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Research on Energy Conservation of VAV System Based on PMV Control

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Abstract
Aiming at the problem that the size of the temperature set value in the temperature control strategy of VAV system is determined by human experience, which may lead to the uncomfortable indoor environment and the waste of energy, the simulation model of an existing office building and VAV system in Shanghai were built based on TRNSYS software, Taking the thermal comfort index PMV as the control target, the simulation operation of the built model was carried out, and the thermal comfort and energy conservation benefits of the two control strategies were analyzed and compared. The results show that the temperature control strategy cannot meet the real time thermal comfort requirements of human body, PMV control strategy is always in a more comfortable indoor environment and has better energy conservation benefits compared with the temperature control strategy.

Keywords: *TRNSYS; VAV system; Thermal comfort; Energy conservation.*

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I. INTRODUCTION

In now days, people are in buildings most of the time, a comfortable indoor environment can make people happy and increase work efficiency, on the contrary, an uncomfortable indoor environment will increase the chances of people suffering from building syndrome and absenteeism [1,2]. Therefore, to improve people's quality of life, a comfortable indoor environment must be created. Air conditioning system is an important equipment to create a comfortable indoor environment. With the number of air conditioning system continues to grow, energy consumption continues to increasein China. Available research data indicate that the total energy consumption of building operation in China accounted for about 22% of the total national energy consumption in 2018 [3], and the energy consumption of air conditioning systems accounted for about 30% to 50% of the total building energy consumption [4]. Energy conservation and emission reduction have become a consensus.

The common control strategy of air conditioning system is temperature control, andthe temperature setting value is basically determined by the user's experience, which will lead to unreasonable temperature settings and energy waste in different scenarios. Related studies have shown that air conditioning systems save 5-10% energy for every 1°C reduction in heating time [5] and 10-20% energy for every 1°C increase in cooling time in temperature setting [6].

PMV is an index for evaluating human thermal comfort, and the International Standards Organization (ISO) established the ISO7730 standard in 1984, in which the recommended value of PMV is between -0.5 and +0.5 [7]. The value of PMV is related to the temperature, wind speed, relative humidity, average radiation temperature, thermal resistance of clothing and metabolic rate of human body in the indoor environment. Di Y H et al [8] studied the effect of indoor wind speed on human thermal comfort in office buildings in summer and showed that under the set thermal environment conditions, the wind speed that the test subjects could accept ranged from 0.15 to 0.35 m/s, and the wind speed that felt neutral was 0.3 m/s. Huang W X et al [9] studied the thermal comfort of side-feed and side-return air supply for air conditioning in a conference room in summer working conditions and showed that indoor temperature and air speed have a greater impact on human thermal comfort.

Research on thermal comfort index control started earlier in western countries. MacArthur et al [10] used PMV value as the control target of air conditioning system, and the research results showed that the energy saving effect can reach 5%~14% compared with temperature control; Sajid Hussain et al [11] used a joint simulation method of MATLAB and Energy Plus to study the comfort and energy efficiency of air conditioning systems based on PMV control, and the results showed that the energy savings could reach 16.1% and 18.1% for cooling and heating conditions. Chinese scholars have also made many research achievements in the field of thermal comfort control. such as Zhang L J [12], who designed the "Shu Yi" intelligent air conditioning controller based on neural network algorithm and fuzzy control technology with PMV value as the control target; Wei D [13], who established a thermal comfort index prediction model for air conditioning system control based on artificial neural network; Zhou W F [14] indirectly controlled the PMV index based on wireless sensor networks and mobile devices to provide a comfortable indoor environment for users.

Aiming at the problem that most PMV control strategies use indirect control, which use one or more of the factors affecting the PMV value as the control parameters to indirectly achieve the control purpose lead to slow control speed, this paper established a simulation model of an existing office building and air conditioning system based on TRNSYS software, and adopts the PMV direct control strategy, which use PMV value as the control parameter of air conditioning system, and the real time data of indoor environment and air conditioning system parameters are obtained to explore the thermal comfort and energy conservation benefits of VAV air conditioning system based on PMV value control more accurately and dynamically.

1 Variable air volume air conditioning system

Variable air volume air conditioning system (VAV system) is an all-air air conditioning system that adjusts the air volume delivered to the room in real time according to the size of the room load to achieve the required temperature and humidity requirements [15], and the principle of VAV system composition is shown in Figure 1, including four main components: Air terminal device, Air conditioning and transportation equipment, Air-line system, and Automatic control system. Air terminal device(VAV box)can receive instructions from the controller and automatically adjust the air supply volume to achieve temperature control; Air conditioning and transportation equipment treats and provides power to the air; Air-line system delivers air to the designated location; Automatic control system measures the parameters of the controlled object and issues commands to the actuating elements, which is a crucial component to achieve the function of the VAV air conditioning system.

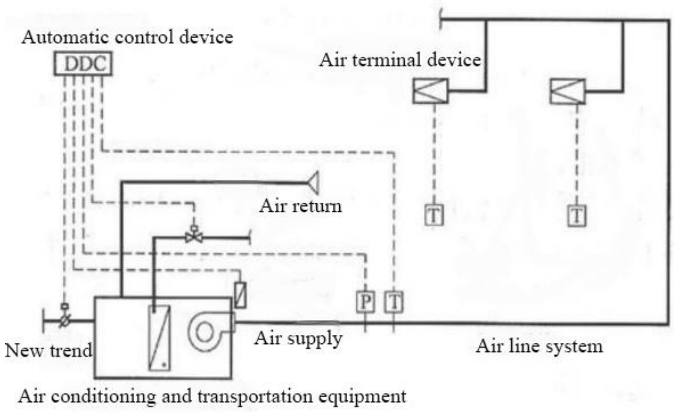

Fig.1 Schematic diagram of VAV system

2 TRNSYS Modeling

TRNSYS is a transient system simulation program, which consists of the following parts: 1) TRNBuild building model building platform, setting building envelope parameters and indoor load parameters; 2) Simulation Studio model building and simulation platform, calling and creating modules; 3) Formation of TRNEdit and TRNExe terminal programs; 4) TRNOPT Optimization simulation calculation. The transient simulation is completed by combining each part with each other.

2.1 Building model construction

The building is an existing office building in Shanghai, and a total of 8 offices on two floors are selected for modeling and simulation, and the shape parameters of each office envelope are shown in Table 1.

Table 1 Parameters of envelope structure

Office	L×W×H (m)	Window Orientation	Window area (㎡)
1-1	7×6×3	south	7.5
1-2	7×6×3	south	7.5
1-3	6×4×3	north	5.4
1-4	6×4×3	north	5.4
2-1	7×6×3	south	7.5
2-2	7×6×3	south	7.5
2-3	6×4×3	north	5.4
2-4	6×4×3	north	5.4

Based on TRNBuild platform, the offices are modeled and the external dimensions and related parameters are input, where the heat transfer coefficient of the external walls is 1.5W/(㎡ • K); the heat transfer coefficient of the external windows is 3W/(㎡ • K) and the shading coefficient is 0.3; the internal walls and the upper and lower floors do not exchange heat with the outside world; the parameters of internal heat sources such as personnel, equipment and lights are set as shown in Figure 2 below.

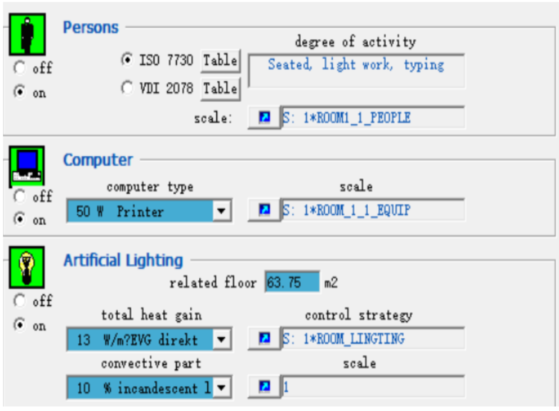

Fig. 2 Internal heat source parameters setting

2.2 Variable air volume air conditioning system construction

The TRNSYS simulation model consists of three parts: building model, atmospheric parameters, and air conditioning system. In TRNSYS, we call the meteorological parameters of Shanghai and the required building and variable air volume air conditioning system modules to build the model and set the corresponding parameters, and the built model is shown in Figure 3.

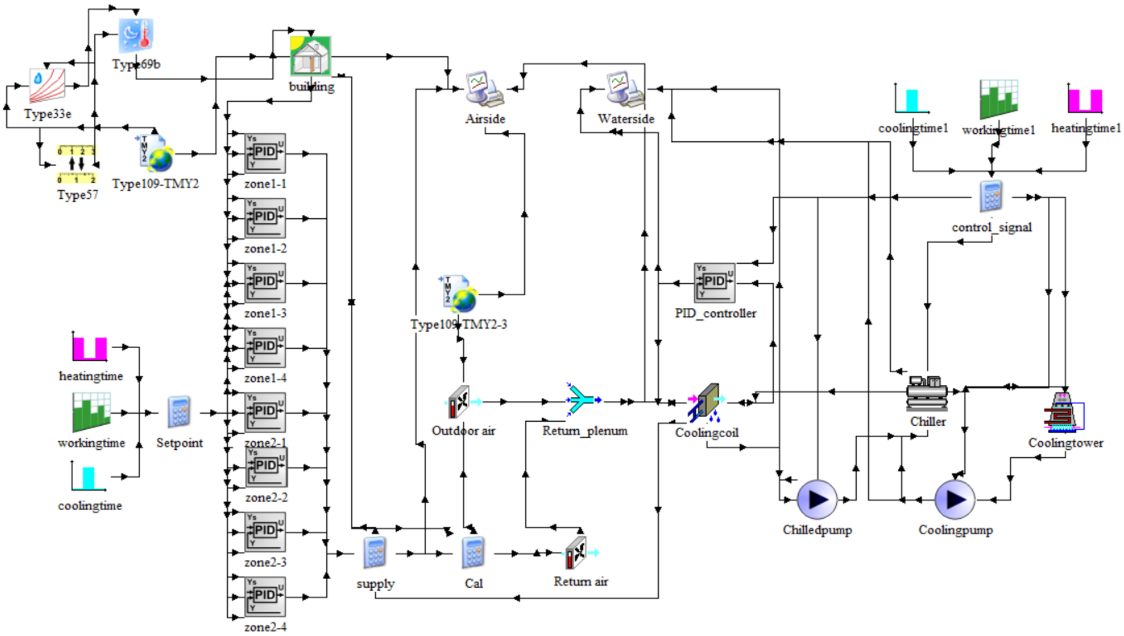

Fig. 3 Simulation model of VAV system

2.3 Model operation logic

The system runs on an hourly basis throughout the year, from 2160 ~ 6192 hours during the cooling season, whichfrom April 1 to September 15, and from 0 ~ 2160 hours and 6192 ~ 8760 hours during the heating season, whichfrom January 1 to March 31 and from September 16 to December 31, and the system works from 8:00 to 18:00 every day.

2.3.1 Air supply logic

The size of the air supply volume of the VAV air conditioning system is controlled by the end device VAV box, but there is no such module in TRNSYS, so the PID module is used to achieve the same function.

The temperature control takes the room set temperature as the control parameter; the thermal comfort control takes the thermal comfort index PMV as the control parameter.

2.3.2 Water circuit operation logic

The water-side model of the VAV air conditioning system consists of two parts: the chilled water circuit and the cooling water circuit. The chilled water forms a chilled water circulation water circuit between the chiller and the fan coil under the action of the chilled water pump, and the cooling water forms a cooling water circulation water circuit between the chiller and the cooling tower under the action of the cooling water pump.

2.4 Model validation

Based on the built variable air volume air conditioning system model selected summer working conditions from August 1 to August 7(5088 ~ 5256 hours) for simulation, the temperature setting value of 24 ℃ .The results are shown in Figure 4, the temperature of each office in the daily working hours can be adjusted by the variable air volume air conditioning system to maintain near the set value, the system shut down back to the natural state, and so on, with the model set up stage the working hours and the expected control results are consistent with the model construction stage, which verifies the accuracy and reasonableness of the model.

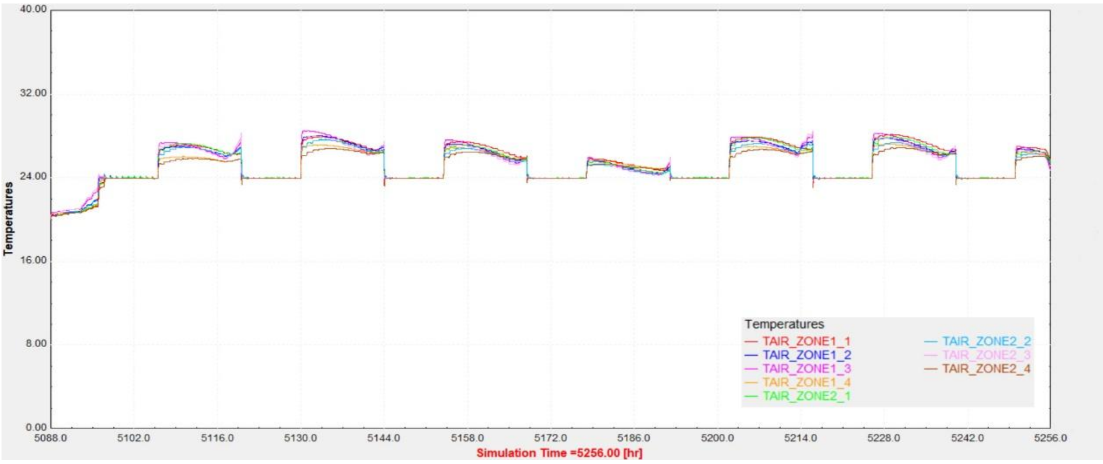

Fig. 4 Operation simulation in summer

3 Simulation analysis

The summer working condition of August 1, which from 5088 to 5112hours, is selected for the comparison and analysis of office 1-1 in terms of indoor thermal comfort and energy conservation benefits by using temperature control and PMV control respectively.

3.1 Thermal comfort analysis

The value of PMV is related to the temperature, wind speed, relative humidity, average radiation temperature, clothing thermal resistance and human metabolic rate of the indoor environment. The parameter settings are selected as the human metabolic rate of the office 1.2met, the thermal resistance of typical clothing in summer 0.5clo, and the rest of the parameters are obtained according to TRNSYS simulation. The temperature control takes temperature as the control target, and the set value is 24°C. The simulation output is shown in Figure 5. The variable air volume air conditioning system keeps the indoor temperature near 24°C by continuously adjusting the air supply volume after opening at 8:00 and returns to the natural state after closing at 18:00. The room temperature is maintained near the set value during the operation phase of the air conditioning system, however, other factors affecting human thermal comfort are constantly changing, so the thermal comfort index PMV value is constantly changing, the range of change is -0.7~0.4, the PMV index in ISO7730 standard divides the human body into seven levels of hot and cold sensation, from -3~3 indicates the human body's hot and cold sensation, the specific levels are divided as shown in Table 2, when PMV is 0, the human body The recommended range is -0.5~0.5, and the indoor environment cannot always be in the most comfortable state under the temperature control strategy.

The thermal comfort control directly uses PMV value as the control target with a set value of 0. The simulation output results are shown in Figure 6. The indoor PMV value is adjusted to 0 after the variable air volume air conditioning system is turned on and is always kept near the value of 0 during the stable operation phase, and the personnel during the working time are always in a comfortable indoor environment. However, the indoor temperature keeps changing, and the range of change is 24~26.6℃, compared to the temperature control most of the time the indoor temperature increases by 1-2℃, and the indoor environment is more comfortable and more energy conservation at the same time.

Table 2 PMV indicator grading table

PMVint	PMV
-3 Cold	< -2.5
-2 Cool	-2.5~-1.5
-1 Slightly cool	-1.5~-0.5
0 Moderate	-0.5~0.5
1 Slightly warm	0.5~1.5
2Warm	1.5~2.5
3Hot	> 2.5

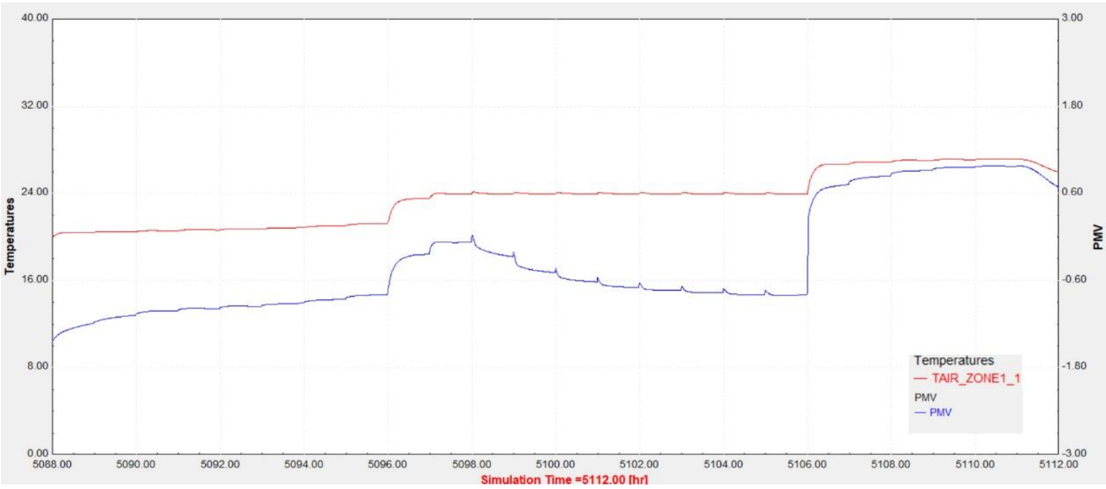

Fig. 5 Simulation results of temperature control

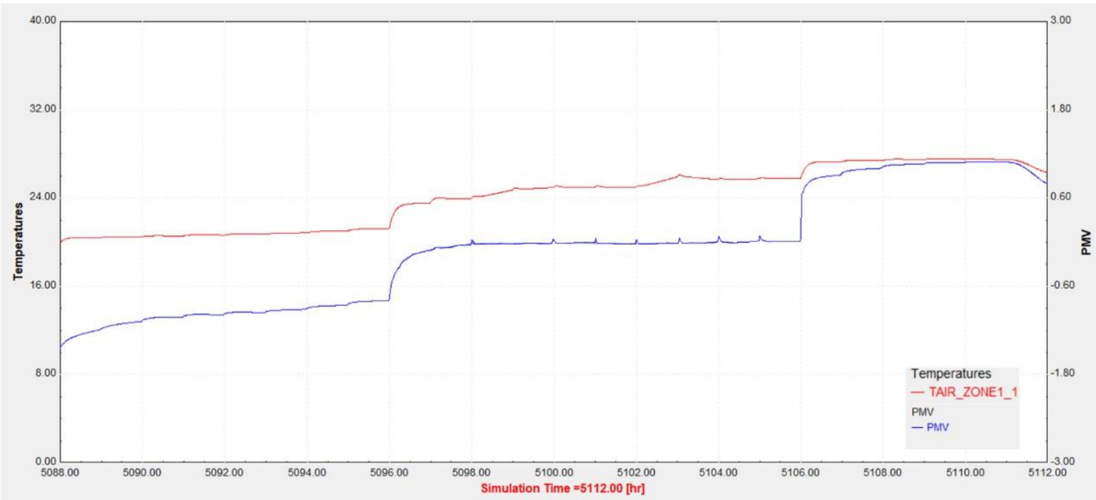

Fig. 6 Simulation results of PMV control

3.2 Energy consumption analysis

To calculate the energy consumption of the building on August 1(5088 ~5112hours), the realtime power of the chiller in the model was output, and the simulation operation results are shown in Figure 7. The total energy consumption of the chiller is about 365.6 Kw • h. The power of the chiller in the stable operation stage of PMV control strategy is about 31.51 Kw, and the total energy consumption is about 315.1 Kw • h.

Compared with the temperature control strategy, the energy consumption is reduced by 50.5 KW • h, saving 13.8%.

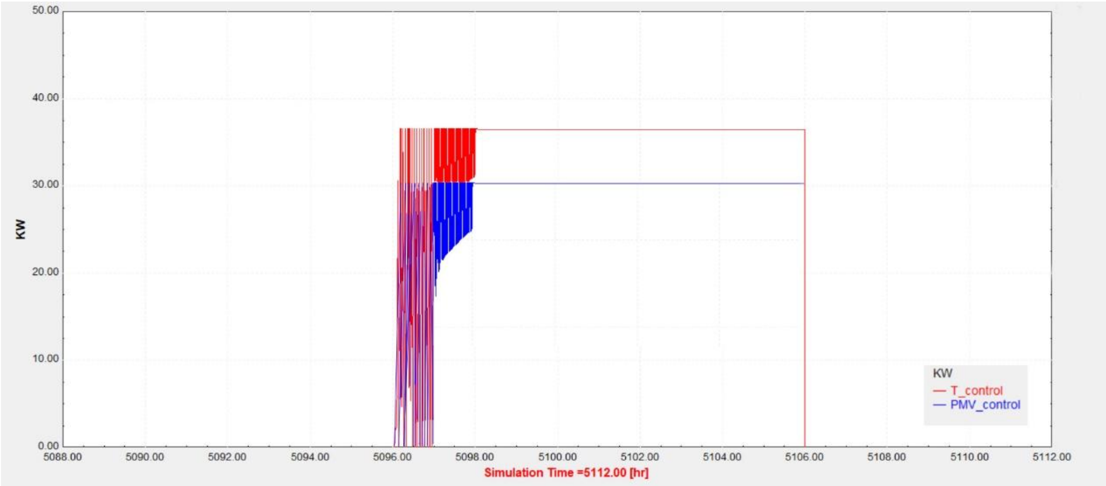

Fig. 7 Power of chiller

II. CONCLUSION

(1) The temperature control strategy of VAV air conditioning system cannot meet the demand of human thermal comfort in real time and may cause waste of energy, so the PMV control strategy of thermal comfort index can be considered.

(2) The PMV value of the VAV air conditioning system operating under the PMV direct control strategy is always kept within the comfort range, and the human body is in a good and comfortable indoor environment.

(3) PMV direct control strategy has a good energyconservation effect, and the energy consumption of chiller operation is 13.8% less than that of temperature control strategy operation.

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