Investigation of the group differences in indoor environmental quality

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Abstract. Based on the field measurements and questionnaires surveys carried out in 22 offices in Harbin, China, the group differences (gender, age, BMI, level of education, location groups) in human comfort for different levels of environmental parameters were investigated. It was found that males, elder subjects (above 25 years old) and the subjects with higher academic degrees have higher comfort votes than other groups. The group differences were larger in a warmer thermal environment and the differences in thermal comfort votes could be larger than 0.5 scale units on the comfort scale among gender, age and level of education groups when the temperature was higher than 26°C in summer or higher than 24°C in winter. For indoor air quality, the differences in comfort votes for air freshness were larger when the CO_2 concentration was less than 960 ppm and the difference in comfort votes for air pollution was larger when $PM_{2.5}$ concentration was higher than 25 μg/m^3. For sound comfort, it was found that the subjects near doors had higher sensitivity to the change in sound levels than the subjects at other locations. For light comfort, the higher illuminance could cause larger group differences. This study can be used to better develop comfort systems, especially personal comfort systems.

Keywords. Group difference, indoor environmental parameters, human comfort.
DOI: https://doi.org/10.34641/clima.2022.392

1. Introduction

Indoor environmental quality (IEQ) of buildings, including thermal, indoor air quality, acoustic and light environments, has significant effects on human comfort [1, 2]. In the previous studies, it has been reported that individual differences in human perceptions existed even when subjects were exposed to the same indoor environmental environment [3, 4]. It is necessary to explore group differences in human perceptions for indoor environmental parameters, which can be used to better decide the comfort systems.

For the gender groups, Lan [5] and Karjalainen [6] found that the thermal sensation values of females were lower than those of males. Nakano et al. [7] conducted a field study in an office in Tokyo and found significant gender differences in thermal comfort. Wang conducted a field study in winter in Harbin, China and found that the neutral temperature of females was 1°C higher than that of males [8]. In contrast, the studies of Peng [9], Choi et al. [10] and Becker et al. [11] found no statistically gender significant difference in thermal sensation votes [11]. For the age groups, Becker [11] and Indraganti [12] found no statistically significant differences in thermal sensation votes. But Peng [9] found that the range of the comfortable temperatures of the elderly subjects who were above 50 years old was narrower than that of the young subjects who were below 18 years old, and the same conclusion was given by Hwang [13]. For the BMI groups, Rupp [14] conducted a field study in offices and found that BMI had a significant impact on occupants' thermal sensation and clothing habits. Compared to the normal weight and underweight groups, the neutral temperature and mean clothing insulation of the overweight group were lower in the previous study [15]. The study of Kang found that subjects near windows had slightly lower thermal satisfaction than subjects at other locations [16]. The study of Yamtraipat et al. showed that people with higher educational degrees preferred lower air temperature [17]. The research on the effect of the level of education and subjects' location on thermal comfort is still lacking.

Although the group differences in thermal responses have been studied in previous studies, the research on the group differences in other environmental factors was rare. It is necessary to explore the group differences in human comfort for all the environmental factors. Kang carried out 231 questionnaire surveys in 19 universities and analyzed the group differences in all indoor environmental factors [16]. This study showed that the elder subjects (24-35 years old) and the subjects near windows had higher mean light comfort votes than the younger subjects (below 24 years old). Also, The elder subjects were more sensitive and had lower acoustic satisfaction than the younger subjects. The subjects at other locations and the subjects near windows and doors were more satisfied with the air quality than the subjects at other locations.

In all the above studies, there was no study discussing the influence of the level of different indoor environmental parameters on group differences in human perceptions. It is necessary to study how big the group differences in human perceptions are when the environmental parameters are above or below the limits in the standard. Therefore, based on the field measurements and questionnaire surveys in open-plan offices in a severe cold region, this study investigated the group differences in human comfort (thermal, indoor air quality, light and sound comfort) for different levels of environmental parameters.

2. Methodology

2.1 Site and building information

In this study, 22 university open-plan offices, which are distributed on different floors (between the 2nd and 6th floors) of different orientations, were selected from four office buildings in Harbin Institute of Technology, which is located in a severe cold region in China. The central heating system was used in all buildings to provide space heating. The radiators were installed on the walls under the windows as the terminal unit, but the subjects cannot adjust the temperature of the radiators. The split-type air conditioner systems were installed in all buildings and the air conditioners can be adjusted by the subjects. The photos of the test sites and the physical characteristics of the offices can be seen in our other studies [18, 19].

2.2 Field measurements

The field study was conducted from August 10, 2018 to May 19, 2019. The outdoor temperature was monitored, and the 5-day average outdoor air temperatures are shown in the previous study [18]. According to QX/T 152-2012 [20], the sampling period was divided into summer, winter and transition seasons in Tab. 1. The point-in-time measurements were performed together with the questionnaire surveys every 3-4 weeks, and the recording interval for each parameter was 10s. The thermal physical parameters include indoor air temperature (°C), relative humidity (%), globe temperature (°C), and air velocity (m/s). For indoor air quality parameters, CO_2 concentration was measured by HOBO MX1102 and particulate matter ($PM_{2.5}$) was collected by GT-1000. The sound level was measured by a sound analyzer HS6288E, and TES1339P was used to measure the illuminance of each subject's location. The measurement of the illuminance of each subject’s location lasted for more than 5 min, while the measurements of other parameters lasted for more than 1 hour. All the devices had self-recording functions and the measured range and the accuracy of all devices are shown in our previous study [19].

Tab. 1 - Division of seasons.

Seasons	Survey dates
Summer	11th August 2018 –25th August 2018
Winter	25th October 2018 –12th April 2019
Transition seasons (Autumn, Spring)	25th August 2018 – 24th October 2018 13th April 2019–19th May 2019

2.3 Questionnaire surveys

The questionnaire was designed based on ASHRAE 55 [21] and EN 16798-1 [22] and it was used to acquire human perceptions during the point-in-time measurement surveys. The survey begins with the individual information of subjects, including gender, age, level of education, body mass index (BMI), and subjects’ location. The second section investigated human comfort for thermal, sound, indoor air quality (air freshness and air pollution) and light environments. Human comfort was investigated by the seven-point scale specified by Appendix E in ASHRAE-55, which is shown in Fig. 1, and the range of comfortable vote was from 4 to 7. Humans can be considered in a steady-state condition after a 30-45 min stay in a thermal environment, thus all the subjects filled out questionnaires after working in the offices for more than 30 min. The subjects were also required not to wear earphones or headphones for 10 min before filling in the questionnaires.

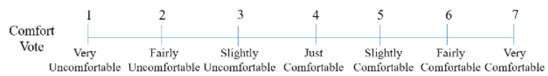


Fig. 1 - The scales of comfort vote [18].

3. Results

The result analysis focuses on the group differences in human comfort for different levels of parameters. The categories of the environmental parameters in EN16798-1 were used to divide the levels of the environmental parameters. Mann-Whitney U tests and Kruskal-Wallis H tests were applied for studying the group differences, and the result of the p-value below 0.05 reveals that a statistically significant difference exists among groups.

3.1 Indoor environmental parameters

A total of 165 point-in-time measurements were carried out. The average values and standard deviations for the indoor thermal parameters during different seasons were shown in Tab. 2 [18]. According to Table 2, the mean air temperatures and globe temperatures in summer and winter were higher than those in transition seasons. In our previous study, it has also been found that during the sampling period, the mean outdoor air temperature in winter was -3.5°C, far lower than that in transition seasons (15.1°C). Thus, the difference between indoor and outdoor air temperatures was larger in winter than in transition seasons, which might cause uncomfortable feelings for subjects. The average values and the ranges for other parameters ($PM_{2.5}$ concentration, CO_2 concentration, A-weighted sound level and illuminance) during all seasons are shown in Tab. 3.

Tab. 2 – Average values for the thermal parameters [18].

Thermal parameters	Average value±SD		
	Summer	Winter	Transition seasons
Air temperature (°C)	26.7 ±1.6	25.5 ±2.0	23.8 ±2.0
Relative humidity (%)	53 ±2	19 ±6	29 ±8
Globe temperature (°C)	26.8 ±1.8	25.2 ±2.1	24.2 ±2.3
Air velocity (m/s)	0.07 ±0.03	0.03 ±0.02	0.04 ±0.02

Tab. 3 – Average values for other environmental parameters during all seasons [18].

Parameters	Average value±SD	Range
$PM_{2.5}$ concentration (μg/m^3)	28±19	3-83
CO_2 concentration (ppm)	897±215	493-1451
A-weighted sound level (dB(A))	50±4	40-61
Illuminance (lux)	433±293	39-1407

3.2 Profile of the sample

A total of 1352 valid questionnaires, filled in by 265 university researchers, were collected, with 227 for summer, 744 for winter, and 381 for transition seasons. The winter in Harbin lasted for almost 6 months, longer than the summer and transition seasons, thus we could obtain more questionnaires in winter. The questionnaires for all seasons covered different genders, ages, levels of education and BMI, and the subjects for different groups sat at different locations in the offices. The occupied zones within 1.5 m from the windows or doors were defined as the locations near windows or doors. The Pearson correlation coefficient between the age and level of education groups was calculated as 0.666 and the significant level p-value was less than 0.001 [18], which revealed that the age and level of education groups had a strong correlation. Due to the upper and lower quartiles for different levels of education, the occupants were divided into three age groups, which were the younger group (<23), the middle age group (23-25) and the elder group (>25). The sample sizes of different groups are listed in Tab. 4 [18]. It should be illustrated that the sample size of undergraduates in summer was only 3 and this small sample size might cause the low-test power for the analysis of group differences among the level of education groups in summer.

Tab. 4 – Sample sizes of different groups [18].

	Total number	Seasons S	W	TS
Gender group				
Male	895	174	482	239
Female	457	53	262	142
Age group				
Younger<23	161	15	101	45
Middle age 23-25	711	144	378	189
Elder age>25	480	68	265	147
Level of education				
Undergraduate	107	3	71	33
Master student	539	106	286	147
Doctoral student	706	118	387	201
Location				
Near window	383	66	201	116
Near door	286	40	159	87
Other location	683	121	384	178
BMI				
<18.5	137	25	71	41
18.5-24.9	921	164	501	256
>24.9	294	38	172	84

3.3 Thermal comfort

For thermal comfort, the p-values and the mean thermal comfort votes among different groups during different seasons are shown in Tab. 5. It can be seen that statistically significant differences in thermal comfort votes occurred in more groups in summer and winter than in the transition seasons. In transition seasons, the statistically significant difference was only found in the BMI group (p-value=0.003).

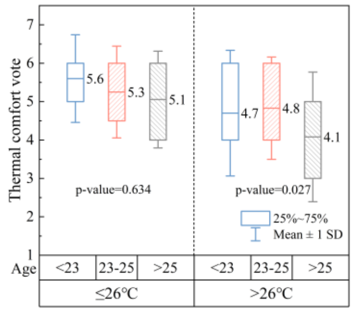
The p-values below 0.05 were further studied. According to EN 16798-1 [22], the temperature range for heating seasons (winter) in the medium category in open-plan offices is from 20°C to 24°C and the range for cooling seasons (summer) is from 23°C to 26°C. The range of air temperatures in winter was from 20.5°C to 28.7°C, and the upper limit for winter (24°C) in EN 16798-1 was used to divide the temperatures into two categories, which were respectively from 20°C to 24°C (comfortable range) and above 24°C (uncomfortable range). The range of air temperatures in summer was from 22.7°C to 29.1°C, and the upper limit for summer (26°C) was used to divide the temperature, which were respectively from 23°C to 26°C (comfortable range) and above 26°C (uncomfortable range). The range of transition seasons was from 20.4 to 28.3°C, and the upper limit temperatures for summer (26°C) and winter (24°C) were used to divide the temperatures into three categories.

Tab. 5 Mean thermal comfort votes during different seasons

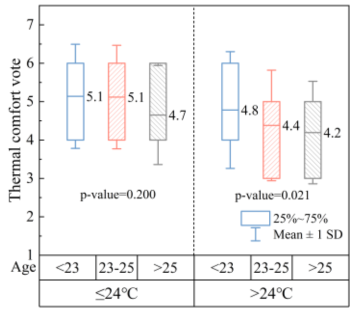
	Thermal comfort vote		
	Summer	Winter	Transition seasons
Gender			
Male	4.8	4.4	5.2
Female	4.7	4.6	5.2
p-value	0.915	0.091	0.614
Age			
Younger<23	**5.0**	**4.9**	5.5
Middle age 23-25	**5.0**	**4.5**	5.2
Elder age>25	**4.3**	**4.3**	5.1
p-value	**0.016***	**0.003***	0.240
Level of education			
Undergraduate	5.3	**5.1**	5.7
Master student	4.9	**4.4**	5.2
Doctoral	4.7	**4.4**	5.1
p-value	0.717	**0.001***	0.240
Location			
Near window	**4.5**	**4.2**	5.1
Near door	**4.8**	**4.6**	5.3
Other location	**5.0**	**4.5**	5.2
p-value	**0.048***	**0.026***	0.494
BMI			
<18.5	**4.8**	**4.5**	**5.2**
18.5-24.9	**4.9**	**4.5**	**5.3**
>25	**4.3**	**4.2**	**4.8**
p-value	**0.042***	**0..021***	**0.003***

For the age groups, the distribution of thermal comfort votes for different categories of temperatures in summer and winter is shown in Fig. 2. It can be observed that statistically significant differences were found for the '>26°C' category in summer (p-value=0.027) and the '>24°C' category in winter (p- value=0.021). The thermal comfort votes for elder subjects were 4.1 for the '>26°C' category in summer and 4.2 for the '>24°C' category in winter, lower than other groups, and the differences in the mean thermal comfort votes among age groups for the higher temperature categories were larger than those for the lower temperature category.

For the level of education groups, the distribution of thermal comfort votes for different categories of temperatures in winter is shown in Fig. 3. It can be observed that statistically significant differences were found for the '>24°C' category. For both two categories, the mean thermal comfort votes for undergraduates were higher than those for the master and doctoral students, but the differences for the '>24' category were a bit larger than those for the '≤24°C' category. For the '>24°C' category, the mean thermal comfort vote for undergraduates was 4.9, 0.6 higher than those for master and doctoral students.



a) Summer



b) Winter

Fig. 2 - Distribution of thermal comfort votes for different categories of temperatures among age groups.

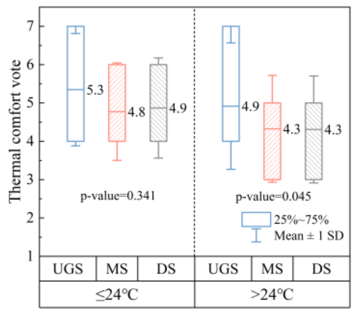


Fig. 3 - Distribution of thermal comfort votes for different categories of temperatures among the level of education groups in winter.
*UGS, MS and DS represent undergraduates, master students and doctoral students.

For the subjects' location groups, the distribution of thermal comfort votes for different categories of temperatures in summer is shown in Fig. 4. It can be observed that statistically significant differences were not found both for the '≤26°C' and '>26°C' categories, but the mean thermal comfort votes for subjects near windows were lower than the subjects near doors and at other locations for both two categories.

For the BMI groups, the mean thermal comfort vote in winter was not larger than 0.5, thus it has not been further studied. The distributions of thermal comfort votes for different categories of temperatures in summer and transition seasons are shown in Fig. 5. In summer, the mean comfort vote for the overweight group was lower than for the underweight and normal-weight groups. However, in transition seasons, the normal-weight subjects had higher comfort votes than other groups for the '24-26°C' and '>26°C' categories.

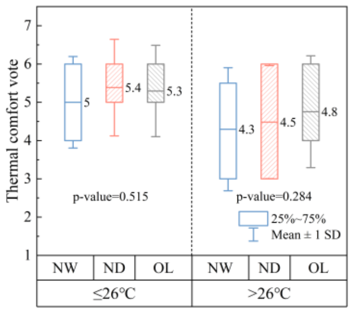
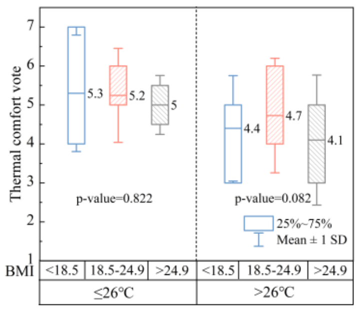
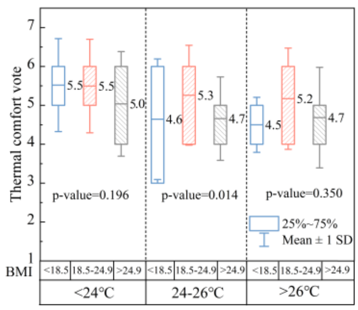


Fig. 4 - Distribution of thermal comfort votes for different categories of temperatures among subjects' location groups in winter.
*NW, ND and OL represent near windows, near doors and other locations.



a) Summer



b) Transition seasons

Fig. 5 - Distribution of thermal comfort votes for different categories of temperatures among BMI groups.

3.4 Indoor air quality

For air freshness, statistically significant differences in comfort votes occurred in gender (p-value<0.001), age (p-value<0.001), level of education (p-value=0.019) groups. According to EN 16798-1 [22], when the indoor CO_2 concentration above outdoor was less than 550 ppm and 800 ppm, the air quality can be considered as high level and medium level. The annual atmospheric CO_2 concentrations in 2018 and 2019 were respectively 409ppm and 411 ppm, thus the outdoor CO_2 concentration was set as 410ppm in this study. Three categories of CO_2 concentrations were set as follows: <960 ppm, 960-1210 ppm and >1210 ppm. The group differences in comfort votes for air freshness for different CO_2 concentrations were calculated and given in Tab. 6. It can be observed that statistically significant differences in comfort votes for air freshness existed in all categories of CO_2 concentrations between male and female groups, but when the CO_2 concentration was less than 960ppm, the difference in comfort votes for males (4.3) and females (3.8) was larger than those for other categories. For the age and level of education groups, the differences in comfort votes among different groups were also largest when the CO_2 concentration was less than 960 ppm and the younger subjects and undergraduates had higher comfort votes than other groups.

Tab. 6 Mean comfort votes for air freshness for different CO_2 concentrations.

Group (Sample size)	Comfort vote for air freshness for different CO_2 concentrations (ppm)		
	<960	960-1210	>1210
Gender			
Male (895)	**4.3**	**4.0**	**3.8**
Female (457)	**3.8**	**3.6**	**3.5**
p-value	**<0.0**	**<0.0**	**0.001**
Age			
Younger<23 (161)	**4.6**	4.1	3.6
Middle age 23-25 (711)	**4.2**	4.0	3.9
Elder age>25 (480)	**3.9**	3.7	3.6
p-value	**<0.0**	0.251	0.446
Level of education			
Undergraduate (107)	**4.5**	4.3	**2.7**
Master student (539)	**4.2**	4.0	**3.8**
Doctoral student(706)	**4.1**	3.8	**3.8**
p-value	**0.02**	0.242	**0.028**
Location			
Near window (383)	4.3	3.9	3.8
Near door (286)	4.0	4.0	3.5
Other location (683)	4.2	3.9	3.8
p-value	0.07	0.848	0.618
BMI			
<18.5 (137)	4.2	3.9	3.6
18.5-24.9 (921)	4.2	3.9	3.7
>25 (294)	4.0	3.8	3.7
p-value	0.33	0.686	0.945

For comfort vote for air pollution, there were statistically significant differences existed in gender (p-value<0.001), age (p-value<0.001), level of education (p-value=0.010) groups. EN 16798-1 [22] adopted the WHO guideline values for indoor and outdoor air pollutants, and the upper limit value for the 24-hour average $PM_{2.5}$ concentration is 25 μg/m³. Thus Tab. 7 shows the comfort vote for air pollution for two categories of $PM_{2.5}$ concentrations, which are <25 μg/m³ and ≥25 μg/m³. The comfort vote for air pollution for male subjects was 0.5 higher than that for female subjects for both two categories of $PM_{2.5}$ concentrations. For the age and level of education groups, the elder subjects and the doctoral students tended to have lower comfort votes for air pollution, and the difference was larger when the $PM_{2.5}$ concentration was larger than 25 μg/m³.

Tab. 7 Mean comfort votes for air pollution for different $PM_{2.5}$ concentrations.

Group (Sample size)	Comfort vote for air pollution for different $PM_{2.5}$ concentrations (μg/m³)	
	<25	≥25
Gender		
Male (895)	**4.6**	**4.0**
Female (457)	**4.1**	**3.5**
p-value	**<0.001**	**<0.001**
Age		
Younger<23 (161)	4.6	**4.1**
Middle age 23-25 (711)	4.5	**4.0**
Elder age>25 (480)	4.3	**3.5**
p-value	0.118	**<0.001**
Level of education		
Undergraduate (107)	4.5	**4.1**
Master student (539)	4.6	**4.0**
Doctoral student (706)	4.4	**3.7**
p-value	0.3	**0.006**
Location		
Near window (137)	4.5	3.9
Near door (921)	4.4	3.9
Other location (294)	4.4	3.8
p-value	0.788	0.539
BMI		
<18.5 (137)	4.2	3.9
18.5-24.9 (921)	4.5	3.8
>25 (294)	4.5	3.8
p-value	0.304	0.889

3.5 Sound comfort

For sound comfort vote, the statistically significant differences occurred in gender (p-value<0.001), age (p-value<0.001), level of education (p-value<0.001) and subjects' location groups (p-value=0.001). According to EN 16798-1 [22], the upper limit of the sound pressure level was 45 dB(A) in landscape offices, thus two categories of A-weighted sound levels (<45 dB(A) and ≥45 dB(A)) were set in this study. For both two categories, statistically significant differences in sound comfort votes occurred in gender and age groups, and the male and younger subjects had higher sound comfort votes than females and elder subjects. For the level of education group, the statistically significant difference was only found in the '≥45 dB(A)' category, but the differences among groups for both two categories were close and the doctoral students had the lowest sound comfort votes (4.9 for the '<45 dB(A)' category and 3.9 for the '≥45 dB(A)' category). For the subjects' location, the subjects near doors (5.7) had the highest sound comfort vote when the sound level was less than 45 dB(A), but when the sound level was higher than 45 dB(A), the subjects near doors had the lowest sound comfort vote (3.8).

Tab. 8 Mean sound comfort votes for different A-weighted sound levels.

Group (Sample size)	Sound comfort vote for different A-weighted sound levels (dB(A))	
	<45	≥45
Gender		
Male (895)	**5.5**	**4.3**
Female (457)	**4.5**	**3.7**
p-value	**<0.001**	**<0.001**
Age		
Younger<23 (161)	**5.3**	**4.3**
Middle age 23-25 (711)	**5.4**	**4.2**
Elder age>25 (480)	**4.6**	**3.9**
p-value	**0.002**	**<0.001**
Level of education		
Undergraduate (107)	5.5	**4.4**
Master student (539)	5.3	**4.2**
Doctoral student (706)	4.9	**3.9**
p-value	0.083	**0.001**
Location		
Near window (383)	5.1	**4.2**
Near door (286)	5.7	**3.8**
Other location (683)	4.9	**4.2**
p-value	0.071	**<0.001**
BMI		
<18.5 (137)	4.8	4.0
18.5-24.9 (921)	5.2	4.1
>25 (294)	4.9	4.0
p-value	0.304	0.504

3.6 Light comfort

For the light comfort, statistically significant differences occurred in gender (p-value<0.001) and level of education groups (p-value=0.006). EN 16798-1 [22] used the limit values of EN12464-1, and the illuminance level in offices should be higher than 500 lux, thus the illuminance levels were divided into two categories: '<500 lux' and '≥500 lux'. Tab. 9 shows the mean light comfort votes for different Illuminance levels. It can be observed that statistically significant differences existed in gender, age and level of education groups when the illuminance is higher than 500 lux, but for the '<500 lux' category, the statistically significant difference only occurred in the gender group. For the mean light comfort votes among the gender, age and level of education groups, the differences were larger for the '≥500 lux' category than those for the '<500 lux' category. For example, the mean light comfort vote for male subjects (5.2) was 0.7 higher than that for female subjects (4.5) for the '≥500 lux' category, and that difference for the '<500 lux' category was 0.3.

Tab. 9 Mean Light comfort votes for different Illuminance levels.

Group (Sample size)	Light comfort vote for different Illuminance levels (lux)	
	<500	≥500
Gender		
Male (895)	**4.5**	**5.2**
Female (457)	**4.2**	**4.5**
p-value	**<0.001**	**<0.001**
Age		
Younger<23 (161)	4.6	**5.5**
Middle age 23-25 (711)	4.4	**5.1**
Elder age>25 (480)	4.3	**4.6**
p-value	0.059	**<0.001**
Level of education		
Undergraduate (107)	4.6	**5.6**
Master student (539)	4.4	**5.0**
Doctoral student (706)	4.4	**4.8**
p-value	0.355	**0.004**
Location		
Near window (383)	4.3	5.0
Near door (286)	4.4	5.1
Other location (683)	4.4	4.9
p-value	0.505	0.537
BMI		
<18.5 (137)	4.3	5.1
18.5-24.9 (921)	4.4	5.0
>25 (294)	4.3	4.9
p-value	0.243	0.841

4. Discussions

In this study, for all the environmental factors, males, elder age and subjects with high levels of education had higher comfort votes than other groups. The study of Hellwig [23] also showed that woman voted for 'extremely' and 'very important' compared to men. The significant level p-value for Pearson's correlation coefficient between the age and level of education groups was <0.001 [18], while for the Pearson's correlation coefficient between the other parameters, the p-values were all greater than 0.5. The result revealed that there was a strong correlation between the age and level of education groups. The range of age in this study was relatively narrow, but there were statistically significant differences in many human perceptions among age group, which might be caused by the statistically significant differences in human perceptions occurred among the level of education groups. The heavier stress of the master and doctoral students might cause them to have higher requirements for the environment than the undergraduates [18].

For thermal comfort, the mean indoor temperatures in summer and winter were higher than those in transition seasons, and according to our previous study, the differences between comfort temperatures and operative temperatures were 1.8°C in summer and 2.0°C in winter, higher than that in transition seasons (1.1°C), which illustrated that the subjects were not inclined to the warmer environment in summer and winter [18]. In section 3.3, it can be seen that the group differences occurred in more groups in summer and winter than in transition seasons, and the differences among groups were larger for the higher temperature categories, which revealed that individual differences could be magnified when people are in a warmer thermal environment.

For indoor air quality, the differences in comfort votes for air freshness among groups were larger when the air was relatively fresh (CO_2 concentration less than 960 ppm). In contrast, the differences in comfort votes for air pollution were larger when the $PM_{2.5}$ was above 25 μg/m^3, which means that serious air pollution could cause larger group differences. For sound comfort, the subjects near doors had the highest sound comfort vote than subjects at other locations when the sound level was less than 45 dB(A), and the opposite trend occurred when the sound level was higher than 45 dB(A), which revealed that the subjects near doors were more sensitive to the change in sound levels than subjects at other locations. For light comfort, the dim environment (<500 lux) caused the lower light comfort votes of subjects compared to the bright environment (≥500 lux), and the relatively bright environment caused larger group differences.

5. Conclusions

This study investigated the group differences in human comfort for different levels of environmental parameters, which can be used to better develop the comfort system, especially the personal comfort systems. For all the environmental factors, the higher comfort votes were found in male, elder age and higher levels of education groups. For thermal comfort, the differences were larger than 0.5 among gender, age and level of education groups for the higher temperature categories ('>26°C' in summer and '>24°C' in winter), and the group differences could be magnified in a warmer environment. For indoor air quality, the differences in comfort votes for air freshness among groups were larger when the CO_2 concentration was less than 960 ppm, and serious air pollution could cause larger group differences in the comfort votes for air pollution. For sound comfort, the subjects near doors were more sensitive to the change in sound levels than those at other locations. For light comfort, the higher illuminance lever (≥500 lux) could cause larger group differences. One limitation of this study is that the environmental parameters at different locations were not monitored, which could be used to better analyze the effects of different locations of subjects on human perceptions. Although the numbers of the subjects for some groups (such as the undergraduate group in the summer) were relatively low in this study, the results could still be used as a practical reference to improve human comfort in offices.

6. Acknowledgment

This work was financially supported by the Chinese National Natural Science Fund Project (Grant No. 51978207, 51927813, 51508133) and the National natural science foundation of Heilongjiang Province (YQ2021E030). Zheng Li acknowledge financial support from China Scholarship Council (Grant No. 202006120330).

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Data Statement

The datasets generated during and/or analyzed during the current study will be available with the permission of the first author upon reasonable request.