Comparative Study on Thermal Sensation and Skin Temperature Passing Different Transitional Spaces with or without Air-Conditioning in a Shopping Mall

Jie Han, Wenheng Zheng, Rong Hu, Zhihong Yang, Guoqiang Zhang, Per Heiselberg and David Hou Chi Chow

Abstract What is the difference between the thermal sensation and skin temperature in transitional spaces with or without air-conditioning? Is it necessary to have intensive air-conditioning in transitional spaces of southern China? In order to answer these questions, this paper presents a comparative study performed in a selected shopping mall with two transitional spaces–one with air-conditioning, the other without. The results show that the thermal sensation and skin temperature is different due to the presentation of air-conditioning. It also indicates that air-conditioning for the transitional spaces is needed in southern China. Meanwhile, the study involves continuous measurements of the skin temperature of twenty students while they simultaneously filled out a questionnaire. When subjects passing these two transitional spaces, different skin temperatures and its variation rates result in inconsistent thermal sensation. However, there was a linear relationship between the thermal sensation and the variation rate of mean skin temperature was obtained. These findings can provide valuable information for a good guide to air-conditioning design in transitional spaces.

Keywords Transitional spaces · Air-conditioning · Thermal sensation

J. Han (✉) · W. Zheng · R. Hu
School of Architecture and Transportation Engineering, Guilin University of Electronic Technology, Guilin, China
e-mail: hanjie@guet.edu.cn

J. Han · Z. Yang · G. Zhang
College of Civil Engineering, Hunan University, Changsha, China
e-mail: gqzhang@188.com

J. Han · P. Heiselberg
Department of Civil Engineering, Aalborg University, Aalborg, Denmark
e-mail: ph@civil.aau.dk

D. H. C. Chow
Sustainability, Complexity and Uncertainty in Building Assessment (SCUBA) Group, School of Architecture, University of Liverpool, Liverpool, UK

Z. Wang et al. (eds.), *Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)*, Environmental Science and Engineering, https://doi.org/10.1007/978-981-13-9520-8_37

1 Introduction

Transitional spaces are defined as the buffer zones and physical link between outdoor and indoor environments, and these spaces having the resilience to changing environment and reducing overall energy demand are, once again, drawing the attention of architects and investigators. Chun et al. [1] introduced three types of transitional spaces: Type I, Type II and Type III. Type I spaces are transitional spaces inside a building, such as hotel lobbies or entry atria; Type II spaces are attached or covered spaces connecting to the main building, like corridors and covered walkway; Type III spaces are semi-outdoor spaces that are shaded such as bus shelters or railway stations. Transitional spaces can reduce the demand of air-conditioning (air-conditioning in China can provide both cooling and heating, and we refer to heating in this paper) because of thermal adaptation and people having more thermal tolerance or forgiving nature [1, 2]. However, some researchers have stated that the energy consumption rate in transitional spaces could be three times the rate inside the main building [3, 4]. In our opinion, the main reasons for the contradictory conclusions might attribute to the thermal comfort requirement and the openness of transitional spaces. In south China, there is a tendency to install air-conditioning as a way to increase thermal comfort of transitional spaces, such as entrances and exits of shopping malls. Is it necessary to have intensive air-conditioning in transitional spaces of southern China? What is the difference between thermal sensation and skin temperature in transitional spaces with or without air-conditioning?

Many researchers have discovered the differences between thermal sensation and thermal comfort among indoor space, transitional space and outdoor space. Pitts et al. [5] found that people who passing through transitional spaces are more tolerant of temperature changes, which lead to widening PMV boundaries. Spangnolo and de Dear [6] stated that the thermal neutrality index of semi-outdoors was significantly higher than that of indoor spaces. Thermal comfort standards, such as the ASHRAE standard [7], ISO 7730 [8] and Chinese Standard GB/T 50785 [9], do not clearly address transitional spaces. Hence, it is necessary to adopt suitable criteria for transitional spaces. Accordingly, the purpose of investigating the feature of thermal sensation and skin temperature in transitional spaces was to improve thermal comfort and energy conservation. In addition, research has addressed thermal sensation and change of skin temperature in transitional spaces over the past decade. Many researchers studied the effect of temperature steps in transitional spaces on human thermal comfort [10–12]. Zhang et al. [13] also carried out an experimental study of human responses to step changes in humidity. Dalilah and Gital [14] studied the hysteresis effects on transient thermal conditions consisting of warm-neutral in a quasi-experiment setting. Yu et al. [15] considered the acceptable temperature ranges of a temporarily occupied space (TOS), e.g. shopping malls could be different from the ranges of normal indoor spaces such as

offices in Tianjing, north of China. Vargas and Stevenson [16] presented that people's thermal perception in lobby spaces can be altered by short-term history. Wu and Mahdavi [17] explored thermal comfort assessments under transitional states. Ghaddar et al. [18] studied thermal comfort parameters in transitional spaces with different air movement levels and three clothing levels. Choi and Loftness [19] studied the possibility of the use of human body skin temperature to assess thermal sensation. Choi and Yeom [20] also proposed a data-driven thermal sensation prediction model as a function of local body skin temperatures in a built environment. Sim et al. [21] developed a thermal sensation estimation model basing on Wrist skin temperature. From reviewed literature, these researches mainly focus on the difference of thermal sensation, influencing factors (environment, physiology, and psychology) and evaluation methodology in transitional spaces. To the best of our knowledge, there is few comparative information available concerning skin temperature and thermal sensation of different transitional spaces with or without air-conditioning. Our specific objectives were:

(1) Identify the difference of thermal environment and thermal comfort in the transitional spaces with or without air-conditioning.
(2) Compare the difference between skin temperature and thermal sensation as people passing through transitional space with or without air-conditioning.
(3) Attain the estimate model of thermal sensation in transitional spaces with or without air-conditioning for a good practice guide to transitional space design in a building.

2 Methods

Zhuzhou, famous for industrial city, is located between 112° 6′–114° E longitude and 26°–28° N latitude. The rapid development of urbanization has resulted in a large number of shopping malls in Zhuzhou. Although large shopping malls mean shortcuts and convenience in shopping, they also cause high-energy consumption due to a large building area, high flow density of passengers and various lighting and electrical equipment. Our investigations were conducted in winter at the shopping mall with two different transitional spaces—one with air-conditioning, the other without, as shown in Figs. 1 and 2.

Field study and tracking measurement were performed from January to February 2016. Two transitional spaces were selected in the shopping mall. Staying time in transitional spaces varies approximately from several minutes to half an hour. For example, someone pass through this place in about 2–3 min. Perhaps, others take more than ten minutes to read the indicators placed in these spaces. The environmental parameters (air temperature, radiation temperature, humidity, and air speed) were measured at outside, transitional and inside spaces of the shopping mall.

Fig. 1 Location of Zhuzhou in China and the picture of the shopping mall

Fig. 2 Transitional spaces and measurement points

Figure 2 shows the measurement points. 377 shoppers and 20 students were recruited for different research aims. A subjective questionnaire survey for studying thermal sensation was carried out with 377 shoppers visiting the shopping mall, going in and out of the transitional space. Thermal Sensational Vote (TSV) was assessed by ASHRAE seven-point scale. Thermal comfort levels were expressed with the Thermal Comfort Votes (TCV) (1-Comfort, 2-Slightly discomfort, 3-Discomfort, 4-Very discomfort, 5-Not endure).We also track monitored the skin temperatures of twenty healthy young students who completed the questionnaire simultaneously basing on their thermal experience while traveling between different spaces. The Origin 8.0 package was applied for the statistics. The research was approved by the Ethics Committee of Guilin University of Electronic Technology under the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Also, all participants carefully read and signed the informed consent, and the participants in the picture agree to publish Fig. 2.

3 Results

3.1 Thermal Environment

The mean air temperature (T_a) of **Transitional Space with Air-Conditioning (TSAC)** was 4.87 °C lower than the indoor environment; 8.39 °C higher than the outdoor environment. The mean T_a of **Transitional Space with No Air-Conditioning (TSNAC)** was close to the outdoor environment, 12.87 °C lower than the indoor environment. The mean globe temperature (T_g) of TSAC was 4.42 °C lower than the indoor environment, 10.27 °C higher than the outdoor environment. The mean T_g of TSNAC was 0.11 °C lower than the outdoor environment, 14.8 °C lower than the indoor environment. The air velocity of TSAC was 0.18 m/s higher than the indoor environment, 0.48 m/s lower than the outdoor environment. The air velocity of TSNAC was 0.06 m/s higher than the indoor environment, 0.36 m/s lower than the outdoor environment.

3.2 Thermal Response

From Fig. 3, the percentage of shoppers who felt thermal environment was acceptable (TSV between −1 and 1) was as high as 92% in TSAC. However, only 64% of shoppers found the thermal environment of TSNAC was acceptable, which is lower than the requirements of the GB/T 50785-2012 [9]. 19% of subjects felt the thermal environment of TSNAC was very cold (TSV = −3) and 17% felt cold (TSV = −2). The low temperature in TSNAC results in people uncomfortable.

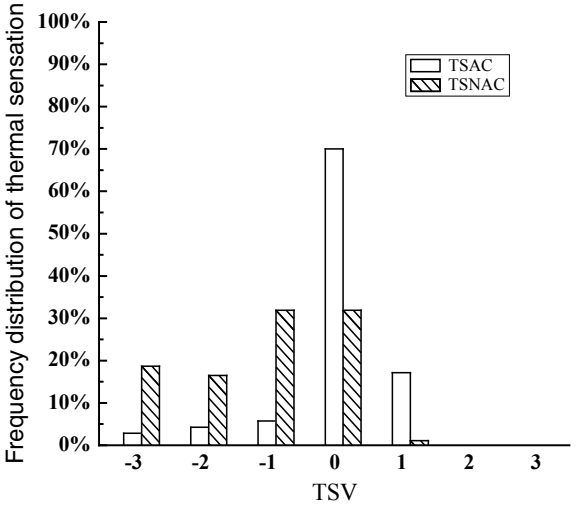

Fig. 3 Frequency distribution of thermal sensation votes

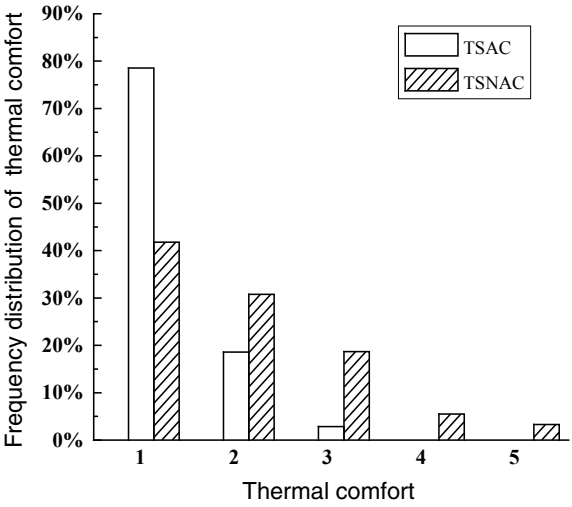

Fig. 4 Frequency distribution of shoppers' thermal comfort votes

When comparing Figs. 3 and 4, the thermal comfort of TSAC was better than TSNAC. The shoppers' thermal sensation votes show that the percentage of people who felt comfortable was higher than the percentage of those who voted thermal sensation as neutral. This indicates that we cannot confirm that thermal neutral when people received a stimulus that responded thermal comfort, and vice versa.

3.3 Variation of Mean Skin Temperature

Figure 5 shows the variation in average skin temperature of students under the two scenarios (1) passing through an air-conditioned transitional space and (2) through a no-air-conditioned transitional space. The mean skin temperature shown in the figure is the average value of measurement results for the subjects under the same condition. Figure 6 shows the variation of the students' Thermal Sensation Vote (TSV).

The variations in skin temperature of students are different in these two scenarios. In the scenario with an air-conditioned transitional space, there was a higher rise in skin temperature when students were transitioning through the warmer air-conditioned transitional space to the inside of the shopping mall, and the skin temperature continued to rise at a faster rate than in the scenario with no air-conditioning. In the scenario where there was no air-conditioning in the transitional space, the students' skin temperature dropped even lower, and the rise of skin temperature was slower and reached a lower peak temperature than the scenario (1).

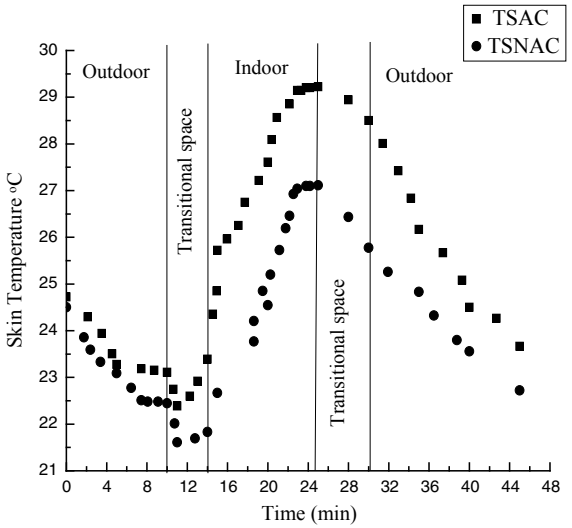

Fig. 5 Variation of mean skin temperature with time

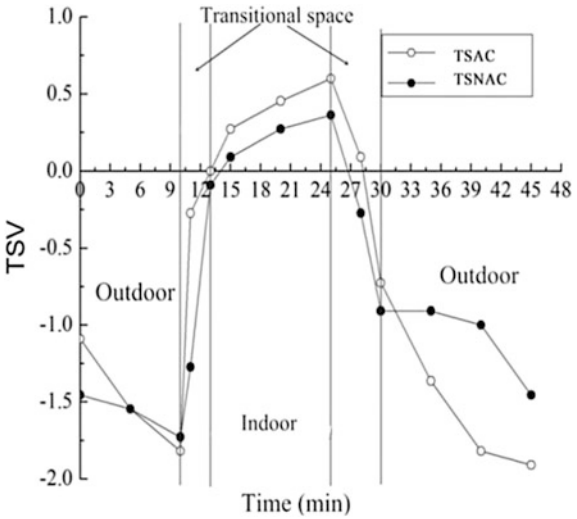

Fig. 6 Variation of mean thermal sensation vote with time

4 Discussion

Some studies by chamber experiments show that there is significant linear or exponential relationship between the thermal sensation and skin temperature in steady-state environment [10]. However, the correlation between skin temperature and thermal sensation during students' transitioning between different areas is not significant according to the field study in a real environment. From Fig. 7, a mean skin temperature of students in TSAC or TSNAC may correspond to different

Thermal Sensation Votes. This could be due to different thermal experience which is similar to Vargas and Stevenson proposed thermal memory [16]. For example, the mean skin temperature of students was 24.5 °C in TSAC; the corresponding thermal sensation value was 0.2 and −0.6 respectively, representing two different states of thermal sensation votes. This could be a result of the students from different spaces, inside or outside. Different thermal experience may lead to different thermal sensation. Thus, the mean skin temperature cannot be used to evaluate the thermal comfort of a human body alone and cannot be directly used to predict the dynamic thermal sensation in the dynamic environment. Previous thermal experience has significant impact on the thermal sensation in transitional spaces.

According to Fig. 7, there was a weak association between mean skin temperature and thermal sensation during students' transitioning between different spaces. And Choi and Loftness [19], by chamber experiments, revealed that change rates (gradients) of skin temperature were more consistent with the thermal comfort condition than with the actual levels of skin temperatures of participants. Therefore, we try to explore the relationship between the variation rate of mean skin temperature and thermal sensation in transitional spaces. Figure 8 shows the fitting curves between variation rate of mean skin temperature and thermal sensation vote (TSV) of students under the two scenarios. The regression equations are as Eqs. (1) and (2).

$$\mathrm{TSV} = 1.155\mathrm{d}T_{\mathrm{sk}}/\mathrm{d}\tau - 0.596 \left(R^2 = 0.438\right) \tag{1}$$

$$\mathrm{TSV} = 1.404\mathrm{d}T_{\mathrm{sk}}/\mathrm{d}\tau - 0.471 \left(R^2 = 0.753\right) \tag{2}$$

$\mathrm{d}T_{\mathrm{sk}}/\mathrm{d}\tau$ in the equations represents the variation rate of mean skin temperature. The time unit in the derivative term is second. In Fig. 8, there is a significant

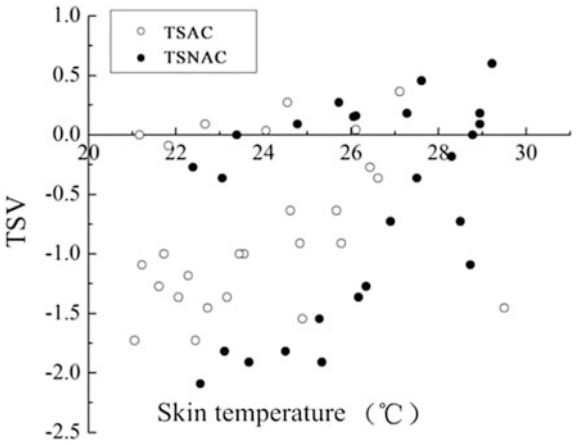

Fig. 7 Relationship between TSV and skin temperature

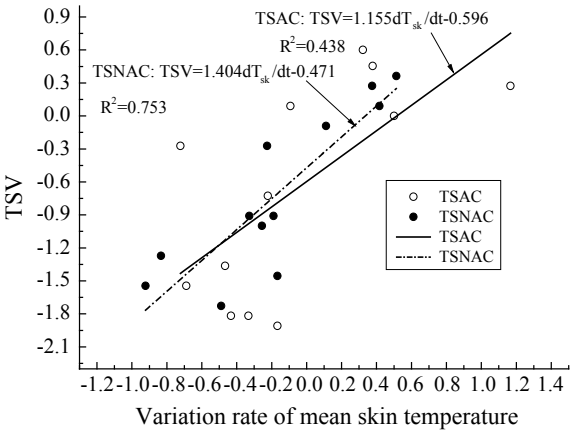

Fig. 8 Relationship TSV and variation rate of mean skin temperature

correlation between the variation rate of mean skin temperature and the thermal sensation vote during the students' transitioning between spaces, especially in the scenario where the students were passing through the no-air-conditioned transitional space.

5 Conclusions

This paper presented the results of a comparative study on skin temperature and thermal sensation of two different transitional spaces (with or without air-conditioning) by field measurement, questionnaires and tracking monitor in a shopping mall during the winter of Zhuzhou, south China. The main conclusions of this study are as follows:

- The thermal environment of the transitional space with air-conditioning is close to the indoor environment, and the thermal environment of the transitional space without air-conditioning is close to outdoor environment. Further study might investigate the effects of different setting values of air-conditioning in the different transitional space.
- The thermal acceptance rate is 92% of the shoppers for the transitional space with air-conditioning and 64% for the transitional space without air-conditioning, which indicates installing air-conditioning can improve the thermal condition of transitional spaces.
- The overall relationship between skin temperature and thermal sensation of both scenarios is not significant according to the field study in dynamic environmental conditions. Therefore, it is not accurate to evaluate thermal sensation of people during their space transitioning by the mean skin temperature. There is a significant correlation between the variation rate in the mean skin temperature and thermal sensation.

Acknowledgements The project is supported by Natural Science Foundation of Guangxi (No. 2018GXNSFAA281212) and Joint Cultivation Fund of Guangxi (No. 2018GXNSFAA 138071), Demonstration and Research on Key Technologies of Low Carbon Green Intelligent Zone in Guilin City (No. 20180107-2). Thank Dr. Leixing Ouyang and Ms. Vivi to improve English writing of this paper.

References

1. Chun, C.Y., Kwok, A., Tamra, A.: Thermal comfort in transitional spaces-basic concepts: literature review and trial measurement. Build. Environ. **39**, 1187–1192 (2004)
2. Pitts, A., Saleh, J.B.: Potential for energy saving in building transition spaces. Energy Build. **39**, 815–822 (2007)
3. Miura, S.: Study on thermal environment and energy consumption in underground shopping centers. J. Arch. Inst. Jpn. **430**, 13–22 (1991)
4. Chun, C.Y., Tamura, A.: Thermal comfort in urban transitional spaces. Build. Environ. **40**, 633–639 (2005)
5. Pitts, A., Saleh, J., Sharples, J.: Building transitional spaces, comfort and energy use. In: 25th Conference on Passive and Low Energy Architecture, Dublin, Paper No: 591 (2008)
6. Spagnolo, J., de Dear, R.: A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. Build. Environ. **38**, 721–738 (2003)
7. ASHRAE.: ASHRAE Standard 55: Thermal Environment Conditions for Human Occupancy. ASHRAE Engineers, Inc., Atlanta, GA (2010)
8. ISO: ISO 7730: Moderate thermal environment-determination of the PMV and PPD indices and specification of the conditions for thermal comfort. International Organization for Standardization, Geneva, Switzerland (1994)
9. Ministry of Housing and Urban-Rural Development of the People's Republic of China: GB/T 50785: evaluation standard for indoor thermal environment in civil buildings. China Architecture and Building Press, Beijing (2012) (in Chinese)
10. Zhang, Z.J., Zhang, Y.F., Ding, E.: Acceptable temperature steps for transitional spaces in the hot-humid area of China. Build. Environ. **121**, 190–199 (2017)
11. Taib, N., Abdullah, A., Ali, Z., Fadzil, S.F.S., Yeok, F.S.: Trends in the air temperature of transitional spaces of a high-rise office building: the effects of season and location. Indoor Built Environ. **23**(8), 1117–1128 (2014)
12. Chen, C.P., Hwang, R.L., Chang, S.Y., Lu, Y.T.: Effects of temperature steps on human skin physiology and thermal sensation response. Build. Environ. **46**, 2387–2397 (2011)
13. Zhang, Y.F., Zhang, J., Chen, H.M., Du, X.H., Meng, Q.L.: Effects of step changes of temperature and humidity on human responses of people in hot-humid area of China. Build. Environ. **80**, 174–183 (2014)
14. Dahlan, D.N., Gital, Y.Y.: Thermal sensations and comfort investigations in transient conditions in tropical office. Appl. Ergon. **54**, 169–176 (2016)
15. Yu, J., Yang, B., Zhu, N.: Effect of thermal transient on thermal comfort in temporarily occupied space in winter-A case study in Tianjin. Build. Environ. **93**(2), 27–33 (2015)
16. Vargas, G.A., Stevenson, F.: Thermal memory and transition in lobby spaces. Energy Proc. **62**, 502–511 (2014)
17. Wu, Y.C., Mahdavi, A.: Assessment of thermal comfort under transitional conditions. Build. Environ. **76**, 30–36 (2014)
18. Ghaddar, N., Ghali, K., Chehaitly, S.: Assessing thermal comfort of active people in transitional spaces in presence of air movement. Energy Build. **43**(10), 2832–2842 (2011)
19. Choi, J.H., Loftness, V.: Investigation of human body skin temperatures as a bio-signal to indicate overall thermal sensations. Build. Environ. **58**, 258–269 (2012)

20. Choi, J.H., Yeom, D.W.: Study of data-driven thermal sensation prediction model as a function of local body skin temperatures in a built environment. Build. Environ. **121**, 130–147 (2017)
21. Sim, S.Y., Koh, M.J., Joo, K.M., Noh, S.W., Park, S.Y., Kim, Y.H., Park, K.S.: Estimation of thermal sensation based on wrist skin temperature. Sensors **16**, 420 (2016)