Research on the operation control strategy of the cooling ceiling combined with fresh air system

Tao Huang¹ and Hao Li²
¹Institute of Building Environment and Energy, China Academy of Building Research, Beijing, 100018, China
²School of Mechanical Engineering, Tianjin University, Tianjin, China

E-mail: huangtao_ht@126.com

Abstract. The cooling ceiling combined with independent fresh air system was built by TRNSYS. And the cooling effects of the air conditioning system of an office in Beijing in a summer typical day were simulated. Based on the “variable temperature” control strategy, the operation strategy of “variable air volume auxiliary adjustment” was put forward. The variation of the indoor temperature, the indoor humidity, the temperature of supplyi

1. Introduction

The advantage of cooling ceiling system is different from traditional air-conditioning system for it has more energy saving potential, and can make the indoor environment more comfortable and healthy. Therefore, it attracts extensive researches and attentions in recent years [1]. But in practical engineering applications, especially in hot and humid areas in summer, the phenomenon on the condensation of radiant roof often occurs because of the improper control of the system. In addition, due to the cooling capacity is small and the room temperature is difficult to control, the popularization and application of cooling ceiling system are hindered seriously[2]. In the cooling ceiling combined with independent fresh air system, the fresh air is sent into the room after the process of dehumidification and cooling, the fresh air not only can undertake indoor wet load and a certain extent indoor cooling load, but also meet the needs of the indoor fresh air. The form of energy exchange between the radiation surface and the indoor personnel is radiation, which greatly improves the indoor comfort, and can create an indoor environment with low wind speed and a uniform temperature field. The air volume of the cooling ceiling system is much lower than that of the conventional air conditioning system, and the energy consumption of the transportation system can be greatly reduced [3].

In order to give full play to the advantages of the cooling ceiling air-conditioning system, and provide a valuable reference for its popularization, the cooling ceiling combined with independent fresh air system was built by TRNSYS, in where the energy matching characteristics between the key components in the cooling system and cooling load demand are considered.
2. Building overview
The research object is an office building facing southwest: the floor area is 185m², concrete wall thickness is 200mm, and the external insulation thickness is 55mm. The building model is shown in figure 1. The outside windows are double-layer hollow Aluminum Alloy broken bridge windows and the window thermal conductivity is 2.2W/(m²·K), the building height is 3.6meters, and the actual ceiling height is 2.8meters. The power density of indoor lighting is 10W/m², and the computer equipment power is 18W/m². The fresh air volume is 1000m³/h, and the office containing 22 people.

![Office model](image)

**Figure 1.** Building model

The ceiling of the room is 20 cm below the floor slab, and the ceiling is made of metal plate. This kind of metal plate ceiling is very suitable for office buildings because of its small thermal resistance, quick response and the integration of cooling and decoration.

The building model is built by TRNSYS, and the cold load of the room is simulated by using the typical year weather data. The result is shown in Figure 2. The maximum cold load of the room is 13.35 kW, which is the basis of system design and equipment selection.

![Cooling load graph](image)

**Figure 2.** Building cooling load

3. System design and control strategy

3.1. System constitution
The cooling ceiling combined with independent fresh air system is a kind of temperature and humidity independent control air conditioning system. The schematic diagram is shown in Figure 3. The chiller is an air source heat pump with the cooling capacity 14kW. The supply and return water temperature are 7°C and 12°C respectively and the running time of system is 07:00~20:00. The main water of the chiller is carried to an independent fresh air unit, in which outdoor fresh air is cooled and dehumidified. The water of the independent fresh air unit is supplied into the radiation coils after the flow is distributed through the distributary three-way valve and mixing valve.
3.2. Control strategy
The operating mode of the system is related to the energy consumption of the system, and also directly affect the indoor thermal comfort. At the same time, in order to prevent the phenomenon of condensation, the water temperature is must higher than the indoor dew point temperature. Generally, cooling ceiling system is not suitable for flow regulation because of small temperature difference and the operation of high flow. The relevant research results show that the influence of regulating flow rate on cooling capacity is little. At the same time the change of flow rate will lead to hydraulic imbalance and exhaust difficulties[4]. Therefore, the flow control is not involved in this study.

In this study, the PID controller is used to monitor the supply water temperature. Under the condition that the supply water flow is constant, the proportion of the flow distribution is adjusted, so that the supply water temperature is higher than the indoor dew point temperature 1℃, so as to avoid the condensation.

The starting and stopping of radiation water pump is according to the change of indoor temperature. The operation mode is: when the indoor temperature is higher than 25℃, the radiation water pump is opened, and the radiation water pump is closed when the temperature is lower than 23℃.

4. Model constructing
TRNSYS software is used to simulate the cooling ceiling combined with independent fresh air system, and the operation and control process is shown in Figure 4.

Figure 3. The schematic diagram

Figure 4. Model composition for TRNSYS
The experimental system built on the TRNSYS platform include the building module, refrigeration system module, control module and monitoring module.

The simulation room is established with the Type65b module in TRNSYS[5]. The indoor initial setting point parameter is 30°C, and the relative humidity is 50%. The structural parameters of the radiant ceiling plate are realized by setting “chilled ceiling” in the “wall type manager” option. The independent fresh air unit is set through Type508h module. In addition, the Type665 module which is air cooled chiller is used in the refrigeration unit, the Type33e module is used to calculate indoor dew point temperature and radiation pump is established with multi-stage transmission pump Type110 module[6].

5. Analysis of simulated result

5.1. “Variable temperature” control strategy

The change curve of indoor temperature and other related temperature parameter were shown in Figure 5, which the “variable temperature” control strategy was employed. In order to ensure that the indoor environment can meet the requirements of work, so the system needs to be opened one hour in advance.

![Figure 5. Change of relative parameters of “variable temperature” control strategy](image)

From the simulation results, we can see that during the first one hour which the radiation pump is opened, the supply water temperature is lower than the dew point temperature, which will cause the radiation ceiling to dew. The indoor temperature can be stable at 24°C from 8:00 to 20:00. In the initial stage of the operating system, due to the hysteresis of PID control, the system runs unstably and the supply water temperature of the radiation water pump is lower than 12°C. In the latter stage of the operating system, the temperature of the supply water is 15~16°C. The temperature of the backwater is stabled at 22~23°C.

5.2. Variable air volume auxiliary adjustment

In order to solve the radiant ceilings dewing phenomenon in the early stage of running system, the operation strategy of “variable air volume auxiliary adjustment” was put forward. That is, in the initial of the system operation only the fresh air system is opened for a period of time, and the circulating air volume is increased, so that the indoor temperature and humidity drops rapidly. AT the working time, the fresh air system is returned to the normal state, and the radiation pump is opened.

The change curve of indoor temperature and other related temperature parameter were shown in Figure 6, which the “variable air volume auxiliary adjustment” control strategy was employed. From 7:00 to 8:00 the supply water temperature is always higher than the dew point temperature, which will not cause the radiation ceiling to dew.
Figure 6. Change of relative parameters of “variable air volume auxiliary adjustment”

The indoor thermal comfort was simulated and the result is shown in Figure 7. During the office work time, 08:00~20:00, the indoor thermal comfort fully meet the ISO7730 recommended value of PMV-PPD indicators, that the PMV value is about 0.1 and PPD is about 5%.

5.3. Energy consumption of system

The total time of the simulation for the cooling season is 2208h and daily operation time is 07:00~20:00. The energy consumption statistics of chiller, water pump and fans are shown in table1 by using the two control strategies.

Table 1. Statistical results of energy consumption

| Energy consumption          | Variable temperature control | Variable air volume auxiliary adjustment |
|-----------------------------|------------------------------|-----------------------------------------|
| kW·h                        | chiller                      | Primary circulation pump                 |
|                             | 1297.98                      | 66.50                                   |
|                             | 1369.54                      | 66.54                                   |
| fan                         | 27.23                        | 35.46                                   |
| Radiation water pump        | 42.72                        | 37.23                                   |
| Total                       | 1434.43                      | 1473.31                                 |


6. Conclusion
From the point of system control strategy, the cooling ceiling combined with independent fresh air system was built by TRNSYS. Based on the strategy of variable water temperature control, the operation strategy of variable air volume auxiliary adjustment was put forwarded in this paper.

(1) Through comparing the two regulation methods, it was found that the indoor thermal comfort with PMV-PPD meets the requirements during the period of 08:00~20:00. The results by using the two regulation methods are close to each other, which values of PMV are about 0.1 and values of PPD are about 5%.

(2) The “variable air volume auxiliary adjustment” eliminates the possibility of condensation on the surface of radiant ceiling at the initial stage of system operation.

(3) The energy consumption of “variable air volume auxiliary adjustment” control mode is slightly higher in the whole cooling season. This is because the returning water temperature of chiller is relatively low, which results in the decrease of COP of the chiller in the early stage of system operation every day.

7. References
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