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Actual thermal and ventilation environment fieldwork test analysis of sun space design strategies in a net-zero house

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Key words: passive design; spatial design; performance-based buildings; fieldwork test.
Abstract: Passive design has widely been identified as one of the most economical and effective strategies for reducing energy demand. This research is based on the physical surveillance, and has adopted physical environment fieldwork test and data analysis methods to evaluate the effectiveness of passive space design strategies and their influence on the main body spaces. The project case is a net-zero house that relies completely on solar energy to supply its energy consumption. Its passive design strategy embody sunspace at the building south façade. The experiment tested several physical parameters such as temperature, humidity, wind speed, CO_2 concentration, and PMV index in winter, summer and trans-seasons to evaluate its effectiveness on thermal and ventilation environment. The research results yielded quantified data regarding the impact levels of the three passive spaces, and allowed researchers to summarize their advantages and disadvantages and provide some possible improvements.

Background

The term “passive architecture” is used to describe buildings designed according to the demands of the local climate that strive to naturally create and maintain a comfortable indoor environment [1]. The term “passive” conveys an architectural design focused on protecting the local natural environment and featuring it for the building’s users. [2] Passive design has widely been identified as one of the most economical and effective strategies for sustainable building [3]. The literature indicates that passive strategies can reduce more than 50% of the primary energy source’s consumption [4-5]. Exceptional passive strategies operate on the premise of comfort, with a goal of minimizing energy consumption demands as much as possible; they commonly involve all aspects of architectural design, including building elevation, window orientation, wall thickness, building envelop thermal performance, glazing detail, sunspace, shading devices, etc. [6].

Experimental Platform

The O-house is an experimental building designed by a Tsinghua University research team; it took three years to design, construct, and monitor. It is a net-zero house that relies completely on solar energy to supply its energy consumption [7]. To achieve net-zero energy consumption, works on the inflow and outflow of energy were both necessary. A ground floor plan plays an important role in the reduction of a building’s energy dissipation. In a building functioning as a house, spaces

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that are the most often used and user-related should be optimized for physical comfort as much as possible. The O-house is based on a principle of passive priority. The most cardinal and comfort-demanding space is at its very center, and three layers of space encircle this core. The micro-environment transitions from outside layer to inner layer. As a consequence of its passive design, the indoor comfort level upgrades and the energy consumption is lowered (as shown in Figure 1and Figure 3).

Fig. 1 Passive strategy for three layers of spaces

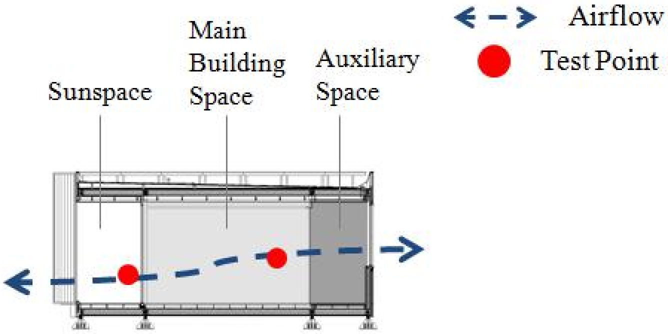

Fig. 2 Nature ventilation airflow design and test point location

Fig. 3 Photo of O-house

Research Methodology

(1) Physical Measurements and Instruments

All of the test instruments in this research were self-recording devices, which facilitated the long-term recording of environmental parameters and eliminated the interference of destabilizing factors (as shown in Table 1and Figure 2). The height of the test points were within the range of 0.7-1.5m, the normal height of the human workplace. Each instrument recorded the environmental data every two minutes [8]. The detectors tested only the air temperature without radiation, and thus were shaded.

Table 1 Test instrument parameters and accuracy

Parameters	Number of Instruments	Instrument Types	Valid range	Accuracy	Manufacture
Ta (℃)	15	WSZY-1A	-20～80	0.1	Tianjian Huayi, Beijing
RH (%)	6	WZY-1A	0 ~100	0.1	
Wind Speed (m/s)	4	FB-1	0~10	0.01	
CO2 concentration (ppm)	6	EZY-1	0~5000	±75	
PMV	2	SSDY-1	-3~3	0.1	

Research Results and Analysis

Figure 4 and Table 2 show the analysis of the test results obtained before and after the windows were opened in the O-House. Because the weather on June 5 through June 7 experienced several changes (it was periodically sunny, rainy, or cloudy), during a rainy period from 5:00pm to 8:30pm on June 6th, the windows and doors were all opened in order to facilitate the natural ventilation. Therefore, it was meaningful to test and analyze the indoor and outdoor thermal environments within this 48 hours. According to the temperature test data curve from 5:00pm to 8:30pm on June 6th, the indoor temperature dropped sharply at 5:00pm (after the windows and doors were opened) from 26.9℃ to 20℃. The total temperature difference was 6.9℃. However, the lowest indoor temperature did correspond to the outside temperature (while it was raining). After 8:30pm, when the windows and doors were closed to block the natural ventilation, the indoor temperature rose dramatically and then remained steady at around 23℃, as compared to the outdoor average temperature at this point of 16.5℃. The temperature difference was 6.6℃. The test results showing that the indoor temperature sharply decreased after the addition of the natural ventilation indicate that the design of the O-house is very successful in realizing its goal of harnessing the benefits of natural ventilation and that it is possible to cool the indoor thermal environment through convection ventilation. However, convection ventilation can only yield heat dissipation that the indoor thermal environment after ventilation will be decided by the outdoor temperature and will never be lower than the outdoor environment temperature.

Table 2 Temperature test data comparison before and after nature ventilation in the O-house (Unit：℃)

	Indoor		Outdoor		Mean Temperature Difference
	T_{min}	$\overline{T}_{indoor}$	T_{min}	$\overline{T}_{outdoor}$	
10 Hours Before Windows Open	26.9	28.6	17.8	23	5.6
Windows Open Period	20	21.7	17.3	19.7	2
10 Hours After Windows Open	21.2	23.1	14.2	16.5	6.6

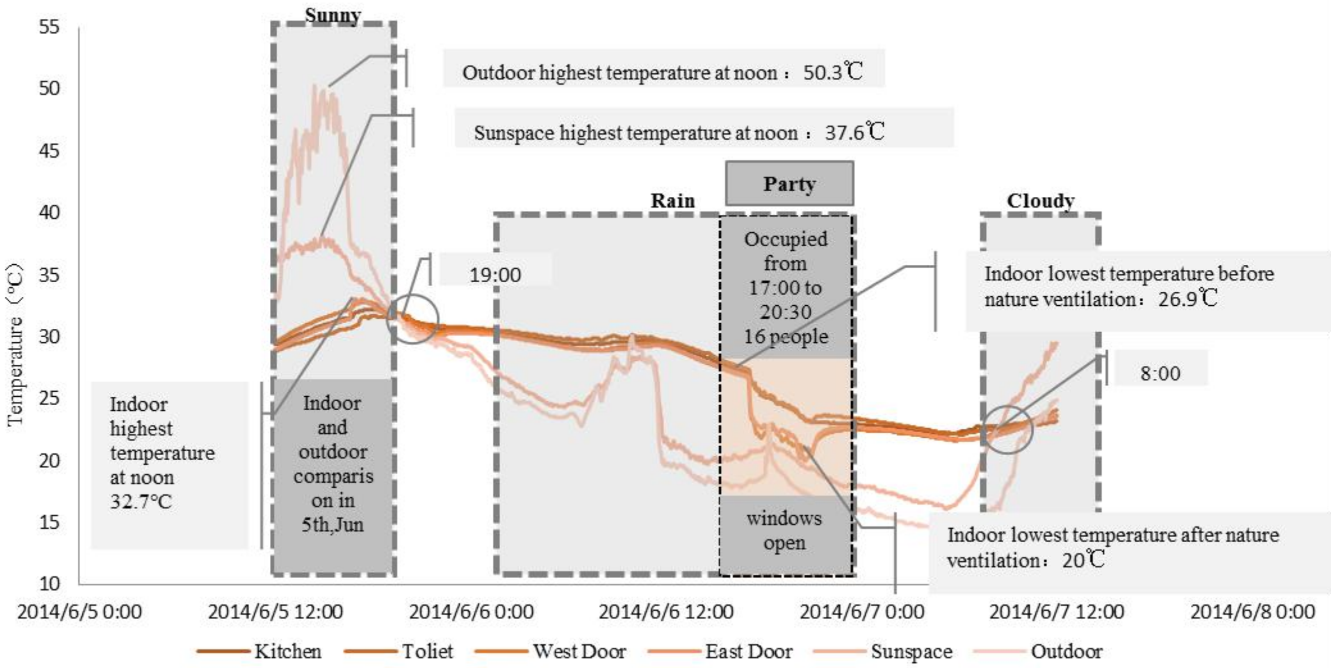

Fig. 4 48 hour temperature variation curve analysis of indoor and outdoor temperatures before and after introduction of natural ventilation in the O-House

Because the indoor temperature sharply decreased and the air speed increased after the windows were opened, the thermal comfort value (PMV) dropped from 1.11 to 0.40, and the “unsatisfied” rating (PPD) dropped from 31% to 8%, which approached the thermal comfort zone in the O-house. Although it was not obvious that the indoor temperature decreased after the wind tower windows were opened, with the higher air speed the thermal comfort value (PMV) and “unsatisfied” rating (PPD) fell from 1.78 to 1.36 (66% to 44%) in the Waterfowl Pavilion (as shown in Table 3).

Table 3 PMV-PPD index before and after natural ventilation in the O-house

Natural Ventilation Status	PMV	PPD
Before Windows Open	1.11	31%
After Windows Open	0.40	8%

Conclusions from the fieldwork test of the wind tower and natural ventilation can be summarized as follows:

(1) Effective cross ventilation can quickly adjust indoor temperatures to be consistent with the outside air temperature. However, ventilation can only yield heat dissipation; after ventilation, the indoor temperature was decided by the outdoor temperature. When the outdoor temperature exceeds the range of human body comfort in summer weather conditions, ventilation is ineffective for cooling down indoor temperatures to a comfortable range.

(2) Natural ventilation can promote human body sweat evaporation, reduce surface temperature, and improve the thermal comfort of the human body in a high temperature environment. In high temperatures, when the average wind speed reaches 0.2 m/s, the “unsatisfied” rating (PPD) as it relates to thermal comfort can be reduced by 10% - 20%.

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