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Applying passive cooling measures to a temporary disaster-relief prefabricated house to improve its indoor thermal environment in summer in the subtropics

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ABSTRACT

Temporary prefabricated houses (PHs) can be effective in quickly providing disaster victims with a temporary living place whenever there is a natural disaster. Unfortunately, PHs commonly used for disaster relief purpose do not ensure a thermal comfortable internal conditions for their occupants. In order to search for approaches of improving PH's thermal environment, a simulation model was firstly developed using Energyplus, and validated by comparing the simulated data with the measured data obtained from a purposely built experimental PH . An analysis on summer heat gain based on the validated model showed that PH's windows were responsible for the lion's share of the total heat gain, followed by the roof and east wall. Besides, the effectiveness of applying various passive measures to the PH was studied. The study results suggested that adding a thin movable fabric layer of 0.9 reflectance to the walls and roof, and external window blinds would lead to a very high percentage reduction in unacceptable hours, without however the need to implement all four passive measures, to save the cost of implementation.

1. Introduction

Natural disaster, as an unforeseen and sudden event that often causes great damage, destruction and human suffering, has an increased occurrence rate in recent decays [1]. Housing provision has been one of the major problems that should be addressed as soon as a disaster happened [2–4]. Temporary prefabricated houses (PH s) can be very effective in providing disaster victims with a temporary living place quickly whenever there is a natural disaster [5]. However, due to lack of suitable environmental control systems, unacceptable indoor thermal environment can be often experienced by PH s' occupants [6–8]. A field test and questionnaire survey showed that the thermal environment inside temporary housings was much worse than that outside and had negative effects on the physical and mental health for disaster victims [9]. Therefore, although PHs can be used to provide disaster victims with a temporary living place, it is essential to take suitable measures to improve the thermal environment inside PHs.

Over the years, improving thermal environment inside temporary housings has attracted considerable research interests worldwide. For example, Salem [10] suggested to build the roof of a tent using a double textile layer with 2.5-cm-thick insulating material. Wang [11,12] also suggested that the use of tents having a three-tier envelope could greatly improve its thermal performance, which could effectively reduce indoor air temperature and internal surface temperature during summer months. Zaki et al. [13] added a canopy-type layer to the roof of tents to reduce the direct solar heat gain. Their experimental results demonstrated that such a simple addition could reduce the daily heat gain by 46–49% during days with clear sky. Furthermore, according to Borge-Diez [14], using a cool roof combined with natural ventilation for a low-cost shelter in hot climates could help improve internal thermal environment. The cool roof was made of concrete with an additional paint layer. The paint layer with a nano-technological and micro-technological additive had a reflectance value of 0.9235. Their study results showed that these combined passive techniques could help improve the thermal conditions inside the shelter. Yang et al. [15] applied a green heat reflective coating to a military tent. By comparing with tents without coating, it was shown that the surface temperature of coated tents was decreased by 10–12 °C and indoor air temperature decreased by 6–8 °C. A passive cooling method

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Nomenclature

T_{Di}	Internal door surface temperature (°C)
T_{Ewi}	Internal east wall surface temperature (°C)
T_{Fi}	Internal floor surface temperature (°C)
T_{in}	Indoor air temperature (°C)
T_{Nwi}	Internal north wall surface temperature (°C)
T_{Nwini}	Internal north window surface temperature (°C)
T_o	Outdoor dry-bulb air temperature (°C)
T_{op}	Operative temperature (°C)
$T_{op\text{-}up}$	Upper limit of acceptable operative temperature (°C)
T_r	Radiative temperature (°C)
T_{Ri}	Internal north roof surface temperature (°C)
T_{Swi}	Internal south wall surface temperature (°C)
T_{Swini}	Internal south window surface temperature (°C)
T_{Wwi}	Internal west wall surface temperature (°C)

Abbreviations

CV	Coefficient of variation of root mean square error
EPS	Polystyrene foam board
PH	Prefabricated house
RH	Relative humidity
RMSE	Root mean square error (°C)

was applied to improving the thermal environment inside military tents by Hu [16]. By spraying water to the external surfaces of a tent where its internal surfaces were covered with aluminium film, the wet bulb globe temperature inside tents was less than 32 °C, suggesting that evaporative cooling was effective. Rash et al. [17] studied the effects of reducing tent sunlit surface area by arranging tents close to one another. However, these studies focused on improving the thermal environment inside tents made of textile fabric. Unlike tents, PHs are made of light-weighted prefabricated color steel sandwich panel and consequently the thermal performances inside PHs are expected to be vey different from that inside tents.

Huang [18,19] studied improving the liveability of post-disaster transitional settlement through optimizing the layout and design for PHs. Several novel designs for PHs were proposed, and the layout for each new design of PHs optimized through CFD simulation. Furthermore, Wang et al. [20] improved the thermal performance inside a PH by adding phase change material to its envelope. However, adding phase change material was not practical for temporary PHs as the cost of phase change material was very high.

Furthermore, while PHs are most likely intended for temporary housing purpose, unfortunately in many cases, they are occupied for much longer durations. Due to lack of mechanical-based environmental control systems, the thermal environment inside PHs can become intolerable, especially in summer months [21]. Therefore, it became highly necessary to improve the thermal environment inside PHs in summer months using passive cooling measures. To this end, an numerical study on applying various passive cooling measures to a PH has been carried out and the study results are reported in this paper. Firstly, a numerical model for the PH is developed and validated by comparing the simulation results with measured results in a purposely built experimental PH. Secondly, a detailed breakdown of summer heat gain of the PH is numerical evaluated using the validated model. Finally, the effectiveness of applying four passive cooling measures, individually or in combination, to the PH was studied using the validated model, and the study results are presented.

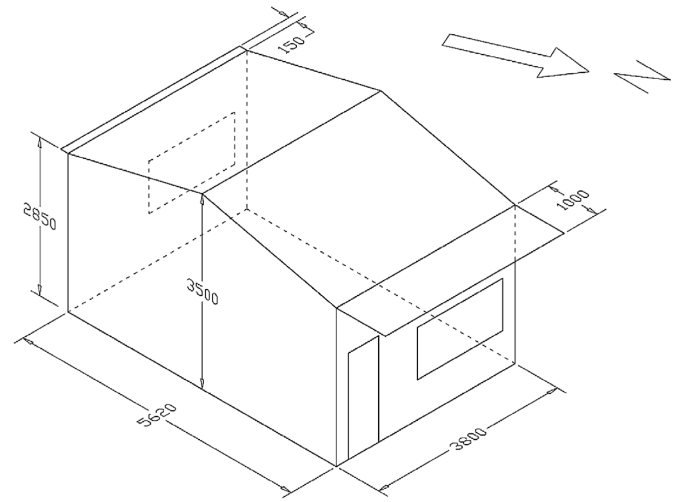

Fig. 1. The dimensions of the PH modelled.

Fig. 2. The photo of the experimental prefabricated house.

2. Model development and validation

2.1. Model establishment

A simulation model for a PH was established using a dynamic whole building energy simulation package, EnergyPlus, which integrates simultaneous solution of thermal zone conditions and HVAC system response [22]. It can simulate both unconditioned and conditioned spaces. The model developed was based on a PH with the following dimensions: 5.62 m (L) × 3.8 m (W) × 3.5 m (H), as shown in Fig. 1. There was a window (1.74 m × 0.95 m) on each of its north and south wall. The north wall had an overhang with 1 m width and south wall an overhang with 0.15 m width. Table 1 lists the construction details for the envelope components of the PH modelled, and Table 2 the physical properties of the materials used in the envelope components.

2.2. Experimental PH and measurement details

For the purpose of model validation, an experimental PH was purposely built. The same dimensions and construction details as those of the PH modelled in Section 2.1 were followed, and a photo of the experiment PH is shown in Fig. 2. It was located in the subtropical Chengdu City, Southwest China, where it is hot in summer