

TECHNICAL ARTICLE

Measurement and Analysis of the Thermal Insulation Effect of the Transition Space of a Building Veranda in the Hot Summer and Cold Winter Zone

Yanyan Huang and Weichang Liu

The thermal environment of a building plays a direct role in the energy consumption of the building. Veranda, considered as a common element of a building in a hot summer and very cold zone, connects indoor and outdoor spaces and provides a transitional space for the building. It has certain influences on the thermal environment of the use space. In this paper, a veranda on the east side of a building in Wuhan, China is taken as the research subject, and the thermal data of indoor and outdoor settings are collected through a network of field sensors. The thermal characteristics of the transitional space are then studied, and the thermal insulation effects of the veranda is comprehensively investigated. The statistical results show that the veranda has a good thermal insulation effect in summer, and the reasonable design of transitional space is instrumental to the improvement of thermal environment and the reduction of building energy consumption.

Keywords: Hot summer and cold winter; Heat insulation effect; Veranda; Field measurement

1. Introduction

In recent years, energy savings and building climate adaptability have become the focus of attention to building energy conservation. As people's living conditions increase, more demand is imposed on how to make buildings more adaptable to human needs through architectural design, especially the design of building exteriors and the selection of exterior materials. Inappropriate exterior design may lead to a building with rooms constant humid, unventilated, and/or cold during winter time. Such design requires more energy from air conditioning devices in order to improve the interior comfortableness of buildings.

Building climate adaptability is closely related to energy savings. A sustainable and green building should be responsive to its local weather conditions (such as natural winds and their prevailing directions, sun lights, and other climate elements). In addition, the building should be built with adaptive materials, reasonable building forms, and efficient space arrangement. As such, the building can be effective in transforming natural energy into the one for the comfortableness of building residents and thus reducing the use of carbon-based energy.

Recent research efforts have been aimed at the relationships among building exteriors, climate adaptability, and

energy savings. For example, Shu developed a concept of weather-adaptable covers for building exteriors and applied this concept in his case studies of buildings within the Su-Zhou region of China (Shu 2013, 2018). He synthesized and classified the cover types within the studied region by the building's adaptability to local weather conditions. Tang and his colleagues did a field test on the heat-transfer performance of various exterior covers within the southern region of China (Tang and Qian 2001). He further extended Shu's concept by adding an additional cover, that is, eco-cover for a building. This eco-cover is a vegetation layer outside of the exterior of a building. It dissolves the radiation of sun lights and blocks energy going into the building. Huang and her colleagues did a field test on double exterior covers of a building within a hot region of China and provided an insightful analysis on the heat-transfer performance of the double covers (Huang et al. 2014; Huang and Zhang 2018). Their analysis results show that the double covers of the building have good performance of heat insulation in summer. Their study concluded that building form and space design are critical to the improvement of a building's thermal environment, energy conservation and emission reduction.

Research efforts have been also concentrated on the use of transitional spaces to improve the inner circulation of heat within a building. For example, Li of Tsinghua University, China has made an in-depth study on the transitional space of buildings (Li 2015; Li and Xia 2019). He proposed that the transitional space of a building is between the external environment and the

interior environment of the building, and is the connection between the external environment and the interior environment. The transitional space acts as a function of linking building residents to the outside surroundings of the building. The transitional space in his research was considered as a supplemental space to reduce the energy consumption during the operation of the building and optimize the comfort of the indoor environment.

Li conducted a set of field tests on inner heat circulation of transitional spaces within hospitals in the northern region of China and concluded that the insulation performance of the hospital buildings is poor. He further studied the buildings through the theoretical and simulation models he developed and proposed strategies on how to use transitional spaces for the insulation of buildings in a cold region (Li 2018). Hou and Zhang of Tianjin University, China analyzed the atrium with different climate and energy factors, and summarized the energy-saving design strategy of atrium space from the perspective of using transitional spaces to achieve the goal of high comfort and low energy consumption (Hou et al. 2016). Chen and Fang also did similar research work on thermal insulation performance and design (Chen et al. 2019; Fang 2019).

All the above research efforts have addressed the issues related to the adaptability of buildings in either cold winter or hot summer region. Few research studies have dealt with build adaptability within hot summer and cold winter regions. This paper aims at the thermal insulation performance of transitional space (or veranda) in a hot summer and cold winter zone. A building associated with the Low Carbon City and Green Building Research Center of Hubei University of Technology, China was

selected as a case building. The veranda on its east side was anchored with a set of sensors. The temporal changes of thermal characteristics of the building were monitored and recorded. The insulation effect of the veranda (as the transitional space of the building) was analyzed and the factors influencing the thermal insulation were identified.

The contribution of this paper is that the thermal insulation performance of transitional space (veranda in this paper) in a hot summer and cold winter zone is measured and analyzed. This research provides a data-driven approach in understanding the thermal impacts of veranda on a building during the summer time. The analysis of the thermal impacts during the cold winter time will be addressed in a separate paper.

This paper is structured as follows. Section two provides a brief description of the case building selected for the study. This section also highlights the sensors used in the indoor and outdoor of the building for monitoring the thermal changes due to the transitional space or the veranda. Section three presents the statistical analyses of the thermal insulation performance of the veranda. The last section concludes the paper by summarizing the research findings of this study.

2. Testing Building and Data Collection

2.1. Testing Building

The selected building (with its latitude of $29^{\circ}58' \sim 31^{\circ}22'$ North and its longitude of $113^{\circ}41' \sim 115^{\circ}05'$ East), located in Wuhan, Hubei Province, China, is in the hot summer and cold winter zone. The building, as shown in **Figure 1**, has four floors in total. The building is shaped of a rectangle with the short north-south side and the

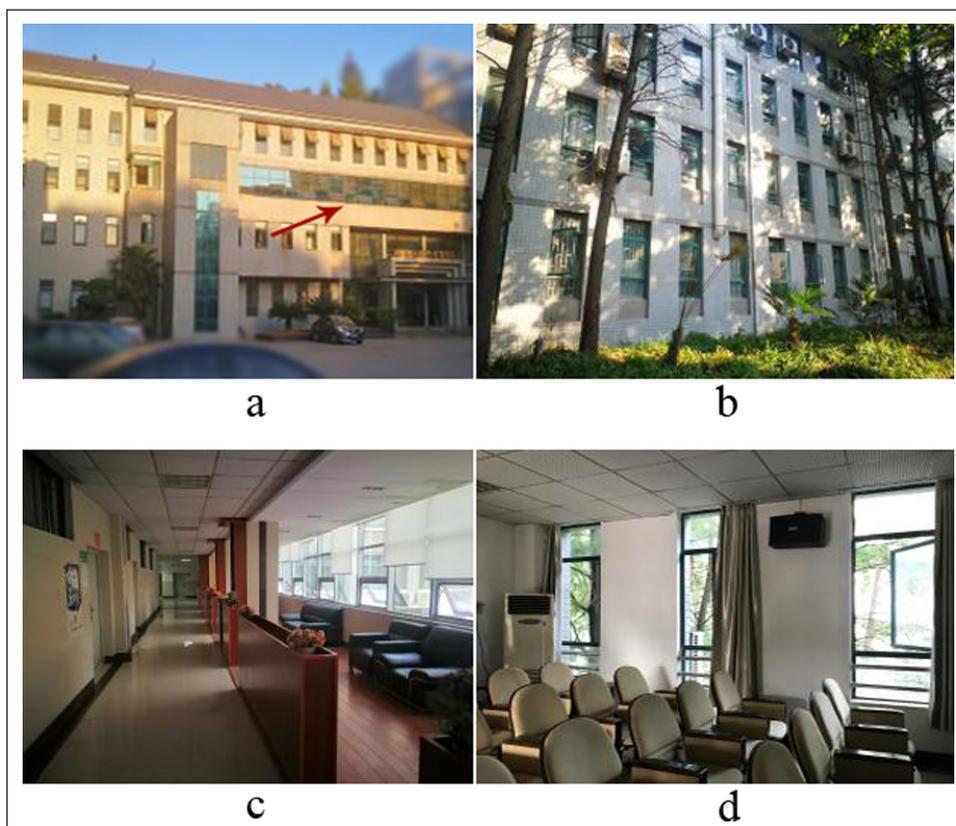


Figure 1: a) East of the building b) West of the building c) Eastern veranda d) Conference Room.

long east-east side. Each floor on the east side has a 4.8 m-wide transitional space (or veranda), which connects to and is perpendicular to the adjacent buildings. No shelter exists outside the east wall of the building. In summer, the solar radiation is strong. The west wall is close to the green vegetation with Metasequoia species. The Metasequoia plants are higher than the building. In summer, the branches and leaves are luxuriant, which offers a shield against sun lights.

The conference room on the third floor was used to install testing sensors for the research project. The conference room has a bay of 15 m in width and 8 m in depth. The east wall of this bay is provided with a long set of horizontal stripe windows. The opposite middle partition wall is provided with high horizontal stripe windows for daylighting, and the west wall is provided with six long vertical windows.

The research team collected the data continuously from the testing sensors from August 3, 2017 to August 9, 2017. These seven days are hottest days in a year within a hot summer and cold winter zone. Considering the same trends of testing data for all seven days, the research team

decided to have a detailed analysis on the testing data collected only on August 6, 2017. During that sunny day, the sun moving profile and the solar incident angle (or the angle between the solar rays and the normal of the window surface) are shown in **Figure 2**.

2.2. Testing Devices

There are three different types of testing devices acquired for this research. The hot-wire anemometer was employed to measure air temperature and moisture, the button type temperature recorder, pasted on the testing surface, was used to measure the temperature of wall or glass surface, while the infrared thermal camera was used to take infrared thermal pictures of wall surface. The information about testing devices can be shown in **Table 1**.

2.3. Testing Network

Two groups of measuring points (with 12 points in total) were arranged for this research project. One group consisted of the air temperature measuring points (No. 1–4). These measuring points were installed 1.5 m above the ground. The other group contained the surface tempera-

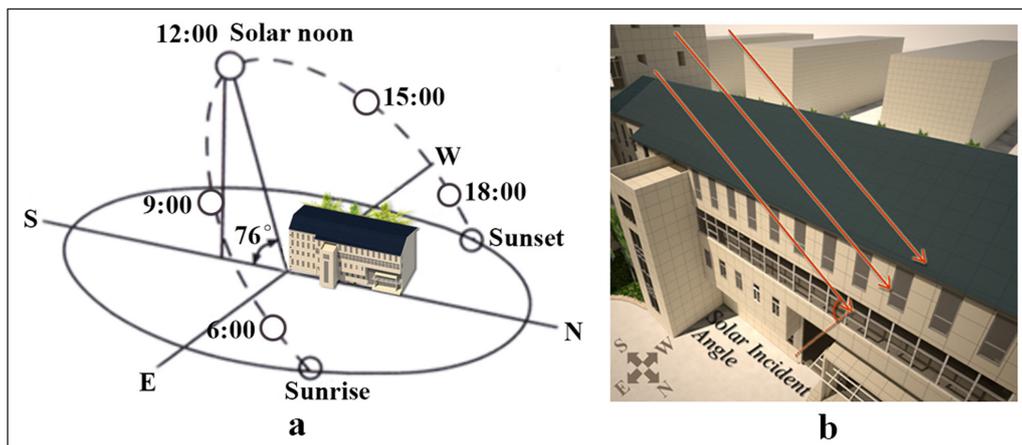


Figure 2: a) The solar apparent motion track b) The solar incident angle.

Table 1: Information about testing devices.

Device Name and Model	Device pictures	Measuring range	Accuracy	Resolution	Recording Interval
Hot-wire anemometer (TES1340)		-20°C~+60°C	±0.5°C ±3%RH	0.1°C	Every 5 minutes
Button type temperature recorder(DS1921G)		-40°C~+85°C	±1°C	0.5°C	Every 5 minutes
Infrared thermal camera (FLUKE-TIS75)		-20°C~+550°C	±2°C	0.08°C	Every 5 minutes

ture measuring points anchored on the wall and window (No. A–F, a–f). The testing network can be shown in **Figure 3**, while the description of the devices for the network is provided in **Table 2**.

3. Statistical Analysis of Testing Data

3.1. Analysis of Air temperatures

As can be seen from **Figure 4**, the air temperatures outside the east wall are always in a relatively high range

before 5:30 P.M. (or 17:30), while the air temperatures in the conference room are almost all at the lowest level. Secondly, the air temperatures outside the east wall fluctuate the most violently, while the air temperatures outside the veranda, the air temperatures inside the conference room and outside the west wall fluctuate in a small range, but are relatively gentle as a whole, which indicates that the air temperature inside the veranda and the conference room is very little influenced by the external environment

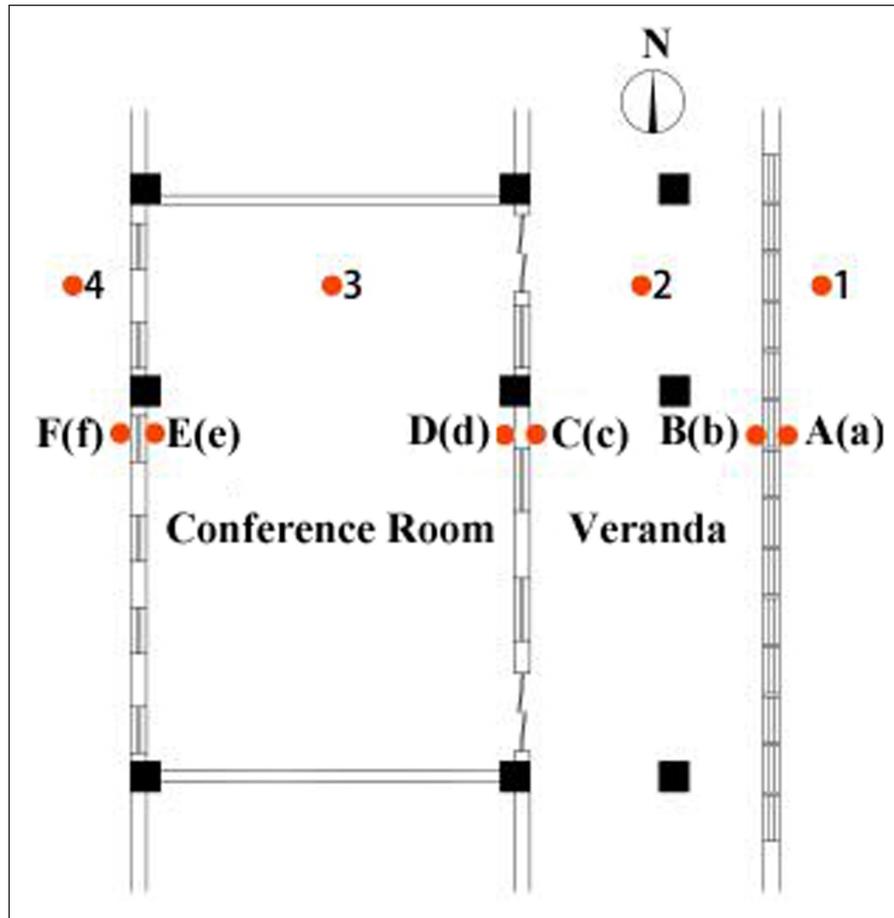


Figure 3: Schematic diagram of the testing network.

Table 2: Setting details of the testing network.

Number	Position	Testing Devices	Contents
1	Outside the west wall	hot-wire anemometer	Air tern perat ure
2	Veranda	hot-wire anemometer	Air tern perat ure
3	Conference Room	hot-wire anemometer	Air tern perat ure
4	Outside the west wall	hot-wire anemometer	Air tern perat ure
A/a	External surface of East wall/East window	Button type temperature recorder	Surface temperature
B/b	Inner surface of East wall/East window	Button type temperature recorder	Surface temperature
C/c	External surface of partition wall/partition window	Button type temperature recorder	Surface temperature
D/d	Inner surface of partition wall/partition window	Button type temperature recorder	Surface temperature
E/e	Inner surface of West wall/West window	Button type temperature recorder	Surface temperature
F/f	External surface of West wall/West window	Button type temperature recorder	Surface temperature

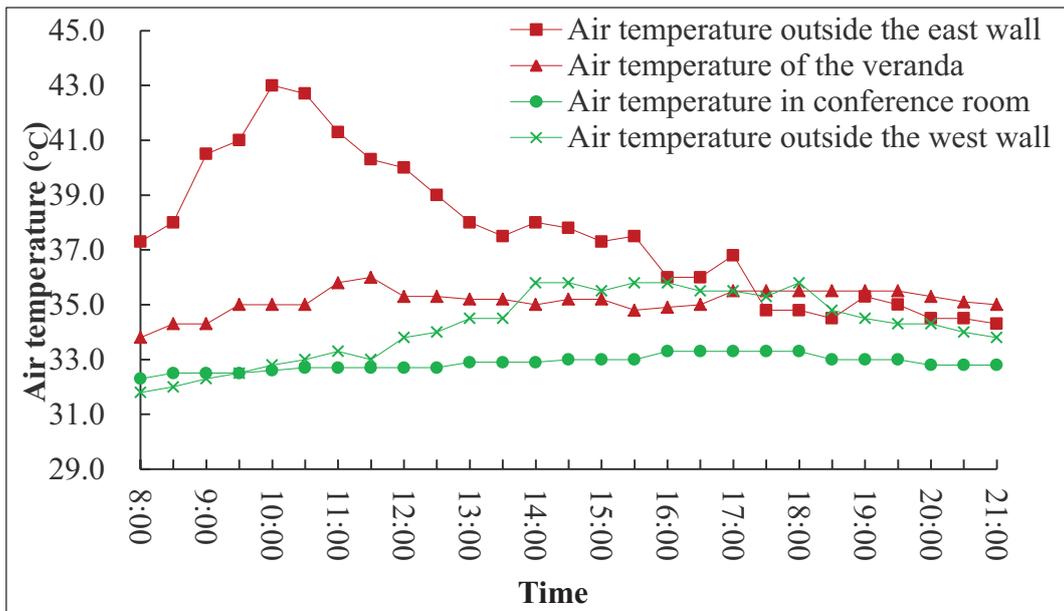


Figure 4: Comparisons of air temperature curves of each measuring point.

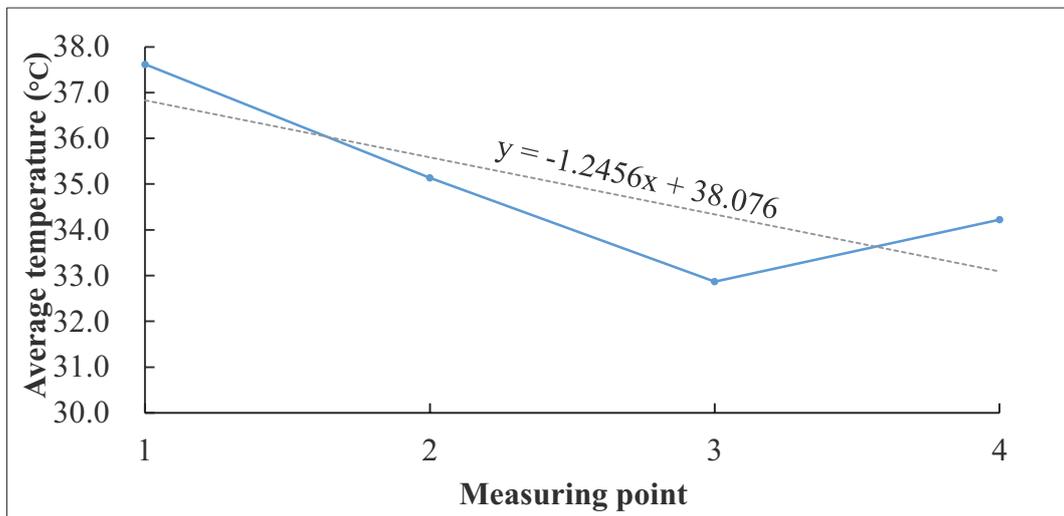


Figure 5: Average temperature change curve of each measuring point.

of the building. As the solar incident angle increases and the solar rays intensifies, the air temperature outside the east wall continues to rise after 8:00 A.M. and reaches at the peak value of 43°C at 10:00 A.M. At this time, the difference between the east wall and the veranda is 8 °C, and the air temperature difference between the east wall and the indoor air temperature is 10.4°C. As the solar incident angle changes and the solar rays sometimes are blocked by clouds, the air temperature continues to decline. The air temperature of the veranda reaches at a peak value of 36°C at 11:30 A.M. and then remains stable although it declines slightly. Passing the noon of the day, the sun starts moving to the west. The west wall gets more solar benefits. The peak value of the air temperature outside the west wall appears at 2:00 P.M., which is 35.8°C, and then it is stable. It can be seen that the air temperature outside the west wall in the afternoon is still lower than that outside the east wall due to the sun exposure. This is the contribution from the vegetation on the west wall which has some influence (or shielding the solar radiation) on

the stability of the air temperature outside the west wall. After 7:00 P.M., the difference of air temperature outside the east wall, outside the veranda, and outside the west wall is not large.

Figures 5 and 6 provide the comparisons of the average air temperature and the average humidity of each measuring point from 8:00 A.M. to 6:00 P.M. Figure 5 also shows that the average air temperature outside the east wall > the average air temperature of the veranda > the average air temperature of the interior, which means that the gradual decreasing trend of the air temperature of the building from the outside to the inside. This finding also indicates that the veranda space has a certain buffering effect on the heat transmission and plays a certain role in blocking heats.

Air humidity is also an important factor impacting people's comfort. In summer, the humidity that makes people feel comfortable is about 50%–65%. This conclusion was made by Professor Youguo Qin from Tsinghua University, China after his numerous studies on thermal impacts on

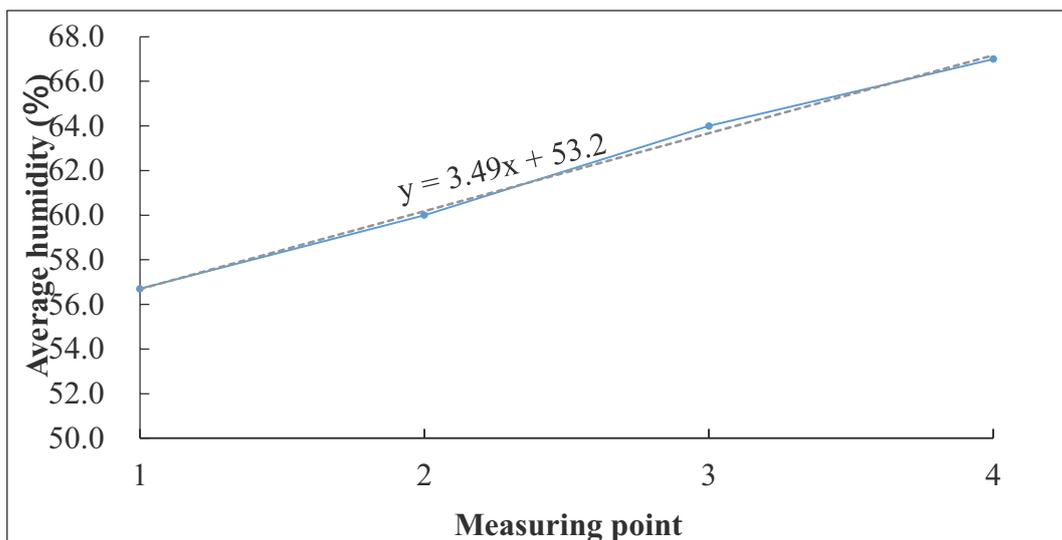


Figure 6: Average humidity change curve of each measuring point.

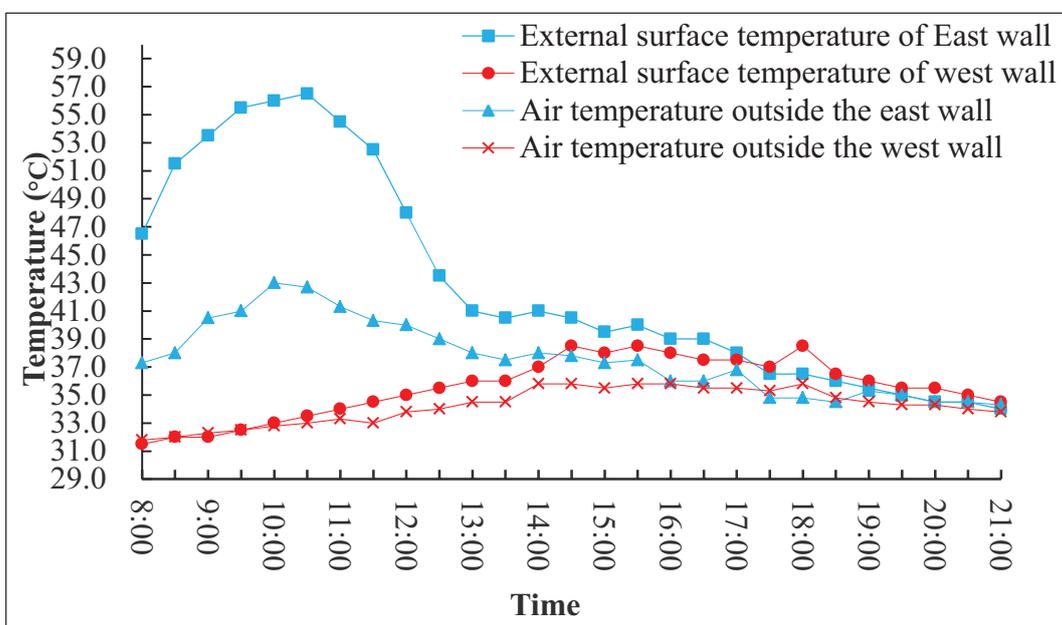


Figure 7: Comparison of the change curves of the surface temperature and air temperature of the east and west walls.

people (Liu and Qin 2015). **Figure 6** shows that the average humidity outside the east wall, in the veranda, and in the conference room are all within this range. However, due to the influences of dense vegetation outside the west wall, the air humidity exceeds the maximum comfort. Although the vegetation has the effects of shielding the solar radiation, it may also have a little negative impact on the indoor environment.

3.2. Analysis of surface temperatures

As shown in **Figure 7**, the air temperatures outside the east wall and the external surface of the east wall are compared. It can be found that the surface temperature is much higher than the air temperature outside the east wall before noon, and the temperature difference even reaches at 13.8°C at 10:30 A.M. This is due to the external surface of the wall which is directly exposed to the sun and absorbs a lot of solar radiation.

The study also finds that the time when the external air temperature outside the east wall reaches at the peak value is not the same as the time when the external surface temperature of the east wall. Therefore, the air temperature reaches its peak at 10:00 A.M., while the external surface temperature reaches its peak at 10:30 A.M., which is delayed for half hour. The temperatures of the west wall surface and the air also demonstrate the same trend, which indicates that the absorption of solar radiation on the external surface of the building is a gradual process and this process is not synchronous with the change of air temperature (outside the building) at any time. When we compare with the surface temperatures of the east wall and the west wall, the surface temperature of the east wall that keeps cooling after the peak value tends to be close to the surface temperature of the west wall that keeps warming due to the west sun exposure. However, the surface temperature of the west wall is always lower than

the surface of the east wall, and the intersection occurs at 5:30 P.M., which is due to the sheltering effect of the west vegetation on the solar radiation.

It can be seen from **Figure 8** that the surface temperatures outside the east window and the inner surface temperature fluctuate greatly and this fluctuating trend is relatively close. The temperature difference between the inner and outer surfaces does not change much during the test period and its maximum temperature difference is 5.5°C. After 11:30 A.M., the temperature of the inner surface of the window begins to be higher than that of the outer surface. On the contrary, the temperature difference between the inner and outer surfaces of the east wall is huge before 12:00, with the maximum temperature difference reaching at 20°C. The temperature change curve

of the inner surface of the wall is relatively gentle, and is not much controlled by the external surface temperature of the wall. In addition, when we compare the external surface temperature of the east wall with the surface temperature of the east window, it is found that their temperature change curves are very close, and the curves overlap in many places, which shows that the surface heat absorption capacity of the wall and the glass is not much different. However, the heat insulation effect of the wall is better than that of the glass.

3.3. Analysis of infrared thermogram

Figure 9 clearly shows the intensity of infrared radiation (i.e. temperature) in different parts of the outer surface of the east and west walls. It can be seen from **Figure 9a**

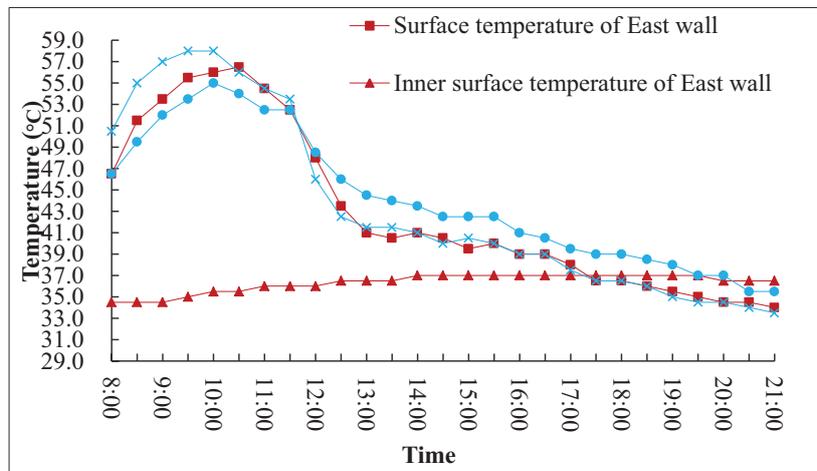


Figure 8: Comparison of temperature change curves of inner and outer surfaces of east wall and window.

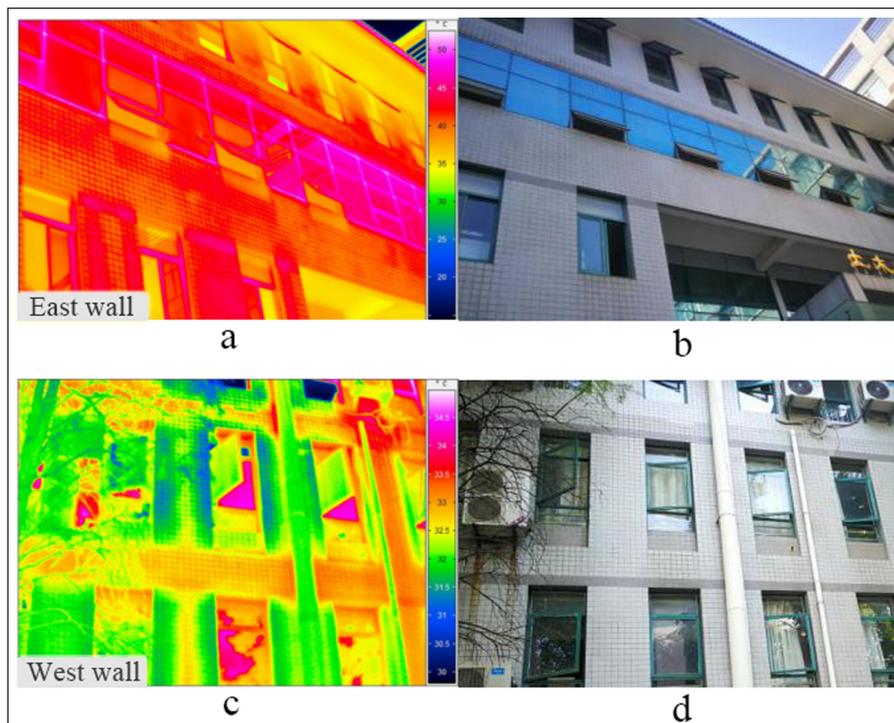


Figure 9: a) Infrared thermal image of the outer surface of the east wall b) Real shot of the outer surface of the east wall at the same angle c) Infrared thermal image of the external surface of the west wall d) Real shot of the outer surface of the west wall at the same angle.

that the temperature of aluminum alloy window frame is much higher than the surface temperature of glass and wall. This is due to the heat absorption capacity (specific heat capacity) of aluminum alloy which is greater than that of glass and ceramic tile; in addition, it is found that the surface temperature of the long horizontal strip windows is higher than the surface temperature of the upper and lower independent windows. This is due to the horizontal strip windows which have a wider solar radiation contact surface. Unlike the independent windows, the horizontal stripe windows conduct or transfer less heat to the wall. Therefore, the window layout and the window frame material of the building facade are also the factors to be considered in the energy-saving design of the building. When we compare **Figure 9a** and **Figure 9c**, it is obvious that the surface temperature of the west wall is lower than that of the east wall, especially in the area where the vegetation shadow exists. The effect of vegetation on the microclimate outside the west wall is not only to block the solar radiation, but also to absorb part of the heat of the surrounding environment. In doing so, the vegetation can reduce the overall environmental temperature.

4. Conclusions and Future Research

Through the comprehensive comparisons and analyses of the measured data, the following conclusions can be obtained:

- 1) It is found that the building is located in an unbalanced microclimate environment, and the air temperature and humidity in each direction are different. Therefore, in the energy-saving design of adaptive climate buildings, this feature needs to be considered, and different building facades should be treated accordingly, so as to increase the energy-saving effect of buildings.
- 2) The average air temperature outside the east wall of the testing building is 4.7°C higher than the average indoor air temperature, and the maximum temperature difference reaches at 10.2°C. Such difference is very noticeable to people. It can be seen that in the hot summer and cold winter zone, the transitional space (or the building's veranda) has a significant heat insulation effect in the hot summer, which has a certain role in adjusting the indoor air temperature.
- 3) Dense and tall vegetation has obvious effect on adjusting the microclimate inside and outside the building. In hot summer and cold winter zones, planting appropriate vegetation outside the building can not only solve the problem of sun exposure, but also beautify the landscape.

The thermal environment of a building plays a direct role in the energy consumption of the building. This paper only studied a veranda (a special transitional space of a

building) in a hot summer and very cold zone. The thermal characteristics of the transitional space and the thermal insulation effects of the investigated veranda show that the veranda could be a good design element which can be instrumental to the improvement of thermal environment and the reduction of building energy consumption. In the future, more verandas are suggested to be studied and more testing data relevant to thermal insulation effects of verandas should be investigated and compared. Additionally, more research should be also placed onto other types of transitional spaces.

Competing Interests

The authors have no competing interests to declare.

References

- Chen, J, Yang, L and Luo, Z.** 2019. Study on thermal insulation design of residential building envelope in Turpan area [J]. *Huazhong architecture*, 37(9): 47–50.
- Fang, Y.** 2019. Study on the technology of improving the performance of the envelope structure of the campus student dormitory in the hot summer and warm winter area [D]. Guangzhou University.
- Hou, H, Zhang, Q and Huang, Q.** 2016. Preliminary study on the construction of low energy consumption design strategy map of atrium space in cold area [J]. *Journal of architecture*, 5: 72–76.
- Huang, Y, Chen, H and Yuan, L.** 2014. Measurement and analysis of the thermal insulation effect of the building skin in the hot summer area [J]. *Journal of Guilin University of technology*, 34(2): 278–282.
- Huang, Y and Zhang, X.** 2018. Measurement and analysis of double skin insulation performance of large space building in Taiyuan South Railway Station [J]. *Industrial building*, 48(2): 59–62 + 78.
- Li, A.** 2018. Study on thermal environment transformation strategy of indoor and outdoor transition space of cold hospital buildings [D]. Shenyang University of architecture.
- Li, J.** 2015. Study on the passive regulation of intermediary space [D]. Tsinghua University.
- Li, J and Xia, H.** 2019. Organic and compound: an analysis of the passive regulation of intermediary space [J]. *New architecture*, 2: 106–109.
- Liu, N and Qin, Y.** 2015. Thermal environment of buildings [M]. Beijing: Tsinghua University Press.
- Shu, X.** 2013. Application of climate adaptive building skin in building reconstruction [J]. *Architectural science*, 29(12): 1–5–123.
- Shu, X.** 2018. Study on design mode of climate adaptive building skin [J]. *Architect*, 6: 112–117.
- Tang, M and Qian, W.** 2001. Improving urban thermal environment by adopting ecological building insulation measures [J]. *Journal of Chongqing University of architecture*, 4: 31–35.

How to cite this article: Huang, Y and Liu, W. 2020. Measurement and Analysis of the Thermal Insulation Effect of the Transition Space of a Building Veranda in the Hot Summer and Cold Winter Zone. *Future Cities and Environment*, 6(1): 3, 1–9. DOI: <https://doi.org/10.5334/fce.86>

Submitted: 21 January 2020

Accepted: 11 March 2020

Published: 22 April 2020

Copyright: © 2020 The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. See <http://creativecommons.org/licenses/by/4.0/>.

]u[*Future Cities and Environment*, is a peer-reviewed open access journal published by Ubiquity Press.

OPEN ACCESS 