# STUDY ON OPTIMIZATION OPERATION STRATEGY OF METRO STATION AIR CONDITIONING SYSTEM WITH VARIABLE WATER TEMPERATURE

by

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*In order to further optimize the variable water temperature operation strategy of the air-conditioning system to improve the energy saving performance, under the premise of meeting the thermal comfort requirements of building rooms in a subway station in Zhengzhou City, the most unfavorable room corresponding to the final equipment of the air-conditioning system was taken as the research object to study the rule of temperature and humidity changes with the supply chillered water temperature in the room during the air-conditioning period. The influence of supply chillered water temperature on indoor comfort under different load rates is analyzed. On this basis, the optimal control strategy of the supply chillered water temperature in the whole cooling season is set according to the room load rate, and the energy saving analysis is carried out. Under the condition that the indoor environment meets the requirements of thermal comfort temperature and humidity, the optimal chillered water temperature under different load rates is calculated. The research results show that the energy saving rate of the chiller is 13.06%, which effectively reduces the energy consumption of the system.*

Key words: *variable water temperature, thermal comfort, energy saving analysis, load rate*

## Introduction

The central air conditioning system is composed of three principal components: the cold source, transmission and distribution equipment, and terminal heat exchange equipment. According to statistical data, the current energy consumption of buildings in China accounts for approximately 30% of the total energy consumption of the country. Moreover, the energy consumption of public buildings accounts for approximately one-third of the total energy consumption of buildings. Furthermore, the energy consumption of chiller units in summer conditions accounts for approximately 50% to 60% of the total energy consumption of air conditioning systems [1, 2]. The design and selection of traditional air conditioning system equipment is based on the maximum load of the building. However, the measured data indicates that in actual operation, more than 90% of the time, the chiller is running under partial load

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condition [3]. In order to adapt to its characteristic operation under partial load for the majority of the time, an air conditioning system should have the ability to effectively regulate.

The regulation of chillered water systems is primarily divided into quantity regulation and quality regulation. The variable water temperature is a quality regulation issue, while pump frequency conversion is a quantity regulation issue. Implementing variable water temperature regulation in air conditioning systems can improve their operational efficiency under partial load conditions. This is achieved by increasing the chillered water temperature to an appropriate temperature, which helps to achieve energy-saving operation of the air conditioning system [4]. In a study conducted by Thu *et al.* [5], the performance of a chiller was evaluated at different supply chilled water temperatures under full load condition. The results indicated that, under AHRI standard conditions, the working efficiency of the chiller increased by approximately 3.5%, and the cooling capacity of the chiller increased by 4% for every 1 °C increase in chilled water temperature. In comparison to the AHRI standard performance, the COP is enhanced by a minimum of 37%, while the cooling capacity is improved by a minimum of 40%. Zhang *et al.* [6] provided the cooling efficiency of low temperature chilled water at 7 °C and high temperature chilled water at 17 °C, and concluded that high temperature chilled water is beneficial to improving the energy efficiency of chillers. Thangavelu *et al.* [7] proposed a variety of energy consumption optimization methods for the chiller. Among the proposed methods, optimization of the chilled water outlet temperature of the chiller from 6.7 °C to 9 °C resulted in a notable reduction in the operating energy consumption of the chiller. Thielman *et al.* [8] proposed a method to enhance the refrigeration efficiency of the chiller by employing an energy-saving control mode of online distribution based on external objective conditions, such as load and wet bulb temperature. Although the aforementioned studies have investigated the performance of chillers at different chilled water temperatures using various methods, their research were constrained to to energy consumption and cooling capacity. The chillers are not integrated with the entire air conditioning system, which precludes consideration of the changes in its overall energy consumption and cooling capacity. Karami and Wang [9] proposed that adjusting the supply chillered water temperature setting is beneficial to reducing energy consumption and improving efficiency of the chiller. They further proposed that the method of adjusting the supply chillered water temperature setting to save energy consumption of the chiller should be implemented without sacrificing thermal comfort in the air conditioning area. However, the authors did not further investigate the specific impact of adjusting the supply chillered water temperature setting on thermal comfort in the air conditioning area. In a study conducted by Chan [10], an air conditioning system for a hotel building was developed using the TRNSYS software. The simulation of supply chilled water temperature optimization demonstrated that an increase in the supply chilled water temperature by 1 °C would result in a 4% reduction in energy consumption. The author did not provide the optimal upper limit for supply chilled water temperature. Kim and Cho [11] developed a multi-zone building VAV air-conditioning system based on TRNSYS simulation, and proposed a control algorithm that could satisfy indoor thermal comfort and contribute to system energy savings. However, the author did not analyze the specific energy-saving effects of the system. Huong *et al.* [12] calibrated the measurement sensors and instruments and evaluated the uncertainty of the measurement temperature and pressure. The study demonstrated that the temperature of the chilled water had a pronounced influence on the evaporation pressure and the COP of the chiller.

It can be observed that optimizing the supply chillered water temperature is crucial for the energy-saving optimization of the entire air conditionging system. However, in order to maximize the supply chillered water temperature under varying loads, it is crucial to comprehensively consider the building's load rate and indoor comfort requirements. This approach ensures that the energy consumption of the air conditioning system is reduced while maintaining indoor comfort.

## Establishment of system model

Considering a metro station in Zhengzhou as an example, it spans a total construction area of 24178 m$^2$. The station features an island platform design, consisting of two levels: a station hall and a platform. The length and width of the platform are 120 m and 14 m, respectively. The station is equipped with three entrances/exits, with entrance/exit number one spanning 97 m, while the lengths of the other entrances/exits is 60 m. The ventilation and air conditioning system for the station is divided into two main systems: a large-scale system and a smaller one. The large-scale system includes the station hall level, platform level, covering an area of 5473.7 m$^2$. The smaller system consists of systems 101, b101, b201, and b301, with a combined area of 1444.8 m$^2$. Both the station hall and platform levels are equipped with air conditioning systems to ensure adequate cooling for public areas and functional rooms.

### *Construction and load calculation of subway station building model*

A 3-D model of the building was generated using TRNBUILD software, encompassing a variety of parameters such as wall materials, thermal transmittance of walls, indoor temperature and humidity levels, ventilation rates and frequencies, and internal heat sources comprising people, equipment, and lighting. These parameters were subsequently configured for each room across various areas of the station. Additionally, a simulation period ranging from 3216 to 6552 hours was established, with the system designed to operate continuously from 6:00 a.m to 11:00 p.m. The final architectural model is depicted in fig. 1.

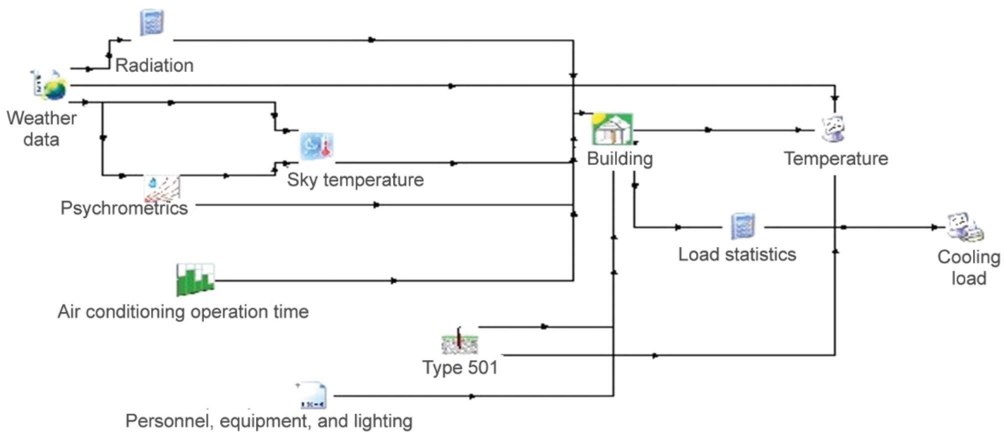


**Figure 1. Station building model**

The hourly cooling load for the station were obtained through the simulation of the aforementioned architectural model, as shown in fig. 2. The data revealed that the maximum simulated cooling load for the site was 967.9 kW. According to the design blueprints, the cooling load for both the large and small systems is 994.3 kW. This suggests a minor discrep-

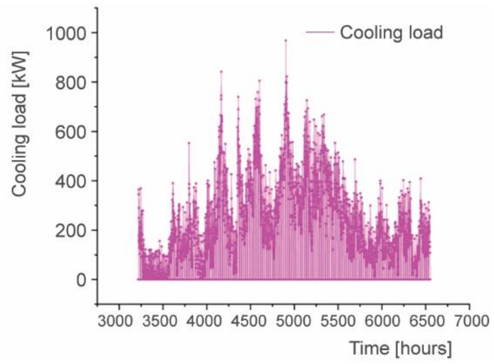


**Figure 2. Hourly cooling load**

ancy of 2.7% between the maximum simulated cooling load and the calculated value. This slight variance attests to the validity and reliability of the architectural model developed using TRNSYS.

Concurrently, the results of the load calculation indicate that the rooms with the greatest potential for discomfort due to the terminal air conditioner are the equipment ticket room, equipment room 1, environmental control room, public work room station hall, platform, and entrance and exit. These rooms have been identified as the focus of the subsequent research.

*Construction of the air conditioning system for the metro station*

The air conditioning system for the metro station is primarily divided into two subsystems: the water system and the air system. The TRNSYS modules are configured according to the parameter data of the equipment, as shown in fig. 3.

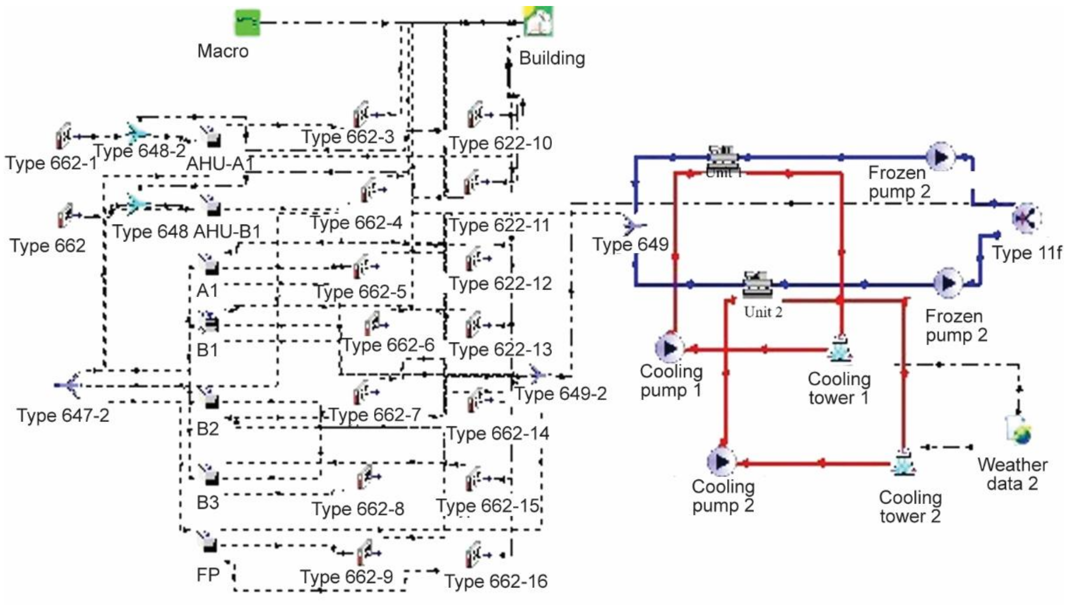


**Figure 3. Air conditioning system diagram**

Both the air and water systems are designed to operate at a fixed frequency. The chiller is initially set to deliver an outlet temperature of 7 °C. Additionally, when the cooling load reaches or exceeds 80% of a single unit rated capacity, a second unit will be activated to collaboratively provide cooling for the metro station.

As depicted in fig. 4, the simulation of the air conditioning system operations reveals temperature oscillations, exemplified by the temperatures in the station lobby, platform, and No. 1 entrance and exit. This phenomenon can be attributed to the intermittent operation of the entire air conditioning system, which results in a significant temperature rise in the rooms during the non-cooling periods. During the cooling periods, the temperatures in the station lobby and platform are typically maintained at 22-24 °C. Although the cooling system is capable of meeting cooling demands of the rooms, the actual temperatures in the rooms are significantly below the design temperatures. It can lead to an unpleasant cooling experience and result in energy wastage.

The total energy consumption of the air conditioning system in the metro station is 449,242.21 kWh during the air conditioning season, As illustrated in fig. 5. The air conditioning system consumed 196,803.81 kWh of energy, whereas the air conditioning water system utilized 252,868.92 kWh. All equipments operated at rated capacities, resulting in relatively high energy consumption.

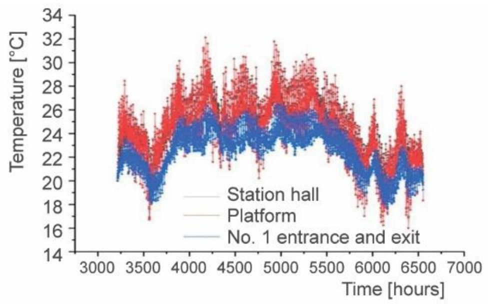


**Figure 4. Large-system room temperature**

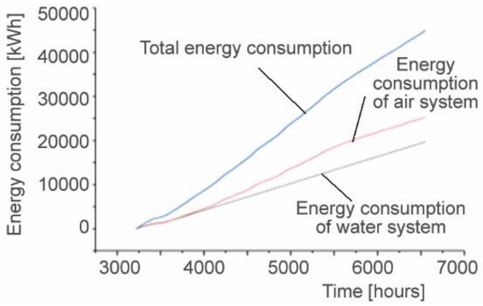


**Figure 5. Energy consumption of air conditioning system**

## Optimizing operation strategy of variable water temperature for chillers

### *Strategies of variable water temperature for chillers*

By integrating Fanger's PMV-PPD thermal comfort model [13] and the CBE thermal comfort calculation tool [14], it becomes feasible to assess the indoor thermal environment of office buildings. It establishes the temperature and humidity combinations that satisfy thermal comfort requirements [15, 16], as shown in tab. 1.

**Table 1. The range of temperature and humidity combinations fulfilling comfort requirements**

| Region | Indoor dry bulb temperature [°C] | Relative humidity [%] |
|---|---|---|
| Large scale system | 21.9-28.3 | 40-70 |
| | 28.3-29 | For every 0.1 °C increase, the upper limit is reduced by 3% |
| Small scale systems | 21.9-27 | 40-60 |

In order to meet the indoor comfort requirements, the daily cumulative cooling load is divided into the following categories: The outlet temperature of the chiller was set to

7 °C-15 °C, respectively, to determine the cooling load required to maintain an indoor comfort level of 100%, 87%, 72%, 61%, 50%, 40%, 30%, 20%, and 10%. The objective is to ascertain whether each room meets the aforementioned temperature and humidity range under varying load rates, with a minimum satisfaction rate of 80% per room as the benchmark. Additionally, the optimal outlet temperature setting under the cumulative load rate for that day is to be determined.

The basic model is set up to demonstrate the effects of varying load rates on temperature and humidity in a hypothetical scenario. To illustrate this, we will consider the case where the outlet temperature of chillers is set at 8 °C. Figures 6 and 7 show the temperature and humidity in the most unfavorable room on the station platform at various load rates. For the majority of the time, the overall temperature and humidity levels are maintained within the acceptable range deemed consistent with thermal comfort. This conclusion is substantiated by the fact that when the outlet temperature of chillers is set at 8 °C, the resulting temperature and humidity levels are within the permissible range.

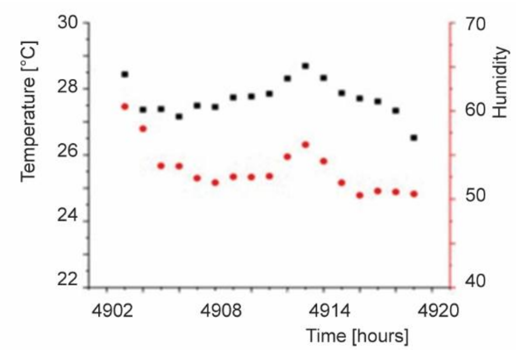


**Figure 6. The T&H in station hall**

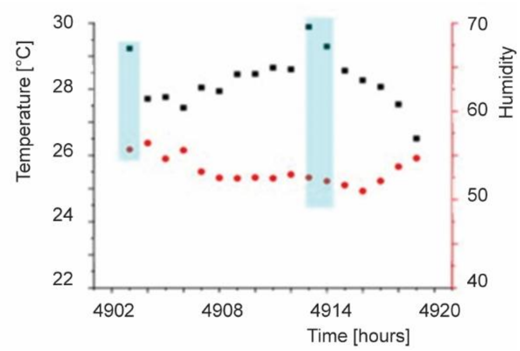


**Figure 7. The T&H in platform**

When the outlet temperature of chillers is set at 9 °C, the equipment ticketing room and the equipment room 1, for example, as shown in figs. 8 and 9, exhibit a satisfaction rate of 35.3% and 59%. The values fall below the threshold of 80%, indicating that the preset temperature has not reached the anticipated performance.

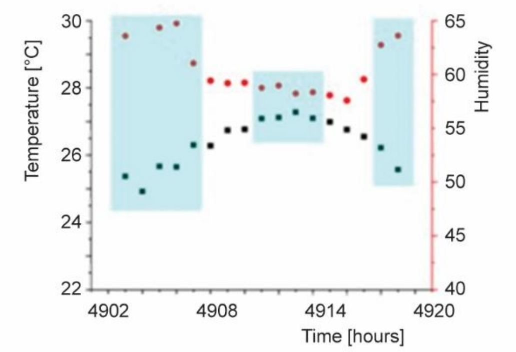


**Figure 8. The T&H in the equipment ticket room**

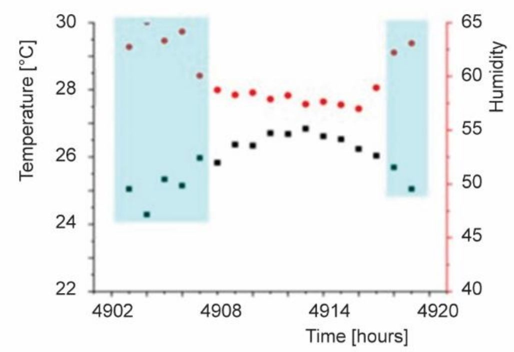


**Figure 9. The T&H in equipment room 1**

In summary, the optimal outlet temperature of chillers on a day with 100% load is 8 °C, and the optimal outlet temperature of other typical days can be obtained similarly. It is presented in tab. 2.

**Table 2. Optimal chillered water temperatures at different load rates**

| Load rate | 0-0.2 | 0.2-0.4 | 0.4-0.61 |
|---|---|---|---|
| Optimal effluent temperature [°C] | 15 | 14 | 13 |
| 0.61-0.72 | 0.72-0.77 | 0.77-0.87 | 0.87-1 |
| 12 | 11 | 10 | 8 |

*Impact of variable water temperature strategies on the energy efficiency of chillers*

The supply chillered water temperature should be set according to tab. 2. The set point for the chiller outlet temperature is inputted via the ype9e module, enabling the chiller to operate according to the prescribed strategy and simulating an entire cooling season. Taking the station hall as an example, during the summer months when the load is high, there are periods where the dry bulb temperature exceeds 29 °C due to the cessation of the air conditioning system at night. However, during the cooling hours, the overall temperature remains below 29 °C. When compared to the operation of an air conditioning system with chilled water temperature of 7 °C, the overall dry bulb temperature in the station hall is approximately 1 °C higher, aligning more closely with the design temperature of 29 °C. It ensures human comfort while simultaneously reducing the system energy consumption and enhancing the operational efficiency of chillers.

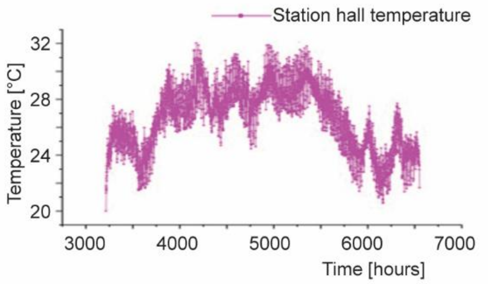


**Figure 10. Dry bulb temperature of Staion hall**

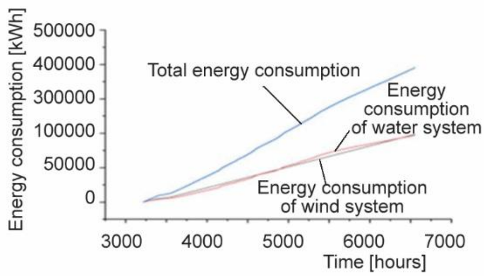


**Figure 11. System energy consumption at variable water temperature**

Figure 11 illustrates the hourly energy consumption of chillers operating at a constant water temperature. The energy consumption of the water system is demonstrably reduced. In contrast to the constant water temperature, the energy consumption of the operational air system during the cooling season remains unaltered. The total energy consumption of the water system is 390581.5 kW. The total cooling capacity of chiller 1 over the entire cooling period was 531787.8 kWh, while the total power consumption was 85259.9 kWh. The total cooling capacity of chiller 2 was 85570.66 kWh, with a total power consumption of 14073.57 kWh. Consequently, the calculated COP of chiller 1 was 6.24, while the calculated COP of chiller 2 was 6.08.

A comparative analysis of the two operation strategies is presented further in the text. Strategies of variable water temperature for chillers have resulted in a notable reduction in total energy consumption, with an associated energy saving rate of 13.06%.

## Conclusions

The following conclusions are made.

- During the cooling season, different chiller outlet temperatures are set based on the daily cooling load. To ensure thermal comfort in the indoor environment, the supply chillered water temperature is adjusted according to maximum load rate of rooms, which varies within a certain range. When the load rate is below 20%, the chillered water temperature may be raised to 15 °C. Between 20% and 40%, it can be increased to 14 °C. Between 40% and 61%, the temperature is maintained at 13 °C. Between 61% and 72%, it is set at 12 °C. Between 72% and 77%, the temperature is set at 11 °C. Between 77% and 87%, it is set at 10 °C. When the load rate exceeds 87%, the chillered water temperature temperature is maintained at a constant 8 °C.
- Implementing an energy-saving strategy that optimizes the supply chillered water temperature under varying load rates, with the objective of maintaining indoor comfort, has the potential to reduce the energy consumption of chillers by 13.06%, when compared to a system that maintains a constant water temperature.

Future research should focus on optimization algorithm [17, 18] and improve the efficiency of the heat exchanger through nanofluids [19, 20].

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