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Air movement preferences observed in naturally ventilated buildings in humid subtropical climate zone in China

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Abstract Occupants' preferences for air movement in naturally ventilated buildings have been extracted from a database of three thermal comfort surveys conducted in the humid subtropical climate zone in China, during winter, spring, and summer seasons. The distribution of draft sensation shows that only 25.7, 38.5, and 28.7% of the subjects in winter, spring, and summer, respectively, felt that the available air movement was just right, suggesting that indoor air velocity may be a big problem in naturally ventilated buildings in humid subtropical China. Air movement preferences show that 15.8, 61.3, and 80.6% of subjects in winter, spring, and summer, respectively, wanted more air movement. Only a handful of subjects wanted less air movement than they were actually experiencing in any season, suggesting that draft was not much of an issue for thermal comfort. Occupants' preference for air movement is strongly related to thermal sensation, showing that people want to control air movement as a means of improving their comfort. The demand for less air movement under cool sensation is much smaller than the overwhelming demand for more air movement when the sensation was warm. The above results indicate that air movement might have a significant influence over the respondents' comfort sensation and that people required a high level of air movement in order to be comfortable during the summer season. Thus, one efficient way to improve the thermal environment in summer in humid subtropical China could be to provide occupants with effective natural ventilation and allow personal control of the air movement. Our findings are also applicable to other buildings, to encourage designers to provide air movement as a low energy cooling strategy and to ensure that sufficient levels of air movement are available.

Keywords Naturally ventilated buildings · Draft sensation · Air movement preference · Thermal sensation

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Introduction

Air movement preferences in real buildings and the effects of air movement on human comfort have, in recent years, been paid attention by thermal comfort researchers. Tanabe and Kimura (1989) have done extensive investigations on the effects of air velocity on human comfort in order to predict thermal sensation under high levels of air movement. They found that subjects regularly preferred air movement of 1 m/s at an air temperature of 28°C, and very few regarded the air movement unpleasant under the conditions studied. Kimura and Tanabe (1993) presented a relationship between air velocity and operative temperature that takes into account the effect of air movement on clothing insulation and skin wettedness. The relationship shows that increasing the relative humidity at high temperatures suppresses evaporative cooling; higher air velocities are thus required to maintain the thermal sensation. Fountain et al. (1994) investigated the locally controlled air movement preferred in warm isothermal environments and proposed the PS model which can predict the percent of satisfied people in an office environment when locally controlled air movement is available. Arens et al. (1998) made a study of occupant cooling by personally controlled air movement and concluded that it is possible to maintain comfortable conditions up to 31°C (1.0 met) and 29°C (1.2 met) if air speed of 1 m/s or greater is available over the upper body, while the cooling effectiveness was significantly affected by the nature of the turbulence of the air movement. Toftum (2004) examined air movement preferences using the ASHRAE field studies in the de Dear (1998) database and found that people who feel cold prefer less air movement, and those who feel hot prefer more air movement, and that the dividing line is 22–23°C. This is true even though the occupants in the database buildings rarely had personal control over air movement. Zhang et al. (2007a) analyzed air movement preferences in office buildings from a database of indoor environmental quality surveys funded by the ASHRAE research project (RP-1161). They found that dissatisfaction with the amount of air motion is very common, with too little air movement cited far more commonly than too much air movement. Higher air movements raised the operative temperatures associated with neutral-to-warm sensations by more than 1 K over the operative temperatures associated with neutral-to-warm sensations at lower air movements.

It was highlighted in the above previous studies that elevated air speed can offset the indoor temperature rise and provide occupants with thermal comfort. This may result in reduced consumption of energy used to cool a building compared with general air conditioning, and underlies that encouraging the use of naturally ventilated buildings would seem a good way to promote energy efficiency (Fountain and Arens 1993). It is believed that air movement considerably impacts occupants' thermal sensation and comfort in naturally ventilated buildings since the indoor air temperature and humidity are almost impossible to modify. Therefore, appropriate design of the buildings that can provide effective natural ventilation and allow individual control of the local air velocity by each occupant is necessary.

In the new ASHRAE Standard 55-2004 (ASHRAE 2004), the operative temperature comfort limits are based on an air speed limit of 0.20 m/s, except in circumstances where the occupants have some degree of control over the air velocity. In such cases, the standard provides a graph showing the amounts of elevated air speed allowed to offset increased temperatures above the upper limit of the comfort zone. The conditions defined in the graph may be applied only to a lightly clothed person with a clothing insulation between 0.5 and 0.7 clo (0.08–0.1 m^2 K/W) and metabolic rates between 1.0 and 1.3 met (58.15–75.6 W/m^2). In addition, the increase in operative temperature cannot be higher than 3.0°C above the values for the comfort zone and the elevated air speed must not be higher than 0.8 m/s. Moreover, the relationship between elevated air speed and the temperature rise is derived from theoretical calculations of equivalent heat loss from the skin, combined with professional judgment about reasonable limitations that should be placed on this allowance. Thus, it may not be appropriately applicable in the real buildings in the subtropical humid climate zone in China where the operative temperature of the naturally ventilated buildings often exceeds 30°C in summer and occupants' clothing levels do not fall within 0.5 and 0.7 clo as prescribed in the ASHRAE standard. Adopting the air movement limits in ASHRAE standard may not be providing occupants in other places in the world such as China with an environment that people prefer, and this may also impose inherent energy costs. Specific knowledge about the influence of air movement on occupant comfort and the air movement preferences of occupants will be helpful in making local thermal comfort standards, and thus give designers much needed information on how to design naturally ventilated buildings. If people remain comfortable in a wider range of conditions in naturally ventilated buildings that provide appropriate air movement in hot summer, significant energy can be saved by relaxing thermal comfort standards and allowing more variable indoor temperatures that cycle or drift in response to the natural swings of the outdoor and indoor climate (Milne 1995; Baker and Standeven 1996). However, our understanding of the effects of air movement on occupant comfort in real buildings in humid subtropical China is limited. Thus, it is worth examining some sources of data on air movement effects in real buildings in this area.

Towards these ends, this paper is expected to produce relevant and recent data to provide a better understanding of the general thermal environment and occupants' air movement preferences in naturally ventilated buildings in humid subtropical China, which would be of relevance for thermal comfort standards in China and other similar regions in the world.

Materials and methods

Site description and climate background

This paper provides air movement preference data drawn from three field surveys of thermal comfort in the humid subtropical climate zone in China. The first survey (spring survey) was conducted in two naturally ventilated teaching buildings in Hunan University, Changsha city, from 24 March to 23 April 2005. The second survey (summer survey) was performed in different types of buildings in five different cities (Changsha, Wuhan, Shanghai, Jiujiang and Nanjing) in summer, from 19 June to 2 September

2006. The third survey (winter survey) was carried out in residences in the city of Changsha and Pingjiang during 2 weeks in winter 2006. During the surveys, great effort has been made to select different building types including private and public, residential and office, flats or two-storey buildings, air-conditioned and naturally ventilated buildings, etc. Since the summer and winter surveys involved both naturally ventilated and air-conditioned buildings, only the data from naturally ventilated buildings were extracted from the two surveys for the analysis in the present paper. A total of 1,572 valid questionnaires were collected during the three surveys. The distribution of sample data is presented in Table 1.

The humid subtropical climate zone in China is located in eastern Eurasia and faces the Pacific on the east, lying between latitudes 22°N and 34°N and longitudes 98°E and 123°E. The climate in summer in this area is characterized by high air temperature, high solar radiation, and high humidity. Under the control of subtropical high air pressure, high temperatures hold up through the whole summer and the maximum temperature can be higher than 40°C. The mean diurnal temperature remains at 32°C during most of the summer period and relative humidity frequently exceeds 75%. The solar radiation can reach as high as 1,000 W/m^2. Compared with other areas in the world at the same latitude, the temperature in humid subtropical China is obviously higher in summer. In winter, the minimum temperature of the coldest month is lower than −18°C and the percentage of sunshine time is very small. It is the coldest area at the same latitude in the world, and the relative humidity is high throughout the year (Feng 2004). During the spring season, the climate is relatively mild, with the mean diurnal temperature ranging from 13 to 18°C. There are two main characteristics of the spring climate in humid subtropical: the temperature may increase greatly and rapidly, and it is the rainy season.

Data collection

Both objective and physical measurements and subjective assessment were adopted on each visit of the three field surveys. The objective measurement aimed to collect indoor environment variables (air temperature, mean radiant temperature, relative humidity, and air velocity), which were necessary for further thermal comfort analysis.

During the spring and summer survey, the air temperature and relative humidity were measured using a portable monitor (TES-1360). The air velocity was measured using a hot-wire anemometer (Testo425). The mean radiant temperature was estimated from the globe temperature, using a 150-mm-diam black globe thermometer. The objective physical measurements were carried out at five points (four points located near the corner and one point in the centre) in each room, and at each sampling point each parameter was

Table 1 Sampling distribution

	n=1,572		
	Spring	Summer	Winter
Number of buildings	25 classrooms	65 offices & residences	56 residences
Sample size	1,342	129	101
Gender			
Male		71	50
Female		58	51
Age (years)			
Mean	22.5	30.9	37.5
SD	9.5	10.9	11.9
Minimum	17	12	12
Maximum	45	60	67
Years living at local address			
Mean	7	10.1	18.8
SD	8.6	15.7	19.6
Minimum	0.5	0.5	0.5
Maximum	25	60	67
CLO			
Mean	1.21	0.28	2.10
SD	0.46	0.09	0.46
Minimum	0.28	0.14	0.92
Maximum	2.60	0.53	2.89

measured three times while each respondent filled out the questionnaire. The average value of each measured variable was used for subsequent analysis. All measurements were taken at a height of 1.1 m above the floor, which represents the height of the occupant at seated level.

The instruments were changed in the winter survey and we used the Swema 3000, a multi-purpose test system for professional measurements in indoor climate, instead. Three probes were equipped with Swema 3000, among which the Swa03 probe measured air velocity and air temperature, the Hygroclip S probe measured relative humidity and air temperature, and the SWAT probe measured globe temperature. The objective physical parameters were recorded at three points in each room along the diagonal, and at each sampling point each parameter was measured at heights of 0.1, 0.6, and 1.1 m while each respondent filled out the questionnaire. The average value of each measured variable was used for subsequent analysis. Figure 1 presents the various instruments in the three surveys. The operative temperature was calculated as the average of air temperature and mean radiant temperature. The accuracy of the instrument conformed to ASHRAE Standard 55–1992 (ASHRAE 1992) and ISO 7726 (ISO 1985). More details about the design of instrumentation can be found in previous papers of the authors (Yang and Zhang 2008; Zhang et al. 2007b).

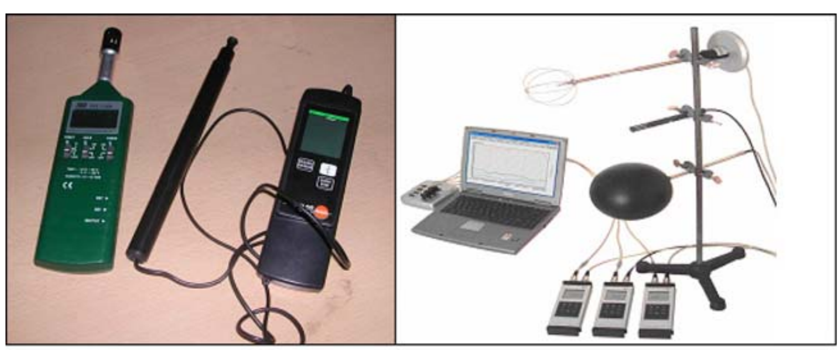
The subjective assessment was based on responses to a questionnaire survey, which was administered simultaneously with the physical measurements on each visit. The questionnaire contains questions about the occupants' thermal sensation, thermal preference, humidity sensation, draft sensation, air movement preference, and other factors. The thermal sensation scale was the traditional ASHRAE seven-point scale, and according to the seven-point thermal sensation scale, we also created a seven-point relative humidity sensation and a draft sensation scale. Thermal preference was assessed by asking occupants this question: "At this point of time, would you prefer to feel warmer, no change, or cooler?" Air movement preference was assessed by asking occupants whether he or she wants to alter the existing air movement (more air movement, no change or less air movement). Table 2 summarizes the various scales used in the surveys. Further details about questions in the three surveys can be found in previous papers of the authors (Yang and Zhang 2008; Zhang et al. 2007b).

Metabolic rate and clothing insulation were estimated in accordance with ASHRAE standard 55–1992 (ASHRAE 1992). The standard provided a checklist of typical activities and their corresponding metabolic rates. As the respondents were seated during the surveys, the metabolic rate was taken to be 1.2 met (1 met = 58.15 W/m^2), which represents the value for sedentary activities. Respondents indicated what they were wearing at the time of the field surveys by means of a clothing checklist that was included in the surveys.

Results

Description of indoor climate

Table 3 summarized the distribution of the indoor climate parameters during the three study periods. The difference between temperatures was obvious in the three seasons. The mean operative temperature in winter was quite low, with a value of 9.8°C; however, it rose to 21.5°C in spring and became even higher in summer (33.3°C). Similar differences were found in terms of mean air temperature and mean radiant temperature, with lowest levels of 9.9 and 9.6°C in winter for mean air temperature and mean radiant temperature, respectively, and highest levels of 33°C and 33.6°C in summer for mean air temperature and mean radiant temperature, respectively. No significant difference was found during the three seasons in terms of relative humidity, with the highest value of 74% in summer. Mean air velocities were 0.05, 0.10, and 0.17 m/s for winter, spring, and summer, respectively.



Humidity/Temperature Meter (TES1360) & hot-wire anemometer (Testo425)

Swema 3000 test system

Fig. 1 Instruments during the three surveys

Table 2 Scales used for subjective assessment in the surveys

ASHRAE scale	Humidity sensation	Draft sensation	Thermal preference	Air movement preference
–3 cold	–3 too dry	–3 too still	+1 warmer	+1 more
–2 cool	–2 dry	–2 still	0 no change	0 no change
–1 slightly cool	–1 slightly dry	–1 slightly still	–1 cooler	–1 less
0 neutral	0 just right	0 just right		
+1 slightly warm	+1 slightly humid	+1 slightly breezy		
+2 warm	+2 humid	+2 breezy		
+3 hot	+3 too humid	+3 too breezy		

Clothing insulation

The mean clothing insulation value was in a wide range, from 0.28 clo in summer to 1.21 clo in spring and to 2.10 clo in winter (see Table 1). The low value (0.28 clo) is smaller than the value of 0.5 clo assumed for the summer season in the ASHRAE Standard 55-2004; the observed high value of 2.10 clo is over twice as high as 1.0 clo assumed for the winter season in the standard. The large scatter of the clothing value observed in the three seasons indicated that people changed their clothing level to try to achieve comfort at different temperatures.

Thermal sensation and thermal preference

Figure 2 shows the distribution of thermal sensation votes for the three seasons. In spring and winter, 96.8 and 80.2% of the subjects voted within the three central categories of the seven-point scale, respectively, indicating that the buildings were successfully meeting the intent of ASHRAE Standard 55 (i.e., at least 80% of the occupants find the thermal environment acceptable by this criterion) during these two seasons. A much lower percentage of 57.4% was found in summer, as expected, since the thermal responses were shifted towards the warmer sensation categories (+2, +3) with a mean vote of 1.29. Ironically, 42.6% of the respondents in summer voted in the +2 and +3 category, which means that these people were dissatisfied with their thermal environments. This is a surprisingly large number of people expressing dissatisfaction. It exceeds the goal of the ASHRAE standard, i.e., to have no more that 20% dissatisfied.

Responses to thermal preference can be better understood by comparing simultaneous votes on both the thermal sensation and preference scales, shown in Table 4. In summer, 75.7% of the occupants voting within the three central categories of the thermal sensation scale preferred to feel cooler and only 20.3% wanted no change. It was also found that in winter 59.3% of those voting within the three central categories wanted to be warmer, and only 39.5% wanted no change. The result was quite different in spring, when a higher percentage (53.7%) of the occupants voting within the three central categories preferred no change in their environments. The trend of thermal preference can also be discovered. As shown in Table 4, 83.0% of the occupants preferred cooler in summer, 52.4% of the occupants wanted no change in spring, and 66.3% of the occupants preferred warmer in winter.

The above results indicate that there was a very clear differentiation between seasons in terms of thermal sensation and thermal preferences. People tended to feel more comfortable in spring and winter than in summer because more than 80% of the occupants voted within the three central categories in spring and winter in comparison with just 57.4% in summer. In addition, a large proportion of the occupants wanted to change their thermal environment in winter and summer, whereas more people preferred no change in spring. Particularly, occupants in summer expressed an urgent preference to be cooler than in spring

Table 3 Statistical summary of indoor climate

	Winter				Spring				Summer			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Air temperature(°C)	9.9	1.9	6.2	14.0	20.8	3.1	15.2	29.4	33.0	2.4	27.8	38.1
Mean radiant temperature(°C)	9.6	2.0	5.8	14.3	22.1	3.6	15.3	30.9	33.6	2.6	28.0	39.4
Relative humidity (%)	71.8	10.5	43.6	85.6	70.2	11.2	40.2	90.6	74.0	11.6	51.0	93.2
Air velocity(m/s)	0.05	0.04	0.00	0.17	0.10	0.12	0.01	0.60	0.17	0.19	0.01	1.10
Operative temperature(°C)	9.8	2.0	6.0	14.1	21.5	3.3	15.7	29.9	33.3	2.4	27.9	38.8

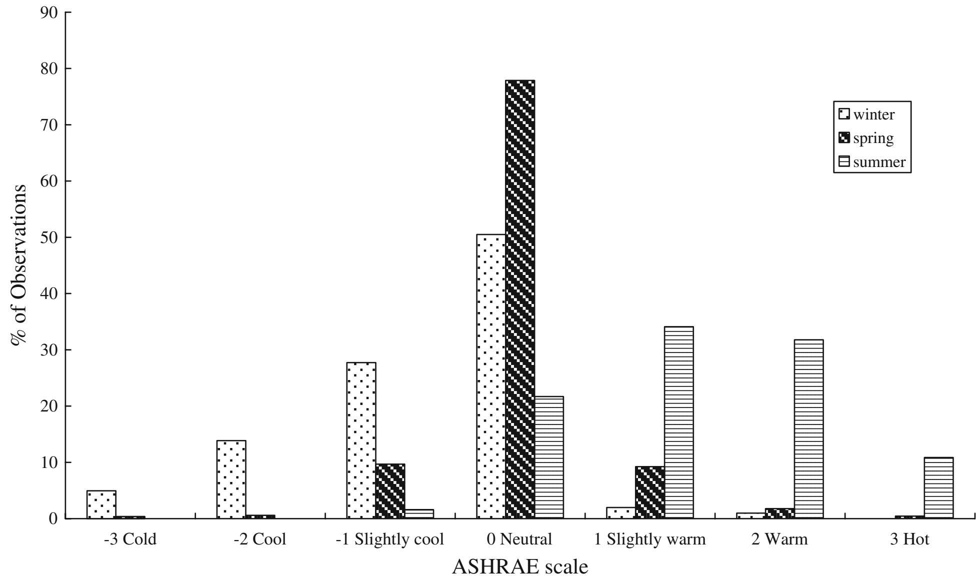


Fig. 2 Distribution of thermal sensation votes

or winter. The large number of dissatisfied occupants gives us a warning that the traditional naturally ventilated buildings could not provide a comfortable indoor thermal environment for occupants during the summer season in humid subtropical China. It raises questions about how to improve the rigorous thermal conditions during the summer season in humid subtropical China, which will be discussed later in the following section.

Air velocity distribution and draft sensations

Figure 3 shows the distribution of air velocity of all the three seasons combined (given the few incidences of elevated air velocities, we needed to aggregate the data to allow a statistical comparison). It was found that air velocities were low to moderate in the buildings, with 88% of the measured air velocity falling below 0.2 m/s (the air speed limit prescribed in the ASHRAE standard). As indicated earlier in Table 3, mean air velocity was 0.05, 0.10, and 0.17 m/s in winter, spring, and summer, respectively. Air movement was lower than we expected, given that people often had their windows or doors open and sometimes turned on the ceiling fans or desk fans in spring and summer. However, we noted that many field studies in naturally ventilated buildings have found air velocities in a similar range to those that we measured. For example, Nicol and Roaf (1996) measured the mean air velocity of 0.05 m/s in winter and 0.22 in summer. Feriadi

Table 4 Cross-tabulation of thermal sensation and thermal preference scales (showing percentages with numbers of respondents in parentheses)

Thermal sensation scale	Thermal preference scale			
	Warmer	No change	Cooler	Total respondents
Winter				
+3,+2	(0)	100% (1)	(0)	(1)
+1,0,+1	59.3% (48)	39.5% (32)	1.2% (1)	(81)
–3,–2	100% (19)	(0)	(0)	(19)
Totals	66.3% (67)	32.7% (33)	1.0% (1)	101
Spring				
+3,+2	3.3% (1)	20.0% (6)	76.7% (23)	(30)
+1,0,+1	26.4% (343)	53.7% (698)	19.9% (258)	(1,299)
–3,–2	100% (13)	(13)	(0)	(13)
Totals	26.6% (357)	52.4% (704)	21.0% (281)	(1,342)
Summer				
+3,+2	(0)	7.3% (4)	92.7% (51)	(55)
+1,0,+1	4.0% (3)	20.3% (15)	75.7% (56)	(74)
–3,–2	(0)	(0)	(0)	(0)
Totals	2.3% (3)	14.7% (19)	83.0% (107)	(129)

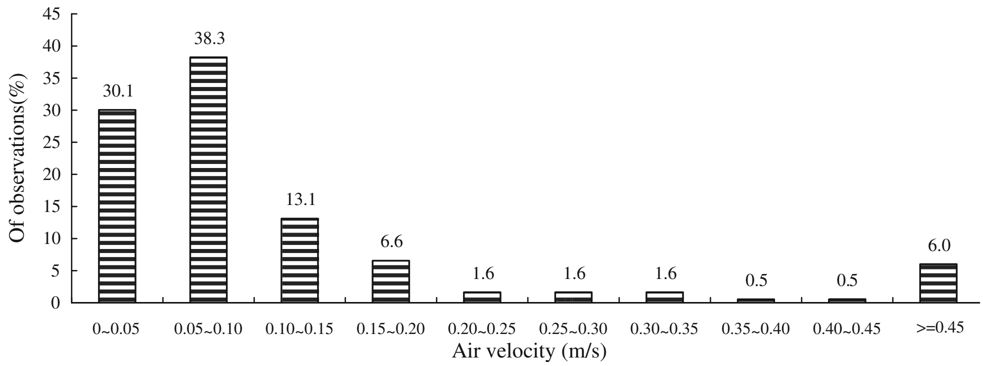


Fig. 3 Air velocity distributions

and Wong (2004) measured the mean air velocity of 0.10 m/s in both rainy and hot seasons.

The distribution of draft sensation votes is plotted in Fig. 4. In summer, only 28.7% of the respondents felt that the air velocity was just right and 7.7% of them felt the air velocity slightly breezy. A relatively larger proportion of respondents (38.5%) considered the air velocity as just right in spring, but simultaneously, a high percentage of respondents (45.8%) voted in the –3 category (too still) during this season. In winter, only 25.7% of the respondents indicated that the air velocity was just right and 2% of them considered the air velocity as breezy. It is important to point out that a negligible percentage of respondents (0.2 in spring, 2.0 in winter, and 0.0% in summer) chose to indicate their draft sensation in the breezy regions (i.e., +2, +3). And the draft sensation votes were shifted towards the still categories (–2, –3) with a mean vote of –1.20, –1.51 and –1.13 in winter, spring, and summer, respectively. The above result suggests that indoor air velocity may be a big problem in naturally ventilated buildings in humid subtropical China, especially at high temperatures during the summer season when the lower air velocities in buildings could not create sufficient cooling effect for occupants.

It can also be seen that, although in general the air movement in the building was low (88% of the physical measurements were less than or equal to 0.2 m/s), air motion was perceptible to the occupants. In the three seasons, 61.2% (summer), 44.6% (winter), and 47.2% (spring) voted that the air motion was “slightly still” and above (“just right” to “too breezy”), which means that these people were able to sense air movement. The result is very similar to the study results of Fanger et al. (1998) and Brager et al. (2004), who found that 50% of the subjects were able to sense air movement at air speeds of 0.15 and 0.05 m/s, respectively.

Air movement preferences and thermal sensation

A cross-simultaneous-votes analysis on both the thermal sensation and air movement preference scales would benefit to understand the air movement preferences of occupants (see Table 5). During the winter, 77.8% of the respondents voting within the three central categories of the thermal

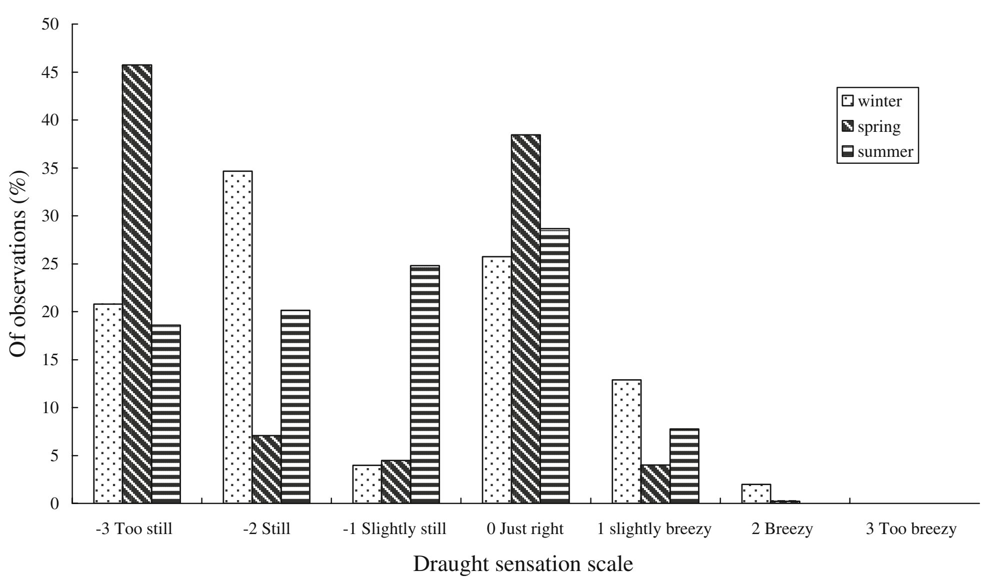


Fig. 4 Distribution of draft sensation votes

Table 5 Cross tabulation of thermal sensation and air movement preference scales (showing percentages with numbers of respondents in parentheses)

Thermal sensation scale	Mean air velocity	Air movement preference scale			
		More	No change	Less	Total respondents
Winter					
+3,+2	0.05 m/s	100% (1)	(0)	(0)	(1)
+1,0,+1		18.5% (15)	77.8% (63)	3.7% (3)	(81)
–3,–2		(0)	84.2% (16)	15.8% (3)	(19)
Totals		15.8% (16)	78.2% (79)	6.0% (6)	(101)
Spring					
+3,+2	0.10 m/s	76.7% (23)	23.3% (7)	(0)	(30)
+1,0,+1		36.4% (473)	62.0% (806)	1.6% (20)	(1,299)
–3,–2		7.7% (1)	76.9% (10)	15.4% (22)	(13)
Totals		37.0% (497)	61.3% (823)	1.7% (22)	(1,342)
Summer					
+3,+2	0.17 m/s	83.6% (46)	14.6% (8)	1.8% (1)	(55)
+1,0,+1		78.4% (58)	18.9% (14)	2.7% (2)	(74)
–3,–2		(0)	(0)	(0)	(0)
Totals		80.6% (104)	17.1% (22)	2.3% (3)	(129)

sensation scale wanted their air movement unchanged and 18.5% preferred more, and 15.8% of all the respondents wanted more air movement. The result indicates that most people were satisfied with the air movement in naturally ventilated buildings in winter, even if the air speed was quite low, with an average value of 0.05 m/s. This is reasonable as the air temperature in winter was relatively low and a high level of air velocity would make people feel drafts. During the spring, 62.0% of respondents who considered their thermal sensation as neutral also wanted no change in their air movement, and 37.0% of all the spring respondents wanted more air movement. During the summer, a large proportion (78.4%) of the respondents preferred more air movement even when they voted within the three central categories of the thermal sensation scale, with only 18.9% of them wanting no change in their air movement, and 80.6% of all the summer respondents wanted more movement. The above results indicate that people in summer had a strong preference to more movement and required a higher level of air speed to keep comfortable than the available indoor air speed in the naturally ventilated buildings.

Table 5 also showed that only 6.0, 1.7, and 2.3% of the respondents wanted less air movement in winter, spring, and summer, respectively, compared to a significant percentage of people wanting more air movement in the three seasons (15.8% in winter, 37.0% in spring, and 80.6% in summer). This is consistent with the distribution of draft sensation votes, with only 2.0 in winter, 0.2% in spring, and no respondent in summer considering their draft sensation as breezy and too breezy. It can be concluded that negative sensations of draft were essentially nonexistent in this building, since very few responses (less than 6% of the votes in either season) called for less air movement, even at the lowest levels of thermal sensation. Even in winter, about 16% of the votes preferred more air movement.

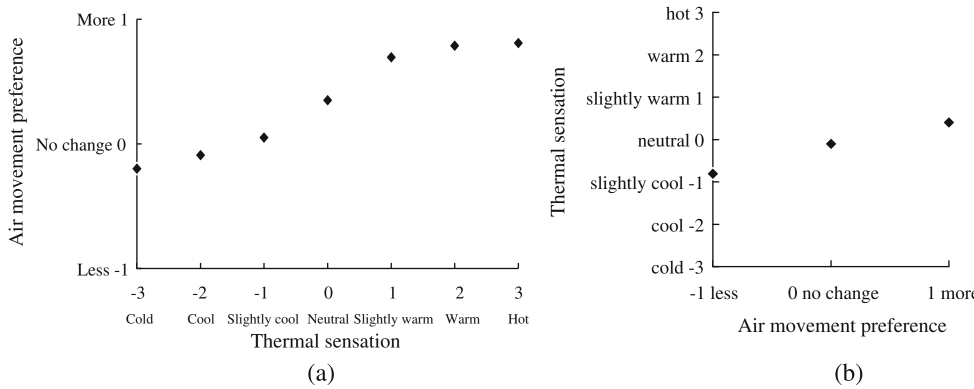
Figure 5a shows the mean air movement preference for each group of people voting a particular thermal sensation. As thermal sensation increased, so did the percentage of people wanting more air movement. Responses were strongly asymmetric, with the overwhelming majority of preference being between "want more air movement" and "want no change."

Figure 5b displays the mean thermal sensation for each group voting for "more," "no change," or "less" air movement. It can be seen that the mean thermal sensations that trigger preferences for more or less air movement are at +0.4 and –0.8, respectively, and that the group of people who are voting for no change have a nearly mean neutral thermal sensation (–0.1). This shows that people consciously recognize air movement as having a direct impact on their thermal comfort, and that their air movement preferences are for a change of air movement as needed (as necessary) to return to comfort (Brager et al. 2004).

Air movement preferences related to measured velocities above the draft limit

About 13% of the votes (n=205) in the three seasons corresponded to air velocities larger than 0.2 m/s (only air

Fig. 5 The relationship between air movement preference (**a**) and thermal sensation (**b**)



velocities in spring and summer had values higher than 0.2 m/s). This velocity is the draft limit for the ASHRAE Standard at a temperature of 25.5°C, if one assumes a normal indoor turbulence intensity level of 40%. The majority of observations when the velocity exceeded 0.2 m/s wanted no change in their air movement (28% wanted more, 69% no change, 3% wanted less; see Fig. 6). This indicates that when the indoor air velocity was higher than 0.2 m/s, more people were satisfied with their air movement compared with the air movement preference from the entire survey database (61.3 and 17.1% wanted no change in spring and summer, respectively). However, the measured air movement higher than 0.2 m/s did not completely change people's preference for more air movement because many occupants (28%) still wanted more air movement given that the available air velocities indoor were relatively high.

Discussion

During winter and spring, when indoor operative temperatures were relatively low (9.8 and 21.5°C for winter and spring, respectively), most of the respondents were satisfied with their thermal environment and air movement. However, when it came to summer, the operative temperature became very high (the mean operative temperature was 33.3°C) and a surprisingly large proportion of respondents (42.6%) were dissatisfied with their thermal environment and 80.6% of them preferred more air movement. In addition, only a handful of subjects wanted less air movement than they were actually experiencing in either season, suggesting that draft was not much of an issue for thermal comfort. In contrast, people who preferred a change in air movement were nearly always asking for more (especially in summer), not less. More importantly, 28% of the respondents still wanted more air movement even when they were experiencing air speed higher than 0.2 m/s, suggesting that measured air movement higher than 0.2 m/s did not seem to completely change people's preference for more air movement. Furthermore, preference for air movement is strongly related to thermal sensation, showing that people want to control air movement as a means of improving their comfort.

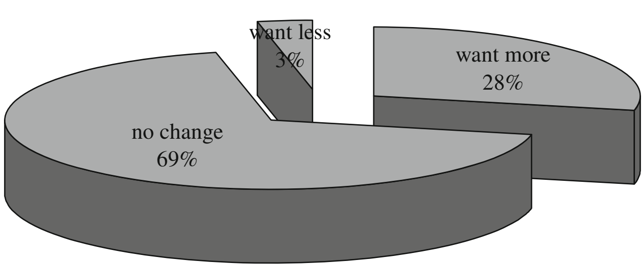


Fig. 6 Air movement preferences recorded when measured air velocity was higher than 0.2 m/s

We can come to the conclusion that air movement might have a great influence over the respondents' comfort sensation and that people required a high level of air movement in order to be comfortable during the summer season. The lack of sufficient air movement was probably the most important reason for the large number of dissatisfied occupants in naturally ventilated buildings in summer. The poor ventilation within buildings during the summer made the available air movement insufficient to offset temperature increases, and it aggravates the effects of high temperature and causes discomfort to the occupants. Given the lack of complaints of drafts, it can be assumed that occupants would happily accept higher levels of air movement over which they have control, and they are quite likely to use it appropriately to keep themselves comfortable (Brager et al. 2004). Therefore, one efficient way to improve the thermal environment in summer would probably be to provide occupants with effective natural ventilation and allow personal control of air movement.

The rigorous thermal environment in summer in naturally ventilated buildings in humid subtropical China is probably due to the overheating of the buildings, which is caused by the high solar radiation in this area. Future research into how the overheating of naturally ventilated buildings in this area can be reduced without consuming too much energy and disrupting the comfort is needed. Due to the high solar radiation coming from the east, west and top directions of buildings in summer in this area, effective thermal insulation measures must be adopted to reduce the solar radiation in these directions. Furthermore, natural ventilation can play an important role in preventing overheating by adopting adequate ventilation (Raja et al. 2001). It is recommended that the layout of the buildings should be such that the long facades are facing north and south. This orientation will increase the potential of using natural ventilation for cooling since the prevailing wind directions in humid subtropical China are north and south in summer. It is also recommended that intermittent ventilation should be advocated in this area. Natural ventilation should be restricted after midday in order to avoid the admission of hot wind when the outdoor air temperature is higher than indoor air temperature during this time. However, the outdoor air temperature is lower than indoor air temperature during summer evenings, so night-time ventilation should be enhanced in this area due to its favorable cooling effect. Furthermore, occupants in this area should be encouraged to use various measures of personal control over air movement, such as ceiling fans or desk fans, to obtain high enough levels of air movement to offset the high temperatures during summer.

This lesson is perhaps also applicable to other buildings, to encourage designers to provide air movement as a low energy cooling strategy and to ensure that sufficient levels of air movement are available. For instance, the set-point temperatures in air conditioned buildings can be lifted higher (perhaps to 30°C) if the air velocities within the occupied zones are increased (e.g., with the assistance of ceiling fans or desk fans) in the humid subtropical zone in China (Yang and Zhang 2008). However, it should be noted that the air velocity should not be elevated higher than 1.6 m/s, because at such high air velocities the pressure on the skin and the general disturbance induced by the air movement may cause discomfort in itself (Toftum 2004). This lesson also has an impact on the various ventilative cooling strategies that are possible in buildings, including fan ventilation, direct evaporative cooling, operable windows, and task conditioning systems using locally controlled air outlets.

Conclusions

This paper presents the air movement preferences of three thermal comfort surveys conducted in naturally ventilated buildings during the winter, spring, and summer season in humid subtropical China. A total of 1,572 valid questionnaires were collected during the three surveys. Major points of the findings can be summarized as follows:

(1) Thermal sensation and thermal preferences in different seasons were different. People tended to feel more comfortable in spring and winter than in summer because more than 80% of the occupants voted within the three central categories in spring and winter in comparison with just 57.4% in summer. Thermal preferences show that 66.3% of the occupants preferred warmer in winter, 52.4% of the occupants wanted no change in spring, and 83.0% of the occupants preferred cooler in summer. The results indicate that the traditional naturally ventilated buildings could not provide a comfortable indoor thermal environment for occupants during the summer in humid subtropical China.

(2) Although the air movement in the buildings was low (88% of the physical measurements were less than or equal to 0.2 m/s), air motion was perceptible to the occupants. Our results confirm previous findings by others that occupants are able to sense relatively low air speeds. The percentage of respondents who found their air movement was just right was 25.7, 38.5, and 28.7% in winter, spring, and summer, respectively, suggesting that indoor air velocity may be a big problem in naturally ventilated buildings in humid subtropical China.

(3) Air movement preferences show 15.8, 61.3, and 80.6% of subjects in winter, spring, and summer, respectively, wanting more air movement. Only a handful of subjects wanted less air movement than they were actually experiencing in either season, suggesting that draft was not much of an issue for thermal comfort. In general, when people were warmer, they preferred more air movement; when people felt cooler, they preferred less air movement. The demand for less air movement under cool sensations is much smaller than the overwhelming demand for more air movement when the sensation was warm.

(4) Air movement might have a significant influence over the respondents' comfort sensation, and people required a high level of air movement in order to be comfortable during the summer season. The lack of sufficient air movement was probably the most important reason for the large number of dissatisfied occupants in naturally ventilated buildings in summer. Therefore, one efficient way to improve the vigorous thermal environment in summer in humid subtropical China could be to provide occupants with effective natural ventilation and allow personal control of air movement.

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