7 Can thermal perception in a building be predicted by the perceived spatial openness of a building in a hot and humid climate?[6]

ABSTRACT

The authors wanted to prove that there is a large correlation between the concepts spatial openness and comfort (visual, wind speed and thermal) perception in people's minds in a hot and humid climate in summer in order to be able to use

6 This chapter is originally published as: Du, X., Bokel, R., & van den Dobbelsteen, A. (2017). *Can thermal perception in a building be predicted by the perceived spatial openness of a building in a hot and humid climate?* Paper presented at the PLEA 2017 Design to Thrive, Edinburgh. Part of the content is slightly modified in this thesis.

spatial configuration parameters such as openness, connectivity and depth as a design tool for a comfortable an energy efficient building in the early design stages. 513 local Chinese college architecture students in 2015 were questioned about the relationship between spatial openness and comfort perception. The main findings for a hot and humid climate are: a. spatial openness of a particular space significantly effects occupants' visual perception, wind speed perception and thermal perception in a particular space ($p < .05$). b. There is a strong effect size between spatial openness and visual and wind perception ($w = .50$ and $.54$); the effect size of the thermal perception is weaker ($w = .14$). c. The comfort perception is strongly influenced by the time of day, therefore visual perception, wind perception and thermal perception can influence occupant movement between different spaces as is the advice of the adaptive thermal comfort.

KEYWORDS Spatial openness, thermal environmental perception, adaptive thermal comfort

7.1 Introduction

Architecture as a shelter protects people from the natural environment through various architectural elements: floors, walls, columns, windows, doors and roofs. These elements can be identified as architectural boundaries, which distinguish the outdoor from the indoor environment and the various indoor spaces from each other. The outdoor and indoor architectural boundaries determine a spatial environment. In a particular spatial environment, next to the basic functional requirements for occupants' activities, the perceptions of the occupants such as aesthetics, delight and comfort, are also very important for the quality of a built environment. Studying the relationship between the spatial environment and the way the spatial environment is perceived can yield important insights into the way architectural design can create more comfortable living environments.

Comfort (especially thermal comfort) is heavily related to building energy consumption; therefore, comfort is one of the most important considerations in modern architectural design within the scope of sustainable development. A wealth of thermal environment studies have investigated the relationship between building shape, geometry and envelop, and thermal environment (AlAnzi et al., 2009; Hirano, Kato, Murakami, Ikaga, & Shiraishi, 2006; Naraghi & Harant, 2013; Ratti, Raydan, & Steemers, 2003; Yi & Malkawi, 2009), yet less research has been carried out on the influence of the spatial configuration, i.e. the relative arrangement of parts or

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elements in a three-dimensional space, inside a building on the thermal environment and occupants' thermal perception.

Common sense tells us that in summer in a hot and humid climate there is a correlation between the concept spatial openness and comfort perception in people's minds. The authors' hypothesis is that there is a large correlation between the concept spatial openness and comfort perception in people's minds. If this hypothesis is confirmed, using spatial configuration is a good design tool for (thermal) comfort in the early design stages.

This hypothesis is tested by questioning around 500 Chinese architecture students about their comfort perception in several spatial environments in summer in a hot and humid climate. Five different spatial environments with different spatial openness were described in writing as indoor space, semi-outdoor space, outdoor space, a room with a large operable area and a room with a small operable area. The three perceptions were visual perception, thermal perception and wind perception. The comfort perception over the day for the different spatial environments was also investigated. A similar questionnaire was given to Dutch architecture students, but the results were inconclusive due to the low number of responses.

7.2 Study method

In 2015, a written questionnaire was administered to 513 Chongqing University bachelor students[7] of architecture during one of their courses within one week. It was estimated that the questionnaire would take about 10 minutes to complete. The filled-out questionnaire had to be handed in when the class was finished.

The written questionnaire was obligatory, anonymous and in Chinese and English, see appendix A. The questionnaire was developed by one of the authors. The questionnaire included 10 questions of four parts. The first part consisted of questions requesting demographic information, such as gender (male, female) and

7 Due to the limitation of financial and human resources, only students were selected as subjects for the questionnaire. This may lead some deviations of the conclusion in this investigation. However, the students have lived there at least more than 2 years, therefore, they are representative we believe.

age (between 17 and 25 years old or not). The second part included questions relating to the general perception of the local climate in summer. This included thermal sensation (slightly cool, neutral, slightly warm, warm and hot), air velocity preference (not noticeable air velocity, low air velocity, high air velocity and very high air velocity) and preferred changes to the student's living room (air movement, operable window size, openness of the living room, presence of balcony or terrace, presence of courtyard or patio). The questions in the third part were related to the visual perception (good, neutral, not so good), wind speed perception (too low, low, neutral, high, too high) and thermal perception (cold, cool, neutral, warm, hot) in the different types of spatial environments: indoor space (a space with small openings), semi-outdoor space (a space with large openings), and outdoor space. The fourth part included questions about occupants' spatial preferences for different spatial environments (indoor space, semi-outdoor space, outdoor space, no preference) at different times (morning, afternoon, evening, and night). The last questions were about the preferred view from the room (good view or no preference and broad or narrow view). It should be note, the students were obliged to fill in the questionnaire. This led to some students not answering the questions fully or not answering the questions seriously. All data was entered in Excel and SPS. All incomplete questionnaires were deleted. Descriptive statistics such as percentages, range (minimum and maximum), or arithmetic mean with standard deviation (SD) were used to summarize the characteristic of the students and their homes.

7.3 Results

7.3.1 General perception of the local climate

The subjects were 62% male and 38% female, aged between17-25. Figure 7.1 shows the general thermal perception and wind speed perception in summer. It was found that 50% of the subjects felt very hot and 60% indicated that the wind speed perception was low under local climate conditions. That means that thermal perception and wind speed perception are negatively perceived and that the local occupants are not satisfied with the thermal environment.

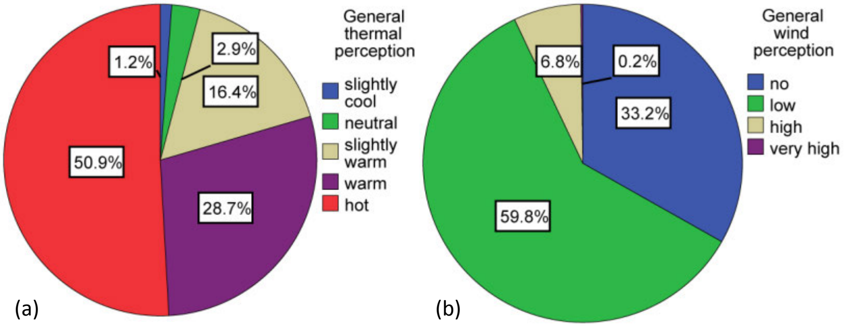

FIG. 7.1 General thermal and wind speed perception of the local climate (Chongqing, China, 2015) by 513 local college students of architecture.

7.3.2 The correlation of spatial openness and subjects' perception

Figure 7.2 shows the visual perception, wind speed perception and thermal perception according to the spatial openness. It is found that the visual perception increases from small opening to indoor space to semi-indoor space to big opening to outdoor space, thus from an enclosed space to an open space, which means the subjects think they can obtain a broader and better view in the more open spaces than in the enclosed spaces. The one-sided ANOVA analysis showed that there was a significant effect of the spatial openness on the view, $F (4, 2543) = 266$, $p <0.01$, $w = .54$. Planned contrasts revealed that more spatial openness significantly increased the view, see figure 7.2(a).

The subjects feel they can catch more wind in the more open spaces than in the enclosed spaces, see figure 7.2(b). Performing a one-way independent ANOVA statistical analysis, the variants are significantly different ($p < 0.01$) according to Levene's test of homogeneity of variances. Therefore, the Brown-Forsythe robust test of equality of means is used. This test indicates a significant effect of the spatial openness on the wind speed perception, $F (4, 2485) = 213$, $p < .01$, $w = .50$. Planned contrasts revealed that wind speed perception is significantly lower in the indoor environment compared to the small opening environment, $t(735) =13.6$, $p < 0.01$ (1-tailed), $r = .44$; wind speed perception is significantly higher in the semi-outdoor environments compared to the indoor environment, $t(713) = 17.8$, $p < 0.01$, $r = .55$; wind speed perception is significantly higher in the large opening environment compared to the semi-outdoor environment, $t(994) = 4.9$, $p < 0.01$, $r = .15$; wind speed perception is significantly lower in the outdoor environment compared to the big opening environment, $t(950) = 1.75$, $p < 0.05$, $r = .06$.

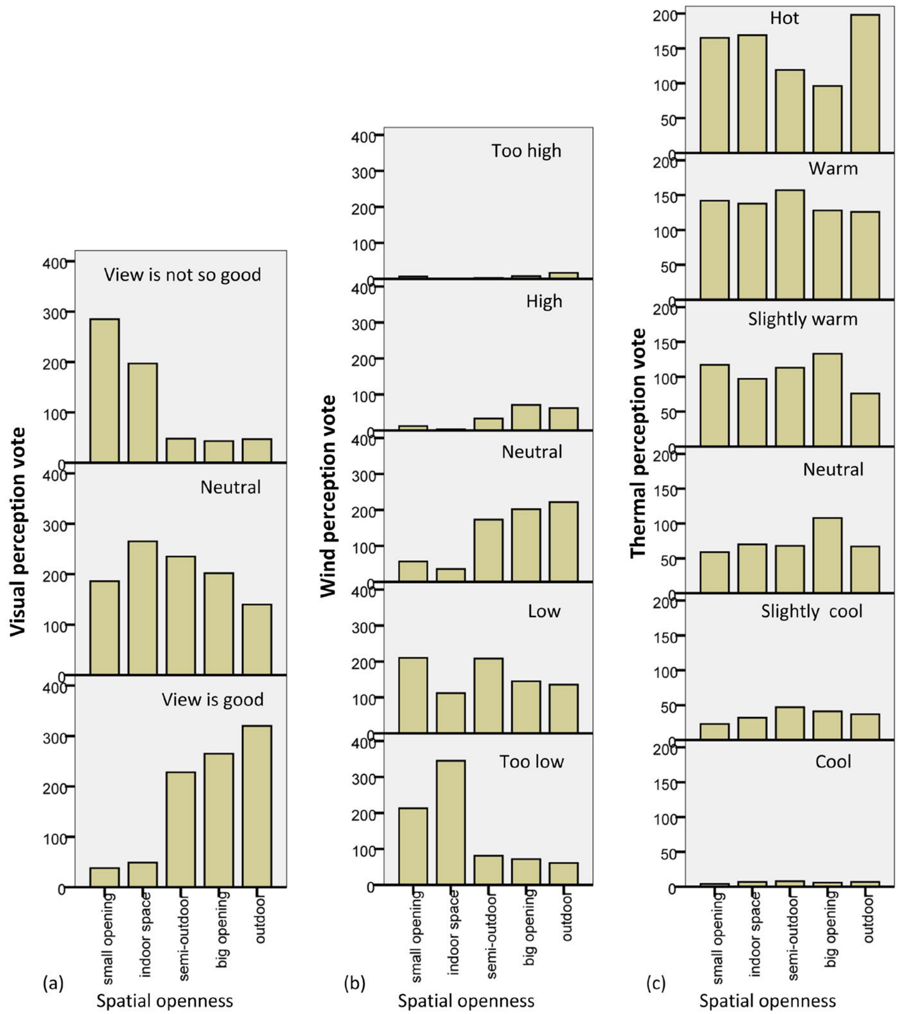

FIG. 7.2 Visual perception, wind speed perception and thermal perception according to spatial openness in a hot and humid climate (Chongqing, China, 2015) by 513 local college students of architecture.

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A significant effect between spatial openness and thermal comfort is also expected for thermal perception from figure 7.2(c), with the exception of the outdoor environment which is perceived to be the hottest of all spatial environments. Performing a one-way independent ANOVA statistical analysis, the variants are significantly different ($p < 0.05$) according to Levene's test of homogeneity of variances. Therefore, the Brown-Forsythe robust test of equality of means is used. This test indicates a significant effect of the spatial openness on the thermal perception, $F(4, 2553) = 13.7$, $p < .01$, $w = .14$. Planned contrasts revealed that thermal perception is significantly hotter in the indoor environment compared to the small openings environments, $t(1016) = 1.82$, $p < 0.05$ (1-tailed), $r = .06$; thermal perception is significantly hotter in the semi-outdoor environments compared to the indoor environment, $t(1000) = 3.32$, $p< 0.01$, $r = .10$; thermal perception is significantly hotter in the large opening environment compared to the semi-outdoor environment, $t(934) = 1.7$, $p < 0.05$, $r = .06$. There was no significant effect between the thermal perception of the outdoor environment and the small opening environment. The effect sizes are smaller than expected. This is probably caused by the fact that more than 40 % of the students consider all spatial environments warm or hot.

A significant effect between visual perception, wind speed perception and thermal perception has been found from a one-way independent ANOVA statistical analysis for the three perception pairs, as shown in table 1. The variants are significantly different for all three pairs ($p < 0.01$) therefore the Brown-Forsythe robust test of equality of means is used to determine if there is a significant effect between thermal, wind speed and visual perception.

The correlation between visual perception and wind speed perception is the strongest $w = .39$. The correlation coefficient between thermal perception and wind speed perception is $w= 0.31$. The correlation between visual perception and thermal perception is relatively weak $w = .20$.

TABLE 7.1 Statistical results of the correlation between visual perception, wind speed perception and thermal perception in a hot and humid climate (Chongqing, China, 2015) by 513 local college students of architecture.

(a)		Wind perception (%)						
		too low	low	neutral	high	too high		Total
Visual perception	good	13.5	30.1	41.3	13.1	2.0		100
	neutral	32.3	35.6	26.2	5.2	0.6		100
	not so good	55.1	30.3	10.6	2.2	1.8		100
Total		31.1	32.4	27.8	7.3	1.4		100
		w=0.39, $p < 0.01$, $F(4,240) = 102$						
(b)		Thermal perception (%)						
		cool	slight cool	neutral	slight warm	warm	hot	total
Visual perception	good	2.0	10.4	19.8	18.2	24.8	24.8	100
	neutral	0.7	6.3	13.7	25.5	28.2	25.5	100
	not so good	1.0		7.9	17.6	28.8	41.4	100
Total		1.2	7.1	14.5	21.0	27.1	29.1	100
		w=0.20, $p < 0.01$, $F(4,484) = 21$						
(c)		Wind perception (%)						
		too low	low	neutral	high	too high		Total
Thermal perception	cool	36.7	16.7	23.3	23.3	0.0		100
	slight cool	14.0	25.3	33.7	23.6	3.4		100
	neutral	14.8	29.0	45.4	9.2	1.7		100
	slight warm	23.7	38.2	31.9	5.5	0.8		100
	warm	28.7	39.7	24.4	6.5	0.6		100
	hot	50.5	26.1	17.8	3.4	2.2		100
Total		31.0	32.6	27.7	7.2	1.4		100
		w=0.31, $p < 0.01$, $F(4, 483) = 50$						

On the basis of the questionnaire results described above, it is found that visual perception and wind speed perception and thermal perception are significantly different in different spatial environments. In general, a more open space is perceived as having a better view, a higher wind speed and a lower temperature. There are a few exceptions. The most open space, outdoor space, is perceived the hottest, probably because the solar radiation in open spaces, such as the outdoor space is stronger than in the indoor spaces. The indoor space is perceived to have a lower wind speed than the more enclosed small opening environment, probably because the description “indoor space” gives too little information about the window openings and students can have imagined closed windows. The outdoor space is not perceived as having a larger wind speed than the large opening environment. This is probably caused by the different activities in the outdoor space and the fact that when there is sun, a larger wind speed is necessary to feel comfortable.

7.3.3 Spatial preference

Figure 7.3 shows the subjects' general spatial preference in summer. It can be seen that more than 90% of the subjects prefer an environment with a good and broad view, and with considerable natural ventilation. The subjects' spatial preference with respect to the time of day is shown in figure 7.4. In the morning, the subjects show little spatial preference for the indoor space, semi-outdoor space or the outdoor space. This can be explained by the fact that the temperature differences between the different spatial environments are relatively small in the morning in the local summer climate. Hence, spatial preference is not strongly determined by the thermal environment, with other factors, such as activities, largely influencing the spatial choice. In the afternoon, half of the subjects prefer to stay in the indoor space, the second preference is the semi-outdoor space and the third preference is the outdoor space. This is probably due to the fact that the subjects know from experience that during the afternoon, as the outdoor temperature rises, the solar radiation in the outdoor and semi-outdoor space is stronger than in the indoor space. In the evening, more than 60% of the subjects prefer to stay in the semi-outdoor and outdoor space. This is probably because the indoor temperature is higher than the temperature in the outdoor or semi-outdoor space in the evening. Moreover, the subjects prefer to stay outside to catch more natural ventilation. At night, almost 40% of the subjects prefer the indoor spaces; however, some 45% of the subjects still prefer to stay in the semi-outdoor or outdoor space. This is probably because the heat in the indoor space is not easily dissipated at night, so that the indoor temperature is still high while the outside temperature has already dropped. The choice of activity is assumed to be the reason for the subjects to withdraw to the indoor space, although in terms of the thermal environment, subjects prefer to stay outside. An investigation by Fu (2002) in the studied region, showed that 60 to 90% of the local inhabitants complained that they were sleepless at night during summer due to the sweltering and sultry weather.

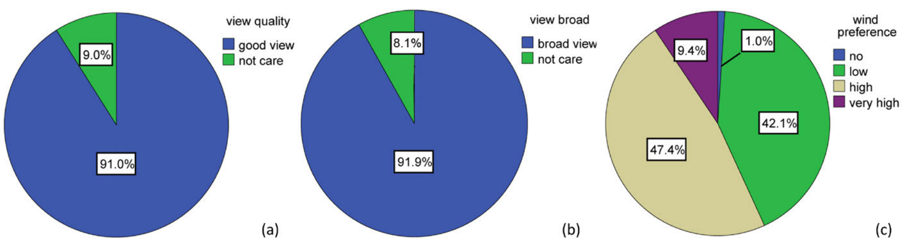

FIG. 7.3 Subjects' general spatial preference in summer in a hot and humid climate (Chongqing, China, 2015) by 513 local college students of architecture

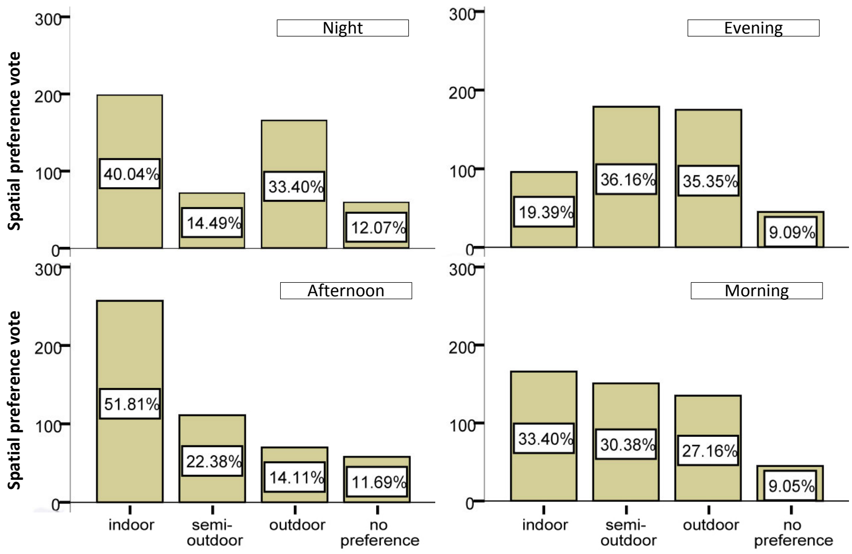

FIG. 7.4 Subjects' spatial preference respect to the time of day in a hot and humid climate (Chongqing, China, 2015) by 513 local college students of architecture

7.4 Discussion

The questionnaire showed that, under hot and humid climate conditions, spatial openness features, occupants' visual perception, wind speed perception and thermal perception are all associated. The strongest correlation is between spatial openness and visual perception and wind speed perception. The correlation between wind speed perception and thermal perception is considerable as well. It may be inferred that if a certain space offers good openness, occupants are likely to have a positive visual and wind speed perception, and even thermal perception. In fact, wind speed perception is the key factor in the chain, see figure 7.5.

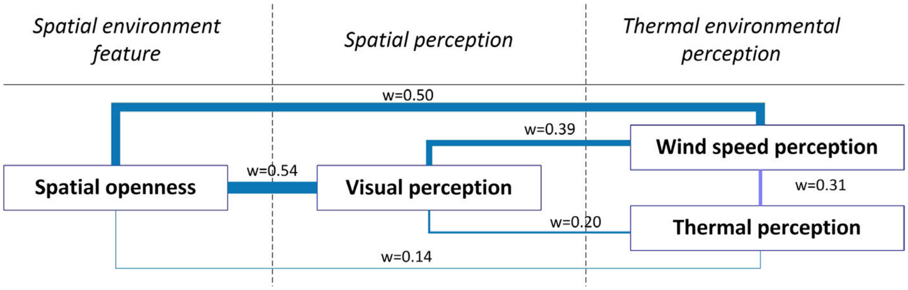

FIG. 7.5 The effect sizes between spatial openness, spatial perception and thermal environmental perceptions in a hot and humid climate (Chongqing, China, 2015) by 513 local college students of architecture

A lower effect size between spatial openness and thermal perception is found than was expected. This is probably caused by the fact that more than 40 % of the students consider all spatial environments warm or hot causing the variants to be were significantly different ($p < 0.01$) according to Levene's test of homogeneity of variances. The different comfort perceptions did not have the same order of preferences. The outside environment was the best visual perception, but the worst thermal perception and an average wind perception. Future research should be more specific on the description of the spatial environments if the expected high correlation between spatial openness and the comfort perceptions is to be found.

Occupants' spatial preference or movement in the domestic building is influenced by their perception with respect to the time of day. This can, besides the high amount of warm and hot votes, also explain the low effect size between spatial openness and thermal perception. The questionnaire did not ask this explicitly, but the opinion of the authors is that a large part of the spatial preference over the day is temperature dependent. This means that the time of day also influences the relationship between the spatial openness and the thermal perception.

The questionnaire proves that spatial boundary conditions can strongly influence occupants' comfort perception, and subsequently influence occupants' spatial choice and movement in a particular thermal environment, given the opportunity, as Humphreys (1997) pointed out: when people are free to choose their location, it helps if there is plenty of thermal variety, giving them the opportunity to choose the places they like.

7.5 Conclusion

In this paper, local architectural students' spatial perception and comfort perception were investigated through a questionnaire. The main findings for a hot and humid climate are: a. Spatial openness of a particular space significantly effects occupants' visual perception, wind speed perception and thermal perception in a particular space. b. There is a strong effect size between spatial openness and visual and wind perception (w = .50 and .54); the effect size of the thermal perception is weaker (w= .14). c. The comfort perception is strongly influenced by the time of day, therefore visual perception, wind perception and thermal perception can influence occupant movement between different spaces as is the advice of the adaptive thermal comfort theory.

The authors' hypothesis that there is a large correlation between the concept spatial openness and comfort perception in people's minds has not been proven. The effect size between spatial openness and thermal perception is too low. However, the effect size between spatial openness and visual and wind speed perception is high, as expected. The low effect size is probably caused by a too large amount of warm and hot votes (< 40%) for all spatial environments, the fact that solar irradiation unconsciously influences the perceived temperature in the outdoor environment and the fact that the preferred spatial environment is shown to change over the day. More research, such as a more advanced questionnaire, is, therefore, needed for further proof.

As already mentioned, spatial openness significantly effects comfort perception for architectural students in a hot and humid climate. This means that architectural students in a hot and humid climate can distinguish the effects of spatial openness on the comfort perception. This fact can be used in the education in the early design stages for buildings in a hot and humid climate. This is important because significant mistakes in spatial design in the early design stages are difficult to adjust later.

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