Load Prediction and Control of Capillary Ceiling Radiation Cooling Panel Air Conditioning System Based on BP Neural Network

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Abstract. Compared with traditional air conditioning system, capillary ceiling radiation cooling panel (CCRCP) air conditioning system has the characteristics of low energy consumption, low noise and can provide comfortable indoor thermal environment. However, there are two problems: (1) the traditional PID control has slow feedback and lag due to the non-linearity, hysteresis and many uncertain interference factors of radiation panel air conditioning system; (2) At the start-up time, the sharp drop of temperature of the capillary ceiling radiant panel surface always cause the condensation problem. The solution adopted in this paper is showed as follows: At first, CCRCP air conditioning system model is established in TRNSYS, and the BP neural network is applied to the real-time load prediction control of the model. Secondly, fresh air pre-dehumidification system is adopted in the model to ensure that the panel condensation will not occur in the start-up stage. The results show that: 1. the correlation coefficient R of BP neural network for load prediction of working day is as high as 0.97, and the MSE is only 0.00425; 2. The temperature difference between the indoor temperature that is adjusted by BP neural network load prediction and the indoor design temperature during working hours doesn’t exceed 1℃; 3. Under the most unfavorable conditions with 1 h pre-dehumidification time, when the fresh air volume of pre-dehumidification is 100m³/h, the panel condensation will be prevented in the start-up stage.

Keywords: BP neural network, Capillary radiation, TRNSYS, Fresh air pre-dehumidification

1. Introduction

Capillary ceiling radiation cooling panel (CCRCP) air conditioning system is a new type of air-conditioning system. Compared with conventional air-conditioning systems, the latent heat load in the air-conditioned room is all borne by fresh air, and the sensible heat load is mainly borne by the radiant capillary. The supply water temperature of the radiant capillary can be 7℃ and raising the temperature to 16~19℃ can increase the COP of the chiller by more than 40% [1]. In addition, during the operation of the capillary radiant air conditioner, not only the noise is small, but also the temperature distribution in the room is more even. Therefore, the indoor environment of CRCCP air conditioning system is more comfortable. However, due to the non-linearity, hysteresis and uncertain interference factors of the
radiant panel air conditioning system, the traditional PID control cannot solve the problems of slow and lagging feedback very well; moreover, the surface temperature of the radiant panel drops sharply during the start-up phase, which cause the surface temperature is lower than the dew point temperature of the indoor air. It will increase the risk of condensation. Therefore, this paper adopts load forecasting control and fresh air pre-dehumidification strategy are adopted to solve the above two problems.

In terms of building load forecasting, artificial neural network has advantages of super non-linear mapping capabilities and strong robustness. Compared with complex physical models, artificial neural networks perform better than physical models in short-term forecasting [2]. In addition, BP neural network is currently the most widely used neural network in the world. Chen Ruibing et al. [3] simulated the load of a large public building in Shenzhen and applied the BP neural network model to cooling load forecasting, and the result showed that the BP neural network model has a good ability to map load and each input variable; Shi Dan et al. [4] forecasted air-conditioning load of a museum and used segmented forecasting based on the BP neural network model, and found that the forecast results were more accurate. Consequently, the BP neural network is used to predict the room load in this article. According to the predicted room load, the quality adjustment is adopted: the capillary water flow is unchanged while the opening of the supply and return water valve of the capillary radiant panel is controlled in real time to adjust the actual supply water temperature in order to control the room temperature. In terms of fresh air pre-dehumidification, Wu Changfeng et al. [5] took an office building in Hengyang as an object and established a capillary radiant ceiling + fresh air system model in TRNSYS software. The simulation results showed that the capillary radiant panel system and the fresh air fan were turned on at the same time during the start-up phase. Condensation will occur on the radiant panel, and the room needs to be dehumidified in advance. This article mainly research on reasonable value of the pre-dehumidification air volume under the most unfavourable conditions with 1 h pre-dehumidification time. The research path is displayed as follows: (1) Doing cooling load calculation and air conditioning system design for the room model; (2) Establishing a BP neural network load prediction model; (3) Building the CCRCP air conditioning system model and call the BP neural network in TRNSYS; (4) Analyzing predicted results: (1)Verifying the accuracy of the BP neural network load prediction and the change of indoor temperature by the load prediction control; (2) Determining a reasonable pre-dehumidification air volume.

2. Air conditioning cooling load calculation and air conditioning system design

2.1. Building overview and related design parameters
This article takes an office room with the CCRCP air conditioning system in Wuhan as the research object. The room is located on the fourth floor of the office building, with a floor height of 3.5m, a room size of 7.2m×6m, and an external wall on the south with an area of 25.2m², the rest are inner walls, and the south outer window is double glazing with an area of 6.84m². Refer to relevant specifications [6], interior design temperature of the room is set to 26°C and interior design relative humidity is set to 60%; there are 6 person in the room; equipment power is 140x6 W and lighting power density is 13 w/m². Working days are set from Monday to Friday, and working hours are set From 8 am to 6 pm.

2.2. Building room model in TRNSYS and calculate room load
In summer, air-conditioned rooms generally do not consider the amount of humidity caused by the penetration of fresh air due to the positive indoor pressure. However, the fresh air dehumidification capacity that bears the humidity load is limited in the CCRCP air-conditioning system, so the humidity load brought by the fresh air cannot be ignored. The calculation of the latent load brought by fresh air infiltration can be calculated by simplified formula (1) [7]:

\[ W = la_1 \rho_0^{1+b} (d_o - d_r)(0.105C_r v_0^2 h^{0.4})^b \]  

(1)
Where $W$ (unit: W) is the latent load brought by fresh air infiltration, $l$ (unit: m) is the sum of the length of the door and window gaps in each direction of the room, $a_1$ (unit: $m^2/(m \cdot h \cdot Pa^b)$) is the wind infiltration coefficient in gaps of exterior doors and windows, $\rho_o$ (unit: $kg/m^3$) is the air density, $b$ is the wind infiltration index of gaps in doors and windows, $d_r, d_o$ (unit: g/kg) are the indoor and outdoor air humidity, $C_r$ is the thermal compression coefficient, $v_o$ (unit: m/s) is the average wind speed, and $h$ (unit: m) is the height of the center line of the doors and windows from the outdoor ground.

Considering the influence of outdoor permeable air and fresh air pre-dehumidification on the sensible cooling load and the latent cooling load of the room, the sensible cooling load and latent cooling load of the room in design condition are calculated by TRNSYS. In addition, the pre-dehumidification time is set to 1h and the pre-dehumidification unit adopts mechanical dew point air supply with the air supply temperature of 16°C. The supply air volume is 100m³/h. The rationality of supply air volume value will be verified in the analysis of the results in Section 5.2. The room model is built by TRNSYS, and the simulation time is from June 1 to September 30 and the step length is set to 1h. Finally, the sensible cooling load and the latent cooling load will be obtained by simulation.

2.3. Design and calculation of the fresh air system and the capillary radiant panel
The fresh air unit also uses mechanical dew point air supply with an air supply temperature of 16°C. The air supply volume is calculated by maximum latent heat load of the room, humidity difference between indoor air and supplied air. The capillary supply and return water temperature is set to 16°C/19°C, the maximum indoor cooling load ($Q_s$) borne by the radiant panel is the maximum cooling load of the room minus the cooling load borne by the fresh air blower. The water flow rate of the capillary radiant panel is calculated by $Q_s$ and the temperature difference of supply and return water.

3. Establishing BP neural network and the CCRCP air conditioning system model
BP neural network is a multi-layer feedforward network that can learn and store the mapping relationship between the input and the output. A total of 2929 sets of input (outdoor temperature, humidity and solar horizontal radiation) and output (total load) have been saved, which are imported into MATLAB as the BP neural network training and test data.

![Figure 1. The CCRCP air conditioning system](image-url)
The establishment of a BP neural network mainly includes the following steps: 1. Data preprocessing: Since the room load difference between working days and non-working days is huge, the previous sample data is divided into 2065 groups of working day data and 864 groups of non-working day data and all of them are normalized; 2. Creating the neural network: MATLAB's own newff function is used to create a neural network and the number of hidden layer neurons is 8; 3. The training parameters set: the maximum number of iterations is set to 1000 times, the learning rate is set to 0.1 and the target error is set to 0.00001; 4. Training neural network and testing neural network, MATLAB's own train function is used to train and test neural network; 5. BP neural network is saved and called for the follow-up TRNSYS model. In the model of the CCRCP air conditioning system, the function of the capillary radiant panel is realized by setting the cooling ceiling in the Layer Type Manager of TYPE56 "Multi-Region Building Model" in TRNSYS. Through the component TYPE155 calling Matlab programs in TRNSYS, the BP neural network model is called at each call of each time step.

4. Analysis of predicted results

4.1. The accuracy of the BP neural network load forecast and the change of indoor temperature

The prediction accuracy of the data grouped (working day and non-working day) and ungrouped BP neural network models are shown in Figure 2 and Figure 3. The correlation coefficient R of the data grouped BP neural network is as high as about 0.97, the mean square error MSE is only 0.00425. However, the correlation coefficient of the data ungrouped BP neural network is only about 0.80, and the mean square error is 0.0304. The prediction accuracy of the grouped BP neural network model is significantly better than that of the ungrouped BP neural network model. Moreover, there is a strong correlation between solar radiation, outdoor temperature and outdoor relative humidity as input variables and the room cooling load as output variable in the grouped BP neural network. Therefore the grouped BP neural network is adopted to predict the room load.
Figure 3. R and MSE of the ungrouped BP neural network

In order to facilitate observation and analysis, only the indoor temperature changes in the fifth and tenth weeks are selected for analysis. Based on the load prediction control strategy, the indoor temperature changes are shown in Figure 4 below. It is easy to find in the figure below that during the working hours, the highest indoor temperature in the fifth week is 26.46°C and the lowest temperature is 25.63°C; the tenth week the highest indoor temperature is 26.87°C, and the lowest temperature is 25.76°C.

Figure 4. Indoor temperature changes in the fifth and tenth weeks

4.2. Determine a reasonable pre-dehumidification air volume
The cause of the ceiling condensation is that the indoor dew point temperature is higher than the ceiling temperature. The indoor dew point temperature is related to the outdoor temperature and humidity and the heat and humidity load of personnel and equipment. The heat and humidity load of personnel and equipment is basically unchanged during the working day, so the main influencing factor is outdoor temperature and humidity. Therefore, the week when the outdoor dew point temperature is the highest is selected as the most unfavorable condition. The set pre-dehumidification air volume is 0m³/h, 50m³/h, 100m³/h, 150m³/h, and the pre-dehumidification time is set to 1h. The indoor dew point temperature and ceiling surface temperature are shown in Figure 5. As shown in the Figure 5, when the pre-dehumidification air volume is 0m³/h and 50m³/h and the capillary radiant panel is turned on, the indoor
air dew point temperature curve intersects the surface temperature curve of the radiant panel and the condensation will occur; But in the condition when the air volume is 100 m³/h and 150 m³/h, the indoor air dew point temperature is lower than the surface temperature of the radiant panel and there is no risk of condensation. In addition, the pre-dehumidification air volume increases from 0 m³/h to 100 m³/h, and the peak indoor air dew point temperature decreases significantly. However, the pre-dehumidification air volume increases from 100 m³/h to 150 m³/h, and the indoor air dew point temperature does not change significantly. It shows that, compared with the air volume of 100 m³/h, the air volume of 150 m³/h has little advantage on preventing condensation and reducing peak indoor air dew point temperature. In consideration of energy saving and economy, it is more reasonable to choose a pre-dehumidification air volume of 100 m³/h.

![Indoor dew point temperature change under different pre-dehumidification air volume](image)

**Figure 5.** Indoor dew point temperature changes under different pre-dehumidification air volume

### 5. Conclusion

In this paper, a load prediction control strategy for CCRCP air conditioning system based on BP neural network is promoted. A system model with load prediction control are established in TRNSYS to simulate the indoor thermal environment. In addition, the reasonable pre-dehumidification air volume is also an important part of the research for condensation prevention and energy conservation. The following three conclusions are obtained:

1. The room load data is grouped according to working days and non-working days to establish a BP neural network model. The prediction accuracy of the grouped data is significantly better than that of the ungrouped BP neural network. The correlation coefficient R of the BP neural network model on working days is about 0.97. The mean square error MSE is only 0.00425.

2. Adopting the control strategy based on the grouped BP neural network, the room temperature fluctuation does not exceed 1 °C during working hours. It indicates that the control effect is ideal.

3. Simulation and analysis of the fresh air pre-dehumidification system are carried out under 4 air volume conditions. The result shows that the ceiling condensation will occur in the condition of the air volume of 0 m³/h and 50 m³/h and will be prevented in the condition of 100 m³/h and 150 m³/h. Moreover, compared with the air volume of 150 m³/h, 100 m³/h has the same effect on condensation prevention but is more energy-saving. Therefore, 100 m³/h is ought to be considered as the most reasonable value of the pre-dehumidification fresh air volume.

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