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Investigations of occupants' behavioural adaptation for improving thermal comfort in workplaces

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Abstract

The interaction of a building's occupants with the environment is complex because it is affected by many factors, such as local climate, economic and cultural background, habits, ambient thermal stimuli and room type. This paper presents the findings from year-long field investigations carried out in China and the UK, respectively. It reveals that subjects' adaptations are a dynamic process that is mainly driven by physical thermal stimuli. Comparisons between UK and Chinese respondents show significant diverse adaptive measures taken depending on seasons. The UK occupants use personal changes (e.g. clothing adjustment, having cold/hot drinks, etc.) more frequently if necessary during the day; while the Chinese occupants adjust their clothing according to the season and less frequently during the day. The existing thermal environmental conditions and systems, such as central or personally controlled systems, as well as occupants' habitat and economic and cultural background, greatly affect the choice of adaptation measures.

Key words
Adaptation, dynamic response, thermal comfort, field study

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1. Introduction

Higher thermal neutral temperatures in warmer climatic areas are revealed from many field studies (Leow 1988; Dear, Leow et al. 1991; Heidari and Sharples 2002; Yao, Liu et al. 2010). In contrast, the derived thermal neutral temperatures are relatively lower for people from cooler climatic areas (Wang 2006; Liu 2007). Field investigations reveal that occupants can adapt their thermal environment, behavioural adjustment and personal control. It has also been demonstrated that thermal preference or thermal neutral temperature is not only dependent on the physical environment, but also on many other factors such as occupants' adaptation, expectations, social and economic issues, cultural background and living habitat. This paper describes the research outcomes from parallel investigations of behavioural adaptation in workplaces carried out in the UK and China. It aims to provide a comprehensive insight into, and understanding of, the effects of physical and non-physical factors on thermal comfort and the adaptive responses of occupants in real office environments by means of comparative analysis.

2. Methodology

The field studies were carried out in office buildings at the University of Reading (UK) and Chongqing University (China) from 2010 to 2011 covering the whole year. Both typical seasons (e.g. summer: June-August; winter: December-February) and transition seasons (e.g. spring: March-May; autumn: September-November) were included. A questionnaire survey regarding workplace thermal sensation and adaptive responses, together with on-site measurements of physical environmental parameters, are employed in this study.

2.1 Local Weather Conditions

Reading is located to the west of London which has a maritime climate characterised by limited seasonal temperature ranges The mean outdoor air temperatures in summer and winter are 16.7^{o}C and 4.9 ^{o}C, respectively; and the year-long mean outdoor air temperature is 10.5 ^{o}C (Station). Chongqing is located in southwest China in the subtropical, humid, monsoon climate zone characterised by hot summers and cold winters. The mean outdoor air temperatures in the coldest and hottest months are 0-10oC and 25-30oC (Standard 1993), respectively. The mean outdoor relative humidity throughout the year is up to 70-80% (Statistics 2010).

2.2 Questionnaire Survey

The questionnaire was designed by referring to the ASHRAE Standard 55 (ANSI/ASHRAE55-2004 2004). There are three sections included. The first section aims at collecting background and anthropological information such as gender and age. The clothing levels of subjects are quantified according to the ASHRAE standard (ANSI/ASHRAE55-2004 2004). The chairs involved in this investigation are of standard type; therefore an additional 0.1clo of insulation has been included in clothing insulation values. The activity level of the occupants is equivalent to the metabolic rate, covering 1.1-1.3met, to determine the index of Predicted Mean Vote (PMV) values, because subjects in the surveyed offices were usually engaged in sedentary activities, such as typing, reading and writing, involving the use of computers. Thermal data including overall thermal comfort sensations, thermal acceptability and preference, previous-day thermal experience and thermal expectations, respectively constitute the second part of the questionnaire. The last section gathers information about the perceived environmental control level, the purpose of control and additional control measures. Table 1 shows the information and voting scale in the questionnaire survey.

Table 1 Summary of voting scale information

Index	Scale						
	-3	-2	-1	0	+1	+2	+3
Thermal Sensation (AMV)	Cold	Cool	Slightly Cool	Just Right	Slightly Warm	Warm	Hot
Thermal Preference	------	Want Much Cooler	Want a Bit Cool	No Change	Want a Bit Warm	Want Much Warmer	------
Previous Day Thermal	------	Much Cooler than	A Bit Cooler	The Same as at the	A Bit Warmer	Much Warmer	------

Experience at the Moment		at Present	than at Present	Moment	than at Present	than at Present	
Thermal Acceptability	------	------	------	Not Acceptable	Acceptable	------	------
Perceived Environmental Control Level	0	1	2	3	4	------	------
	No Control	Light Control	Medium Control	High Control	Total Control	------	------

2.3 General Information

The buildings surveyed in the UK survey are located at the Whiteknights campus, University of Reading. They are the Urban and Regional Studies (URS) building, the Engineering building and the Physics building, respectively. For reasons of accessibility, the main field of this research is in the URS building. The data collecting from the other two buildings only occupies typical seasons (e.g. summer and winter) and plays a supplementary role. The three surveyed buildings are multi-functional with a south-north orientation, of brick-concrete structure. The windows are single-glazed with aluminium frames and are operable. Central heating systems (e.g. radiators) are used for space heating in winter. No air-conditioners are available in offices but additional fans and portable fan heaters are available. The surveyed building in the Chinese case is a four-story, naturally-ventilated, office building (the No.3 Lecture Building) which is located on campus B, Chongqing University. It is of masonry construction with north-south orientation and was built over fifty years ago. All windows are operable and single-glazed with aluminium frames. Separate air-conditioners are installed in each surveyed office and can be operated individually according to the occupants' thermal wishes.

Physical environmental parameters including air temperature (Ta), velocity (Va), humidity (RH) and global temperature (Tg) were measured at three vertical levels of 0.1m, 0.6m and 1.1m representing the position of the ankle, waist and neck for a seated person while subjects were completing the paper questionnaire.

A total of 41 and 148 respondents participated in the Reading and Chongqing field investigations and provided a total of 1022 and 1178 datasets, respectively. Although the Chongqing sample size is larger, they were not always available to participate in the survey due to their other responsibilities. Thus the numbers of datasets collected are similar for the two cases. The compositions of the two samples are similar, namely staff and postgraduate students. The survey was conducted two days per week and lasted a whole year. All subjects were visited twice in a survey day (morning and afternoon session). The general information on the surveyed buildings and subjects are summarised in Table 2.

Table 2 Summary of general information

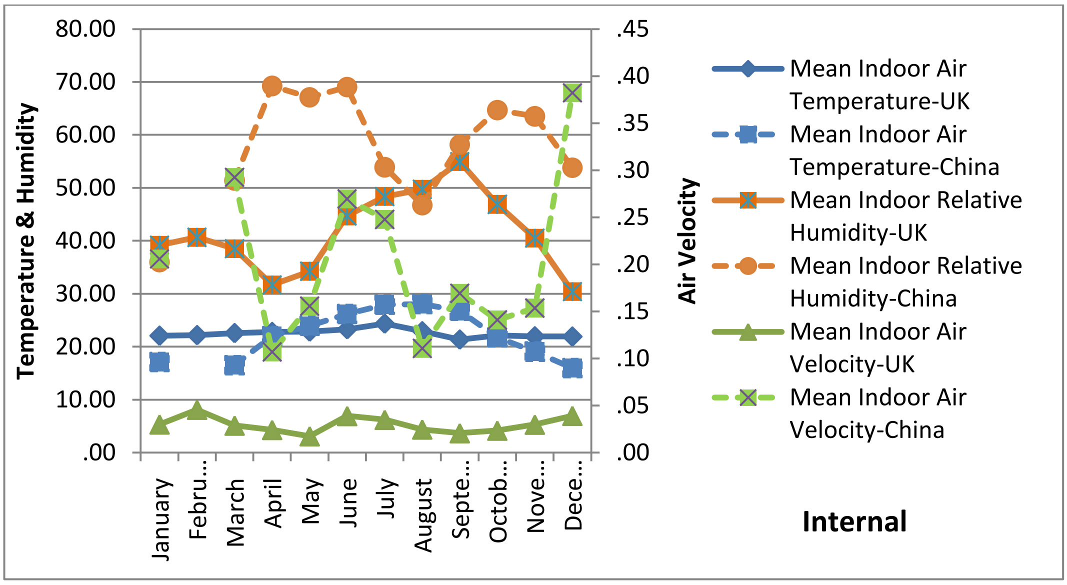
		Building in China	Building in UK
Surveyed Building	Year	>50 years	>40 years
	Orientation	South-north	
	No. of Stories	5	4
	Function	Lecture, administration, office	
	Envelope	Masonry	
	Window	Single glazing with aluminium alloy frame	
	Air-	Separated Units	No

	conditioner		
	Heating	No	Central heating (Radiators)
Subjects	Sample Size	148	41
	Datasets	1178	1022
	Gender	Male (55.6%)	Male (39.0%)
	Activity	Sedentary Activities	

3. Results and Discussion

3.1 Internal and External Thermal Conditions

The variations in the main internal and external environmental parameters are shown in Figure 1. From June to September, the mean monthly indoor air temperature in surveyed offices in Chongqing is higher than that in Reading. Chongqing has higher mean outdoor air temperatures throughout the year. The indoor thermal environment in Chongqing offices is more humid compared with that in offices in Reading. But Reading basically has greater mean monthly outdoor humidity levels. The indoor air speed in Chongqing is higher than that in Reading, and it fluctuates significantly.



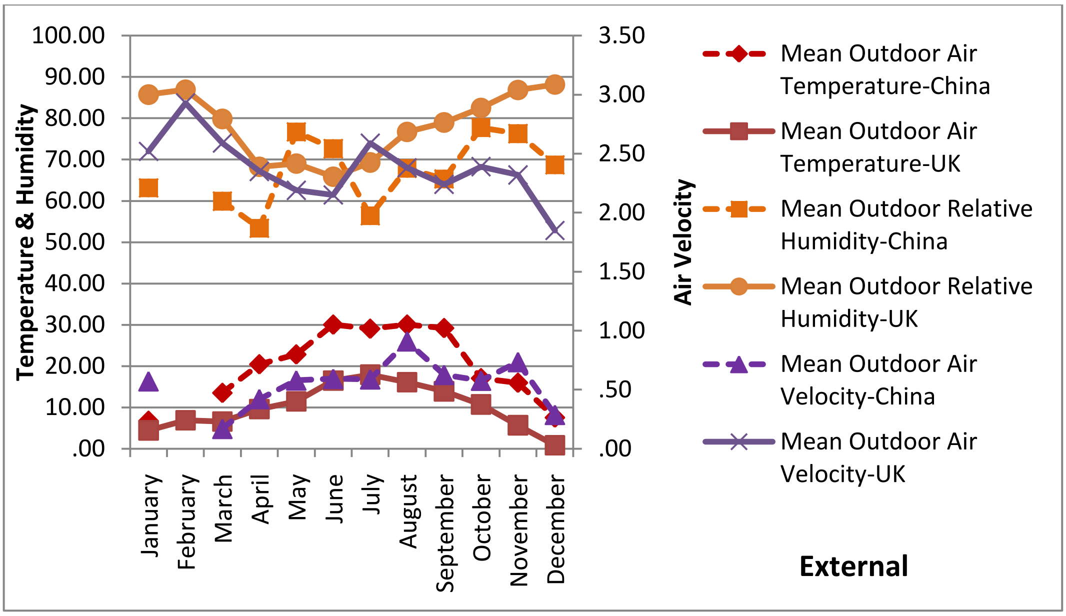


Figure 1 Internal and External Thermal Conditions

3.2 Thermal Sensations

Occupants' thermal sensations are quantified by applying ASHRAE's seven-point scale. The influence of semantic issue is minimised by means of standard translation, which is as standardize application of ASHRAE's seven-point scale in China. In order to compare thermal sensations of occupants in two studies, we need to exclude the influences of factors which are impacting thermal sensation by means of calculating corresponding offset effects on AMV. For example, as stated in CIBSE Guide A (CIBSE-Guide-A 2006) that the three degrees changes in temperature would change the response on the scale of subjective warmth by about one scale unit for sedentary persons, the discrepancy in indoor air temperatures could then be quantified to values of thermal sensation. Similarly, the influences of velocity and clothing insulation level could be offset by calibrating AMV values. The compensation effects of those factors on temperature are converted to calibration AMV values and the results are presented in Table 3.

Table 3 Thermal Sensations

		Thermal Sensation Vote (AMV)						Calibrated AMV		T_{in}		Clo		V	
		Min.		Max.		Mean									
		CHN	UK	CHN	UK	CHN	UK	CHN	UK	CHN	UK	CHN	UK	CHN	UK
Sp	South	-2	-2	+3	+2	-0.17	0.01	-0.08	0.01	22.01	21.52	0.88	0.73	0.18	0.02
	North	-3	-3	+2	+2	-0.37	0.04	-0.22	0.04	20.86	20.57	0.80	0.74	0.18	0.03
Su	South	-2	-2	+3	+2	0.31	0.31	-0.22	0.31	27.99	25.71	0.45	0.58	0.17	0.04
	North	-1	-3	+1	+3	0.01	0.17	0	0.17	26.40	25.53	0.41	0.62	0.22	0.03
Au	South	-3	-3	+3	+2	0.11	0.19	-0.39	0.19	24.60	23.09	0.72	0.72	0.14	0.02
	North	-2	-3	+3	+3	-0.06	0.18	-1.14	0.18	23.30	20.02	0.71	0.83	0.16	0.03
Wi	South	-3	-3	+2	+2	-0.49	0.10	0.92	0.10	17.23	20.42	1.18	0.82	0.25	0.02
	North	-3	-2	+2	+2	-0.51	0.11	0.99	0.11	15.98	19.02	1.22	0.87	0.38	0.04

CHN- China; Sp-Spring; Su-Summer; Au-Autumn; Wi-Winter

In table 3, it is noticeable that subjects in Chongqing have cooler thermal sensations in summer and warmer thermal sensations in winter compared to the subjects in Reading. In transition seasons (e.g. spring and autumn) respondents from Chongqing feel cooler under a similar thermal environment.

The results obtained in typical season cases demonstrate that people in Chongqing have acclimatized to the local hot summer and cold winter climate and subsequently have a broader tolerance of temperature variation. On the other hand, the running of various environmental controls in summer and in winter, especially the air-conditioners, further enhances the achievement of thermal sensations which are close to thermal neutrality. The pooled effects of psychological and behavioural adaptations can be used to explain the observations in transition seasons. In the UK, until early spring or from the end of autumn, the heating systems are on. That is to say, the relative better indoor thermal conditions in transition seasons in the UK are achieved partly by using heating systems. Under such conditions, although the external temperatures are lower, subjects have the sense that they can control their ambient environment, which enables occupants to accept occupying the environment easily. By contrast, people in Chongqing basically think the transition seasons should be the most pleasant seasons with a moderate thermal environment compared with summer and winter. Under such psychological assumptions, subjects would like to adapt to ambient thermal conditions mainly by operating windows and, less frequently, by the use of fans, air-conditioners and fan heaters. That is to say, the thermal environment in transition seasons in Chongqing is more natural. Thus, people's thermal sensations in Chongqing are more easily influenced by the local climate and subsequently produce the cooler feelings.

3.2 Adaptive Responses

The adaptive responses performed by occupants reflect the effect of thermal stimuli, habit and local social, economic and cultural factors on behavioural adaptation. In this section, the technological responses including environmental controls use frequencies and complementary strategies, personal adaptation in terms of clothing insulation and psychological adaptation are compared between Chongqing and Reading.

3.2.1 Technological Responses

Technological responses include the adaptive behaviours of running environmental controls that occupants may carry out in response to an undesirable thermal environment. The availability of environmental measures under certain environment, which is usually denoted as 'adaptive opportunity' (Baker and Standeven 1995), reveals the freedom and diversity that subjects can use to diminish the thermal discomfort caused by thermal stimulus. Table 4 shows the result of the availability of environmental controls in the two places.

Table 4 Availability of Environmental Controls in Office Environments (%)

China/UK		Window	Sun-shading Devices	Heating Units (e.g. fan heater)	Heating (e.g. radiator)	Fans	Air-conditioner
Orientation	South	100/39.1	83.8/43.5	56.6/78.3	N/A /56.5	36.4/56.5	97.3/ N/A
	North	100/42.9	63.6/42.9	72.7/78.3	N/A /42.9	37.8/38.1	100/ N/A

Some offices in Reading have deep plan, therefore for those whose seats are far away from the window are assumed that the operation of window, heating and blinds are not available to them. From the table we can see that the availability of operation of windows in the UK is significantly lower than that in Chongqing. The purpose of using windows is mainly for fresh air and cooling. Similarly, occupants in Chongqing have access to a greater level of sun-shading devices. The occupants in the two places with access to shading devices use them mainly for protection from glare rather than the reduction of solar gain. Although a central heating system is available in Reading during the winter, additional fan heaters are still available. Split air-conditioners together with heating units are available to the occupants in Chongqing. Fans are available for both the Chongqing and Reading offices in summer.

After understanding the availability and running purposes of environmental controls, how often the occupants would like to use them is of interested. Subjects in the two places have different environmental controls use frequencies in each season. During the whole year period, the window opening frequencies are always higher in Chongqing, particularly during transition seasons (at least 30.8%). But such differences decrease in typical seasons and are less than 5% in summer. In order to guarantee the efficiency of air-conditioner, windows are basically closed when air-conditioners are in operation. Although the offices in Chongqing are equipped with air-conditioners, the operation of heating units (e.g. fan heaters) and fans in typical seasons is still frequently, 47.1% and 63.9% on average, respectively. It indicates that even though the air-conditioners are in use, the running temperatures are set up at moderate levels (e.g. on average 22 ^{o}C in summer and 24 ^{o}C in winter). This phenomenon is confirmed by the higher mean indoor air temperatures in summer and lower mean values in winter in Chongqing. However, the proportions of operations of heating units in transition seasons are less in Chongqing due to the local moderate climate conditions. The sun-shading device is the only environmental control measure used more frequently by occupants in Reading. Overall, occupants in Chongqing are more active in utilizing environmental control measures to adjust the ambient thermal environment. Through reviewing the indoor physical environmental conditions presented in section 3.1 and noticing the less than one scale deviation from thermal neutral sensations (maximum 0.51 deviations in the cool direction), the contribution of running environmental controls to diminish the negative influence of physical environmental factors on the thermal sensation of occupants is significant. In addition, it is also indicating that physical environmental conditions are an important issue driving subjects to use environmental controls in non-air-conditioned workplaces.

The thermal comfort of occupants sometimes cannot be achieved in a real environment by utilizing a single environmental control measure, particularly under extremely thermal conditions. Thus, in such cases, people may operate more than one environmental control simultaneously. For purposes of comparison, the measure of cooling/heating units (e.g. fan, fan heater, etc.) is termed as ‘technological responses’ and the adaptive actions of clothing adjustment, having cold/hot drinks and changing activity level are denoted as ‘personal adaptation’, respectively.

The occupants in Chongqing are more active in utilizing technological responses such as fans, fan heaters, etc. as complementary approaches. But the respondents in Reading take supplementary adaptive actions less frequently when the windows are in use. They are more likely to perform personal adaptations such as clothing adjustment, having cold/hot drinks and changing physical activity level, etc. In terms of sun-shading devices, people in Reading would like to use sun-shading devices alone rather than performing other adaptive actions simultaneously as complementary. By contrast, adjusting the screen position or contrast is the most common complementary adaptive behaviour conducted together with sun-shading devices by subjects in Chongqing. Although fans are the only environmental control facilities for cooling sense in

Reading, subjects there are seldom use other adaptive approaches simultaneously which are as complementary when fans are in use. It indicates that the use of fans alone is sufficient to enable subjects in Reading to ameliorate the thermal discomfort caused by higher temperatures. By contrast, the majority of respondents in Chongqing would like to utilize other adaptive actions together with fans. This, on the one hand, reveals the poor thermal conditions in summer in Chongqing whilst on the other hand, confirming that the temperatures of air-conditioners are set up at moderate levels. Contrasting with the previous observations, people in Reading are more active in taking other adaptive actions as complementary when the heating is operating.

Overall, there are differences in complementary adaptations between the two places. People from Chongqing are generally more active in running technological environmental controls. People from Reading basically prefer to make personal adjustments. Providing the same level of adaptive opportunity, the local climate conditions seem to be the factors which determine the choice of actions in the real environment.

3.3.2 Personal Adaptations

After averaging the clothing insulation values in each 0.5^{o}C of indoor air temperature, the differences in seasonal tendencies of clothing adjustments are demonstrated in Figure 2.

In spring, the clothing insulation values of occupants from Chongqing are greater when the indoor air temperatures are less than 21 ^{o}C. After exceeding that temperature, the subjects from the UK case are generally wearing more. The subjects in Chongqing wear less than occupants in Reading during the whole summer season. In autumn, the values of clothing insulation of respondents in Chongqing are higher until the indoor air temperature rises to 22 ^{o}C. The clothing insulation values of the subjects in the two places are relatively constant in winter, fluctuating around 1.2clo and 0.8clo in Chongqing and Reading, respectively. But in the Chongqing case, the clothing insulation drops to around 0.6clo when the indoor air temperature reaches 26 ^{o}C.

Overall, the changes in the clothing insulation levels of occupants in Chongqing are greater both within and between seasons. Although subjects in Reading prefer to make personal adjustments as a complementary approach, the variations in the extent of clothing levels are moderate, particularly during the autumn and winter heating seasons.

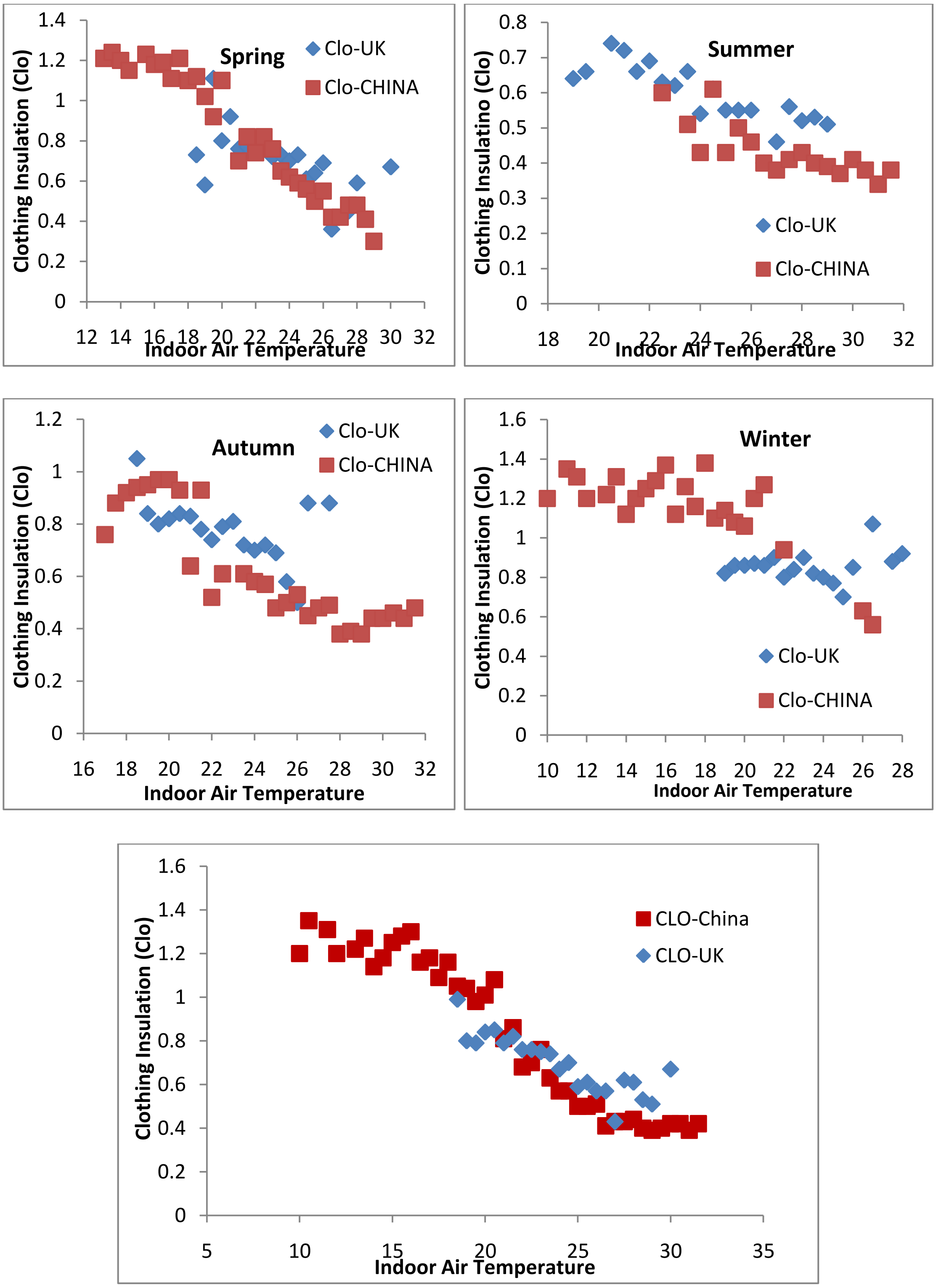


Figure 2 Clothing Insulation Variation against Indoor Air Temperature

3.3.3 Psychological Adaptation

In the context of the built environment, the research on the effect of psychological adaptation on thermal comfort of occupants focuses on perceived environmental control level and the thermal expectations (Andersen, Olesen et al. 2007). The effects of psychological adaptation are considered in terms of perceived environmental control level and past thermal experiences because past thermal experience directly affects people's expectations (Nikolopoulou and Steemers 2003).

Psychologists have concluded that occupants may be less irritated by the undesirable external stimuli under a certain thermal environment if they perceive they have control over them (Kaplan and Kaplan 1982; Paciuk 1989). In order to quantify the environmental control levels perceived by occupants, a question of 'how much would you consider the level of environment control in your office' is included in the questionnaire. A corresponding 5-point scale covering from 0, no control, to 4, total control, with a medium value of 2, medium control, was used to quantify occupants' perceived environmental control level. In order to perform the comparison analysis, the collected data are further divided into two sub-categories: lower control level (levels 0 or 1) and higher control level (levels 3 or 4), respectively. The quantitative effect of perceived environmental control level is assessed by comparing mean thermal sensation votes using a two-tailed t-test, the results of which are shown in Table 5. Even though the discrepancies in mean values of AMV are not statistically significant in each season, particularly in China case, the mean thermal sensation experienced by occupants in the higher-level category is cooler than that of those with a perceived environmental control level in the lower-level category in summer. Meanwhile, people with a higher perceived environmental control level rate thermal conditions in workplaces as warmer than those who think they have a lower level of control over their surrounding thermal environment in winter. Overall, people in the UK case during typical seasons who have a perception of a higher environmental control level would like to produce more pleasant thermal sensations, compared with those who regard their environmental control level as lower. The non-statistically-significant results from China case can be attributed to the following two reasons: firstly, the sample size in China case is relative small. For example, only 7 datasets representing 'high level' of perceived environmental control level are gathered in winter. Such small sample size has limited representatives of mean thermal sensations of occupants who perceive environmental control level in their workplace as 'high level'. Secondly, although there is discrepancy in perceived environmental control level, the running of air-conditioners in China case has direct effect on diminishing the difference in mean thermal sensation between two sub-groups of occupants. In China case, people who are in 'low level' category operate air-conditioners with mean set-up temperature of 22.65℃ in summer, which is lower than subjects who are in 'high level' category, 23.33℃. Similarly, in winter the mean set-up temperatures are 22.33℃ and 21℃ for occupants who perceive environmental control level in workplace environment as 'low level' and 'high level', respectively. Therefore, the lower set-up temperature in summer and higher one in winter decrease/promote the mean thermal sensations of occupants who are in 'low level' category, and subsequently reduce the differences in mean thermal sensations between subjects in those two level categories.

Table 5 Results of two-tailed t-test of perceived environmental control level

China/UK		Spring		Summer		Autumn		Winter	
		High Level	Low Level	High Level	Low Level	High Level	Low Level	High Level	Low Level
Sample Size		14/38	51/174	73/29	14/104	0/37	0/113	7/30	34/63
AMV	Max	+2/+2	+1/+2	+2/+2	+3/+3	n/a/+3	n/a/+3	+1/+2	+1/+1
	Min	-2/-1	-3/-3	-2/-2	-1/-3	n/a/-2	n/a/-3	-2/-3	-3/-2

	Std. Deviation	0.802/ 0.995	0.949/ 0.870	0.770/ 0.937	0.896/ 1.435	n/a/ 1.173	n/a/ 0.917	1.113/ 1.048	1.203/ 0.635
	Mean	-0.14/ 0.18	-0.39/ -0.01	0.14/ 0.20	0.58 /0.45	n/a/ 0.11	n/a/ -0.27	-0.29/ 0.07	-0.65/ -0.13
Significance of (High-Low)		No (P-value=0.38)/ No (P-value= 0.051)		No (P-value=0.076)/ Yes (P-value<0.001)		n/a/ No (P-value=0.301)		No (P-value=0.46)/ Yes (P-value=0.013)	

The sense of higher control level gives occupants the psychological assumption that, despite the current thermal environment being seen as unsatisfactory, they can adjust it toward their own thermal preference later by applying various environmental controls. Such psychological suggestions predispose subjects to readily forgive the deviations in the physical parameters and enhance the sense of comfort. In these two studies, taking typical seasons as examples, the objective available environmental controls are different. In summer, occupants in Chongqing can operate fans and air-conditioners; but in Reading, only cooling fans are available. If we ignore that they are two studies in different locations but regard them as one field investigation in a certain place in which some subjects are provided with both air-conditioners and fans whilst other subjects can only access either one, undoubtedly, the latter subjects will have a lower perceived environmental control level and consequently be more likely to have unpleasant thermal sensations. But, if most buildings in a place provide similar environmental controls to all occupants, the situation with relatively fewer environmental controls in the comparison cases (e.g. Chongqing and Reading in this case) may be regarded as a higher control level, such as in the Reading case, and produces more pleasant thermal sensations. Similarly, although air-conditioners and fan heaters are available in Chongqing in winter, the efficiencies and perceived comfort level are far less than that provided by radiators, but most subjects in Chongqing still have thermal-neutrally thermal sensations which are even warmer sensations than occupants in Reading. This indicates that occupants usually do not take into account any unavailable environmental controls, which might have even better environmental improvement and comfort-inducing performances, when they assess the perceived environmental control level in a space. Thus, people's assessment of the environmental control level is based on the available level of environmental control measures in the objective environment they occupy. For example, if air-conditioners are commonly installed in a majority of office buildings in an area/city, people in buildings without air-conditioners may perceive that their level of control over their ambient environment is low, no matter whether air-conditioners are really suitable environmental control facilities for that condition. Therefore, the perceived environmental control level is socially conditioned.

The subjective benchmarks or norms for environmental evaluations are the result of personal past thermal experience (Helson 1964; Wohlwill 1975). Thus, the past and current thermal experiences have direct effects on people's thermal sensations and thermal acceptability. Therefore, with respect to past thermal experience, a question on 'the thermal environment you were occupying in the previous day at the moment was' was designed with responses on a 5-point scale (-2 to +2). The responses -2 and -1 are categorised as a cool orientation with the warm orientation including answers of +1 and +2, respectively. Similarly, the effect of short-term thermal exposure is assessed by comparing mean thermal sensation votes using a two-tailed t-test. The results of this test are given in Table 6. The phenomenon that respondents who experience the cooler thermal conditions on the previous day at the moment would produce a relatively warmer thermal sensation if the current day's thermal conditions do not deviate too much is observed in both cases. Short-term experience is related to the memory and seems to be responsible for the changes in people's expectations from one day to the next (Nikolopoulou and Steemers 2003). Therefore, people who experience a cool/warm thermal environment at a given time (short-term exposure) on previous day may presume that the similar thermal conditions would appear again on the following day. In such cases, they have prepared to experience that thermal conditions once more and form their benchmarks or norms for thermal environment assessment (the short-term thermal experience on previous day is as reference) on the following day. The only difference is that in transition seasons the effect of short-term exposure on thermal sensations reaches the statistically significant level in Reading, unlike in Chongqing. This may be associated with the lower variation in environmental conditions in transition seasons and relative smaller datasets in Chongqing case.

Table 6 Results of two-tailed t-test from both China and UK

China/UK		**Spring**		**Summer**		**Autumn**		**Winter**	
		Cool Orientation	Warm Orientation	Cool Orientation	Warm Orientation	Cool Orientation	Warm Orientation	Cool Orientation	Warm Orientation
Sample Size		32/112	55/98	52/44	31/89	51/83	28/71	38/49	26/37
AMV	**Max**	+1/+2	+1/+2	+3/+3	+1/+3	+1/+3	+3/+2	+1/+2	+1/+1
	Min	-2/-2	-2/-2	-2/-1	-1/-3	-2/-2	-2/-3	-2/-1	-3/-1
	Std. Deviation	0.821/ 0.899	0.712/ 0.797	0.893/ 1.138	0.629/ 1.061	0.77/ 0.827	1.30/ 0.954	0.981/ 0.764	0.970/ 0.605
	Mean	-0.19/0.17	-0.29/-0.28	0.71/0.77	-0.06/-0.01	0.12/0.11	-0.14/-0.49	-0.11/0.29	-0.69/-0.46
Significance of (Warm-Cool)		No (P-value=0.554)/ Yes (P-value<0.001)		Yes (P-value<0.001)		No (P-value=0.264)/ Yes (P-value<0.001)		Yes (P-value=0.021<0.05)/ Yes (P-value<0.001)	

3.3 Dynamic Process of Adaptive Behavioural Responses in Real Environments

Based on the above adaptive responses analysis, people are actively to adapt to their thermal environment by utilizing various approaches from season to season and from time to time, even on the same day. Their adaptive responses in a real environment demonstrate the dynamic processes. In general, subjects are more actively seeking for adaptive strategies to eliminate the unpleasant thermal perceptions in typical seasons (e.g. summer and winter) compared with those carried out in transition seasons (e.g. spring and autumn).

By linking their adaptive behavioural responses to both indoor air temperature and outdoor air temperature, the graphic descriptions of such dynamic processes are presented (see Figure 3). It is apparent that the variation of indoor air temperature is quite limited in the UK case. Meanwhile, the seasonal changes in adaptive behavioural responses in the UK case are not obvious compared with those occurring in the China case. Windows and blinds are the most frequently used approaches in both places. However, people in the UK use those two environmental controls within a broader outdoor temperature range. As the main cooling facility in summer, subjects in the UK normally switch on a fan covering the indoor air temperature of 20.6°C to 28.8°C, which corresponding to the outdoor temperature range from 12.1°C to 23.5°C; people in China use fans indoor temperature ranges are 25-28°C corresponding to outdoor temperature between 28 and 31°C. In the UK, the operation of a fan heater nearly covers the whole temperature range in heating seasons. But in China, fan heaters are normally used by subjects in winter and cover the outdoor temperature range from 0°C to 17°C. The clothing adjustment behaviour occurs in the whole temperature ranges during the year-long survey period in the UK; subjects in China do not adjust their clothing levels as frequently as people in the UK. They would like to adjust clothing insulation within the outdoor temperatures of 15-25.5°C. This is because personal adjustments are the most popular adaptive responses made by occupants in Reading. Besides, the significant discrepancies between internal and external temperatures and the habit of wearing out-layer clothing also result in such a phenomenon. The overlaps of adaptive behaviours indicate that several adaptive approaches may occur simultaneously under certain thermal conditions. The comparison of adaptive behaviour processes indicates that, although the physical environmental differences determine the discrepancies in the choice of adaptive approaches, the habits of subjects are also a kind of feedback affecting the interaction between occupants and buildings.

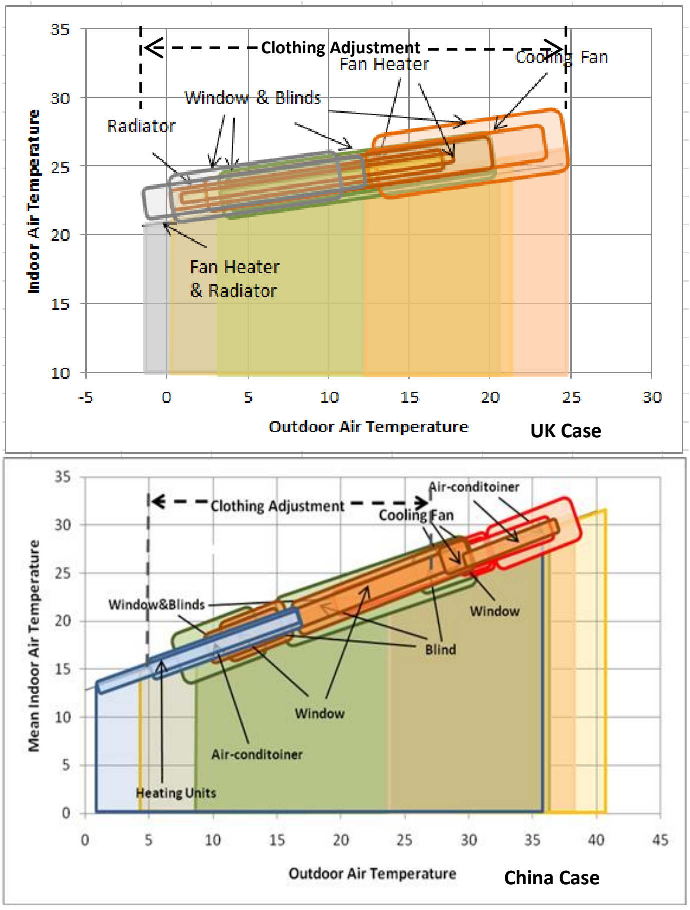


Figure 3: Dynamic Processes of Adaptive Behaviours

3.4 The Comprehensive Effect of Adaptation

The comparative analysis of the results of thermal acceptability, which are derived from the direct and indirect approaches, reveals the footprint of the adaptations of the subject in their real thermal environment.

Table 7 Cross-tabulation of Thermal Acceptability and Thermal Sensation Votes

China/UK			Thermal Sensation Vote (ASHRAE 7-point Scale)							Total
			Cold (-3)	Cool (-2)	Slightly Cool (-1)	OK (0)	Slightly Warm (+1)	Warm (+2)	Hot (+3)	
Temperature Acceptability	Unacceptable	Count	6/3	12/11	8/19	7/7	24/15	8/19	7/1	72/75
		% within Temperature Acceptability	8.3%/ 4.0%	16.7%/ 14.7%	11.1%/ 25.3%	9.7%/ 9.3%	33.3%/ 20.0%	11.1%/ 25.3%	9.7%/ 1.3%	100.0%
		% within Temperature	60.0%/ 60.0%	30.0%/ 47.8%	3.1%/7.4%	1.2%/1.4%	10.4%/ 8.2%	36.4%/ 35.8%	50.0%/ 20.0%	6.1%/ 7.3%
	Acceptable	Count	4/2	28/12	252/239	595/487	206/169	14/34	7/4	1106/ 947
		% within Temperature Acceptability	0.4%/ 0.2%	2.5%/ 1.3%	22.8%/ 25.2%	53.8%/ 51.4%	18.6%/ 17.8%	1.3%/ 3.6%	0.6%/ 0.4%	100.0%
		% within Temperature	40.0%/ 40.0%	70.0%/ 52.2%	96.9%/ 92.6%	98.8%/ 98.6%	89.6%/ 91.8%	63.6%/ 64.2%	50.0%/ 80.0%	93.9%/ 92.7%
Total		Count	10/5	40/23	260/ 258	602/ 494	230/ 184	22/53	14/5	1178/ 1022
		% within Temperature Acceptability	0.8/ 0.5%	3.4/ 2.3%	22.1/ 25.2%	51.1/ 48.3%	19.5/ 18.0%	1.9/ 5.2%	1.2/ 0.5%	100.0%
		% within Temperature	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

In theory, people who cast thermal sensation votes of -1, 0 and +1 in ASHRAE's seven-point scale are viewed as accepting the current thermal conditions. Otherwise, conditions are not acceptable. Table 7 shows the results of comparison between thermal acceptability and thermal sensation votes in two studies. There are at least 50% of respondents whose thermal sensation votes are not within the central three categories but who still regard thermal conditions in workplaces as acceptable, accounting for 61.6% and 60.5% in the China and UK cases, respectively. It is noticeable that the proportions of subjects who sense the thermal environment as being cool (-2 and -3) but find such thermal conditions to be acceptable is higher in the China case than in the UK case, 64.0% and 50%, respectively. By contrast, there is a greater percentage of occupants in the UK case who regard the thermal conditions as being warm (+2 and +3) but still accept them. Such a phenomenon indicates that with the assistance subject controlled adaptations, people can be tolerant of cold or warm thermal environments to some extent. However, based on this analysis, there is insufficient evidence to reach the conclusion that people in the UK case are more likely to accept a warmer thermal environment. Because the definition of 'hot' or 'cold' is definitely different due to the discrepancies in physical environmental parameters between the two studies, we have to add a restriction of 'under local climate conditions' to avoid any ambiguity.

Table 8 Cross-tabulation of Thermal Acceptability and Thermal Preference

China/UK	Thermal Preference	Total

			Want Much Cooler	Want a Bit Cooler	No Change	Want a Bit Warmer	Want Much Warmer	
Temperature Acceptability	Unacceptable	Count	5/6	38/31	4/6	21/28	4/4	72/75
		% within Temperature Acceptability	6.9%/8.0%	52.8%/41.3%	5.6%/8.0%	29.2%/37.3%	5.6%/5.3%	100.0%
		% within Thermal Preference	38.5%/85.7%	13.5%/22.6%	0.7%/1.0%	7.8%/11.4%	80.0%/33.3%	6.1%/7.3%
	Acceptable	Count	8/1	243/106	606/615	248/217	1/8	1106/947
		% within Temperature Acceptability	0.7%/0.1%	22.0%/11.2%	54.8%/64.9%	22.4%/22.9%	0.1%/0.8%	100.0%
		% within Thermal Preference	61.5%/14.3%	86.5%/77.4%	99.3%/99.0%	92.2%/88.6%	20.0%/66.7%	93.9%/92.7%
Total		Count	13/7	281/137	610/621	269/245	5/12	1178/1022
		% within Temperature Acceptability	1.1%/0.7%	23.9%/13.4%	51.8%/60.8%	22.8%/23.9%	0.4%/1.2%	100.0%
		% within Thermal Preference	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Literally, a thermal environment in which people wearing reasonable clothes are willing to adjust/change the thermal conditions is being regarded as unacceptable. Based on such principle, the results demonstrated in Table 8 reveal that in this study there are 85.4% and 74.3% of occupants in the China and UK cases, respectively, who want to change the thermal environment towards a cool direction (e.g. want much cooler or want a bit cooler) but still accept current thermal conditions. Similarly, about 90.9% and 87.5% of subjects in the China and UK cases accept the ambient thermal environment but wish to have warmer thermal conditions. It is noticeable that, no matter whether the thermal preference is in the cool or warm direction, the proportion of occupants who view their thermal conditions as acceptable is greater in the China case. Such a difference between the two cases reflects the Chinese subjects' broader tolerance of environmental variations. Comparing the thermal acceptability percentage between respondents whose thermal preferences are in the cool direction and within warm direction (e.g. want much warmer and want a bit warmer), people who would like to change the thermal environment in the warmer direction provide greater thermal acceptability in both studies. This figure is slightly higher in China (90.9% vs. 87.5%). It happens to indicate that occupants in the China case are more likely to complain in a cold thermal environment.

4. Conclusions and Discussions

The investigation results from the two parallel field investigations conducted in China and the UK have been compared and analysed. The conclusions of this study are summarized as below:

The corrected thermal sensations of occupants are cooler in summer and warmer in winter in the Chongqing case. Their thermal history and living background enable subjects in Chongqing to form more flexible thermal requirements. A corresponding flexible thermal expectation is formed gradually by long-term exposure to the extreme thermal conditions in Chongqing.

Subjects from both cases would like to utilize different adaptive behaviours to eliminate the passive effect of ambient thermal conditions on thermal comfort. Generally, subjects from Chongqing are more active players in operating technological approaches to adjust the ambient thermal environment, such as fans and air-conditioners. Respondents from Reading are not as active as people from Chongqing in utilizing environmental control measures. They are more likely to make personal adjustments, for example, adjusting clothing insulation, having cold/hot drinks and changing physical activity levels. The behaviour of clothing adjustment occurs covering the whole temperature range during the year-long survey period in Reading although the variations of clothing insulation levels are not as broad as those in Chongqing in each season. The seasonal characteristic of clothing insulation variations is obviously observed in the Chongqing case. Their adaptive responses are dynamic processes and are varying from season to season and from time to time, even on the same day.

The analysis of psychological adaptation in terms of perceived environmental control level, short-term exposure and previous thermal experience clearly illustrates that they are positive influences on the thermal sensations of occupants, particularly for the UK case.

Overall, physical environmental parameters are the deterministic factor for performing adaptive responses, but Thermal history and living background enable subjects form different thermal requirements, preferences and expectations. Local economic and cultural factors help determine the predominant environmental control measures.

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