Indoor Thermal Environment Control System Based on Maximum Work Efficiency

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Abstract. Based on the indoor thermal environment on the influence of the office personnel work efficiency on the basis of experimental research. In this paper, a control method based on maximizing work efficiency is proposed, which aims at maximizing indoor staff's work efficiency and rest efficiency, and takes Predicted Mean Vote (PMV) as control parameter to control indoor environment, taking into account the requirements of comfort. The operation effect of the control method based on maximum work efficiency is estimated. It is found that compared with the traditional control system based on PMV index, the system not only improves the work efficiency and rest efficiency of indoor personnel, but also is more comfortable. The indoor environment control system based on maximizing work efficiency is still in the theoretical stage. The construction and actual operation effect of the system need to be further studied.

1. Introduction
People began to study the indoor thermal comfort of human body in the 1940s. Many researchers have studied how to apply the existing thermal comfort indicators (such as PMV) to indoor thermal environment control, considering various environmental factors, hoping to achieve a comprehensive comfortable indoor environment. The common indoor thermal environment control method is through building automation system or user set temperature value to control. However, the experimental results show that the user-set temperature values can not maximize the efficiency of indoor workers, and even more than 50% of the temperature setting values do not meet the comfort range of 23.5-27 degrees Celsius in summer [1].Because there are many drawbacks in direct temperature control, researchers have tried many new control methods. Marc Fountain et al. use the fuzzy control method, and only have two options of "heating room" and "cooling room" [2]. Weixiong He has disclosed a patented human comfort sensor, which has a human motion detector for acquiring human thermal and cold perception information, and a microprocessor for calculating and judging the perception information output by the human motion detector, and then automatically controls the operation of the air conditioner [3]. Professor Fulin Wang of Tsinghua University summarized the development process of indoor thermal environment automatic control methods into four stages: temperature setting value control method, PMV parameter control method, thermal sensation expression control method and thermal sensation predictive control method [4]. Henderson et al. changed the control strategy of setting temperature to that of setting PMV. Through simulation, it was found that in most cases, the purpose of improving indoor comfort and reducing energy consumption of air conditioning system was achieved [5]. Liangjie Zhang et al. used PMV=0 as the target of thermal environment control and air conditioning intelligent controller for thermal environment control method [6]. Jiaming Xu’s patent refers to an indoor environment control system, which can regulate the parameters of temperature,
wind speed, humidity, air pressure and light brightness that will affect human thermal comfort, and improve human living environment [7]. Therefore, the author puts forward a control system based on maximizing work efficiency, taking into account the requirements of comfort, and strives to provide a more efficient and comfortable working and learning environment for people.

2. Control System Based on Maximizing Work Efficiency
The control system based on maximizing work efficiency is shown in Figure 1, which is divided into three parts: information collection module, intelligent control module and terminal execution module.

![Figure 1. Flow diagram of control system based on maximizing work efficiency](Image)

① Experimental environment information; ② Experimental result information; ③ Subject information; ④ Indoor environment information; ⑤ Indoor personnel information; ⑥ Information collection module; ⑦ Intelligent control module; ⑧ End-execution module; ⑨ Fan; ⑩ Fan coil; ⑪ Radiation ceiling; ⑫ Air humidifier; ⑬ Air dryer

3. Estimation of operation effect of control system
Through the analysis of the literature and the experimental verification of the influence of indoor thermal environment on the work efficiency of office workers (see Table 1), it can be seen that for easterner, when the environmental parameter PMV = 0, the human body is not in the best thermal comfort state, and the work efficiency is not the highest. Therefore, the seemingly reasonable control goal of PMV = 0 cannot bring us the most efficient and comfortable working and living environment.

| Season          | Option                  | Working phase | Resting phase |
|-----------------|-------------------------|---------------|---------------|
| Heating season  | Highest thermal comfort | PMV=0.445     | PMV=0.1943    |
|                 | Highest Efficiency      | Not measured  | PMV=0.12      |
| Transition      | Highest thermal comfort | PMV=-0.869    | PMV=-0.794    |
| season          | Highest Efficiency      | PMV=-0.81     | PMV=-0.77     |
In this paper, a control system based on the maximization of work efficiency is proposed, which takes the maximization of work efficiency as the primary objective and takes into account the requirement of comfort. At present, the system is estimated by using the existing experimental data (the experimental data of transition season improved by the experimental scheme to ensure the accuracy of the estimation results), and the results show that the system improves the work efficiency, rest efficiency and comfort compared with the traditional system with PMV=0 as the control target.

3.1. Estimation of Work Efficiency Improvement
When the number of errors in the clock test is $Z$ and the reaction time is $t$, the correct rate is $x=(500-Z)/500$ (Note: 500 is the total number of clock beats in the clock test). When $y=500/t$ is used to express the working speed of the subjects, $XY$ can reflect the working efficiency. In the experimental study of the influence of indoor thermal environment on the working efficiency of office workers, the relationship between PMV and $XY$ is described by data analysis. The quadratic regression curve formula of the relationship:

$$xy = -0.1033PMV^2 - 0.1667PMV + 1.2238$$ (1)

It is known that the working efficiency of PMV=-0.81 is the highest in the transition season. Under this condition, $xy=1.29$. The working efficiency of PMV=-0.81 is 100%. The working efficiency can be calculated by the following formula:

$$\eta = \frac{-0.1033PMV^2 - 0.1667PMV + 1.2238}{1.29}$$ (2)

It can be seen from the figure above, compared with the thermal neutrality (PMV = 0) control adopted by the ordinary PMV parameter control method, the indoor staff's work efficiency has been improved by 5.4%.

3.2. Estimation of Rest Efficiency Improvement
According to the questionnaire data obtained from the self-evaluation of the subjects in the transition season experiment, the quadratic regression curve formula describing the relationship between resting effect $R$ and PMV was obtained through analysis in the experiment part.

$$r = -0.2324PMV^2 - 0.3559PMV + 4.2977$$ (3)

It is known that the rest efficiency is the highest at PMV=-0.77 in the transitional season. Under this condition $r=4.434$, the work efficiency at PMV=-0.77 is 100%. The rest efficiency can be calculated by the following formula:

$$\eta = \frac{-0.2324PMV^2 - 0.3559PMV + 4.2977}{4.434}$$ (4)

It can be seen that compared with the thermal neutrality (PMV = 0) control adopted by the ordinary PMV parameter control method, the degree of comfort of the indoor staff has increased by 3.17%.

3.3. Estimation of Comfort Improvement in Working Stage
According to the questionnaire data obtained from the self-evaluation of the subjects in the transition season experiment, the thermal comfort evaluation $m$ (1 is very comfortable, 2 is comfortable, 3 is a little uncomfortable, 4 is uncomfortable, 5 is very uncomfortable, 6 is intolerable) in the questionnaire was transformed into the percentage index $s$. The conversion formula is as follows:

$$s = \frac{6-m}{6} \times 100$$ (5)

The percentile comfort index was used to describe the average thermal comfort of the subjects under different PMV conditions during the working stage. As shown in Table 2, the quadratic regression analysis was carried out from the data in Table 2.
### Table 2. Subjects Comfort at Work Stage

| Stage         | Working condition | Subject Comfort Index (Percentage System) |
|---------------|-------------------|------------------------------------------|
| Working stage | PMV=0.5           | 54.17                                    |
|               | PMV=0             | 62.5                                     |
|               | PMV=-0.5          | 61.67                                    |
|               | PMV=-1            | 62.5                                     |
|               | PMV=-1.5          | 63.83                                    |
|               | PMV=-2            | 57                                       |

By quadratic regression analysis, the relationship between the comfort index (percentage system) and PMV working conditions was obtained as follows:

\[ s = -4.7971PMV^2 - 8.2797PMV + 60.265 \]  \( (6) \)

According to the experimental part, the indoor environment control system based on maximizing work efficiency will run under the condition of PMV=-0.81. At this time, the comfort index of the subjects is 63.84, while the ordinary PMV parameter control method runs under the condition of PMV=0, and the corresponding comfort index s of the subjects is 60.27.

It can be concluded that in the working stage, the comfort of indoor personnel is increased by 5.92% compared with the thermal neutrality (PMV = 0) control adopted by the ordinary PMV parameter control method.

### 3.4. Estimation of Comfort Improvement in Rest Stage

According to the questionnaire data obtained from the self-evaluation of the subjects in the transitional season experiment, the percentage system was used to describe the average thermal comfort of the subjects under different PMV conditions during the rest period. As shown in Table 3, the quadratic regression analysis was carried out from the data in Table 3.

### Table 3. Comfort during the rest period

| Stage         | Working condition | Subject Comfort Index (Percentage System) |
|---------------|-------------------|------------------------------------------|
| Rest stage    | PMV=0.5           | 54.69                                    |
|               | PMV=0             | 63.02                                    |
|               | PMV=-0.5          | 60.65                                    |
|               | PMV=-1            | 62.04                                    |
|               | PMV=-1.5          | 66.2                                     |
|               | PMV=-2            | 54.17                                    |

By quadratic regression analysis, the relationship between comfort index (percentage system) and PMV working conditions was obtained as follows:

\[ s = -5.4057PMV^2 - 8.5846PMV + 60.672 \]  \( (7) \)

According to the experimental part, the indoor environment control system based on maximizing work efficiency will run under the condition of PMV=-0.77, when the comfort index=64.08, while the ordinary PMV parameter control method runs under the condition of PMV=0, the corresponding comfort index=60.672.
It can be concluded that in the rest stage, compared with the thermal neutrality (PMV = 0) control adopted by the ordinary PMV parameter control method, the comfort of indoor personnel is increased by about 5.62%.

4. Conclusion
In this paper, a control method based on maximizing work efficiency is proposed, and its operation results are estimated. The system aims at maximizing the work efficiency and rest efficiency of indoor personnel, and takes PMV as the control parameter to control indoor environment, taking into account the requirements of comfort. The control system is mainly composed of information collection module, intelligent control module and terminal execution module. It can collect the information of the subjects in the early stage to expand the sample of this experiment, and also can intelligently control the indoor environment, providing a more efficient and comfortable working and learning environment for people. By estimating the operation effect of the system, it is found that compared with the traditional PMV-based control system, the working efficiency of indoor personnel in the system is increased by 5.4%, rest efficiency by 3.17%, work stage comfort by 5.92% and rest stage comfort by 5.62%. The system not only satisfies the improvement of indoor staff’s work efficiency and rest efficiency, but also provides a more comfortable environment for indoor staff. However, the control system based on maximizing work efficiency is still in the theoretical stage, and the construction and effect of the actual control system need to be further studied.

References:
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