Research on theoretical energy saving rate of cooling and heating with intelligent temperature control of office buildings in Xinjiang typical climate zone

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Abstract: At present, many office buildings in Xinjiang generally use continuous movement of heating and cooling systems, heating and cooling excessively caused the energy waste, the use of intelligent control equipment system can effectively save energy. This paper uses the parametric performance simulation toolset (Ladybug tools) to model the energy consumption of office buildings in four typical climatic regions in Xinjiang. It simulates two methods of intelligent control (ICS) and continuous operation (COS) in different window-to-wall ratio (WWR) the influence of heating and cooling energy consumption load. Considering the additional equipment energy consumption (\(\Delta E\)) of ICS, the control energy saving rate (\(\eta\)) is compared ICS with COS. The results show that in different climate zones and with different WWR, ICS is more energy-efficient at the heating and cooling methods than COS. Moreover, in different climate conditions, office buildings with different WWR have different energy-saving rates. The change of the WWR has a small effect on the \(\eta\) value in the Severe Cold Zone C, and the \(\eta\) value in the Cold Zone A region decreases with the WWR becomes larger. This study further proves that the contribution of intelligently controlled heating and air-conditioning systems of building energy conservation and provides a favourable basis for refined energy development.

1. Introduction

With the improvement of living standards, people's demand for energy is also increasing, and the world today is facing some serious energy crisis problems. How to improve energy efficiency and reduce energy waste has become a concern of all countries. Discovered in the public building operation process, the energy consumption of heating and cooling of buildings has a large proportion of the overall energy of the building [1]. Intelligent temperature control is a method that mainly monitors the indoor temperature in real time through a temperature sensor, and adjusts physical quantities such as temperature, capacity and speed in real time through a transmitter. Compared with the continuous operation of traditional equipment, it realizes more refined management of heating and air-conditioning systems to prevent indoor overheating or overcooling [2].

Indicated on the present findings, after the temperature achieved specific value, in the construction room may no longer absorb heat. However, when the temperature reaches below this standard line, the energy supply will increase as the temperature continues to decrease [3]. Therefore, the use of more optimized energy supply methods has become a hot issue for building energy conservation, and the corresponding temperature control and regulation equipment has been further improved [4, 5]. The traditional heating air conditioning is mainly by continually the central heating and the split cooling
way primarily. Its characteristic lies in the heating to belong to the plan ration for the total cold quantity, the supply and demand relations are not balanced, not only creates the massive energy waste (Such as vacant room heating), in the room the comfort level has not been improved. Therefore, intelligent temperature control can make better use of energy and achieve energy saving [6].

Existing research uses intelligent algorithm-optimized PID controllers to generate more controllable temperatures, improve the comfort of indoor spaces, and reduce the energy consumption of the overall equipment for continuous operation [7-9]. Data processing functions using the Internet of Things Platform (IoT), intelligent devices can be used to remotely control the operation of indoor equipment, combined with intelligent control methods can effectively improve energy efficiency[10-12]. According to the real-time operation data of energy and user demand analysis, it can effectively reduce the electricity cost and peak-to-average ratio (PAR) of residential buildings, and on the premise of ensuring the comfort of the building space, adjust the waiting time of the equipment to increase or decrease its comfort. Degrees [13, 14]. The realization of the building energy management system (BEMS) can also monitor and control the building’s heating, ventilation, and air conditioning (HVAC). The combination of the RNN-based estimator and the door sensor node makes the accuracy of the hybrid RNN occupancy estimator 88% [15, 16]. Besides, using a reasonable energy control management strategy to focus on the performance improvement of energy generation or distribution in the network. Compared with traditional models, the intelligent controller can increase the thermal comfort of the clinic by approximately 16.2%, and improve the thermal comfort of the office. 2.4%, increasing the thermal comfort of residential buildings by 7.1%, saving about 24.7% of total energy costs [17, 18]. Building projects using intelligent control strategies and technologies have been carried out in different regions and have been found to have excellent energy-saving performance through field tests [19, 20].

Existing research mainly focuses on the realization of intelligent control technology and the effective management of energy consumption. Research on the combination of different climate environments and different building envelope parameters has not been in-depth and carried out yet. In this paper, through simulation experiments, more experimental control schemes are set up to explore the performance of these two control methods in typical climatic regions of Xinjiang with different WWR. Prove the excellent performance of ICS in different situations.

2. Methodology

2.1. Energy simulation platform

In recent years, the parametric design and simulation of buildings have continued to develop around the world, which has many advantages over traditional energy simulation [21]. Rhinoceros (RH) can create complex 3D models combined with Grasshopper (GH) to assist in building parameter models. The Ladybug + Honeybee (LH) toolset in the GH platform can flexibly construct a variety of building performance simulation programs. Ladybug can parse building meteorological data in EPW format files, realize multiple ways of analyzing and visualizing meteorological data, and perform some necessary building performance simulations [22]. Honeybee structured outputs building form parameters and meteorological data to calculation engines (such as EnergyPlus, Radiance, Daysim, Therm.) through visual programming to implement building performance simulation scheme construction and data conversion on the GH platform, and numerical calculation results Read into the GH platform for analysis and visualization of calculation results.

EnergyPlus (EP), the engine of energy load calculation is used in this research, developed by the Department of Energy (DOE), which can be used for comprehensive energy simulation analysis for building heating, cooling, lighting, ventilation and other energy consumption [23]. The research uses temperature control curves to control the operation of equipment under different temperature conditions. During the refrigeration period, the indoor control temperature is set to 26°C during the time when personnel are present, and the equipment is turned off during the rest of the time. During the heating period in winter, the temperature is controlled at 20°C during the work period, and the
indoor low temperature operation (5°C) is maintained during the rest of the time. The heating and cooling system in continuous operation considers the influence of solar heat, and the indoor temperature is not changing. Therefore, the continuous operation control temperature used during operation is a variable value. Its main performance is that the indoor temperature during continuous operation will reach a relatively stable and higher (lower) heating (Cooling) target temperature value for heating (Cooling), and the indoor temperature will rise by 2~3°C under the effect of solar radiation. The simulation strategy for heating and cooling equipment operation through temperature control is shown in Figure 1 (Cooling (C) and Cooling (I) are intelligently controlled cooling and continuous operation cooling; Heating (C) and Heating (I) are intelligently controlled heating and continuous operation heating).

Figure 1. Controlled temperature settings for two control methods and person presence rate.

2.2. Design of simulation experiment
In order to explore the office buildings of different WWR and adopt the change of energy consumption in different regions of Xinjiang utilizing intelligent control and continuous operation. In this paper, Urumqi, Turpan, Kashi, and Altay are selected as typical cities in Xinjiang’s Severe Cold Zone and Cold Zone. On the one hand, these four regions are representative of the geographical distribution and city size of Xinjiang. On the other hand, these four regions represent different thermal zones in Xinjiang. The monthly average temperature and monthly solar radiation of each region are relatively different (Figure 2).

Figure 2. Month mean temperature and month mean solar radiation data in typical climate zones

Table 1. Comparison table of three groups of improvement programs.

| Region   | Climatic zone      | Control method                  | WWR     |
|----------|--------------------|--------------------------------|---------|
| Urumqi   | Severe Cold Zone C | Intelligent Control (ICS);      | 0.3; 0.5; 0.7 |
| Turpan   | Cold Zone B        | Continuous Operation (COS)      |         |
| Kashi    | Cold Zone A        |                                |         |
| Altay    | Severe Cold Zone B |                                |         |
Existing research shows that under the condition that the thermal performance of other non-transparent envelope structures is reasonable, the change of the building WWR will have a greater impact on the energy consumption of the building. According to the relevant provisions of the “Design Standards for Energy Efficiency of Public Buildings”, the WWR of single façade (including transparent curtain walls) of Class A public buildings in Severe Cold Zone should not be greater than 0.6, and Cold Zone should not be greater than 0.7 [24]. Buildings have different WWR, so the Institute selected WWR uses 0.3, 0.5, and 0.7 for comparison of energy consumption. The study discussed energy consumption in four typical climate zones, three values of WWR, and two control methods. A total of 24 experimental groups were set up for simulation discussion (Table 1).

2.3. Simulation evaluation index
This study mainly discusses the heating and cooling energy consumption, equipment energy consumption, and energy consumption per unit area with the two control methods. Among them, the energy consumption per unit area of intelligent control and continuous operation is $E_I$ and $E_C$. When the building's thermal properties are reasonably set, and the building form parameters are equally changed, the control energy-saving rate $\eta$ between the two control modes is calculated. The energy-saving rate calculation formula of the intelligent control operation mode compared to the continuous operation mode is as follows:

$$\eta = \frac{E_C - E_I - \Delta E}{E_C} \times 100\%$$

$\eta$ — control the energy-saving rate;
$E_C$— Continuous heating and cooling energy consumption (kWh/m²);
$E_I$— Energy consumption by intelligent temperature control (kWh/m²);
$\Delta E$— Energy consumption increased by the intelligent temperature control device (kWh/m²);

$$\Delta E = \frac{(P \times K \times 365)/1000}{A}$$

$P$—power of the device(W);
$A$— Standard room area (m²);
$K$— Equipment running time (h), the value of this article uses 14;

This study assumes that two temperature control devices are installed in each 50m² room, and the rated power of each device is 20W (Select the larger energy consumption of current conventional equipment), and the annual energy consumption per unit area of intelligent control equipment is calculated based on the operating time. Because the energy consumption load assessment is performed by simulation, the outdoor temperature, indoor non-heating and cooling dry bulb temperature and indoor heating and cooling dry bulb temperature of different control methods are extracted. Based on the simulated temperature changes, we can know whether the heating and cooling equipment is operating and judge whether the intelligent control and continuous operation scheme that operates through temperature settings are correct.

3. Data selection and analysis
This article analyzes the EPW file of the hourly weather data of the Chinese Standard Meteorological Data (CSWD) of these four typical climate zones and analyzes the daily average temperature through the weather analysis module in the LH toolset. The time outside the critical heating temperature (5℃) is defined as the heating period [25]. Taking into account the characteristics of the dry and hot climate in Xinjiang, the time when the daily average temperature is higher than the critical outdoor temperature of the air conditioner (26℃) is defined as the air conditioning period, and the heating and cooling periods are obtained through analysis of meteorological data (Figure 3).

The object studied in this article is a multi-story enclosed office building. The building sits north toward the south, the lowest layer 2, top 5-layer, layer height is 3.6 m, building an overall height of 18.6 m, the building has a total area of 1430.76m². This object contains the main functions of the office building, such as offices, conferences, transportation spaces. The thermal performance
parameters of the main envelope structure of each part meet the requirements of “Xinjiang Public Building Energy Saving Design Standards” [26] (Table 2). In order to reduce the interference of the variables on the results, all models use the same envelope structure. Except for the WWR, if the other thermal parameters change little in Xinjiang without setting variables. After uses the workflow of RH + GH + LH, the energy consumption model used for simulation was obtained (Figure 4).

Figure 3. Heating and cooling periods based on data Analysis of typical meteorological years.
Table 2. Building material parameters for simulation.

| Property (Opaque) | Wall | EWI | Floor | ERI | Property (Transparent) | Window |
|------------------|------|-----|-------|-----|------------------------|--------|
| Roughness        | rough| rough| rough | rough| Thickness(m)            | 0.08   |
| Thickness(m)     | 0.24 | 0.07 | 0.12  | 0.1 | Conductivity(W/m*K)     | 1.8    |
| Conductivity(W/m*K)| 1.74 | 0.02 | 1.74  | 0.02| Solar transmittance (%) | 0.6    |
| Density(kg/m³)   | 2500 | 38  | 2500  | 38  | Solar reflectance (%)   | 0.06   |
| Specific heat(kJ/(kg*K)) | 1010 | 1010 | 1010  | 1010| Visible transmittance (%) | 0.7    |
| Roughness (Optics) | 0.1  | 0.1  | 0.1   | 0.1 | Roughness (Optics)      | 0.02   |
| Reflection coefficient(ρ) | 0.4  | --   | 0.3   | --  | Reflection coefficient(ρ) | 0.78   |

1. Property (Opaque): non-transparent material property; Property (Transparent): transparent material property.
2. EWI: external wall insulation; ERI: external roof insulation.

Figure 4. Building functional block diagrams and energy consumption models with different WWR.
4. Analysis of simulation results

4.1. Indoor temperature changes

After sorting through the simulation data of all experimental groups, a data was selected for analysis. The heating period was selected on December 21. Since it is a challenge to select uniform standardized daily data for the summer cooling period in the four regions, Urumqi and Turpan chose July 21, Kashi chose August 6, and Altay chose August 1. In order to facilitate data analysis and visual display, the outdoor dry bulb temperature is defined as OT (date), and the indoor temperature without heating and cooling is IT (date); the indoor temperature under intelligently controlled heating and cooling is IT (date) + I, and the indoor temperature under continuous operation heating and cooling is IT (date) + C.

According to the temperature data obtained from the simulation (Figure 5), the typical days in the four selected regions are both correct using ICS and COS. During the defined working hours, the heating and cooling settings are operated according to the control temperature set by the control strategy, and there is a temperature adjustment with the indoor temperature line without heating and cooling, so $E_C$ and $E_I$ obtained from the simulation results are available to calculate the value of $\eta$.

![Figure 5](image-url)  
**Figure 5.** Temperature data obtained from data analysis and simulation. (a) Outdoor temperature and indoor temperature without condition, (b) Indoor temperature in two control modes.
4.2. Comprehensive discussion of energy consumption

Through carries on the data analysis to the analog result to be possible to know, in the same WWR, different climatic conditions have a more significant impact on heating and cooling energy consumption (including ICS and COS). Among them, the Altay region has the most massive energy consumption load for winter heating (150-180 kWh/m² in continuous operation and 140-160 kWh/m² in intelligent control), followed by Urumqi, Turpan and Kashi with a smaller difference of 60-80 kWh/m². Turpan’s cooling energy load is the largest among four cities (continuous operation mode is 70-100 kWh/m², intelligent temperature control mode is 55-85 kWh/m²), and Urumqi is the smallest, which is 5-10 kWh/m² (Figure 6).

The simulation results also clearly show that the heating and cooling energy load of the four regions using ICS is lower than that of COS, such as in Altay region which have an enormous difference in winter heating energy consumption is close to 20 kWh/m², followed by Urumqi, and the remaining two regions have small differences. Turpan’s two different operating modes have the most extensive summer air-conditioning cooling energy consumption, between 12-16 kWh/m²; Kashi and Altay differ by 6-10 kWh/m², and Urumqi has the smallest difference, less than 1 kWh/m². Therefore, the ICS method can effectively save energy, and the amount of energy savings will be affected by meteorological conditions.

Besides, the WWR also has a large impact on the heating and cooling energy consumption of the building. With the same weather data and building thermal parameters, the energy consumption for heating and cooling increases with the increase of the WWR. Besides, when ICS is used, the increase of the WWR has less effect on the incremental effect of energy consumption load. In other words, the ratio of ICS’s energy consumption increases with the increase of window wall is smaller than that of COS. For example, when the WWR value in Altay area changes from 0.3 to 0.7, the energy consumption of winter heating energy increases by 23.7 kWh/m² in continuous heating mode, and 10.9 kWh/m² in the use of ICS. Through data analysis, it is found that with the increase of the WWR, the cooling and heating loads are also increasing in various regions, and the increase is affected by the heating and cooling operation modes. When the WWR is 0.3 and 0.7, the maximum difference in heating power consumption varies around 23 kWh/m² (Altay region), and the maximum difference in cooling power consumption in summer varies around 26.5 kWh/m² (Turpan region). Therefore, under the premise of meeting the thermal requirements, the change of the WWR has less impact on ICS than COS.

4.3. Analysis and evaluation of energy saving rate

According to the simulation result data, the control energy-saving rate analysis of the ICS and COS methods is obtained (Figure 7). The η is affected by meteorological conditions and the WWR, and weather conditions are more affected. The energy-saving rate of refrigeration control in Kashi and Altay regions is as high as 28%~38%, in Turpan region is 13%~18%, Urumqi is a minimum of 3~5%.
The energy-saving rate of winter heating control varies from 8 to 14% in different regions. Except for Turpan, the energy-saving rate of winter heating under different WWR in the intelligent control mode remains the same, and Urumqi is 9%; around 12%–14% in Kashi, and 8% in Altay. Turpan and Kashi’s summer cooling control energy-saving rate decreases with the increase of the WWR. For the WWR is relatively large, the glass curtain wall system is difficult to block the change of the ambient temperature. When the cooling system is closed, the indoor and outdoor temperature difference is small (Figure 4), only continuous cooling can better maintain the indoor cooling target temperature.

5. Conclusions
This study fully considers the different climates in Xinjiang and the ratio of windows to walls in buildings to discuss the calculated values of Heating, Cooling and control energy saving rate in the two operating states of COS and ICS. The following conclusions are obtained through data analysis of simulation experiment results: a) The heating and cooling system of office buildings in Xinjiang region adopts intelligent control operation mode to effectively save energy; b) A reasonable selection of WWR for office buildings in Xinjiang can effectively reduce the building's cooling/heating load. c) WWR has an impact on the energy-saving rate of ICS, and the control energy-saving rate decreases with the increase of the WWR. In short, in order to better adapt to changes in the climate environment, it is necessary for buildings to use equipment to improve indoor comfort; However, reasonable parameter selection in the architectural design stage and refined management in the operation stage play a significant role in the sustainable development of buildings.

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