THERMAL ENERGY CONTROL IN BUILDING ENERGY HEATING SYSTEM BASED ON BUILDING INFORMATION MODELLING

by

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Original scientific paper
https://doi.org/10.2298/TSCI2104941W

This article introduces the principle of the glass curtain wall heating and cooling cycle constant temperature control test system in the building energy heating system and studies the constant temperature control strategy of its core cooling and heating circulation system. The author designed an adaptive fuzzy control algorithm with a self-learning function realize the thermal energy constant temperature control of the cooling and heating cycle experimental system and conducted the first model test. The test results show that the thermal energy constant temperature control strategy of the circulatory system and its adaptive fuzzy control algorithm have good control characteristics and effects. During the test, the thermal energy constant temperature control accuracy is within 0.4 °C when the system is dynamically heated and cooled, and the temperature fluctuates when the constant temperature is maintained. Within 0.2 °C, the test system fully meets the requirements of the American building energy heating AAMA501.5.98 glass curtain wall cycle test standard.

Key words*: glass curtain wall, cooling and heating cycle, thermal energy, building energy heating, building information modelling, adaptive fuzzy control,*

Introduction

The glass curtain wall composed of metal components and glass panels has a history of nearly a century and a half since its appearance in 1851. My country also built the first modern high rise building with a glass curtain wall in 1985 Beijing Great Wall Hotel. Since then, the glass curtain wall has quickly gained the favor of the Chinese construction industry. According to incomplete statistics, the total area of curtain walls of buildings completed nationwide is about 15 million m^2. At present, the glass curtain wall is still increasing at a rate of 5 million square meters per year. However, through the magnificent glass curtain wall, there are many hidden dangers in safety and energy saving. Therefore, the reinforced glass curtain wall's quality inspection is a crucial part of the glass curtain wall's safety. At present, the glass curtain wall's testing content is mainly *three characteristics* testing, that is, the air tightness, water tightness, and wind pressure deformation resistance of the glass curtain wall. However, as a building envelope, the glass curtain wall has withstood the harsh external environment test for many years. The requirements for the glass curtain wall in different climate regions are also very different, so the ability of the glass curtain wall to withstand the degree of cold and heat

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should also be its quality a critical indicator to measure, high quality glass curtain walls can still have useful *three characteristics* characteristics in the harsh cold and hot environments [1]. However, there is no standard for glass curtain wall heating and cooling cycle test in China, and there are few platforms for testing glass curtain wall heating and cooling cycle test. To this end, the author was commissioned by the Institute of Building Science and Technology, according to the requirements of American AAMA501.5.98 glass curtain wall thermal cycle test standard, the glass curtain wall cold and heat cycle system test. During the test, the glass curtain wall's harshest environment in practical application is simulated, and the heat and cold resistance performance of the glass curtain wall is tested by simulating the drastic alternation of ambient temperature. The test system's goal is to provide indoor and outdoor simulation environments for glass curtain wall inspection.

Test system requirements

The test system requires that it can meet the cold and heat cycle test of the building glass curtain wall specimens with an area of 100 m^2 and a heat transfer coefficient of 3 W/(m^2°C) under the four seasons climate conditions in Shanghai. The glass curtain wall heating and cooling cycle test requirements strictly follow the American AAMA 501.5.98 test method for thermal cycling of exterior walls. This is the standard for the cooling and heating cycle test of glass curtain walls issued by AAMA in 1998. The test system includes boxes on both sides of the indoor and outdoor. The air temperature inside the boxes on both sides is manually controlled to simulate the thermal environment on both sides of the actual glass curtain wall building. The indoor side box simulates the residential environment temperature, and the outdoor side box simulates Climate environment temperature [2].

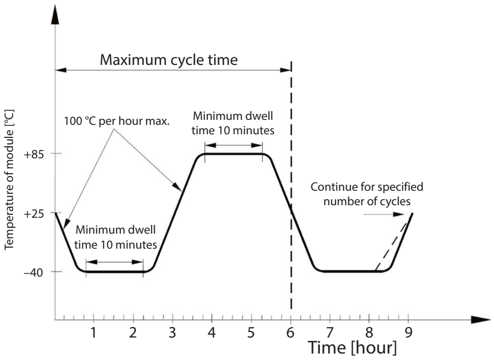

Figure 1. Requirements for a temperature change of outdoor environment simulation box

According to the AAMA 501.5.98 standard, the air temperature in the simulated indoor box is constant at 24 °C, and the relative humidity is less than 30% during the test. After the simulated outdoor environment reaches 24 °C and keeps it for one hour, the air temperature change cycle is shown in fig. 1. For each specimen, the cycle should be cycled at least three times.

The AAMA 501.5.98 stipulates thermal constant temperature control accuracy: the inner temperature control box keeps 24 °C±3 °C, and the relative humidity is less than 30%. The outdoor environment simulation box meets the accuracy requirement of ±3 °C at each thermal energy constant temperature control point and the uniformity requirement of ± 3°C in the indoor and outer box space. During the cooling and heating cycle, the temperature rise process rate is 1 °C±0.2 °C per minute, and the temperature drop process rate is 0.7 °C±0.2 °C per minute.

Test system structure and process

According to the test bench's temperature and humidity control requirements, the author designed an indoor environment simulation system and an outdoor environment simulation system, figs. 2 and 3. The indoor side system is designed according to the process shown in fig. 2. We use a *twin* refrigeration system in which two compressors are connected in parallel. The refrigeration system's evaporator serves as the surface cooling section provide cold cooling

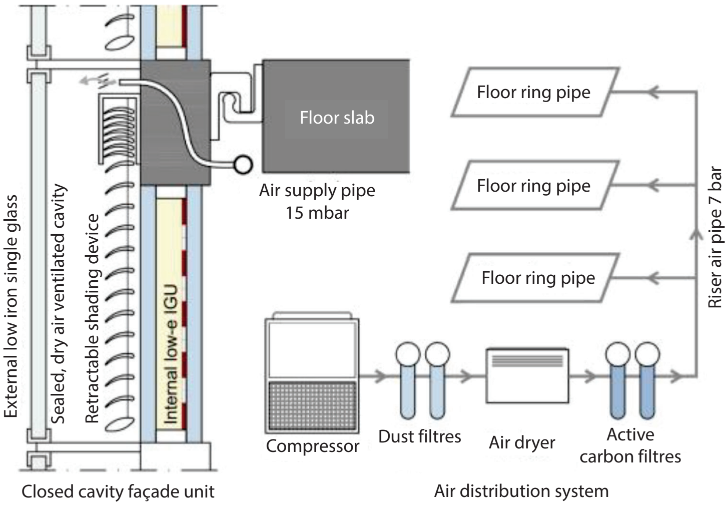

Figure 2. Flow chart of the indoor system

air for dehumidification. The simulation box's return air-flows through the surface cooling section, the electric heating section, and the fan section of the air handling box successively and is sent back to the simulation box after a series of treatments [3]. To control the humidity within 30%, the unit can control the indoor humidity within 30% by controlling the evaporator's surface temperature, that is, the dew point of the machine.

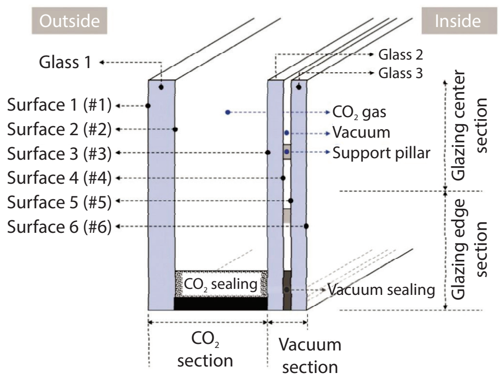

Figure 3. Outdoor system flow chart

The structural process of the outdoor environment simulation box is shown in fig. 3. Because the air temperature in the simulation box varies between 82 °C and –18 °C, from the perspective of the refrigeration system's safety, the system uses glycol solution as the refrigerant. The air handling box's surface cooler is connected in parallel with the glycol solution storage tank, and the ratio of the glycol solution flowing through the two is adjusted by controlling the electric three-way valve [4].

System control strategy research

Control of the outdoor environment simulation box

The outdoor environment simulation box temperature is required to achieve the periodic change shown in fig. 1, and the rising process and the falling process require linear changes. Simultaneously, because the refrigeration system adds a glycol carrier cooling system to save energy, it is adopted to control the electric three-way valve. To adjust the amount of refrigerant entering the surface cooler. As a result, the outdoor side analog system's control is far more complicated than that of the indoor side. It is a dual-output control system. The control system block diagram is shown in fig. 4. The refrigeration system is a non-linear, considerable lag, multi-variable system, and the outdoor simulation environment itself is also a strongly

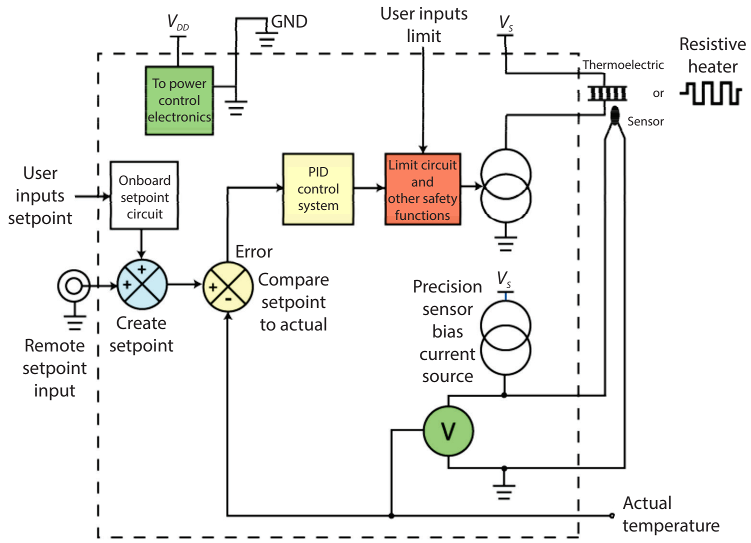

Figure 4. Block diagram of the outdoor simulation environment control system

non-linear system. It is difficult to achieve satisfactory control results with traditional PID control algorithms. Therefore, the author uses an intelligent control algorithm-fuzzy control to realize the outdoor simulation environment [5].

Adaptive fuzzy control

Fuzzy control algorithm design has the problem that it is difficult to determine the fuzzy control rules, and the refrigeration system is a non-linear system with multi-variable, considerable lag, and substantial interference. We concluded from the manual control experience that a better fuzzy control rule requires a longer time and a more immense workload. However, it is possible to adapt to different refrigeration systems' corresponding control parameters by relatively large adjustments. For this reason, the author designs a fuzzy controller-adaptive fuzzy controller SOFC with self-learning and adaptive capabilities through further research based on necessary fuzzy control [6].

During the entire periodical change process, although the control system is a dual-output system, if a suitable control strategy is selected during the control process, the heating part and the cooling part of the system can be realized at the same time so that the system can save energy (no need for cold and heat offset). Therefore, this paper designs the adaptive fuzzy controller as a dual-input single-output structure. The structure of the adaptive fuzzy controller is shown in fig. 5.

Compared with the primary fuzzy controller, three links in the dotted line are added in fig. 5, namely performance measurement, control amount correction, and control rule correction. The SOFC calculates the deviation and its rate of change every time it samples, and then through the control quantity correction link, the correction quantity of the control quantity is obtained, and then the fuzzy control rules are revised. Therefore, the adaptive fuzzy controller's function is to perform the fuzzy identification of the system first and then perform on-line real-time closed-loop control. In the performance measurement link, the direct measurement system's output characteristics are compared with the predetermined set value, and the amount of correction that should be made to the output characteristics is calculated according to the mag-

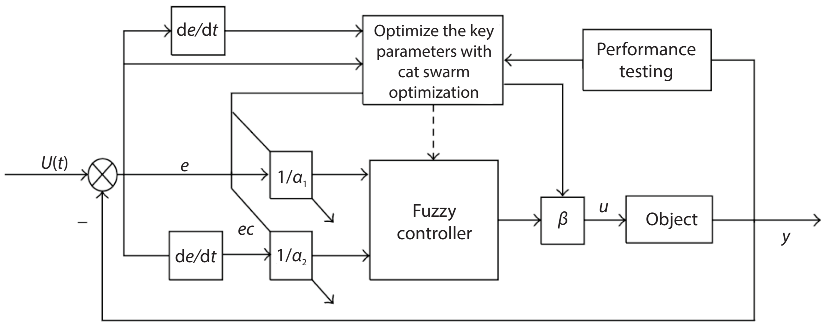

Figure 5. Structure diagram of adaptive fuzzy controller

nitude of the difference [7]. The output characteristics are generally based on each sampling period's deviation, and its deviation rate of change is characterized by these two parameters. According to these two values, the deviation between the actual output characteristics and the desired characteristics is measured, and the fuzzy set method is also used to summarize specific performance measurement rules, as shown in tab. 1.

Table 1. Performance measurement calibration table

	PB	PM	PS	ZE	NS	NM	NB
PB	PB	PB	PM	PS	ZE	ZE	ZE
PM	PM	PM	PM	PS	ZE	ZE	NS
PS	PS	PS	PS	ZE	ZE	NS	NS
ZE	PS	ZE	PS	ZE	ZE	NS	NM
NS	ZE	ZE	ZE	ZE	NS	NM	NM
NM	ZE	ZE	ZE	ZE	NS	NM	NB
NB	ZE	ZE	ZE	NS	NM	NB	NB

Its language expression is: when the actual superheat is very large, and the superheat becomes large quickly, the output characteristic rises quickly, and a large amount of correction is required and when the actual superheat is small, but the superheat is still small, the output characteristics deviate from the expected characteristics, so more extensive corrections are required. Can be written as:

IFE = PBANDC = PBTHENP = PB

IFE = NBANDC = NBTHENP = NB

Take the basic quantitative domain of deviation, E, deviation change rate, C, and correction amount, P, as: (–6, –5, –4, –3, –2, –1, 0, 1, 2, 3 , 4, 5, 6}.

Then using the same method as the primary fuzzy controller to construct the fuzzy control table, the performance measurement table can be calculated according to the quantified domain of E, C, and P, and the performance measurement correction table in tab. 1. The output response correction amount $r(nT)$ obtained by the performance measurement needs to be converted into the input correction amount to the process and applied to the process so that the system's output changes in the desired direction [8]. For the two-input single-output system used in this article, the control amount correction should be:

$$r(nT) = kP(nT) \tag{1}$$

Because the control quantity and output quantity are normalized, the coefficient $k = 1$. Consider a system with a certain lag, suppose the control effect of the past m samples affects the current performance, if $e(nT - mT)$, $ec(nT - mT)$, and $u(nT - mT)$ are the previous deviation, the rate of change of deviation and the control quantity, respectively, and the corrected control quantity $u(nT - mT) + r(nT)$, which can be obtained by fuzzifying these quantities:

$$E(nT - mT) = F\{e(nT - mT)\} \tag{2}$$

$$EC(nT - mT) = F\{ec(nT - mT)\} \tag{3}$$

$$U(nT - mT) = F\{u(nT - Mt)\} \tag{4}$$

$$V(nT - mT) = F\{u(nT - mT) + r(nT)\} \tag{5}$$

where F is the fuzzification process of a single element. The original control rules:

$$Ife = E(nT - mT)andec = EC(nT - mT)thenu = U(nT - mT) \tag{6}$$

The control rules should be:

$$Ife = E(nT - mT)andec = EC(nT - mT)thenu = V(nT - mT) \tag{7}$$

Previous control rules in the form of a relationship matrix:

$$R(nT) = E(nT - mT) \times EC(nT - mT) \times U(nT - mT) \tag{8}$$

$$R_2(nT) = E(nT - mT) \times EC(nT - mT) \times V(nT - mT) \tag{9}$$

The new modified relationship matrix:

$$\begin{aligned} R(nT + T) &= \{R(nT)butnotR_1(nT)\}elseR_2(nT) \\ R(nT + T) &= \{R(nT)elseR_2(nT)\}butnotR_1(nT) \end{aligned} \tag{10}$$

After obtaining the new modified relationship matrix $R(nT + T)$ according to eq. (10), according to the currently observed deviation $E(nT)$, the deviation change rate C, and the composition, the fuzzy set of the control quantity is obtained. Then after defuzzification, the specific control quantity change is obtained. Add it to the system [9].

Test and result analysis

The author designs an adaptive fuzzy controller for the outdoor temperature and uses a programmable logic controller PL$C(nT)$ as $R(nT + T)$ the implementation platform. Simultaneously, the whole glass curtain wall cold and heat cycle test system was developed, and the glass curtain wall test was conducted. The temperature change of the indoor and simulated outdoor environment is shown in fig. 6.

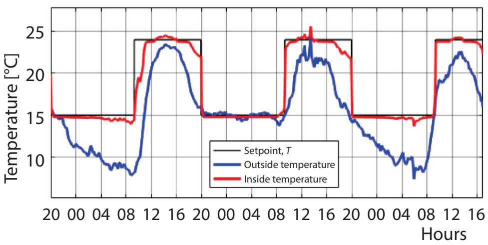

Figure 6. Indoor and outdoor simulated temperature change curve

Figure 6 shows the curve of the indoor simulated ambient temperature and simulated outdoor temperature of the glass curtain wall cold and heat cycle test system within eight hours. It can be seen from fig. 6 that the curve is entirely following the American AAMA 501.5.98 glass curtain wall thermal cycle test standard requirements: the indoor temperature is kept constant at 24 °C, and the outdoor temperature rises from 24-82 °C within 1 hour and keeps it for 2 hours, then within 1 hour, the air temperature in the outdoor environment simulation box is reduced from 82-24 °C. Within 1 hour, the air temperature in the outdoor simulated environment box was decreased from 24 °C to –18 °C and kept for 2 hours, then within 1 hour, the air temperature in the outdoor simulated environment box was increased from –18 °C to 24 °C. Simultaneously, the adjustment deviation during the whole temperature rise and fall process is within 0.4 °C, and the temperature fluctuation is within 0.2 °C when the temperature is maintained. But when the temperature rises to 82 °C. Due to the air's thermal inertia in the climate simulation box during the temperature rise, the thermal energy constant temperature control has an overshoot of about 2.0 °C, but this is within the control accuracy of ±3 °C. Similarly, there is a small amount of overshoot in the initial stage when the temperature drops to –18.0 °C and remains stable, and the overshoot is within 1.0 °C. It can be seen that the adaptive fuzzy control algorithm has better adjustment accuracy and control quality [10].

Figure 7 shows the glass curtain wall sample's indoor and outdoor temperature change curve tested in three cycles according to the American AAMA501.5.98 glass curtain wall thermal cycle test standard. It can be seen from fig. 7 that the thermal constant temperature control of this test system has good accuracy and good reproducibility.

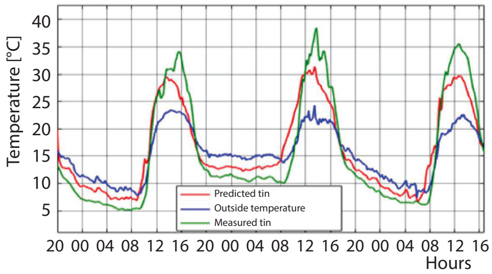

Figure 7. Indoor and outdoor temperature change curve

Conclusion

This paper introduces in detail the principle and composition of the glass curtain wall heat and cold cycle test system developed by the author. The core of the glass curtain wall cold and heat cycle test system-the heat energy constant temperature control strategy of the cold and heat cycle system is studied. The glass curtain wall heat and cold cycle test are designed system self-adaptive fuzzy control algorithm. Developed and tested a glass curtain wall cooling and heating cycle test system. The test results show that the adaptive fuzzy control algorithm has better control quality and control effects. During the test, the accuracy of thermal constant temperature control during the dynamic heating and cooling of the system is within 0.4 °C, and the temperature fluctuation is within 0.2 °C when the constant temperature is maintained. The test system fully meets the requirements of the American AAMA 501.5.98 glass curtain wall cycle test standard.

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Paper submitted: November 10, 2020
Paper revised: December 18, 2020
Paper accepted: January 20, 2021