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Research Paper

Influence of Thermal Experience on Thermal Comfort in Naturally Conditioned University Classrooms

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ABSTRACT

This study aimed to investigate the relevance of thermal experience on students' thermal perceptions in the naturally conditioned university classrooms, and identified the suitable values of indoor thermal parameters for students' thermal comfort in Hot-summer and Cold-winter Climate Zone of China. Field measurements on environmental parameters and questionnaire surveys of students' thermal perceptions were conducted in the whole duration of twelve lectures in summer and winter. Thermal perceptions of TSV, TAV and TPV were recorded 3 times (15min, 45min, 95min) within each survey. It was found that, the indoor thermal conditions for students were more comfortable and acceptable in summer than in winter. Positive correlation of thermal sensation and indoor operative temperature occurred in summer, while negative correlation occurred within the indoor operative temperature range of 9.8~15.3℃ in winter, and only when the initial temperature was upon 15.7℃, could the normal response of students' thermal sensation on the ambient environment return back. Thermal memory will make impact on the thermal perception as the on-site temperatures lose their control of current thermal response gradually, especially under the extremely cold thermal conditions. Meanwhile, TSV, TAV and TPV were unsynchronized in both summer and winter, especially in winter.

1. Introductions

Indoor thermal environment of educational buildings has great influences on students' comfort sensation and their learning performance (Haverinen-Shaughnessy et al., 2015). Due to the complicated reasons of geographical characteristics, climatic factors, economic affordability, etc., cooling/heating and ventilation systems are generally lacking in the educational buildings of Southeast China. Although the climate of this area is relatively mild than it of North China, some extreme indoor thermal conditions are still inevitable because of the huge influence of outdoor thermal environments in the hot summer and cold winter, thus students feel uncomfortable occasionally. Therefore, the investigation on the status quo of students' thermal perception and thermal comfort in the naturally conditioned classrooms of Hot-summer and Cold-winter Climate Zone of China is necessary.

According to ISO Standard 7730 (CBCA, 2013), occupant's thermal comfort is defined as 'the condition of mind which expresses satisfaction with the thermal

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environment'. Although occupant's thermal comfort can be partially influenced by different cultural or psychological factors, this kind of comfort is primarily an effect of the heat exchange between the human body and the ambient environment (Olese et al., 2002). In most of the earlier studies, occupant's thermal sensation and satisfaction were obtained by questionnaires that we called it 'point-in-time' survey, which can reflect the exact body perception against the ambient thermal condition of that specific moment directly (Mishra et al., 2013; Wang et al., 2017; Zomorodian et al., 2016). It is worth noting that, in some of those researches, how the past thermal experience influenced the current thermal perception were rarely considered. In fact, due to the special learning process of university students, thermal experience becomes an indispensable impact factor on their thermal perception. In contrast to the office workers who are normally staying in a steady state environment with well air conditioning supply even for a whole day, students undertake a significantly different thermal experience in their study course per day. Namely, after a spatial transition between different rooms even buildings, they shift to a sedentary state by seating in the classrooms for 1~2 hours, with only 5~10 min relax break during their learning process. Hence, a better understanding of students' thermal perception as they adapting to the environment of classrooms is urgently needed.

Nowadays, more and more studies have focused on occupant's thermal responses which were mostly influenced by occupant's thermal experience. Thermal response to step-changed temperature has been studied by numerous researchers in climate chamber, where the physical parameters such as air temperature, humidity, etc. can be accurately controlled (Luo et al., 2015; Liu et al., 2014; Zhou et al., 2017, Xiong et al., 2015). It was found that by controlling the temperature climb up step by step in the climate chamber, a lower room temperature than the suggestion of EN 15251 (Indoor CEN, 2007) was more acceptable to the young people at the beginning period as they transited from outside into an internal space (Bourdakis et al., 2018). Overshoot phenomenon of human thermal sensation was also observed along with the increasing of the ambient temperature, and the variation of body sensation caused by cold stimulation was more intense than that caused by hot stimulation (Ji et al., 2017). In aforesaid context, physical conditions were manually operated to the target setting points, thus some set-up or set-down temperature changings stepped over even 3~5℃ within 1h, while this kind of situation can rarely be observed in the real buildings indoor environments, therefore field study is an essential supplement. Linear relationship between mean thermal sensation and operative temperature was observed in the temperature ramp research of the office buildings (Kolarik et al., 2017). From a certain point of view, the evaluation of thermal comfort depends on the history of the body exposure (Plama et al., 2015; Velt et al., 2017). For example, when entering a similar environment, the participants who previously experienced higher temperature reported a lower thermal sensation than those with cooler initial experience (Chun et al., 2008).

In particular, comparing with the physical parameters of air-conditioned environments, the physical parameters in naturally conditioned environments were generally influenced strongly by the outdoor environments (de Dear et al., 1997), whereas field studies on occupant's thermal experience in naturally conditioned environments are rare. Consequently, the objective of present study is to explore the relevance of thermal experience on students' thermal perception, to identify the suitable values of indoor thermal parameters, and provide guidelines for the improved design of indoor thermal conditions which can improve the thermal comfort of students in this climate area.

2. Materials and methods

A series of experience investigations were conducted in Zhejiang University City College(ZUCC) in Hangzhou, China (latitude 30° 16′ north and longitude 120° 12′ east), which is located in the hot summer-cold winter zone according to China's national standard (Ministry of Housing and Urban-Rural Development of PRC, 2016). A total of twelve normal lectures in daytime were selected as the experiment investigation groups in present field study, six lectures in summer (from 15. May to 8. June of 2017) and six lectures in winter (from 11. December of 2017 to 11. January of 2018). Each lecture was scheduled as 2×45 min with a 5 min break in between. Field measurements and 'point-in-time' questionnaire surveys were carried out simultaneously. The data were collected from 9 classrooms of 4 educational buildings, and all of the buildings were of a masonry structure with aluminium alloy single-layer windows. Each classroom (15m ×9m ×3.0m) can accommodate up to around 80 persons. All of these classrooms were under the natural conditions with no cooling/heating and ventilation systems, and located in the south orientation of the buildings, of which the indoor environments can reflect obvious fluctuations by gaining solar heat during the daytime. The investigation mainly observed that, how the thermal experience influenced the student's thermal perception and thermal comfort through the following process: collecting physical parameters alongside subjective surveys, then correlating objective and subjective results to get a conclusion.

Table 1. Instruments technical specifications

Parameters	Instrument/Sensor	Time interval	Range	Accuracy
Air temperature & Globe temperature	T-type thermocouple-GRAPHTEC Midi Logger GL220	1min.	0-50 ℃	±0.3 ℃
Relative humidity	Thermo Recorder TR-72Ui	1min.	10-95%RH	±5%
Air velocity	Hotwire Anemograph Testo 425	10sec.	0-20m/s	±0.03m/s+5%

2.1 The environmental measurements

Indoor thermal parameters as air temperature(T_a), globe temperature(T_g), relative humidity(RH) and air velocity(V_a) were measured in each classroom. The instruments which were summarized in **Table 1**, were located centrally and settled at a height of 1.1m above the floor as prescribed in ISO 7726 (ISO, 2012) in the classrooms. The indoor globe temperature was measured by using a T-type thermocouple installed within a black painted table tennis ball. The outdoor air temperature (T_{aout}) was measured by T-type thermocouple with Midi Logger GL220 which located in ZUCC campus. All of the instruments were calibrated regularly according to the manufacturer's instructions.

The ISO standards 7730 (CBCA, 2013) provided the design values for the standard of comfort, these values were determined from the operative temperature (T_{op}) in the school, thus T_{op} was used to quantify the thermal sensation as a thermal comfort index. The operative temperature (T_{op}) can be calculated as the follow Equation [1] which based on ASHRAE Handbook (ASHRAE, 2009). Where T_a is the air temperature (℃), T_{mr} is the mean radiant temperature (℃), A is selected from the following values as a function of the air velocity V_a (m/s), i.e., A equal to 0.5 as V_a < 0.2m/s, 0.6 as 0.2< V_a < 0.6m/s and 0.7 as 0.6< V_a < 1.0m/s, respectively.

$$T_{op} = AT_a + (1\text{-}A)\,T_{mr} \qquad [1]$$

The mean radiant temperature(T_{mr}) can be calculated as the follow Equation [2] from ISO 7726 (ISO, 2012). Where T_g is the black globe temperature (℃), V_a is the air velocity (m/s), T_a is the air temperature (℃).

$$T_{mr} = [(T_g + 273)^4 + 2.5 \times 10^8 \times V_a^{0.6}(T_g – T_a)]^{0.25} – 273 \qquad [2]$$

2.2 The experience survey

Thermal experience survey was continuously conducted during the whole process of 95 min in each lecture. It was assessed that people usually take about 15 min to calm down from the previous activity and adjust to a new thermal environment (Mishra et al., 2016a; Mishra et al., 2016b), then they get the possibility to respond to the current thermal environment accurately (Montazami et al., 2017). Hence, for the purpose of minimize the impact of the high activity rate which coursed by spatial transition, the first time point (Survey Time-A) for the experience survey was chosen as 15 min later of the lectures' beginning. Then the second time point (Survey Time-B) was at 45 min which before the 5 min break for rest, and the last time point (Survey Time-C) was at 95 min with the ending of the entire lecture. Therefore, the whole experience survey was separated into three periods, namely Period A, Period B and Period C, thus the students were requested to evaluate their thermal perception three times as the lecture was in progress. This survey time-line is presented in **Fig.1**.

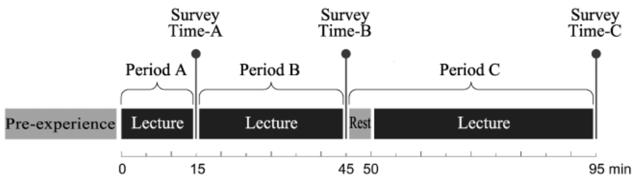

Fig. 1. Schedule of the thermal experience survey

A total of 601 questionnaires were distributed in the twelve lectures, missing or uncertain answers were disregarded, thus 587 participants successfully completed the entire experience procedure and returned the questionnaires as effectual, 311 students in summer and 276 students in winter. These responses included 313 male replies (53.3%) and 274 female replies (46.7%), who were all between the ages of 19 to 21, with an average age of 20.1 years. One week prior to each survey, students were briefed regarding the survey by their faculty that they would be expected to participate into an experience investigation and their participation was to be entirely voluntary, therefore all of the participants in present study provided their feedback as their consent. Questionnaires were disseminated before the beginning of each lecture, brief but clear explanation was given to ensure that the terminology of the questionnaire was comprehensible to the students. General information such as gender, age and clothing wearing were filled by students at this moment. The main contents of the clothing option in questionnaires are shown in **Table 2**. Students circled the option from this table to determine their clothing insulation (Icl), then an ensemble clo value in each group was calculated by summing individual clo values. Since the chairs in the classrooms are wooden, chair insulation was ignored in present field study. After a 15 min settled process at the beginning of the lecture, students were considered as performing sedentary activities through the following class duration, thus the metabolic rate(Met) value was assumed to be fixed at 1.0 Met (55W/m2). Both the values of clothing insulation, chair insulation and metabolic rate in present field study were based on ASHRAE Standard 55 (ASHRAE, 2017).

Table 2. Clothing Insulation (I_{cl}) Values

Summer clothing	(clo)	Winter clothing	(clo)
Garments ensembles	I_{cl}	Garments ensembles	I_{cl}
(1).Walking shorts, short-sleeve shirt	0.36	(1). Trousers, long-sleeve shirt	0.61
(2).Walking shorts, long-sleeve shirt	0.40	(2).(1) plus long-sleeve sweater	0.93
(3).Knee-length skirt, short-sleeve shirt	0.54	(3).(1) plus suit jacket	0.96
(4).Knee-length skirt, long-sleeve shirt	0.58	(4).(2) plus suit jacket, long underwear bottoms	1.30
(5).Trousers, short-sleeve shirt	0.57	(5). Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
(6).Trousers, long-sleeve shirt	0.61	(6).Insulated coveralls, long-sleeve thermal	
(7).Ankle-length skirt, short-sleeve shirt	0.57	underwear tops and bottoms	1.37
(8).Ankle-length skirt, long -sleeve shirt	0.61	(7).(1)~(5) plus overall	+0.30
(9).(1)~(8) plus short-sleeve knit shirt	+0.17	(8).(1)~(5) plus coverall	+0.49
(10). (1)~(8) plus long-sleeve knit shirt	+0.25		

There were mainly three subjective items to evaluate the on-site feeling of students' thermal perception, which were thermal sensation vote (TSV), thermal acceptability vote (TAV) and thermal preference vote (TPV). TSV was assessed through the 7-point ASHRAE scale ranging from -3(cold) to 3(hot) (ASHRAE, 2017). TAV was assessed as -1 (unacceptable) and 0(acceptable). TPV was assessed through the 3-point numerical scale as follows: -1 (want cooler), 0 (no change), 1(want warmer). The scale for each question is shown in **Table 3**.

Table 3. Clothing Insulation (I_{cl}) Values

Scale	TSV	TAV	TPV
3	Hot		
2	Warm		
1	Slightly warm		Warmer
0	Neutral	Acceptable	No change
-1	Slightly cool	Unacceptable	Cooler
-2	Cool		
-3	Cold		

3. Results and analysis

A total of twelve lectures were surveyed in this field study, six series in summer and the same in winter. Lectures numbering arrangement in summer (Ls1~Ls6) and winter (Lw1~Lw6) were all ranked in ascending order of the indoor air temperature (Ta) on Survey Time-A, which means that with the growth of the lectures serial number, the starting measurement points of indoor air temperature were getting warmer and warmer. IBM SPSS Statistics 22 was used for the statistical analysis in present study.

3.1 Gender comparison

Gender distribution of each lecture in summer (L_{s1}~L_{s6}) and in winter (L_{w1}~L_{w6}), and the p-values for the results of TSV, TVA and TPV between the male and female participants are shown in **Table 4**. No significant gender difference against these three thermal perceptions was found in all of the research groups, which indicated that thermal perception results were similar to being normally distributed against the gender factor in present field survey. Therefore, the subsequent analysis of the thermal perception will use mean values and standard deviation based on all of the samples.

Table 4. P-values for a gender difference in thermal perception votes

Lectures in summer	Gender: Male	Gender: Female	*P*: TSV	*P*: TAV	*P*: TPV
L_{s1}	38	19	0.7	0.81	0.19
L_{s2}	25	54	0.28	0.76	0.35
L_{s3}	14	30	0.45	0.67	0.31
L_{s4}	36	16	0.42	0.91	0.24
L_{s5}	22	29	0.58	0.36	0.52
L_{s6}	6	22	0.68	0.48	0.72
Total	141	170			
	311				

Lectures in winter	Gender: Male	Gender: Female	*P*: TSV	*P*: TAV	*P*: TPV
L_{w1}	23	4	0.34	0.39	0.11
L_{w2}	34	20	0.31	0.53	0.23
L_{w3}	33	10	0.35	0.68	0.14
L_{w4}	29	23	0.19	0.63	0.21
L_{w5}	12	30	0.25	0.31	0.25
L_{w6}	41	17	0.7	0.37	0.65
Total	172	104			
	276				

3.2 Environmental conditions

The ranges of values and the average values for various environmental parameters which obtained on the daytime (8:00~15:30 for indoor parameters) during the present field study are shown in **Table 5**, and the statistics of the environmental parameters for each survey group are summarized in **Table 6**. The results showed that ranges of the outdoor air temperature ($T_{a(out)}$), indoor air temperature (T_a) and indoor globe temperature (T_g), were all presented broader spans in summer than in winter. This is mainly because of that, the climate fluctuation from May to June was more complicated than the variation of it from December to January in Hangzhou, China.

3.2.1 Outdoor air temperatures

Many previous field studies used prevailing mean outdoor air temperature ($T_{pma(out)}$) as the outdoor air temperature value to evaluate the outdoor thermal conditions (Mishra et al., 2017; Jiao et al., 2017).

Table 5. Statistics of outdoor and indoor environmental parameters

	Outdoor			Indoor												
	$T_{a(out)}$(℃)			T_{op}(℃)			T_g(℃)			RH(%)			V(m/s)		
	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD
Summer	19.2	35.2	28.8 ±4.2	22.4	33.0	28.2 ±2.5	24.4	33.3	28.4 ±2.4	37	68	48.1 ±8.8	0.01	0.20	0.10 ±0.03
Winter	3.2	13.1	8.3 ±2.5	9.8	16.8	12.4 ±2.1	9.5	16.8	12.1 ±2.0	40	78	52.5 ±7.9	—	—	—

Table 6. Summary of outdoor and indoor environmental parameters

	Time		Outdoor	Indoor								
			$T_{ma(out)}$ (℃)	T_{op}(℃)			V(m/s)			RH(%)		
Summer	Date	Measurement Period	Mean ±SD	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD	Min.	Max.	Mean ±SD
L_{s1}	2017/5/15	8:00~9:35	20.2±0.6	24.4	26.8	25.4±0.8	0.01	0.13	0.11±0.04	42	59	49.8±2.7
L_{s2}	2017/5/22	8:00~9:35	23.5±0.8	25.3	27.8	26.7±0.9	0.01	0.15	0.08±0.03	41	50	44.6±2.0
L_{s3}	2017/5/18	9:50~11:25	28.3±0.5	26.1	28.1	27.2±0.5	0.01	0.15	0.13±0.02	37	46	43.2±2.1
L_{s4}	2017/6/2	13:30~15:05	30.2±0.7	27.3	29.3	28.3±0.7	0.01	0.12	0.05±0.03	58	68	63.2±1.6
L_{s5}	2017/5/29	13:30~15:05	31.1±0.5	29.1	30.2	29.6±0.3	0.01	0.20	0.09±0.07	40	44	42.2±1.7
L_{s6}	2017/6/8	10:40~12:15	34.9±0.6	31.0	33.0	31.9±0.6	0.01	0.18	0.14±0.06	35	40	38.5±1.3
Winter												
L_{w1}	2018/1/11	8:00~9:35	4.3±0.6	9.8	11.1	10.3±0.4	—	—	—	40	43	41.1±1.3
L_{w2}	2018/1/8	9:50~11:25	5.6±0.9	10.1	12.8	11.3±0.8	—	—	—	48	51	49.6±1.0
L_{w3}	2017/12/18	8:00~9:35	5.9±0.5	10.5	12.3	11.4±0.7	—	—	—	65	78	71.1±1.7
L_{w4}	2017/12/11	9:50~11:25	8.8±0.9	11.2	13.1	12.2±0.8	—	—	—	40	52	45.2±2.1
L_{w5}	2017/12/22	9:50~11:25	10.2±0.7	11.9	15.3	13.4±1.1	—	—	—	51	65	57.1±1.0
L_{w6}	2017/12/25	10:40~12:15	11.8±0.8	15.7	16.8	16.3±0.4	—	—	—	53	60	56.3±1.7

Prevailing mean outdoor air temperature is based on the arithmetic mean value of seven sequential days before the survey day and should be observed for 24 hours per day (ASHRAE, 2009). Nevertheless, the on-site outdoor temperature was a key factor to evaluate the thermal experience perception of students when they transferred from outside to the classrooms in present field study. Therefore, the mean outdoor air temperature ($T_{ma(out)}$) for each survey group was calculated out against the outdoor air temperatures ($T_{a(out)}$) that 2 hours before the beginning of the lecture. In present field study, all of the groups' mean outdoor air temperatures in summer were higher than the indoor air temperatures except L_{s1} and L_{s2}, whereas all of the mean outdoor air temperatures of six winter survey groups were lower than the indoor air temperatures.

3.2.2 Overview of thermal environmental

The present field study was carried out during the daytime in both summer and winter. Due to the functions of solar heating in the daytime, all of the variations on indoor operative temperatures in these twelve groups presented a climbing-up trend. Namely, for the three Survey Time of A, B, C as presented in **Fig.1**, the indoor operative temperatures climbed up step by step. As shown in **Table 6**, the variation ranges of the indoor operative temperature (ΔT_{op}) for all of the survey groups were 1.1~2.5 ℃ in summer, and 1.3~3.4℃ in winter. The maximum upward variation of this value was observed in L_{s2}(ΔT_{op} = 2.5 ℃) and L_{w5} (ΔT_{op} =3.4 ℃), respectively. The indoor globe temperatures(T_g) were extremely close to the operative temperatures(T_{op}) with a significantly high correlation coefficient as r=0.99 (p<0.001). No large differences were observed on the relative humidity (*RH*) in both summer and winter.

The indoor air velocities were with an average value of 0.10±0.03m/s in summer and approximately 0 m/s in winter. The reason is that, students were permitted to open or close the windows freely in progress of the survey, while they were reluctant to open it in winter for the cold inside condition. Hence the air velocity values are omitted in winter.

3.3 Clothing insulations

One of the key factors that influenced the clothing wearing of occupants was the outdoor air temperature (T_{aout}) (Schiavon et al., 2013), especially for the naturally conditioned indoor environment. Comparing with the indoor environment which can be controlled by air conditioning system, the condition of naturally conditioned classroom was generally out of control, which means that, the indoor temperature under this condition was affected by the outdoor air temperature directly. Students knew clearly of this harsh situation in hot summer and cold winter, so they usually adjusted their clothing by the meteorology forecasting before they went out of the dormitory, then they didn't readjust it anymore over the lecture duration. This kind of situation was totally different with some previous studies which focused on the adaptive behavior on occupants' thermal comfort. In those studies, occupants adapted to the unacceptable indoor environment by putting on or taking off clothing during the whole survey procedure, whereas in present field study, students kept no changing on their clothing during the lecture. The main reason of this phenomenon is that, they have no choice of changing their wearing: they generally wore lighter in summer to counteract the poor classroom condition of hot, thus they had no extra clothing to take off anymore. And they generally wore clothing as thick as possible in winter, to counteract the severe classroom condition of cold. Even if there were someone took another coat with them when they went out of the dormitory, they usually wore on it before they arrived at the classroom, for the outdoor temperature was colder than indoor, thus they had no extra clothing to put on anymore when they staying in the classroom.

As shown in **Table 7**, mean clothing insulation (I_{cl}) both in summer and winter were inversely proportional to the mean outdoor air temperature($T_{ma(out)}$). The value in summer had a significant correlation with the $T_{ma(out)}$ (r= -0.850, p<0.05), whereas weak correlation in winter was found (r= -0.683, p=0.135). This result indicated that students responded positively to the outdoor air temperature by changing their clothes during the entire six surveys in summer, while there were almost no changes of their clothes during the six surveys in winter. Related verification was also found in **Table 8**, that the variation of mean clothing insulation in summer (ΔI_{cl} = 0.22 clo) was obviously larger than it in winter (ΔI_{cl} = 0.04 clo). This was mainly resulted from that, the range of outdoor air temperature in summer (ΔT_{aout} = 14.7℃) was broader than it in winter (ΔT_{aout} = 7.5 ℃). More importantly, the indoor air temperature of classroom in winter was extremely cold, thus students predicted this severe situation by their prior experience, then wore almost all of clothes they could find to keep themselves warmer, whereas this kind of negligence on the changing of outdoor temperature was not found in present field study in summer.

Table 7. Correlation of the mean Icl and $T_{ma(out)}$

Items	r	*P*
Summer	-0.850	0.032
Winter	-0.683	0.135

Table 8. Statistics of clothing insulation (I_{cl})

Summer	I_{cl} (clo)			Winter	I_{cl} (clo)		
	Max.	Min.	Mean±SD		Max.	Min.	Mean±SD
L_{s1}	0.78	0.36	0.63±0.17	L_{w1}	1.79	1.3	1.43±0.21
L_{s2}	0.78	0.36	0.60±0.13	L_{w2}	1.79	1.3	1.43±0.18
L_{s3}	0.74	0.36	0.62±0.12	L_{w3}	1.79	1.26	1.40±0.16
L_{s4}	0.74	0.36	0.53±0.11	L_{w4}	1.79	1.3	1.42±0.13
L_{s5}	0.57	0.36	0.43±0.10	L_{w5}	1.67	1.26	1.41±0.13
L_{s6}	0.57	0.36	0.41±0.11	L_{w6}	1.79	1.1	1.39±0.21

3.4 The whole body thermal perception

Over each lecture duration, the thermal sensation vote (TSV), thermal acceptability vote (TAV) and thermal preference vote (TPV) were filled by students three times, to evaluated the variation of their whole body thermal perception.

3.4.1 Thermal sensation vote (TSV)

The comparing result of students' TSV between summer and winter is shown in **Fig.2** It illustrates that during the summer, 40.8% of the responses classified their thermal sensations as 'neutral' (TSV=0), and 51.7% voted for their thermal sensations from 'slightly warm' to 'hot' (TSV =1,2,3). And also, there were 7.5% of them voted their thermal sensations as 'slightly cool' (TSV = -1) and 'cool' (TSV = -2). The mean thermal sensation (MTS) of all responses in summer was 0.65, which was between 'neutral' and ' slightly warm', especially more inclined to 'slightly warm'. While in winter, TSV attained the peak value at 'slightly cool' (TSV = -1) with 36.2% of total responses, then 33.5% for 'cool' (TSV =-2) and 18.5% for 'cold'. Additionally, there were only 9.3% of responses voted for 'neutral'

(TSV=0) in winter, thus the MTS dropped to -1.56, which indicated that the students' feelings were more severe than 'slightly cool'.

These results presented that in winter of present field study, students' thermal sensations diverged from 'neutral' more obviously than in summer.

TSV' s experience results of the three survey period which corresponded with the survey timeline (**Fig.1**) are shown in **Fig.3.**

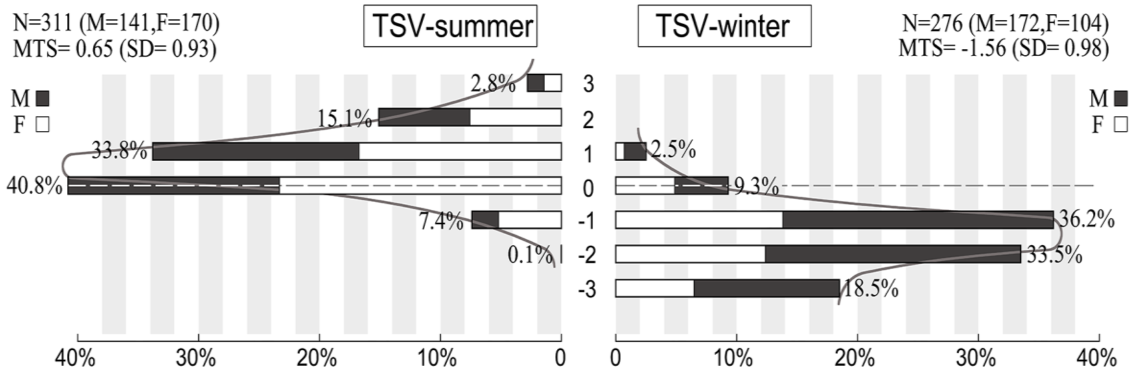

Fig. 2. Distributions of TSV in summer and winter

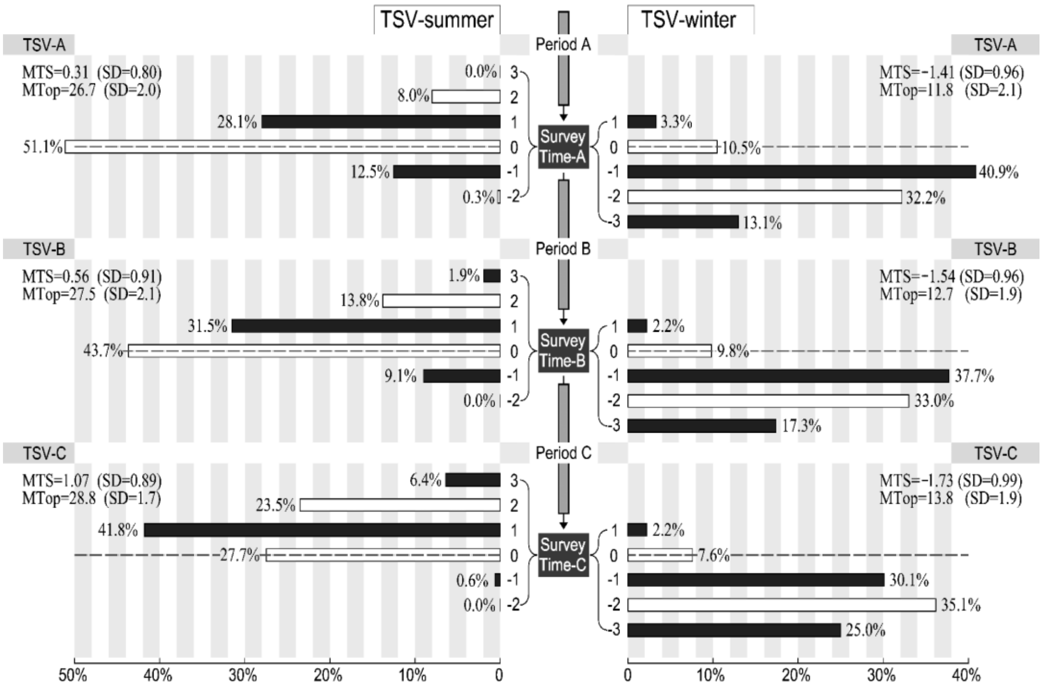

Fig. 3. Distributions of TSV in summer and winter against each survey period

In summer, the TSV for 'neutral' (TSV=0) declined from 51.1% to 43.7% firstly, then fell down to 27.7% on Survey Time-C. Meanwhile, responses for 'slightly warm' (TSV =1), 'warm' (TSV =2) and 'hot' (TSV =3) all presented a climbing up trend. Among them, the votes for 'slightly warm' (TSV =1) maintained a relatively higher level from 28.1% to 31.5%, then 41.8%, progressively. MTS in summer rose from 0.31 to 0.56, then reached at a peak of 1.07 on the last survey time. In winter, the highest level of TSV occurred in the voting for 'slightly cool' (TSV = -1) on Survey Time-A, then it declined from 40.9% to 37.7% firstly, then fell down to 30.1% on Survey Time-C. Meanwhile, responses for 'cool' (TSV = -2) and 'cold' (TSV = -3) increased rapidly in the following two survey times. MTS in winter decreased from -1.41 to -1.54, then touched the bottom with the value of -1.73, which indicated that students' thermal sensations in winter were getting worse as the time losing. It should be noted that, indoor temperatures were observed increased from Survey Time-A to Survey Time-C progressively in all twelve survey groups of summer and winter, which have been mentioned in Section 3.2.2.

(1). TSV in summer

The crosstab of three survey times on TSV and the six lectures in summer is presented in **Table 9.**

Table 9. TSV's distribution for each lectures in summer

summer	TSV-A					TSV-B					TSV-C				
	-2	-1	0	1	2	-1	0	1	2	3	-1	0	1	2	3
L_{s1}		15	38	4		14	38	5			1	34	17	5	
L_{s2}	1	22	47	9		14	48	17			1	26	38	14	
L_{s3}		1	35	7	1		27	16	1			18	23	2	1
L_{s4}		1	23	22	6		12	33	6	1		5	23	22	2
L_{s5}			16	25	10		11	24	14	2		3	29	12	7
L_{s6}				20	8			3	22	3				18	10
Total	1	39	159	87	25	28	136	98	43	6	2	86	130	73	20
Percentage	0.3%	12.5%	51.1%	28.1%	8.0%	9.1%	43.7%	31.5%	13.8%	1.9%	0.6%	27.7%	41.8%	23.5%	6.4%

It can be found that, vast majority of the students who classified their thermal sensations as 'slightly cool' (TSV = -1) and 'cool' (TSV = -2) assembled in L_{s1} and L_{s2}, while the votes were mainly occurred on Survey Time-A and Survey Time-B. From **Table 6**, it can be observed that both of these two lectures were held in the early morning, thus the indoor operative temperatures during Period A and Period B were under a relatively lower level (24.4~26.3℃) among all of the six survey durations. Similarly, most of the voting for 'hot' (TSV = 3) were occurred on Survey Time-B and Survey Time-C, which mainly assembled in L_{s5} and L_{s6}, for the temperatures during Period B and Period C were extremely high (30.2~33.0℃) in these two lectures. The general trend of TSV' s distribution in summer was correlated to the increasing temperature in progress of each lecture.

Depending on the increasing indoor operative temperatures, **Fig.4** illustrates how did PMV (predicted mean vote) and MTS change in summer. Where PMV was calculated by the combinations of the known six key parameters (T_a, T_{mr}, RH, V_a, Met and I_{cl}) that based on ASHRAE Standard 55 (ASHRAE, 2017). For each lecture, three values of PMV and MTS were calculated respectively on three consequent survey times. Meanwhile, three MTS in each lecture was connected by an dark dotted line, hence the thermal sensation trend of variation can be provided more clearly.

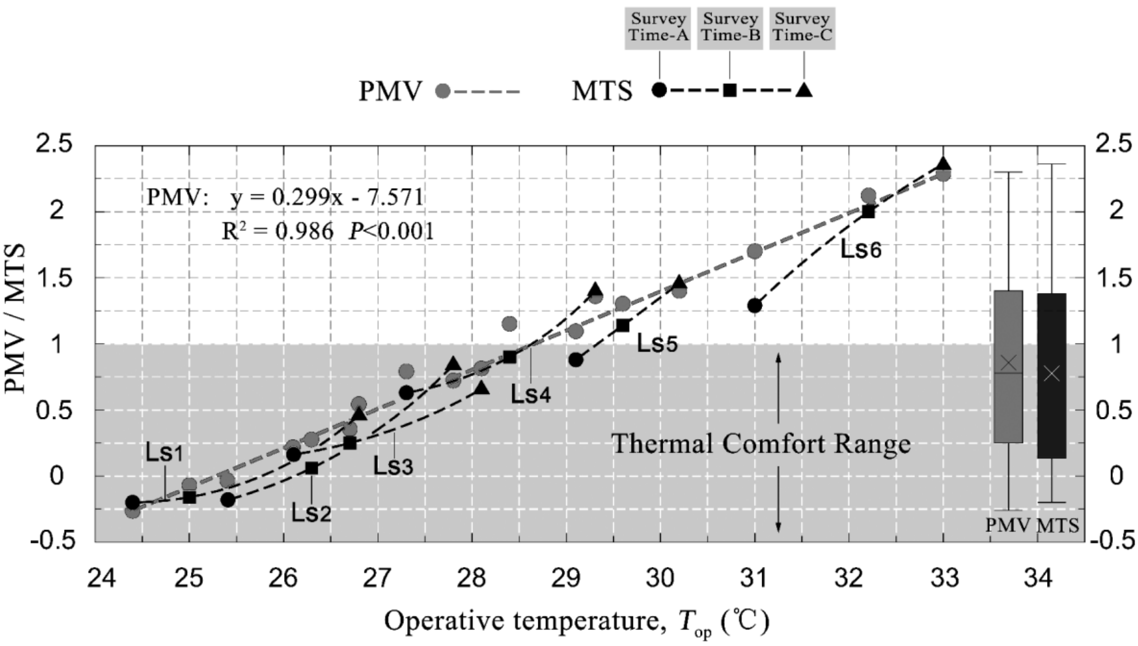

Fig. 4. PMV and variation of MTV as a function of T_{op} in summer

As shown in **Fig.4**, thermal sensation's variation of the six lectures were all correlated closely to the increasing indoor operative temperatures in summer. The first two MTS of L_{s1} and the first MTS of L_{s2} were below 'neutral' (-0.20 ≤ MTS ≤ -0.16), which mainly because of the lower outdoor and indoor temperatures in the early morning ($T_{a(out)}$ = 20.2~23.5℃, T_{op} = 24.4~25.4℃). While all of the other MTS were above 'neutral' (0.06≤ MTS ≤ 2.36). Among these MTS of L_{s3}~ L_{s6}, values on Survey Time-A and Survey Time-B were all below the corresponding PMV, which indicated that PMV tended to underestimate students' endurance against the hot environment in the prophase of each survey duration, for that students have adapted to a higher indoor temperature under the condition without air conditioning cooling system, and possessing a lower expectation for the thermal environments. This phenomenon also can be explained as a kind of psychological adaptability (Liang et al., 2012; Wang et al., 2017). Additionally, the factor of spatial transition between outside and inside should also be considered.

As shown in **Table 6**, outdoor temperatures of L_{s3}~ L_{s6} were all higher than indoor temperatures. Although students were given a 15 min sedentary time to settled down then regained their normal metabolic rates (Met), the experience of exposing under the previous higher temperature may also affect their thermal sensations on Survey Time-A even Survey Time-B, accordingly, confused students' response to the current temperatures. This can be supposed as another reason that why PMV were higher than MTS at the beginning of L_{s3}~ L_{s6}. We defined this phenomenon as the influence of a 'thermal memory' which will be discussed in **Section 4**. While at the end of all six survey durations, four of MTS climbed over the corresponding PMV on Survey Time-C (L_{s2}, L_{s4}~ L_{s6}), among which three of them (L_{s4} ~ L_{s6}) were under the condition of falling out of the thermal comfort range (MTS > 1) within higher temperatures (T_{op} = 29.3~33.0℃). According to China GB 50785 (Ministry of Housing and Urban-Rural Development of PRC, 2012), the suggested design value of the indoor temperature in summer is lower than 28 ℃. Thus it can be supposed that after a long thermal experience of high indoor temperature, especially when the thermal sensation was out of the thermal comfort range, students tended to be losing their endurance of the ambient temperature gradually.

Table 10. TSV's distribution in different survey time for each lectures in winter

Winter	TSV-A					TSV-B					TSV-C				
	-3	-2	-1	0	1	-3	-2	-1	0	1	-3	-2	-1	0	1
L_{w1}	10	9	7	1		12	9	6			22	5			
L_{w2}	7	19	23	3	2	10	19	20	5		14	20	17	3	
L_{w3}	6	19	15	2	1	10	16	16		1	14	18	11		
L_{w4}	11	11	20	9	1	12	18	14	8		15	24	8	5	
L_{w5}	2	14	18	6	2	4	15	21	1	1	4	18	19	1	
L_{w6}		17	30	8	3		14	27	13	4		12	28	12	6
Total	36	89	113	29	9	48	91	104	27	6	69	97	83	21	6
Percentage	13.1%	32.2%	40.9%	10.5%	3.3%	17.3%	33.0%	37.7%	9.8%	2.2%	25.0%	35.1%	30.1%	7.6%	2.2%

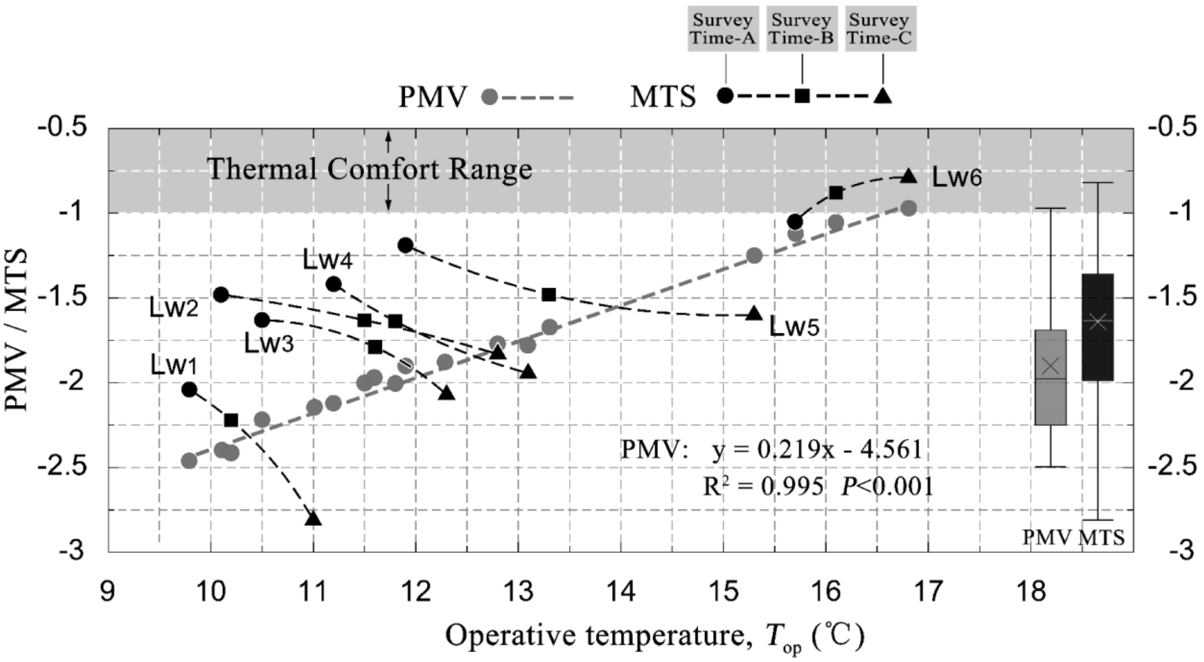

Fig. 5. PMV and variation of MTV as a function of T_{op} in winter

(2). TSV in winter

The crosstab of three survey times on TSV and the six lectures in winter is presented in Table 10. All of the responses voted for 'cold' (TSV= -3) except responses in L_{w6}, which intimated that the indoor thermal environments in L_{w1}~L_{w5} were severe. In particular, these voting for 'cold' increased gradually from Survey Time-A to Survey Time-C in all of the five lectures, while the voting for 'neutral' (TSV=0) and 'slightly warm' (TSV=1) declined significantly on Survey Time-B and Survey Time-C, even though the temperatures were all increased in the class durations. The distribution of TSV in winter was not so regular than it in summer, the variation trends of TSV in winter were diametrically opposed between L_{w1}~L_{w5} and L_{w6}.

As shown in **Fig.5**, except L_{w6}, all of the five variation trends of MTS in winter exhibited an illogical declined slope depending on the increasing temperatures, while L_{w6} was the only sample that the sensation's variation was correlated to the variation of temperatures as normal. Furthermore, although the first MTS of L_{w1} was around 'cool' (MTS= -2.04), the first MTS of L_{w2}~L_{w5} were between 'slightly cool' to 'cool' (-1.42≤ MTS ≤ -1.63), all of these five MTS were far beyond the corresponding PMV. For the second MTS of L_{w1}~L_{w5}, they were still higher the corresponding PMV even though these five values all fell down obviously. As time progressed, they sank down below the regression line of PMV at the end of the survey duration eventually. Additionally, the last MTS of L_{w1} almost touched the lowest limit of thermal sensation (MTS= -2.80), which scattered down far away from the corresponding PMV.

It can be observed that, these five lectures (L_{w1} ~ L_{w5}) which occurred the negative-correlation phenomenon were all conducted under a relatively low level of temperature. According to China GB 50785 (Ministry of Housing and Urban-Rural Development of PRC, 2012), the lowest limit thermal condition of physiology for human body is 12 ℃, while the design value of indoor temperature is recommended as higher than 18 ℃. For present field survey in winter, these five lectures were all conducted below 15.3℃, while all of them were started under the temperatures which were below 12 ℃ — the lowest limit of the physiology endurance for human body. Although MTS on Survey Time-A and Survey Time-B were all keeping above the regression line of PMV, they fell out of the thermal comfort range (MTS < 1) entirely, thus the thermal experience of prolonged exposure in this kind of severe cold condition impacted on the thermal sensation incessantly in progress of the survey duration. Accordingly, under the condition of a sedentary state in this kind of indoor environment, thermal experience which based on the time factor became the determining factor that affected the thermal sensation significantly, whereas the on-site indoor temperature lost the control of the thermal sensation gradually, for the rising of merely 2~3℃ can't warm the cold body up entirely. It can be supposed that, during the prophase of these five lectures, students had possessed enough endurance to the cold environment, until this severe condition's continuance pushed their thermal sensations fell down into the gorge finally. The only sample which the variation of MTS correlated closely to the rising temperatures was L_{w6}. Apparently, thermal sensations responded the on-site temperatures promptly as the starting indoor temperature of Lw6 was higher enough than other samples. Although temperatures didn't touch the winter limit design value of 18 ℃, most of the MTS in Lw6 were within the thermal comfort range.

In addition, as shown in **Table 6**, outdoor temperatures were all lower than indoor temperatures within all of the six survey groups in winter. It can be supposed that, the experience of exposing under the previous lower temperature affected students' thermal sensation on the beginning of the lectures, that when they entered a new environment which was better than before, the thermal sensation gave more rewards back.

3.4.2 Relationship of TSV, TAV and TPV

Relationship between TSV, TAV and TPV in both summer and winter is presented in **Table 11**. In summer, when students voted for 'hot' (TSV=3) and 'cool' (TSV= -2), all of them expressed that the thermal conditions were 'unacceptable' (TAV=-1) and preferred a 'colder' (TPV= -1) or 'warmer' (TPV=1) temperature, respectively. While when students classified their thermal sensations from 'slightly cool' to 'warm' (TSV= -1, 0, 1, 2), 68.2% of the total responses expressed that the thermal conditions were 'acceptable' (TAV=0), whereas there were only 48.0% of them preferred 'no change' (TPV=0). In winter, all of the responses for 'cold' (TSV= -3) voted for 'unacceptable' (TAV=-1) of thermal conditions and preferred a 'warmer' (TPV=1) temperature. While when students classified their thermal sensations from 'cool' to 'slightly warm' (TSV= -2, -1, 0, 1), 44.6% of the total responses expressed that the thermal conditions were 'acceptable' (TAV=0), whereas there were only 25.2% of them preferred 'no change' (TPV=0). Moreover, the percentage of thermal acceptability in summer (68.2%) was higher than it in winter (44.6%), while the percentage of thermal preference of no change in summer (48.9%) was also higher evidently than it in winter (25.2%). (de Dear et al., 2001) suggested that the 'neutral' voting of TSV was not always considered as the preferred condition. Similar results were also found in other researches (Damiati et al., 2016, Humphreys et al., 2007).

Distributions of TSV, TAV and TPV in process of the three survey times in summer and winter are shown in **Fig.6** and **Fig.7**, respectively. Each scale (-3,-2,-

1,0,1,2,3) of TSV consists of two voting tendencies: the dark columnar in **Fig.6** and **Fig.7** denote the track for ‘unacceptable’ (TAV= -1) in summer and winter, respectively. While the vacant columnar denotes the track for ‘acceptable’ (TAV= 0) in both of the two seasons. As shown in **Fig.6**, within the thermal comfort range of TSV from ‘slightly cool’ to ‘slightly warm’ (TSV= -1,0,1). The proportion of students who voted for ‘acceptable’ (TAV=0) were all higher than ‘unacceptable’ (TAV= -1). In contrast, when TSV were out of thermal comfort range (TSV< -1 or TSV> 1), the tendencies of their thermal acceptability reversed entirely, and the ‘unacceptable’ trend increased rapidly from Survey Time-A to Survey Time-C. The same results were also presented in winter as shown in **Fig.7**.

Table 11. The crosstab of TSV, TAV and TPV

TSV	Summer					Winter			
	TAV		TPV			TAV		TPV	
	-1	0	-1	0	1	-1	0	0	1
3	2.8%	—	2.8%	—	—	—	—	—	—
2	13.5%	1.6%	14.6%	0.5%	—	—	—	—	—
1	13.5%	20.2%	25.2%	8.5%	—	0.2%	2.3%	2.5%	—
0	1.0%	39.9%	7.0%	33.9%	—	1.0%	8.3%	7.7%	1.6%
-1	0.9%	6.5%	—	5.1%	2.3%	13.2%	23.1%	11.7%	24.6%
-2	0.1%	—	—	—	0.1%	22.6%	10.9%	3.3%	30.2%
-3	—	—	—	—	—	18.4%	—	—	18.4%
Total	31.8%	68.2%	49.6%	48.0%	2.4%	55.4%	44.6%	25.2%	74.8%
	100%		100%			100%		100%	

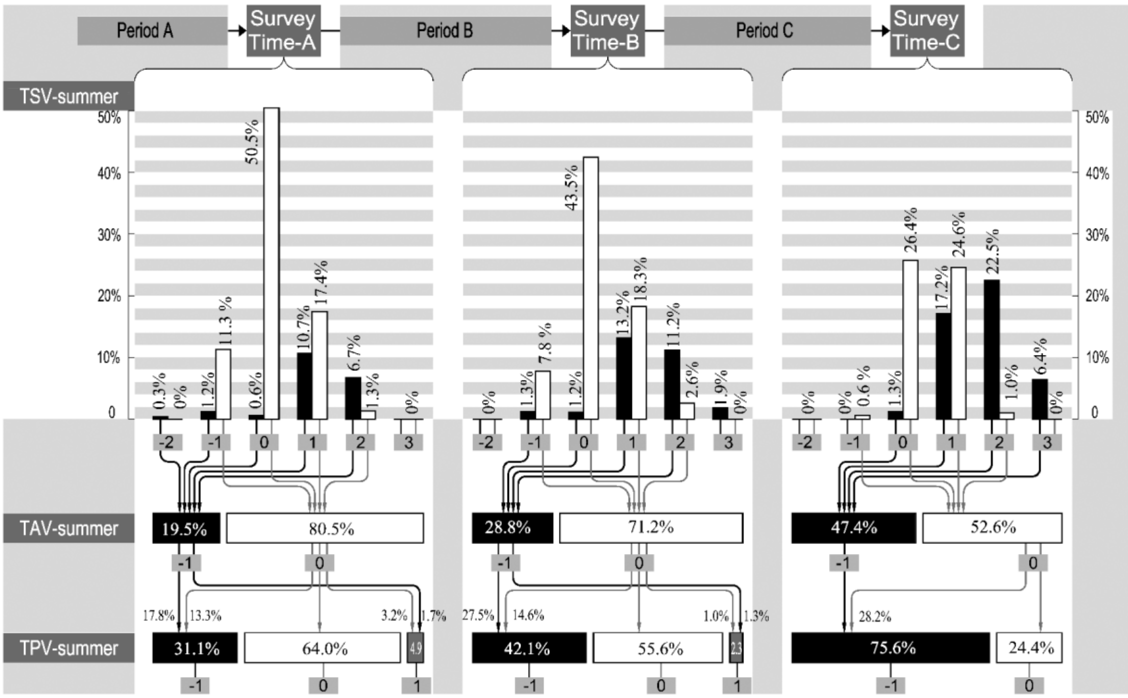

Fig. 6. Distributions of TSV, TAV and TPV in summer

This result is coincided with the common sense of that, when students’ thermal sensations are within the thermal comfort range (TSV= -1, 0, 1), the thermal environments are more acceptable. Furthermore, there were still some differences of TAV between summer and winter. Although the tendency to ‘unacceptable’ (TAV= -1) rose up progressively in both of the two seasons, the maximum proportion of it in summer was merely 47.4% on Survey Time-C, which indicated that even until the end of the survey duration, more than half of the students accepted the thermal condition. Whereas in winter, TAV expressed a strongly unwilling proportion with 45.3% from the beginning of the survey, then more than half of students (52.6%) couldn’t accept the thermal condition in the middle of the survey duration, finally this proportion climbed up to 68.2% on Survey Time-C. This result can be considered as a proof of that, in present field study, the indoor thermal conditions in winter were more severe than the conditions in summer, thus more students couldn’t endure them. there were also some of them preferred ‘change’. In summer, there were a small proportion of students because of that their TSV were within ‘cool’ and ‘slightly cool’ (TSV= -2, -1). The rest of voting for ‘change’ were all preferred to ‘cold’ (TPV= -1), and the proportion of these voting rising up from 31.1% to 42.1%, then finished with 75.6% eventually. In winter, no students preferred to ‘cold’, while there were more than half of proportion (58.3%) preferred ‘warm’ (TPV= 1) on the beginning of survey, then this proportion accelerated its increasing trend from 76.8% to 89.1% in the following survey duration, which indicated that students strongly wanted to change the extremely cold ambient environment in winter.

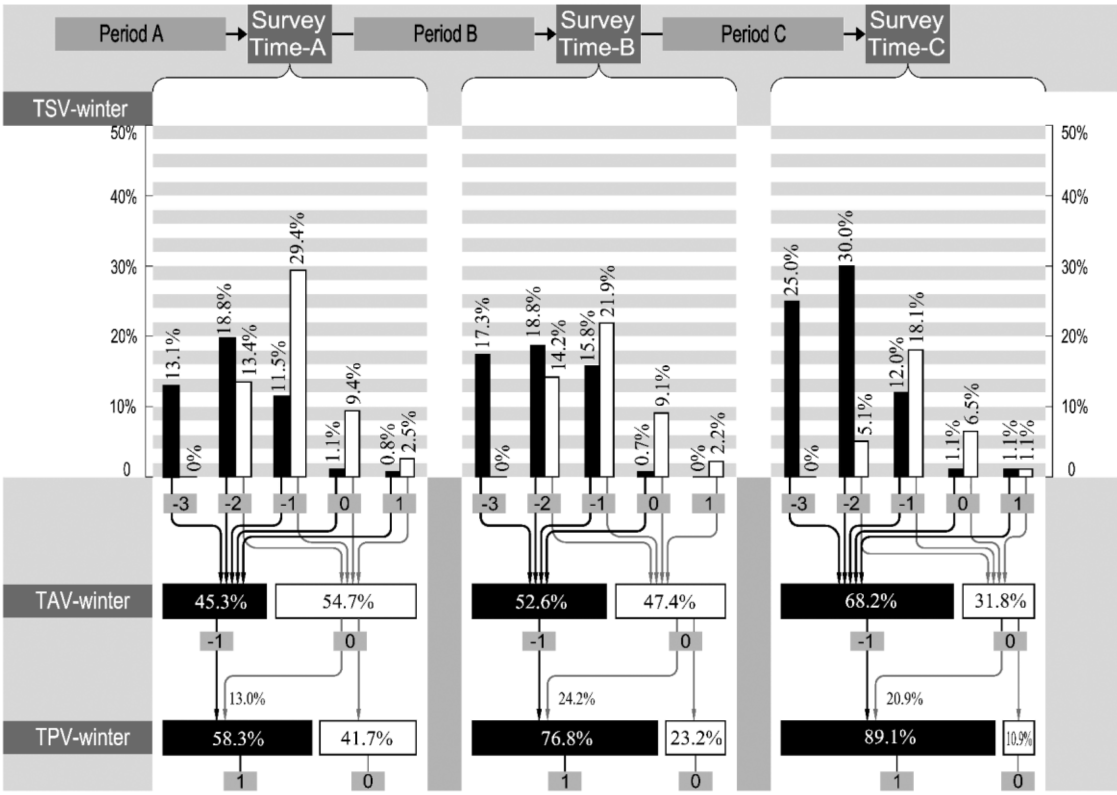

Fig. 7. Distributions of TSV, TAV and TPV in winter

4. Discussions

4.1 The variation of the thermal sensations under comparison

In present field study, significant difference on thermal sensations’ variation was observed between the experience survey in summer and winter. In summer, variation of thermal sensations correlated closely to the rising indoor operative temperatures. While in winter, negative-correlation phenomenon occurred in five independent survey durations (L_{w1} ~ L_{w5}) when indoor operative temperatures were within the range of 9.8~15.3℃ (**Fig.5**).

By excluding the orange dotted lines which connected the MTS points in **Fig.4** and **Fig.5**, and classify the thermal sensation results from the three survey times (Survey Time-A, B, C), the overall correlations of MTS and indoor operative temperatures in summer and winter are provided in **Table 12**. Part I presents the correlations in each of the three survey times, hence the number of calculations MTS are all 6 for each group. Part II presents the gradually accumulated correlations from Survey Time-A to Survey Time-C, hence the number of calculations MTS increases by degrees of 6 each time. The r-values in Part I pertain to the on-site thermal sensation of each survey period (Period A, B, C) for all of the participants, thus there is no interrelation of the values between each other. While the r-values in Part II represent an interrelation of successive survey periods and the overall correlations trend for all of the responses.

It can be observed that in summer, no matter in Part I or Part II, MTS showed high correlations with indoor operative temperatures significantly (0.973< r < 0.990, P <= 0.001), especially as time progressed in Part II, the correlations still maintained on a high level. While in winter, significant difference was presented between Part I and Part II. In Part I, high level of correlations occurred on Survey Time-B (r = 0.959, P = 0.002) and Survey Time-C (r = 0.951, P = 0.004), and this value on Survey Time-A (r = 0.817, P = 0.047) was also highly enough to be considered as an intimate correlation, although it was lower than the followed values of the other two. However, the variation trend of the correlations slid down gradually in Part II, and as the times losing, correlation ended with the value of r = 0.680 (P = 0.002) finally, which was pretty low by comparing with the result in summer. It should be noted that, the positive-correlation results (r -values) of Part I in winter (**Table 12**) should be distinguished from the negative-correlation phenomenon which was observed in the five independent survey durations (L_{w1} ~ L_{w5}) in **Fig.5**. For the result of Part I was concluded by collecting all of the six lectures' MTS on the three certain survey times, respectively. This result indicated that for different groups of participants, their total thermal sensations can correspond clearly with the temperatures in each survey period (Period A, B, C), whereas these thermal sensations and temperatures were entirely cut off from the consecutive experience for the certain group of participants, consecutive survey time and consecutive variation of indoor temperatures. From this perspective, the negative-correlation phenomenon which was observed from certain group of participants is more representative and meaningful to this thermal experience survey. Meanwhile, the downward trend of r -values (Survey Time $_A$~ Survey Time $_{A+B+C}$) from Part II in winter, demonstrated that this trend was mainly resulted from the accumulation of independent negative-correlation of L_{w1} ~ L_{w5}.

Table 12. Overall correlations of MTS and T_{op}

	Summer	*Number of MTS*	*r*	*p*	Winter	*Number of MTS*	*r*	*p*
Part I	Survey Time $_A$	6	0.973	0.001	Survey Time $_A$	6	0.817	0.047
	Survey Time $_B$	6	0.990	<0.001	Survey Time $_B$	6	0.959	0.002
	Survey Time $_C$	6	0.978	0.001	Survey Time $_C$	6	0.951	0.004
Part II	Survey Time $_A$	6	0.973	0.001	Survey Time $_A$	6	0.817	0.047
	Survey Time $_{A+B}$	12	0.977	<0.001	Survey Time $_{A+B}$	12	0.811	0.001
	Survey Time $_{A+B+C}$	18	0.974	<0.001	Survey Time $_{A+B+C}$	18	0.680	0.002

4.2 The function of 'thermal memory' on thermal sensations

The occurrence of negative-correlation phenomenon in present field study is unanticipated, which means that in progress of the survey duration, on-site indoor temperatures lost their control of students' thermal sensations. It can be conjectured that, this negative-correlation phenomenon only accompanied by the occurrence of the severe cold thermal conditions. Collins (Collins et al., 1981) indicated that indoor air temperatures below 15 ℃ negatively affect health by increasing the burden on the body circulatory system. Many previous researches also mentioned about that, human organs maintain their collaborative work when the circulatory system is under a proper function. In winter, due to the continuous low temperature in the classrooms, for that students all performed sedentary state in the whole survey duration, the blood circling dropped down gradually, especially for their body bottoms, e.g. hands and feet. Prolonged exposure of their body to a cold condition resulted their insensitive responses to the on-site temperature, even that the temperature was climbing up about 2~3℃. Similar results were also observed in Florida (Manasrah et al., 2016), that after having sat in classroom through an hour, students could not distinguish between temperature conditions different by 2℃.

Then question comes as follow—who played the key role in affecting the thermal sensation when the on-site temperature lost effectiveness gradually? We suppose that a kind of 'thermal memory' which depended on the previous thermal experience will be responsible for human's current thermal sensation. The worse the thermal condition, the stronger the function of 'thermal memory'. As shown in **Fig.5**, the five lectures (L_{w1} ~ L_{w5}) which occurred the negative-correlation phenomenon were all out of 'thermal comfort range', thus the extremely cold temperatures delayed students' response to current thermal conditions. 'Thermal memory' won't stop working on thermal sensation unless the indoor temperature is drawn back to a normal level which can warm the human bodies up until they recover their normal function. Then step by step, thermal sensation is reawakened to respond the on-site temperature opportunely again.

'Thermal memory' also played a key role when thermal condition suddenly changed. In present field study, when students entered the classroom where the indoor temperature was relatively lower than outside temperature in summer, or relatively higher than outside temperature in winter, their thermal sensations improved by comparing the different thermal conditions through ‘thermal memory’, which means that the previous thermal experience ‘deceived’ the current thermal sensation and gave the body an imaginary signal. The more severe the thermal condition, the more obvious the gap between the real thermal sensation and PMV. That’s the reason why MTS of L_{s5} and L_{s6} on Survey Time-A were both far below the corresponding PMV as **Fig.4** illustrates, and why MTS of L_{w1}~ L_{w5} on Survey Time-A were all beyond the corresponding PMV as **Fig.5** illustrates. Additionally, although the five MTS in winter were significantly higher than PMV, the values were all below -1. In other words, the thermal experience for the students of these five lectures were poor from the beginning. We therefore believe that, holding indoor temperature on a normal lever from the initial time of the lecture, can stop or delay the following phenomenon of negative-correlation in winter. Due to the illustration of L_{w6} in **Fig.5**, indoor temperature around 15.7℃ can be assumed as the minimum which can guarantee students to possess normal response against the ambient environment in naturally conditioned classrooms.

4.3 The interrelation of TSV, TAV and TPV

As seen in **Section 3.4.2**, TSV, TAV and TPV were observed unsynchronized in both summer and winter in presented field study, especially in winter. That means that even when participants voted for the thermal condition as ‘acceptable’ (TAV=0), there were still some of them preferred ‘change’ (TPV= -1) the current thermal condition. Depending on the high proportion of TSV which within the thermal comfort range (TSV= -1,0,1) in summer, the variation of students’ TAV and TPV corresponded with the TSV more closely than in winter. The high proportion of ‘unacceptable’ (TAV= -1) and preferred to ‘change’ (TPV=1) in winter, just corresponded with the suppose as before, that although students had tried to endure the extremely cold indoor condition, they strongly want to change it.

5. Conclusions

(1) Both the current feelings and the feelings of the past thermal experience can affect the evaluation of thermal sensation. And which one will play a key role in this evaluation will depend on whether the thermal condition is holding in a normal level. In present field study, current feelings worked on the thermal sensations most of the time in summer, while thermal experience replaced current feelings and affected the thermal sensations as the surveys were in progress in winter.

(2) Thermal memory will make impact on the thermal sensation as the on-site temperatures lose their control of current thermal sensation gradually, especially under the extremely cold thermal conditions (9.8~15.3℃) when students are all preforming sedentary state in naturally conditioned classrooms.

(3) Under the severe cold thermal condition, the ‘negative-correlation phenomenon’ will occur, and the downtrend of thermal sensation will be accumulated continuously until the thermal condition is drawn back to a normal level progressively.

(4) At the beginning of the lecture in winter, holding the indoor temperature on a level upon 15.7℃, which is around 2℃ lower than the recommended value of Indoor Thermal Evaluation Standard of China, can promote students’ thermal sensations stepping into a virtuous cycle and feel more comfortable.

(5) TSV, TAV and TPV are unsynchronized in both summer and winter, and the more severe the indoor thermal condition is, the more obviously the unsynchronized phenomenon presents.

Efforts on improving the indoor thermal condition of educational buildings in Hot-summer and Cold-winter Climate Zone of China is urgently. Thermal experience should be considered as an essential impact factor on students’ thermal comfort. The results of present study can provide a guideline for evaluating the indoor thermal environment and a target for improving the students’ thermal comfort of educational buildings in this climate area.

Acknowledgements

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Symbol and abbreviations

I_{cl}	Clothing insulation
Met	Metabolic rate
MTS	Mean thermal sensation vote
p	Probability
r	Correlation coefficient
RH	Relative humidity
SD	Standard deviation
T_a	Indoor air temperature
T_g	Globle temperature
T_{mr}	Mean radiant temperature
T_{op}	Operative temperature
$T_{outdoor}$	Outdoor temperature
$T_{pma(out)}$	Prevailing mean outdoor air temperature
ΔT_{op}	Change of operative temperature
$\Delta T_{outdoor}$	Change of outside temperature
TAV	Thermal acceptability vote
TPV	Thermal preference vote
TSV	Thermal sensation vote
V_a	Air velocity