dominated Climate- A Case Study of Singapore.

Damiloju Lydia Adeyina[1], Timothy Anderson[1] and Ali GhaffarianHoseini[2]

[1] *Department of Mechanical Engineering, Auckland University of Technology, Auckland, New Zealand*
[2] *Department of Built Environment Engineering, Auckland University of Technology, Auckland, New Zealand*

1.0 Introduction

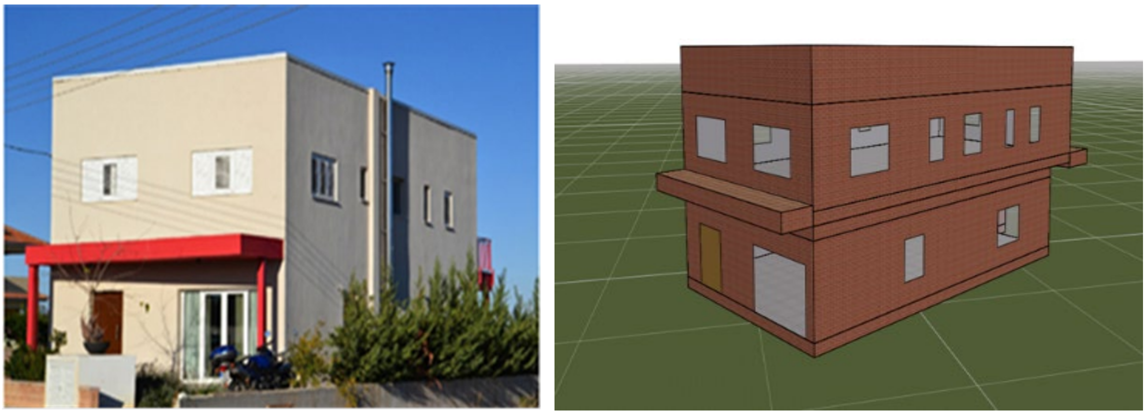
Growth in sustainable buildings and energy efficiency is expected to be the principal driver of new buildings and existing buildings in many climates. The Passive House (PH), which has gained much recognition due to its achievement in energy efficiency and thermal comfort, place heavy emphasis on reducing the energy demand for heating and cooling in buildings. The Passive House movement and standards trace their origin to buildings designed for a Central European climate, i.e., Germany. It has now been significantly adopted in similar heating-dominated climates worldwide. Despite this development, there are few examples of Passive House buildings in cooling dominated climates (Passivhaus Institut, 2019). According to (Alejandro Moreno-Rangel, 2021), the Passive House leans heavily on the idea of reducing heat loss. Thus, it explores strategies such as super-insulation, thermal bridge free design, airtight construction, highly insulated windows, and mechanical heat recovery ventilation system (Passipedia, 2020). In heating-dominated climates, these techniques have proven beneficial in meeting the Passive House standard. However, it is unclear if the standard can be met in cooling dominated climate.

2.0 Methodology

A parametric exploration of a reference building is undertaken for Singapore. To answer whether the Passive House standard (i.e., annual cooling demand ≤ 15kwh/(m^2a) can be met in a cooling dominated climate relying on the techniques mentioned above. The reference model was based on a certified Passive House named "the Tseri Passive House". The passive house was designed and constructed for the semi-tropical climate of Cyprus. As described in (Paris A. Fokaides, Elias Christoforou, Milos Ilic, 2016), the two-storey building has a total area of 185 m^2, a clear room height of 2.5m. It is equipped with class A+ domestic appliances (i.e., energy efficient appliance). Thus, the internal gain is calculated as 3.1 W/m^2. Further details of the building can be found in (Paris A. Fokaides, Elias Christoforou, Milos Ilic, 2016).

In this study, the indoor temperature was set at 25^{o}C, using a simple constant volume energy recovery system to provide ventilation in the building. The energy recovery system technical data includes efficiency of 82% and outlet air volume of 370 m^3/h. The reference building was modelled using the Integrated Environmental Solution - Virtual Environment (IES-VE) software 2020. **Figure 1** shows the IES-VE model compared to the reference building as built.

Initially certified as a Passive House in Cyprus, the building was modelled in a Singaporean climate, and its energy consumption and indoor environment were considered a base case. Subsequently, some strategies such as the application of 1.5 m overhang (see **Figure 2**) to limit the exposure of the wall to direct sunlight, building envelope insulation (wall, roof, floor) and night cooling (from 2200-0800) were investigated for possible optimisation of the reference building.



a. The reference Building b. IES Model

Figure 1:Comparison of As-built Tseri building and model in IES-VE

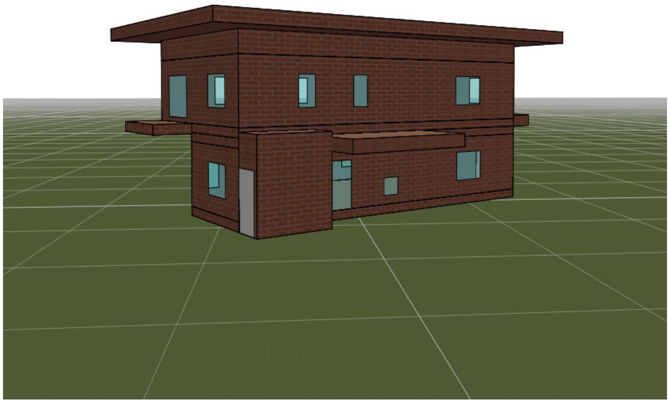


Figure 2: The Reference Passive House with 1.5m overhang.

3.0 Analysis and Results

The energy consumption for the reference building modelled in the Singaporean climate and some explored optimisation strategies are shown in **Table 1**. From this, the building does not meet the Passive House requirements for cooling (≤15 kWh/(m^2a)) as set out in (Passive House Institute (PHI), 2015). Also, although the application of overhang, removal of floor insulation on all floors and night cooling proved effective in reducing the annual cooling demand (**Table 1**), the cooling demand standard was not met. However, the peak cooling load (10 W/m^2) was achieved.

Table 1: Peak load & Annual cooling demand of the reference building and optimisation

Energy demand for reference building in Singapore	**Base case**	**Application of overhang**	**Removal of floor insulation**	**Night cooling (2200 – 0800)**
Annual Cooling Demand (kWh/(m^2a))	80	78.16	76.56	48.22
Cooling Load (W/m^2)	10.61	9.40	11.10	11.25

Regarding thermal comfort, the Passive House comfort range recommended by Schnieders et al., 2015 was used for analysis. As presented in **Figure 3**, the reference building in the Singaporean climate does not present a conducive indoor environment. However, it was observed that the indoor condition of the building was improved and mainly within acceptable range with the application of overhang and removal of floor insulation (**Figure 4**). Also, in the case of optimising the building by opening the windows to encourage night cooling, the annual cooling demand was reduced to 76.6 kWh/(m^{2}a). However, it did not present a conducive condition in the building (**Figure 5**).

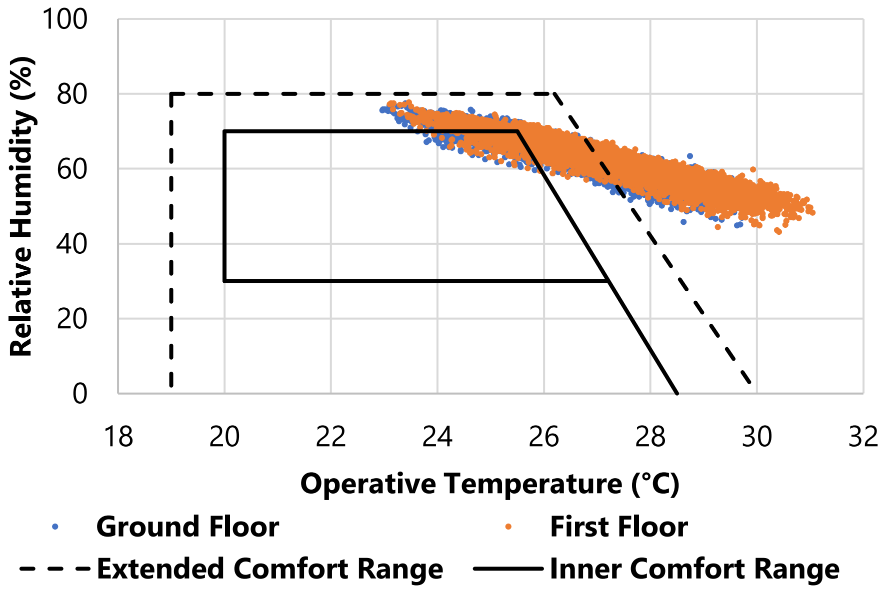


Figure 3:Indoor Temperature and Humidity of Reference Passive House in the cooling dominate climate of Singapore.

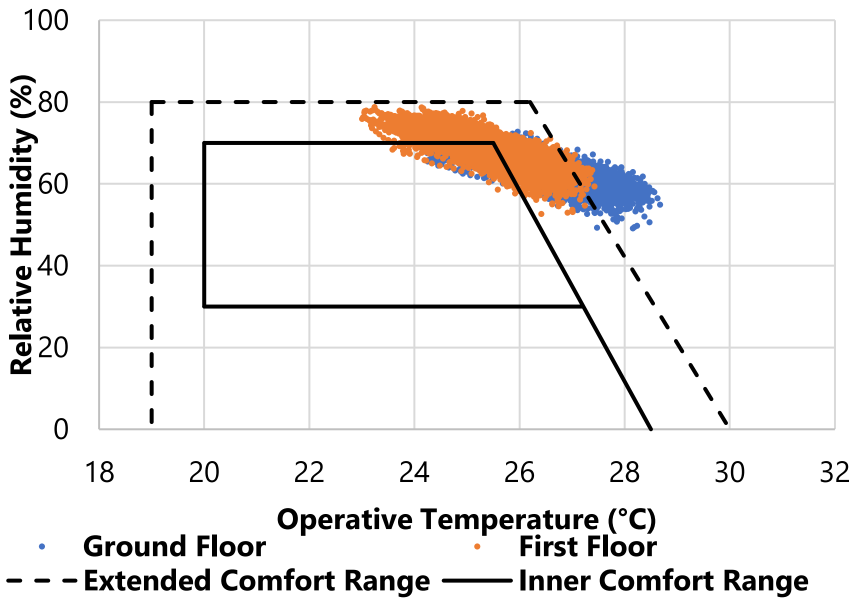


Figure 4: Indoor Temperature and Humidity of Optimised Reference Building.

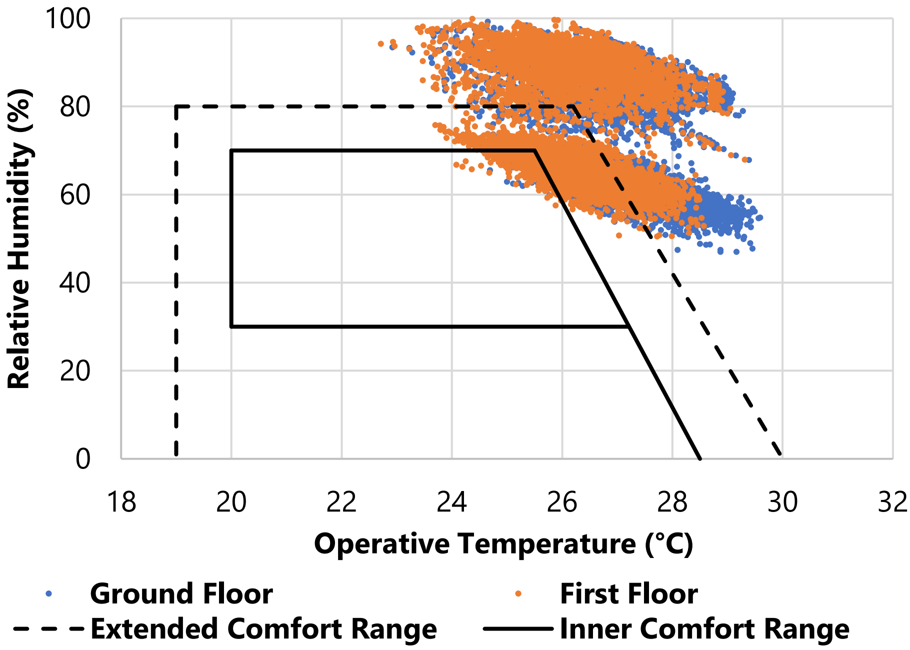


Figure 5:Indoor Temperature and Humidity of Optimised Reference Building with Night Cooling.

4.0 Conclusion

In this study, the Passive House requirements were investigated for a building in cooling dominated climate. The study showed that although the reference Passive House with the applied optimisation strategies, does not meet the passive house standard of 15 kWh/m^{2}a for cooling demand, the peak cooling load of 10W/m^2 was attained.

It was also observed that optimising the reference building with the application of roof overhang (to reduce solar heat gain) proved effective in reducing cooling demand and improving indoor conditions. Additionally, the Passive House relies on super-insulation of building envelopes (walls, floor, and roof) to minimise heat transfer in the building. However, in this study for a cooling-dominated climate, the floor's insulation increased the cooling demand, preventing heat loss in the building. Hence, removal of floor insulation proved advantageous in reducing cooling demand.

Furthermore, it was noted that while night cooling reduced cooling demand, it posed a non-conducive indoor environment due to increased humidity. Finally, the approach to adapt a passive house from a different climate may have posed some challenges in providing clarity on useful PH strategies to achieve the passive house standard in this climate.

In further study, to gain more clarity on the passive house in a cooling dominated climate, its main strategies are applied to a conventional building designed for this climate. As such its impact on energy demand and thermal conditions are assessed.

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