Experimental Research on Indoor Thermal Environment Control and Work Efficiency

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Abstract: In order to explore the relationship between work efficiency of office staff and human thermal sensation index PMV, in this paper, the method of combining experimental test and subjective evaluation is adopted to bring seasonal preference into the research scope of work efficiency, and the experimental data are analyzed by quadratic regression. It was found that the highest working efficiency of indoor staff did not appear in the thermal neutral state, but in the preferred environment. Subjects preferred slightly warm indoor environment in heating season and slightly cool indoor environment in transition season. This paper can provide some reference value for the study of the factors affecting the work efficiency of indoor staff.

1. Introduction
Indoor thermal environment has a great impact on indoor personnel's comfort and work efficiency. A large number of scholars have studied the relationship between single indoor environmental parameters and work efficiency. It is necessary to further study the relationship between indoor thermal environment and indoor working efficiency. Ye xiaojiang et al. of Shanghai jiaotong university conducted experiments in two factories in zhenjiang and Shanghai. Through environmental parameter measurement and questionnaire survey, they found that when employees are in thermally neutral state, their work efficiency is not the highest, but the highest in a slightly cool environment. There are many disputes about the relationship between indoor thermal environment and working efficiency of indoor personnel, and whether the most comfortable state of indoor personnel is the most efficient state has not been determined. In order to deeply study the influence of indoor thermal environment (temperature and humidity) of central air conditioning system on personnel's work efficiency and find the intelligent control method of indoor thermal environment that can maximize work efficiency, this paper conducts preliminary experimental research.

2. Experimental preparation
The test bench (Figure 1) is set up in a teacher's office in a university in Beijing. The experimental site is an office space divided into three workstations. In this experiment, Stroop test (Figure 2) and clock test (Figure 3) were selected to better meet the working difficulty of office staff. Response time and error number in the test were used to reflect the working efficiency of indoor staff.
3. Heating season experiment
In the experiment, in order to ensure comfort requirements and time constraints, the test conditions were set to -1, 0, +1 three. The subjects were allowed to wear the same thermal resistant clothing, and then the radiant temperature, relative humidity and relative wind speed of the experimental environment were measured, and the corresponding PMV conditions were achieved by controlling the indoor air temperature.

3.1. Self-reported data analysis
By collecting and sorting out the data of thermal sensation and thermal comfort in the questionnaire survey of the subjects, it can be concluded that the thermal sensation and thermal comfort under different PMV conditions vary greatly in the working and rest stages. Quadratic regression analysis was used, as shown in Figure 4.

The number in the ordinate of Figure 5 means the degree of change of pressure of subjects compared with the last time they answered the questionnaire. The number 4 represents the constant pressure; the larger the number is, the more the pressure increases; on the contrary, the pressure decreases. It can be seen from the figure, the stress level of the subjects has been decreasing in the rest phase. In the working phase, when the subjects are in the cold state, the pressure tends to decrease.
When the subjects are in the normal and hot state, the pressure level increases and decreases with the beginning and the end of the work.

Figure 4. Changes of thermal comfort of subjects at different stages.

From Figure 6 (the meaning of the ordinate is the same as above), when the subjects are in the optimal thermal comfort state, they can pay more attention. The best resting PMV value was obtained by using quadratic regression curve. In Figure 7, the ordinate is the rest effect, and the abscissa is the PMV value, so when PMV=0.12, the rest effect is the best. Here, PMV=0.12 is the environmental condition with the highest resting efficiency, and PMV=0.1943 is the most comfortable resting condition.

Figure 5. Changes of stress in subjects at different stages.

Figure 6. Changes in concentration at different stages.

Figure 7. Resting effect of subjects under different PMV.
3.2. Cognitive task data analysis
When PMV = -1, 0 and 1, the number of errors in Stroop experiment and response time in clock test are shown in the figure. According to the number of errors in cognitive tasks and response time, both errors and response time decrease with the warming of indoor environment.

3.3. Summary of heating season experiment
For the heating season, the PMV value of the most comfortable state of the subjects is PMV=0.445 in the working stage, PMV value of the most comfortable state is PMV=0.1943 in the rest stage, and PMV value in the highest rest efficiency is PMV=0.12.

4. Transition season experiment
The transition season experiment was divided into six working conditions: PMV= 0.5, PMV= 0, PMV=-0.5, PMV= -1, PMV= -1.5, and PMV=-2. In the experiment, we will test the radiation temperature, relative humidity, relative wind speed and indoor air temperature of the experimental environment, and achieve the corresponding PMV conditions only by controlling the thermal resistance of the subjects' clothing.

4.1. Self-report data analysis
The self-report section obtained data from the questionnaire survey, including the results of thermal sensation, thermal comfort, pressure changes, changes in concentration and rest levels. Experimental data were analyzed by quadratic regression, as shown in Figure 8.

![Figure 8. Changes of comfort level of subjects at different stages.](image-url)

As can be seen from Figure 8, PMV values for the most comfortable state of work and rest in the transition season are all negative, indicating that subjects prefer a slightly cold environment in the transition season. According to the data sorting and analysis of pressure changes and concentration changes of subjects at different stages (as with the heating season experiment, I will not repeat them here), Figure 9 is obtained.
4.2. Cognitive task data analysis
According to the average number of errors and the average reaction time in the clock test, the number of errors and the reaction time both decrease and increase with the cooling of indoor environment, reaching the minimum value in the micro-cooling condition. Combined with the heating season experiment, the following conclusions can be drawn: for the heating season working condition, when the indoor environment is slightly warm, the working efficiency and rest efficiency of indoor personnel are relatively high; for the transition season working condition, when the indoor environment is slightly cold, the working efficiency and rest efficiency of indoor personnel are relatively high. Figure 10 shows the change curve of work efficiency of subjects with PMV value in transition season:

4.3. Summary of the transition season experiment
After the improvement of the experimental scheme, the author conducted further experiments in six PMV conditions in the transition season. For the transition season experiment, the subjects preferred a slightly cold environment. When the indoor environment was slightly cold, the indoor staff had higher work efficiency and rest efficiency.

5. Conclusion
In order to further study the influence of indoor thermal environment (temperature and humidity) of central air conditioning system on personnel's work efficiency, the subjects were tested and self-
evaluated under different PMV environments in heating season and transition season, as shown in Table 1:

| Season          | Options                  | Work stage | Rest stage |
|-----------------|--------------------------|------------|------------|
| Heating season  | Highest thermal comfort  | PMV=0.445  | PMV=0.1943 |
|                 | Highest efficiency       | Not measured| PMV=0.12   |
| Transition season| Highest thermal comfort  | PMV=-0.869 | PMV=-0.794 |
|                 | Highest efficiency       | PMV=-0.81  | PMV=-0.77  |

It was found that the highest working efficiency of indoor staff did not appear in the thermal neutral state, but in the preferred environment. Subjects preferred slightly warm indoor environment in heating season and slightly cool indoor environment in transition season. This experimental research has certain reference value to the practical application of indoor thermal environment control system based on maximum work efficiency.

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