Influence of Physical Environment of Learning Space on Comfort and Emotional Perception in Severe Cold City in Winter

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***Abstract*—The cold winter in severe cold area is long, and the heating period is about 6 months. People spend more than half a year in a closed room, so the study of learning space comfort is particularly important. Learning space is the main place for students' daily learning and life. Its physical environment affects users ' comfort and emotional perception. In order to explore the in-fluence of physical environment on human comfort and emotion in winter of learning space in severe cold cities, and the relationship between different indoor environment comfort and human emotion, therefore, this study investigated the change range of temperature, illumination and sound pressure level of learning space, and selected 27 different environmental conditions for controlled indoor environment experiments. The results show that, temperature has significant influence on thermal comfort, acoustic comfort and visual comfort, and people will feel more comfortable in neutral temperature environment. Sound pressure level has significant influence on acoustic comfort and visual comfort, which are better in quiet environment. Illumination only has a significant impact on visual comfort, and visual comfort is poor in too bright environments. The overall environmental com-fort is affected by thermal environment, acoustic environment and luminous environment, and the overall environment is the most comfortable at 22 ℃, 35 dBA and 100 lux. Emotional perception is affected by three physical environmental factors, and has a significant relationship with environmental comfort. In a comfortable experimental environment, the perception of positive emotion is more obvious, and in an uncomfortable environment, the perception of negative emotion is more obvious.**

***Keywords*—physical environment, comfort perception, emotion perception**

I. Introduction

Studies have shown that places where learning activities occur are called learning spaces, which are divided into formal, informal and virtual learning spaces [1]. This paper mainly studies the indoor space of the main activities of college students, namely the formal learning space such as classrooms and reading rooms on campus. The indoor physical environment mainly includes thermal environment, acoustic environment and luminous environment, which affect the overall indoor environment quality (IEQ), and the indoor environment quality has an important impact on people. And due to the climatic characteristics of Harbin, the outdoor temperature is extremely low in winter, and students will choose to stay indoor for a long time. Therefore, it is very important to study the physical environment of learning space in cold severe cities in winter.

In the indoor environment, physical environment factors are never independent. People' s perception of indoor physical environment is realized by mutual stimulation between various feelings [2]. In the study, different physical environments should be considered comprehensively. Li H. et al. [3] studied the in-fluence of acoustic environment, luminous environment and thermal environment on the comprehensive comfort of office space, and found that the thermal environment and acoustic environment have one-vote veto power on the overall comfort. Hangzi W. et al. [4] studied the combined effects of thermal, acoustic and visual comfort in open spaces, and found that there are interactions between different physical environments. At the same time, studies have shown that in-door physical environment has an important impact on people ' s emotions and mental health [5].

Although there are many studies on indoor environment, there are few studies on the influence of physical environment comfort and emotional perception in learning space. This paper studies people' s environmental perception and emotional perception in different physical environments, and provides guidance for future physical environment control in learning space.

II. Methods

A. Experimental Environment and Instruments

Multiple environmental parameters need to be measured in, and the selected instruments and corresponding measurement parameters are shown in Table I. The experiment is carried out in the audiometric room of Harbin Institute of Technology. The audiometric

Manuscript received November 1, 2022; revised November 25, 2022; accepted December 12, 2022.

doi: 10.18178/ijscer.12.1.13-19

room is an acoustic laboratory established for language and hearing tests, and the background noise is 11 dB. The whole room does not have a window, and the door is also very good in sealing, which avoids the interference of air flow with the outside world while isolating the noise from the outside. The floor plan of the room is shown in Fig. 1. The thermal environment is regulated and controlled by air conditioning. The sound source of the acoustic environment uses the audio collected in the real learning space, and uses the speaker to play the audio and control the sound pressure level. The spectrum of the noise is shown in Fig. 2. The luminous environment mainly achieves or approaches the expected light conditions by installing fluorescent lamps in the room. And color temperature of fluorescent lamp is 4000K. In the experiment, the relative humidity is monitored in real time by humidity meter, and the relative humidity is controlled at 38 % (±5%) by air conditioning and humidifier. The instrument in Table I is used to monitor the environment in real time. The thermal environment and acoustic environment detection point is 1.2 meters away from the ground, and the luminous environment detection point is located in the working face. The experimental site is shown in Fig. 3.

TABLE I. CHARACTERISTIC PARAMETERS OF EXPERIMENTAL INSTRUMENTS.

Parameters	Instrument	Range	Precision
Air velocity	Kestrel 5500 weather meter	0.4-40.0m/s	±0.1m/s
Globe temperature	BES-01 temperature acquisition recorder	−30-+50℃	±0.5℃
Air temperature Relative humidity	BES-02 temperature and humidity recorder	−30-+50℃ 0%-99% RH	±0.5℃ ±3% RH
Illumination intensity	TES1332A illuminometer	0.1-200000Lux	±3%
equivalent continuous sound level A	BSWA801 noise vibration analyzer	19dB(A)~137dB(A) 24dB(C)~137dB (C)	±0.7dB
Heart rate, Blood pressure	OMRON-T10 blood pressure instrument	0-299mmHg 40-180 times/min	± 3mmHg ±5%

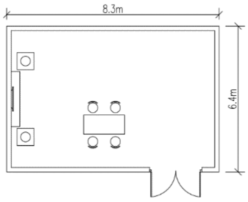


Figure 1. The floor plan of the room

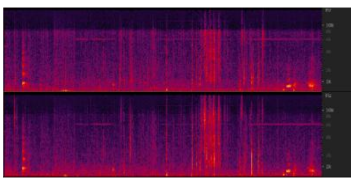


Figure 2. The spectrum of the noise

Figure 3. Photos of the experimental site

B. *Experimental Conditions*

In order to make the conditions of the experimental environment more in line with the actual situation, the physical environment parameters of the typical learning places on Harbin university campus, namely the library and the teaching building, were measured during the winter heating in 2021. The measured data were selected from 08 : 00 to 20 : 00 on November 17, 2021. In order to test the difference of illumination in different directions and different learning spaces, the measurement was carried out in the classrooms in the south and north directions, and the reading rooms of the library.

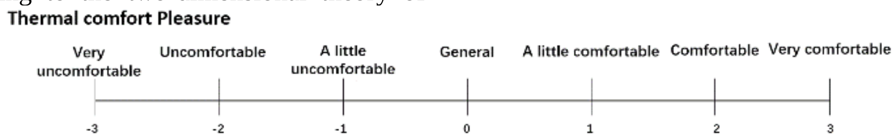
The instruments in Table I are selected to measure the thermal environment, acoustic environment and luminous environment of the measuring points. The thermal environment parameters are recorded by the instrument every minute. The operation of luminous environment and acoustic environment measurement is to record the illumination of working face and equivalent continuous sound level A every half hour, the integration time is set to 1 minute and three values are measured each time.

The measured air temperature ranges from 17.78 ℃ to 25.67 ℃, and the globe temperature ranges from 18.08 ℃ to 26.59 ℃. According to GB 50736' Design code for heating ventilation and air conditioning of civil buildings' [6], the heating design temperature of main rooms in cold and severe cold areas should be 18-24 ℃ And Seppanen et al. [7] found that people get the highest job performance at 22 ℃. Combined with research results, the temperature parameters of 18 ℃, 22 ℃ and 26 ℃ are used as the temperature conditions of partial cold, neutral and partial heat. The measured range of continuous equivalent A sound level is 34.80 dBA-57.60 dBA. In ordinary classrooms, the overall environment is relatively quiet due to the closed learning space. But, in the open learning environment of the library, the learning environment is relatively free, and the learning forms are various, so people will be more relaxed. At the same time, the elevator will also produce some noise, and the sound pressure level in this environment is relatively large. According to the ' Code for design of sound insulation of civil buildings s ' GB50118-2010[8], the allowable noise level of reading room is40dB, and the allowable noise level of ordinary classroom is45dB. Combining the measured values with the standard the sound pressure level parameters of 35 dBA, 45 dBA and 55 dBA are used as the sound conditions of partial quiet, neutral and partial sound. The range of illuminance is 90lux-353lux. The reason for the difference in illuminance is that the outdoor environment is relatively bright at dawn, which will provide better lighting for the indoor environment. However, in the evening, the indoor illumination will be lower than that in the daytime only by artificial lighting. The range of illuminance is 90lux-353lux. According to the provisions of ‘Standard for lighting design of buildings’ GB 50034 – 2013 [9], the standard value of illumination of educational building working face is in the range of 300lux–500lux, indicating that the measured illumination is slightly dark and does not meet the specification requirements. Combining the measured values with the standard the illuminance parameters of 100 lux, 300 lux and 500 lux are used as the dark, neutral and partial illumination conditions.

C. Questionnaire Surveys

A questionnaire survey was conducted to evaluate the environmental comfort under different physical environments, including thermal comfort, acoustic com-fort, visual comfort, overall environmental comfort. The subjective comfort indexes of each environment are evaluated using the Likert 7 scale, as shown in Fig. 4 (a).

Chinese scholars divided academic emotions into four categories according to the two-dimensional theory of emotions in the study of academic emotions : positive-high arousal emotions (happiness, pleasure, pride, etc.), positive-low arousal emotions (relaxation, calmness, etc.), negative-high arousal emotions (anger, anxiety, shame, etc.) and negative-low arousal emotions (depression, sadness, fatigue, etc.) [10]. American psychologist D. Krech[11] divided human emotions into primitive emotions, emotions related to sensory stimulation, emotions related to self-evaluation and emotions related to others (including love, hate, etc.). Emotions related to sensory stimulation include pleasant and un-pleasant emotions, which point to individuals with positive or negative goals. In the experiment, emotions related to physical sensory stimulation were selected in academic emotions. Combined with the actual situation of this study, typical emotions were selected from the four dimensions of academic emotions shown in Table II. The questionnaire used five-level scale, as shown in Fig. 4 (b), 0-4 represents nothing at all, a little bit, some, quite, very.



(a)

(b)

Figure 4. Examples of scale.

TABLE II. ACADEMIC EMOTIONS SURVEYED

	Positive emotions	Negative emotions,
Low arousal emotions	Happiness and pleasure	Annoyance and anxiety
High arousal emotions	Relaxation and calmness	Fatigue and depression

D. Participants and Experimental Process

A total of 30 participants participated in the experiment, all of them were voluntary students. The specific information of the subjects was shown in Table III. Each subject experienced three experiments, each experiment experienced nine conditions. In order to control the variables, the clothing of each participant was guaranteed to have an insulation value of about 1.01clo (estimated by ASHRAE 55[12]). During the experiment, the subjects were kept silent for learning, and the metabolic rate was about 1.2met. Chow et al. found that it took 30 minutes for people to adapt to different thermal environments. Tang et al. found that the change cycle of people’ s adaptive loudness was 82 seconds, and it took 5 minutes for people’ s eyes to adapt to the change of light. Therefore, the 27 experimental conditions are divided into three experiments, each experiment has three different test groups, each test group contains three different environ-mental conditions. The temperature and illumination between different conditions are the same, and the acoustic environment is mainly randomly trans-formed.

In this study, Latin square experimental design was used to avoid the influence of sequence and the prediction of test conditions. Firstly, the third-order Latin square is used to combine the illuminance at three different temperatures to form nine different experimental thermo-optic combination environments. Then the different order of sound pressure level audio playback in nine experiments are combined in Latin square experiment as shown in Table IV.

Before each experiment, the subjects had 30 minutes to adapt to the first thermo-optic environment combination [13]. After the beginning of the experiment, the controller adjusted the three audios with different loudness according to the experimental design. The participants were treated with five minutes learning tasks under different loudness audios, then filled out the questionnaire. After completion, the audio was changed, and the operation of learning and filling out the questionnaire was repeated. After the completion of three audio playback, according to the experimental design to change the light environment, with five minutes to adapt to the new light environment, and then repeat the audio play-back operation, the experimental process is shown in Fig. 5.

TABLE III. BASIC INFORMATION OF PARTICIPANTS

	Min	Max	Mean	standard deviation
Age	19	27	23.31	1.903
Height /cm	150	186	170.50	9.989
weight W/kg	36	80	59.52	10.45
BMI	15.58	24.67	20.35	2.32

TABLE IV. LATIN SQUARE EXPERIMENTAL DESIGN

Air temperature/℃	18			22			26		
Illumination intensity/ lux	100	300	500	300	500	100	300	500	100
Sound pressure level of the first audio /dBA	35	55	45	55	35	45	45	35	55
Sound pressure level of the second audio /dBA	45	35	55	35	45	55	55	45	35
Sound pressure level of the third audio /dBA	55	45	35	45	55	35	35	55	45

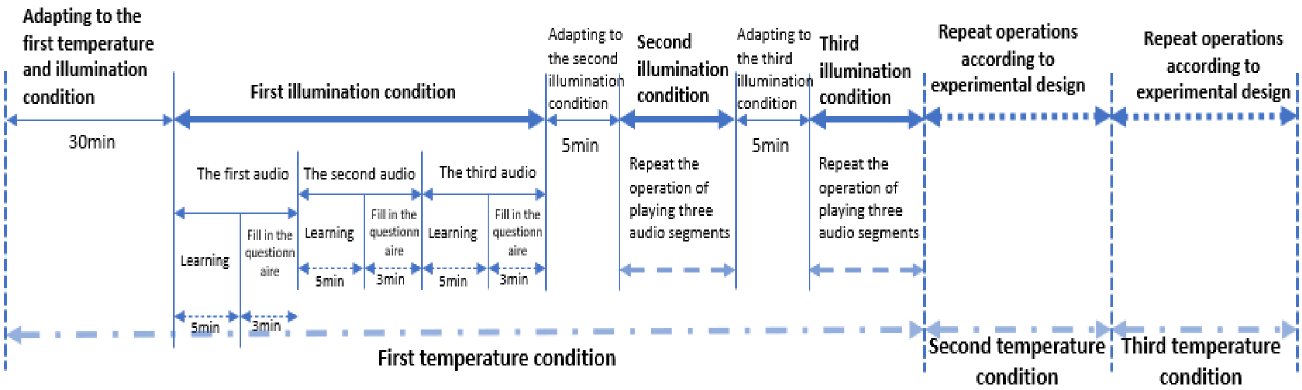


Figure 5. Experimental process.

III. RESULTS

A. *Influence of Physical Environment on Thermal, Acoustic and Visual Comfort*

One-way analysis of variance is used to analyze the influence of different physical environment factors on thermal, acoustic and visual comfort. Table V shows the significance analysis of the influence of physical environment factors on thermal, acoustic and visual comfort. It can be found that the environmental factors that have significant effect on thermal comfort are only temperature, and the sound pressure level and temperature that have significant effect on acoustic comfort, and the three environmental factors have significant effect on visual comfort.

Fig. 6 (a) shows the percentage of votes for thermal comfort at different temperatures. In all indoor temperature conditions, most votes are 'general' at 18 ℃. Under the neutral temperature condition of 22 ℃, the majority of voters feel comfortable. The proportion of comfortable voting at 26 ℃ was 50.01%, and 33.61% was 'general'. By comparing the different voting ratios under different conditions, it can be found that the neutral temperature is the most comfortable temperature condition in the indoor environment in winter, but people prefer to stay in a warmer environment than in a colder environment.

Fig. 6 (b) is the percentage of acoustic comfort votes at different sound pressure levels, and most votes are partial comfort at 35 dBA accounting for 78.53 %. At 45 dBA, the highest proportion of ' general ' was 56.56%, and the average proportion of uncomfortable and comfortable was 21.72%. At 55 dBA, most votes were uncomfortable. It can be seen that people prefer to have a quiet acoustic environment in the learning space, and the lower the sound pressure level, the better the vote of acoustic comfort. Fig. 6 (c) is the percentage of acoustic comfort votes at different temperatures. The voting percentage at 18 ℃ and 22 ℃ is similar, and the proportion of uncomfortable at 26 ℃ is significantly higher than that of the other two temperature conditions. It shows that people' s acoustic comfort will be reduced in the hot environment of learning space.

Fig. 6 (d)is the percentage of votes for visual comfort at different illuminations. The proportion of light comfort between 100 lux and 300 lux is similar. The proportion of ' a little uncomfortable ' increases significantly under 500 lux illumination. Show that too bright luminous environment will reduce people ' s visual comfort. Fig. 6 (e) is the percentage of visual comfort votes at different temperatures. The proportion of visual comfort votes at cold and neutral temperature conditions is similar, and the visual comfort votes at hot conditions are significantly worse. Fig. 6 (f) is the percentage of visual comfort votes at different sound pressure levels. As can be seen, 35dBA feel comfortable voting ratio is the highest, 45dBA and 55dBA voting ratio is similar, indicating that quieter acoustic environment will improve visual comfort.

TABLE V. SIGNIFICANCE ANALYSIS OF THE INFLUENCE OF PHYSICAL ENVIRONMENT FACTORS ON THERMAL, ACOUSTIC AND VISUAL COMFORT.

	Thermal comfort		Acoustic comfort		Visual comfort	
Physical environment factors	F	Sig	F	Sig	F	Sig
Air temperature	178.892*	0.000*	8.760*	0.000*	13.689*	0.000*
Sound pressure level	0.834	0.435	474.443*	0.000*	3.114*	0.045*
Illumination intensity	1.501	0.224	0.618	0.539	10.194*	0.000*
* stands for p<0.05						

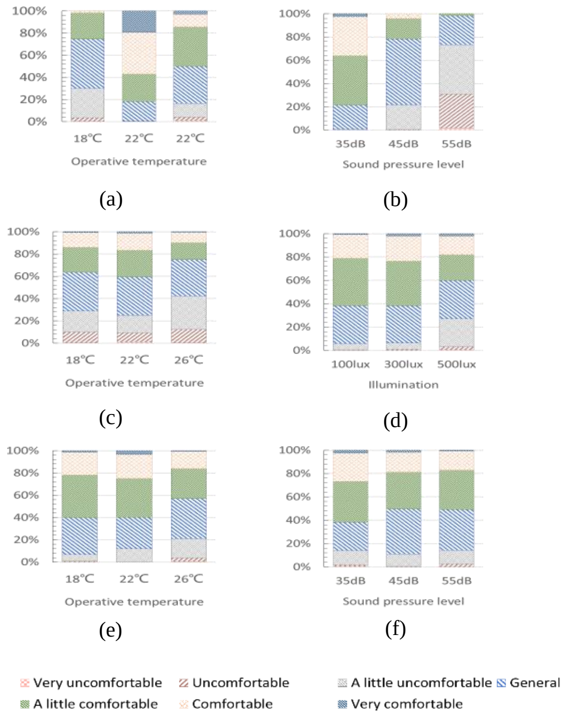


Figure 6. Percentage of comfort votes under different environmental factors.

B. *Influence of Physical Environment on Overall Environmental Comfort*

Single factor analysis of variance is used to analyze the influence of different physical environmental factors on the overall environmental perception. Table VI shows the significant analysis of the influence of environmental factors on the overall environmental comfort. It can be seen that temperature, sound pressure level and illumination have significant effect on the overall environment perception.

Fig. 7shows the percentage of overall environmental comfort votes in different environments. It can be found that when the temperature is 22 ℃, the voting percentage of partial comfort is significantly higher than that of 18 ℃ and 26 ℃, and the voting percentages of 18 ℃ and 26 ℃ are similar. Under different sound pressure levels, the proportion of comfortable voting in the overall comfort voting decreases with the increase of sound pressure level. When the illuminance is 500lux, the proportion of comfortable voting in the overall comfort voting is lower than that of 100lux and 300lux, and the proportion of 100lux and 300lux is close. It shows that when the overall comfort is in a neutral temperature environment, a quieter sound environment and not in a bright light environment, the voting situation is better. In summary, the overall environmental comfort is affected by the thermal environment, acoustic environment and luminous environment, and the overall environmental comfort is the highest at 22 ° C, 35 dBA and 100 lux.

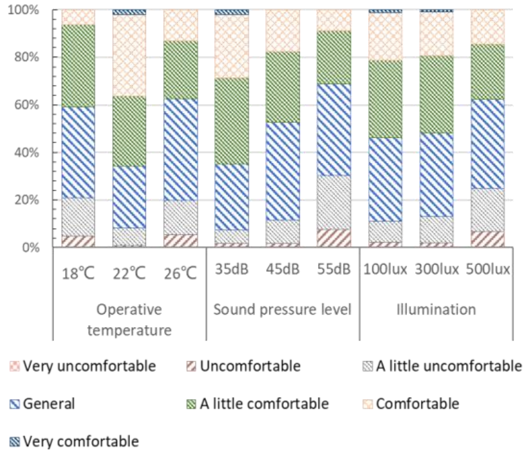


Figure 7. Percentage of overall environmental comfort votes in different environments

TABLE VI. SIGNIFICANT ANALYSIS OF THE INFLUENCE OF ENVIRONMENTAL FACTORS ON THE OVERALL ENVIRONMENTAL COMFORT.

Physical environment factors	overall environmental comfort	
	F	Sig
Air temperature	48.864**	0.000**
Sound pressure level	52.007**	0.000**
Illumination intensity	16.416**	0.000**
*P<0.05 **P<0.01		

C. *Influence of Physical Environment on Emotion Perception*

After one-way analysis of variance on the influence of physical environmental factors on emotional perception, it was found that temperature had no significant effect on calmness(P>0.05), but had significant effect on other emotions(P<0.05). Sound pressure level and illuminance had significant effect on various factors of emotional perception(P<0.05).

Fig. 8(a) is the percentage of votes of emotional perception factors at different temperatures. Among positive-high arousal emotions and positive-low arousal emotions, 22 ℃ has more votes. Among the negative-high arousal emotions and negative-low arousal emotions, the voting proportion was the highest at 26 ℃ and the lowest at 22 ℃. It can be seen that people are more likely to experience positive emotions at 22 ℃ and negative emotions at 26 ℃. Fig. 8(b) is the per-centage of votes of emotional perception factors at different sound pressure levels. It can be seen that the proportion of positive-high arousal emotions and positive-low arousal emotions decreases with the increase of sound pressure level, and the proportion of negative-high arousal emotions and negative-low arousal emotions increases with the increase of sound pressure level. It shows that people in the learning state, quiet acoustic environment will make people feel more positive emotions. Fig. 8(c) is the percentage of emotionally perceived votes at different illuminations. Similar to the voting pattern under different sound pressure levels, the proportion of positive emotions decreases with the increase of illuminance, and the proportion of negative emotions in-creases with the increase of illuminance. In conclusion, the change of single physical environment factors has no obvious effect on emotional arousal. There is no obvious comparison between high and low arousal emotions, but there is a significant difference between positive and negative emotions.

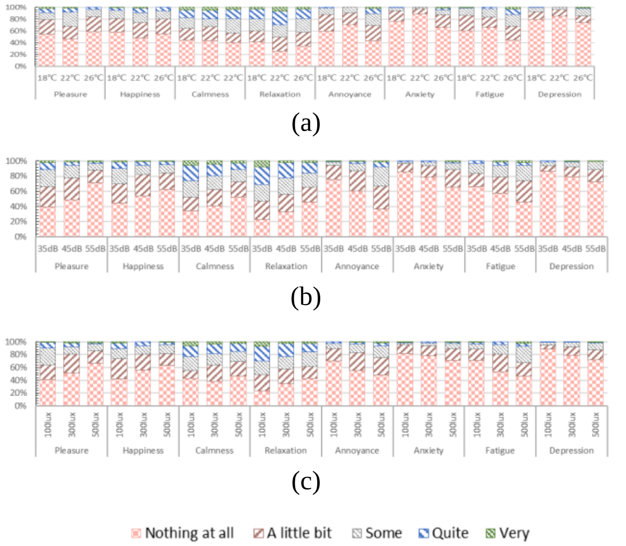


Figure 8. Voting percentage of environmental comfort under different environmental factors

E. *Relationship between Physical Environment Comfort and Emotional Perception*

Pearson correlation analysis was used to explore the relationship between thermal, acoustic, visual comfort and emotional perception, as shown in Table VII. There is a significant positive correlation between physical environment com-fort and positive-high arousal emotions. The correlation between acoustic com-fort and two emotions is the strongest, followed by thermal comfort. In positive-low arousal emotion, thermal comfort and acoustic comfort have significant positive correlation with two different emotions, and acoustic comfort has the strongest correlation with calmness and relaxation. The relationship between visual comfort and calmness is weak, there is no significant correlation, and has obvious positive correlation with relaxation. There is a significant negative correlation between physical environment comfort and negative-high arousal emotions. The correlation between acoustic comfort and these two emotions is the strongest. The correlation between visual comfort and annoyance is slightly higher than that of thermal comfort, but the correlation between visual comfort and anxiety is lower than that between thermal comfort and anxiety. Physical environment comfort is negatively correlated with negative-low arousal emotion. The highest correlation with fatigue is acoustic comfort, but the highest correlation with depression is thermal comfort. In conclusion, environmental comfort is positively correlated with positive emotions and negatively correlated with negative emotions, and the strongest correlation between physical environmental comfort and most emotional perception is acoustic comfort. There-fore, the comfort of acoustic environment should be focused on in the design of indoor physical environment in learning space.

TABLE VII. CORRELATION BETWEEN ENVIRONMENTAL COMFORT AND EMOTIONAL PERCEPTION

	Pleasure	Happiness	Calmness	Relaxation	Annoyance	Anxiety	Fatigue
Thermal comfort	0.163*	0.114*	0.076*	0.166*	-0.157*	-0.192*	-0.179*
Acoustic comfort	0.307*	0.134*	0.170*	0.180*	-0.336*	-0.286*	-0.246*
Visual comfort	0.147*	0.084*	0.029	0.178*	-0.182*	-0.144*	-0.190*
*P<0.05							

IV. CONCLUSION

By analyzing people' s comfort and emotional perception in different physical environments, this paper explores the influence of learning space physical environment on people' s comfort perception and emotional perception, and the relationship between the two perceptions. Temperature has significant influence on thermal comfort, acoustic comfort and visual comfort, and the comfort level is higher in neutral temperature environment. Sound pressure level has a significant impact on sound comfort and light comfort. Comfort level is higher in quiet environment. Illumination only has a significant impact on visual comfort, people feel uncomfortable in the too bright environment. The overall environmental comfort is affected by three environmental factors. The voting value is the highest in neutral temperature environment, quiet acoustic environment and neutral illumination environment. Physical environmental factors mainly affect the valence of emotions. In the comfortable environment, people ' s emotions are more positive, in the uncomfortable environment is more likely to feel negative emotions.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Wenjuan Li conducts experiments under supervision and writes this paper. Hong Jin funding support for the research for this article, and full guidance for this study.

REFERENCES

[1] Y. Yafeng, H. Yin, and Z. Jiping, "Learning space: Connotation, research status and practice progress," *Modern Distance Education Research*, vol. 3, pp. 82-94, 2015.

[2] E. L. Krüger and P. H. Zannin, "Acoustic, thermal and luminous comfort in classrooms," *Building and Environment*, vol. 39, no. 9, pp. 1055-1063, 2004.

[3] H. Li, Z. Yingxin, O. Qin, et al. "A study on the effects of thermal, luminous, and acoustic environments on indoor environmental comfort in offices," *Building and Environment*, vol. 49, pp. 304-309, 2015.

[4] W. Hangzi, S. Xiaoying, and W. Yue, "Investigation of the relationships between thermal, acoustic, illuminous environments and human perceptions," *Journal of Building Engineering*, vol. 32, 101839, 2020.

[5] G. Yubo, H. Bo, D. Meng, et al., "Combined effects of visual-acoustic-thermal comfort in campus open spaces: A pilot study in China's cold region," *Building and Environment*, vol. 209, 108658 2022.

[6] Design code for heating ventilation and air conditioning of civil buildings (GB 50736-2012), National Standards of People's Republic of China, 2012.

[7] O. Seppanen, W. J. Fisk, and Q. H. Lei, "Room temperature and productivity in office work," Lawrence Berkeley National Laboratory, 2006.

[8] Code for design of sound insulation of civil buildings (GB 50118-2010). National Standards of People's Republic of China (2010).

[9] Standard for lighting design of buildings (GB 50034-2004). National Standards of People's Republic of China (2010).

[10] D. Yan and Y. Guoliang, "The development and application of adolescent academic emotion questionnaire," *Building and Environment*, vol. 39, no. 5, pp. 852-860, 2007.

[11] D. Krech, R. S. Crutchfield, and N. Livson, *Elements of Psychology* (2nd ed.). New York: Alfred Knopf, 1969.

[12] Thermal Environmental Conditions for Human Occupancy (ASHRAE Standard 55-2010). American Society of Heating, Refrigerating and Air Conditioning Engineers (2010).

[13] T. T. Chow, K. F. Fong, B. Givoni, et al., "Thermal sensation of Hong Kong people with increased air speed, temperature and humidity in air-conditioned environment," *Building and Environment*, vol. 45, no. 10, pp. 2177-2183, 2010.

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