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Analysis and numerical simulation of indoor thermal environments in some university classrooms

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Abstract: In order to study the indoor thermal environments in university classrooms in Tianjin, a field study and a questionnaire survey for a main teaching building are carried out. First, the thermal sensations of participants in the typical classrooms are studied by 180 questionnaires. Then, based on the measured data, the temperature changes in the classrooms during a year are simulated by the DeST software. The results show that the indoor thermal environments in the northern classrooms on the first floor are better than those in other classrooms. And the measurement results accord with the simulation results. These results can be used as a reference for the study of the indoor thermal environments in other seasons.

Key words: university classroom; indoor thermal environment; field study; DeST simulation

The indoor thermal environments in classrooms of teaching buildings exert a direct influence on the comfort of people[1-3]. Many methods, such as questionnaire survey and field measurements, are used to study the indoor thermal environments[4]. In addition, the use of simulation software is a scientific way to study the indoor thermal environment[5]. In this paper, a questionnaire surveys and a field study are carried out to appraise the indoor thermal environments in university classrooms in Tianjin. And the DeST software is used to imitate the indoor temperature changes during a year under the natural ventilation conditions in the classrooms.

1 Research Object and Test Condition

1.1 Research object

The main teaching building in Hebei University of Technology is selected as the research object. It lies in the Beichen District of Tianjin. This building includes five districts named zones A, B, C, D, E. The plane diagram is shown in Fig. 1. Considering the overall arrangement of the building and the factors such as the number of classrooms, the heights of the floors, the orientations of the classrooms and outdoor environmental factors, a questionnaire survey, a field study and a simulation for typical classrooms are carried out. The seats in the classrooms are not always fully used and the seat utilization rate depends on the schedule of the school and the occupation rate of the classrooms. The classroom conditions are listed in Tab. 1.

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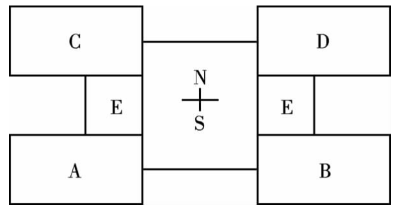

Fig. 1 Plane diagram of main teaching building

Tab. 1 Classroom conditions

Classroom number	Area/ m^2	N/ person	Seat utilization rate/%
E302	104	300	45
B110, B116, B502, B510	88	143	56
D105, D115, D501, D505	79	128	42

Note: N means the maximum number of persons in classroom.

1.2 Test condition

The questionnaire survey, the field measurement and the simulation were carried out on April 26th, April 27th, June 18th and June 19th, 2008. Each test was carried out from 8:00 to 20:00 with intervals of 2 h. The parameters of the outdoor air were measured at the height of 1.1 m. The wind speed changes between 0.25 and 1.03 m/s in transition season and between 0.26 and 1.98 m/s in summer. The temperature and the relative humidity curves are shown in Fig. 2.

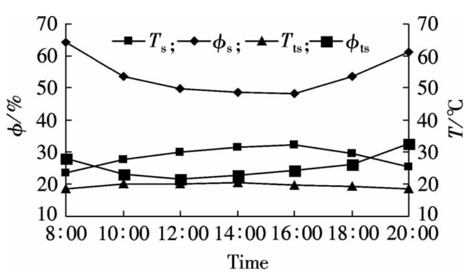

Fig. 2 Temperature and relative humidity

2 Questionnaire Survey

The thermal sensations of the participants in the classrooms are studied by 180 questionnaires. The recovery rate of the questionnaires is 100%. The proportion of males and females is 1:1. The participants seem to adapt to the indoor environments when they have been in the classrooms for more than 15 min.

Thermal comfort can be directly described by thermal sensation vote and humidity perception vote[3,6]. Figs. 3 to 5 show the results of the thermal sensation vote, the humidity perception vote and the draught perception vote. In transition season, most participants feel a little dry and the indoor thermal environment is generally accepted. But in summer, most participants feel hot and slightly moist while others feel moist. The flow of the indoor air is controlled by opening or closing the windows.

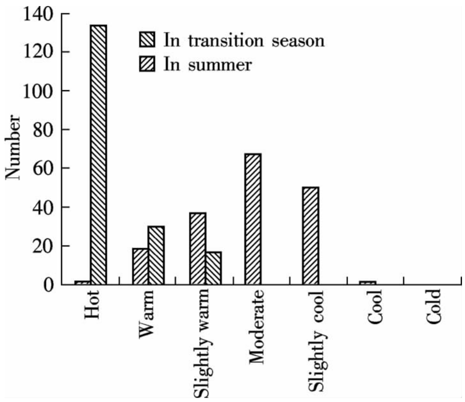

Fig. 3 Thermal sensation vote

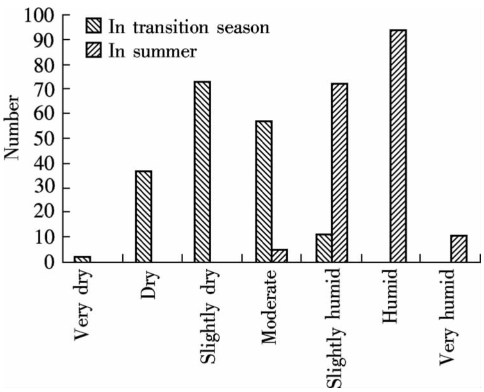

Fig. 4 Humidity perception vote

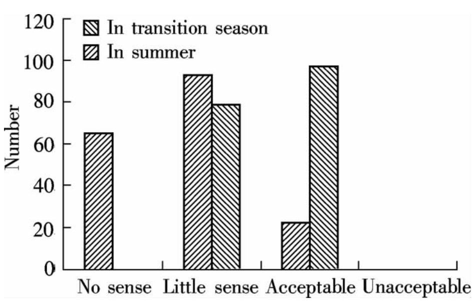

Fig. 5 Draft perception vote

Based on the above analysis, the thermal environment is acceptable in transition season. But under natural ventilated conditions, a higher indoor temperature and a higher indoor humidity have a greater influence on the thermal comfort of a human body in summer. The thermal environment cannot be accepted by most participants in summer. So the whole thermal environmental quality is poor and should be improved in summer.

3 Field Measurement

The physical data including the air temperature, the air relative humidity and the air velocity are measured by a five-point measurement at a height of 1.1 m in the classrooms[7]. Temperature is the most important factor. The indoor temperature and the relative humidity curves in transition season are shown in Fig. 6. The change trends of the indoor temperature are similar to those of the outdoor temperature. Compared with the southern classrooms, the indoor thermal stability in the northern classrooms is better and the temperature change range is greater. The indoor relative humidity is low in transition season. When the relative humidity is between 30% and 85% and the temperature is between 20 and 25℃, the humidity has little impact on the thermal comfort of the human body. Because the measured maximum temperature is 21.5 ℃ in transition season, the impact of the relative humidity on thermal comfort is small.

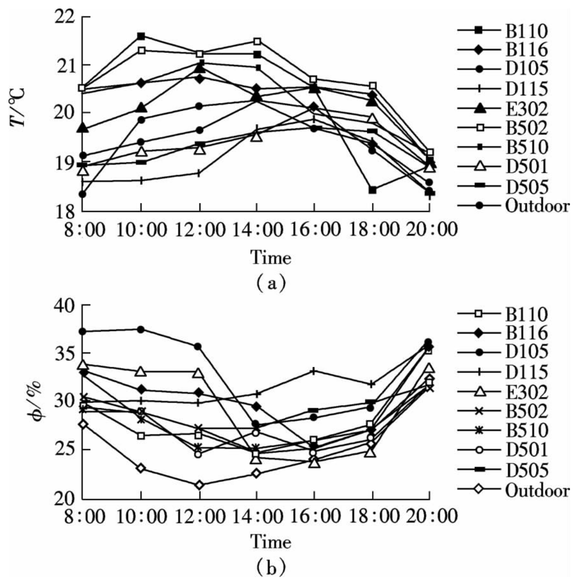

Fig. 6 Temperature and relative humidity of indoor air in transition season. (a) Temperature; (b) Relative humidity

The curves of the indoor temperature and the indoor relative humidity in summer are shown in Fig. 7. The average temperature is over 26.21 ℃. The thermal environment qualities in all tested classrooms in summer are similar.

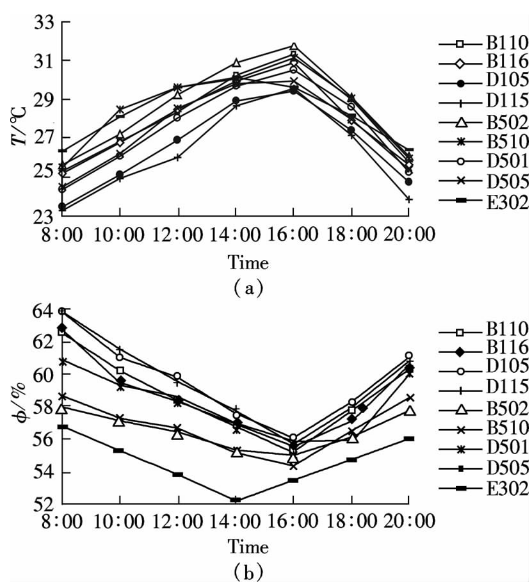

Fig. 7 Temperature and relative humidity of indoor air in summer. (a) Temperature; (b) Relative humidity

Because the indoor temperatures of the classrooms on the first floor in zone D are lower than those in zone B, the thermal environment quality in zone D is better than that in zone B. And the relative humidities of the classrooms in zone D are higher than those in zone B. The relative humidities in summer are almost twice those in transition seasons. If the temperature is above 25 ℃ and the relative humidity is between 30% and 85%, the humidity has a relatively obvious influence on thermal comfort. Therefore, in summer, the influence of the humidity cannot be ignored.

4 PMV of Indoor Thermal Environment

A PMV equation includes six factors: the human metabolic rate, the clothing insulation, the air temperature, the mean radiant temperature, the relative air velocity of flow and the relative humidity[8]. The PMV equation is used to appraise the thermal environment on the basis of the thermal balance between the human body and the thermal environment. Corresponding to the ASHRAE thermal sensation scale which includes seven numbers −3, −2, −1, 0, 1, 2, 3[9], the meanings of these numbers are cold, cool, slightly cool, moderate, slightly warm, warm, hot, respectively. Several assumptions are made as follows:

1) The human metabolic rate is assumed to be 58.2 W/m^2 because the participants keep sitting in the classrooms;

2) The participants' average clothing insulation is 0.713 clo in transition season and 0.337 clo in summer by calculation[1];

3) The heat consumption is assumed to be 0 W;

4) The mean radiant temperature is assumed to be the same as the air temperature because it is difficult to distinguish between them.

The curves of the PMV values in transition season are shown in Fig. 8(a). The change trends of the curves in the classrooms are similar and the PMV values in zone D are smaller than those in zone B. The curves of the PMV values in summer are shown in Fig. 8(b). Most participants feel "hot" from 10:00 to 12:00 and "slightly hot" during the morning and evening in summer.

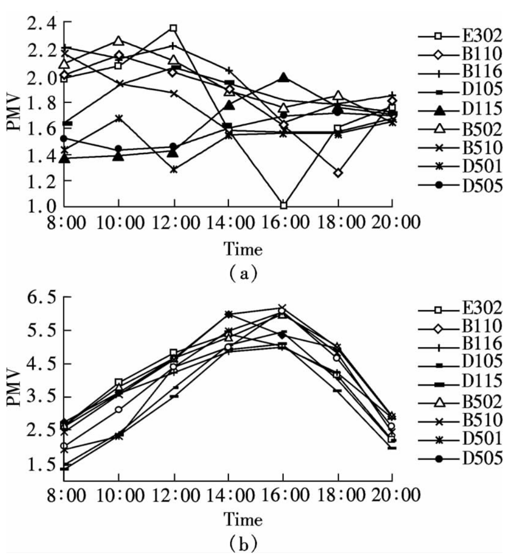

Fig. 8 PMV values in transition season and in summer. (a) In transition season; (b) In summer

5 DeST Simulations

The DeST software is adopted to simulate the changes in the indoor temperatures under natural ventilation condition in the classrooms. The simulation temperature curves in transition season are shown in Fig. 9(a). The change trends of the simulated temperatures in all the classrooms are similar except for E302. Compared with other classrooms, the temperature in E302 is higher from 7:00 to 12:00 and the temperature range changes more greatly. The simulated temperature curves in summer are shown in Fig. 9(b). The simulated temperatures in the classrooms are similar. The changes in the temperature ranges are still relatively great in E302. The temperature in E302 quickly increases after 6:00 and gradually decreases after 11:00. Thus, the change trends of the measured and simulated temperatures are similar.

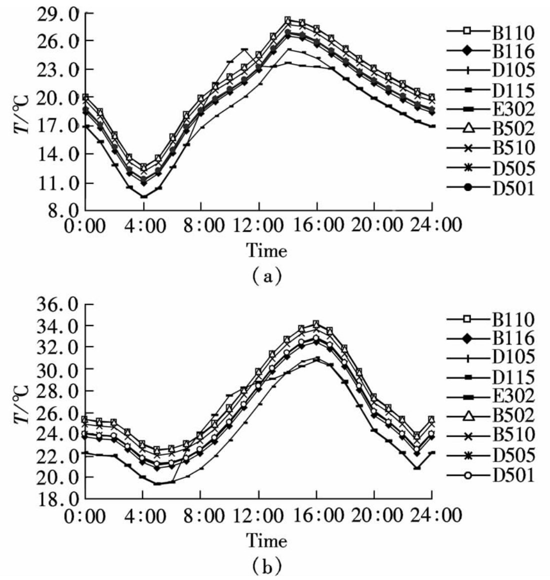

Fig. 9 Simulated temperature curves in transition seasons and in summer. (a) In transition seasons; (b) In summer

The simulated results are similar to the results of the field measurements. The DeST software is accurate in simulating the indoor temperature. So the method combining the field measurement and the DeST simulation is advisable.

6 Conclusions

The results of the thermal sensation vote and the field measurement show that in transition season, the indoor thermal sensations of the participants are "moderate". However, in summer, the indoor thermal sensations of the participants are "slightly hot" and even "hot" between 12:00 and 18:00. The indoor thermal environments on the first floor in the northern classrooms are relatively better than those in other classrooms in transition season and in summer.

The corresponding measures are put forward to improve the indoor thermal environments in transition season and in summer as follows:

1) The natural ventilation should be frequently adopted. When the natural ventilation does not meet the ventilation requirement, the machinery ventilation can be used as a supplementary means to advance the ventilation in summer.

2) The air supply by a central air conditioning system should be adopted to improve the heat exchange efficiency.

3) Green coverage outside the classrooms should be increased by planting trees.

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某高校教室室内热环境分析及数值模拟

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摘要:为了研究天津地区高校教室室内的热环境状况,以天津某高校主教学楼为研究对象,进行了现场测试和问卷调查. 首先,收集了 180 份问卷用以调查参与者在教室内的热感觉. 然后,以现场测量数据为基础,利用 DeST 软件对全年教室内的温度变化进行模拟. 研究结果表明:在过渡季节和夏季,教学楼一楼阴面的教室室内热环境较好;现场测试结果与模拟结果一致. 该结果对研究其他季节室内热环境提供了参考依据.

关键词:高校教室; 室内热环境; 现场测量; DeST 模拟

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