A Central Air Conditioning Control Strategy to Enhance Thermal Comfort in Library Buildings

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A central air conditioning control strategy to enhance thermal comfort in library buildings

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Abstract. A comfortable indoor thermal environment is usually controlled through air conditioning, which can greatly improve work efficiency. However, current air conditioning system design may not consider the spatio-temporal distribution of the indoor environment for large-scale buildings, so the air conditioning system needs to be optimized. Few studies have examined such optimization related to different weather conditions outside the building. This study presents a method to formulate an air condition adjustment strategy for each specific zone in a library with large glass curtain walls, based on the diurnal change of thermal environment. We measured the indoor thermal environmental conditions and recorded the thermal comfort perception of room occupants. The Predicted Mean Vote (PMV) and apparent temperature model were adopted to predict the occupants' thermal comfort, resulting in a suggested comfort range. Based on our results, the comfortable range of PMV and apparent temperature was identified, and this comfortable range could be used as a basis for an example of adjusting the air conditioning system to improve indoor thermal comfort.

Keywords: Central air conditioning; PMV; Thermal comfort; Library

1 Introduction

Indoor thermal environment refers to the environmental factors that affect the human body's sense of cold and heat, including indoor air temperature, humidity, airflow speed [1]. Suitable indoor thermal environment enables people to maintain thermal balance and feel comfortable. Considering the spatial and temporal distribution of temperature in the interior architecture can help adjust air conditioning control strategy to enhance thermal comfort.

For the trade-off between improving thermal comfort and energy saving, the use of the air conditioning system needs to be optimized [2]. Previous indoor studies mainly used simulation models related to Predicted Mean Vote (PMV) or adopted observational approach to assess indoor thermal environment [3]. This study combines meteorological observation, questionnaires and PMV to present a method for formulating an air conditioning adjustment strategy for specific zones in a library. Previous studies mainly examined the influence of outdoor temperature on indoor thermal comfort. This study shows the impact of outdoor environment under different weather conditions. The aim of this study is to provide a set of air conditioning adjustment strategies that can be adapted to different weather conditions in specific areas of indoor thermal environment, in order to enhance thermal comfort.

2 Methods

We conducted the study in the Sun Yat-sen University Library in Zhuhai, Guangdong Province, China (figure 1). July and August are the months with the highest temperature in Zhuhai, with a monthly average temperature of 28.5°C. As a pilot study, thermal comfort surveys (n = 73) were compared with meteorological measurements in the library.

Fig. 1. The Sun Yat-sen University Library in Zhuhai (left) and the interior of the library with the sensors for recording indoor thermal environment (right)

2.1 Experiment site

The seating arrangement is adjacent to the bookshelf in a flat layout, with air conditioning provided on each floor. The enclosure structure of the library is a large-area glass curtain wall. According to the layout of the 8th floor of the library, the partition was divided according to the apparent temperature distribution measured in the first measurement on 25th July (figure 2). Places with similar apparent temperature distribution were divided into the same area.

2.2 Meteorological measurement

For each zone, we set up the ibutton (DS1922T, Temperature Logger), HOBO U23-001 Temperature/Relative Humidity Data Logger, the HouseGo smart air housekeeper, black globe thermometer (HQZY-1) for data collection. The data were block averaged into 10-min intervals. The sensors were fixed on desks, columns and book shelves. Black globe thermometers were placed on the tabletop or on a tripod. The location of the sensors is described in Figure 1 and Figure 2.

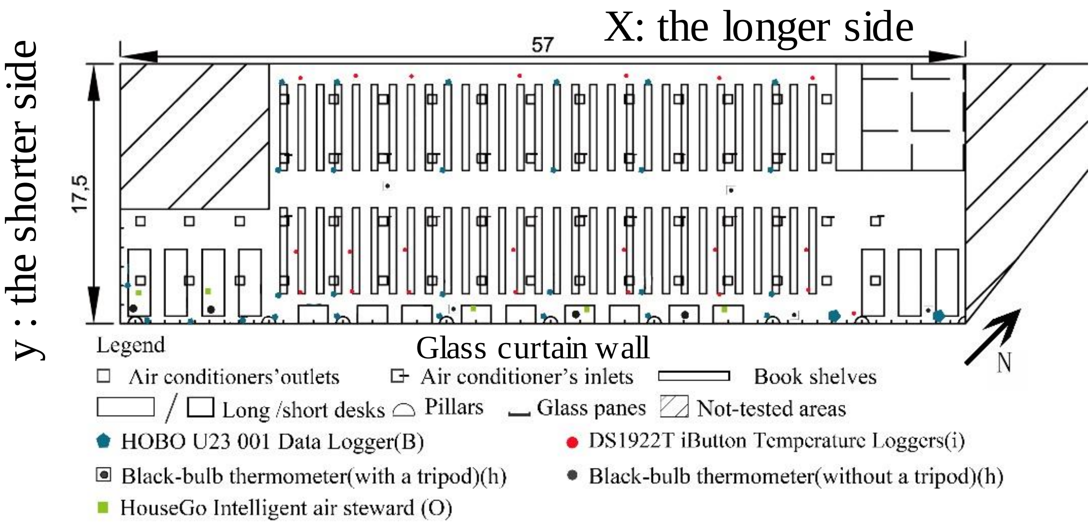

Fig. 2. Floor plan of the Sun Yat-sen University Library in Zhuhai (8th floor)

2.3 Thermal comfort survey

In order to measure the personal preference of thermal comfort, we surveyed the occupants in the library during the meteorological measurement. The time and the location of each questionnaire were recorded.

The questionnaire includes three main questions. The first question is about the perception of the indoor temperature. The options are -3, -2, -1, 0, 1, 2, 3 for cold, cool, slightly cool, neutral, slightly warm, warm and hot, respectively. The second question is about the perception of the indoor air humidity, and the options are -2, -1, 0, 1, 2 for wet, slightly wet, neutral, slightly dry and dry, respectively. The third question is about the thermal comfort vote of the indoor temperature and humidity environment, and the options are -2, -1, 0, 1 for very uncomfortable, uncomfortable, comfortable and very comfortable, respectively. Individuals interpreted the thermal sensation scale differently, which has a direct impact on the number of people dissatisfied.

2.4 PMV and apparent temperature calculation

We adopted the PMV and apparent temperature model for predicting comfort measurement. According to Fanger's PMV/PPD model [4], we calculated and multiplied the PMV by a coefficient (0.7) for China. Equation 1 and 2 were used to calculate apparent temperature (T_c) according to [5].

$$T_c = -2.653 + (0.994 \times T_a) + (0.0153 \times {T_d}^2) \tag{1}$$

$$T_d = \frac{243.04[\ln\left(\frac{rh}{100}\right) + \frac{17.625T_a}{243.04+T_a}]}{17.625 - \ln\left(\frac{rh}{100}\right) - \frac{17.625T_a}{243.04+T_a}} \tag{2}$$

where T_c is the apparent temperature (°C), T_d is the dew point temperature (°C), T_a is the air temperature (°C), and *rh* is the indoor relative humidity.

2.5 Data analysis

In order to obtain the comfort temperature range for adjusting air conditioning, we identified the PMV and apparent temperature for specific locations in the library, including the time and the location of the space. We also calculated the necessary change in indoor temperature for maintaining thermal comfort based on different relative humidity values, which was derived from the apparent temperature.

3 Results

3.1 Meteorological condition

During the days when surveys were conducted in the library (25th – 26th July 2018 and 29th August – 2nd September 2018), the average temperature was around 27.5 °C outdoor and 26.5 °C indoor. There was heavy rain on 29th August and light rain on other days except for 25th July. The study period included both sunny, cloudy and rainy days.

3.2 Spatio-temporal distribution of apparent temperature in the library

Figure 2 presents the floor plan of the 8th floor of the library, as well as the points of air temperature and relative humidity measurement. Based on the apparent temperature calculated from equation 2, the apparent temperature field map was drawn by interpolation (csa3lx) in NCAR Command Language. As shown in figure 1, the glass curtain wall is the main way for solar radiation to enter the indoor space of the library. Changes in outdoor weather conditions such as cloudiness and raining could influence the indoor thermal environment.

On rainy days, the air conditioner was set at a lower temperature point to reduce the relative humidity. However, if the temperature decreases too quickly, the indoor environment may remain too cold (apparent temperature < 26.6 °C, figure 4b) with limited solar radiation from outside.

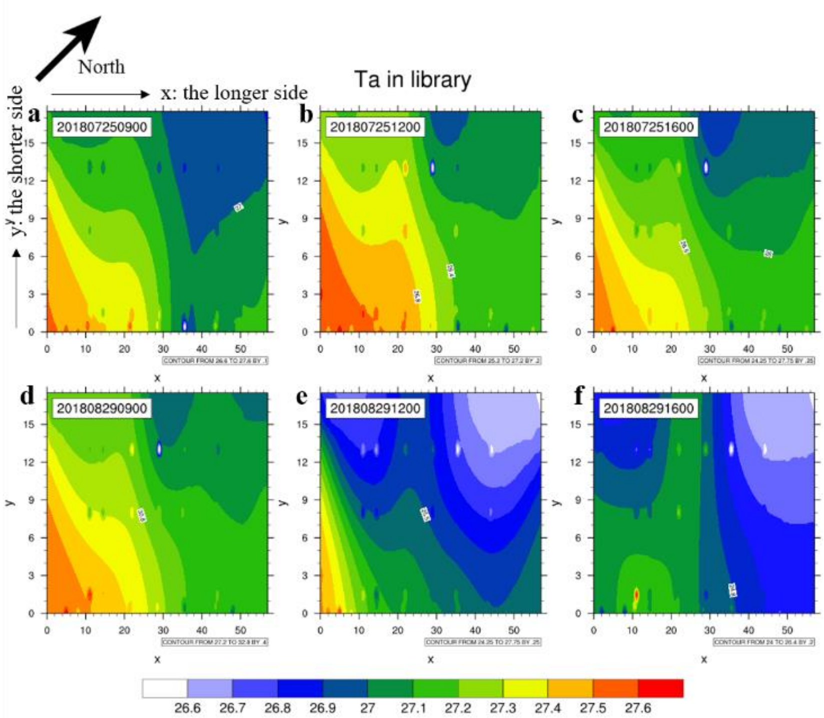

Fig. 3. The spatio-temporal distribution of apparent temperature in the library. The apparent temperature distribution in the library on 25th July 2018 (sunny): a. 9am, b. 12pm, c. 4pm, as well as the apparent temperature in the library on 29th August 2018 (rainy): d. 9am, e. 12pm, f. 4pm.

3.3 Thermal comfort range of library occupants

We identified the comfortable range of PMV (figure 4c) and apparent temperature (figure 4b), and this comfort zone of apparent temperature could be used as a basis for controlling the central air conditioning system. There was a strong, linear correlation between apparent temperature and PMV (figure 4a). Once the comfort zone for apparent temperature (26.6 °C to 30.7 °C) is identified, the corresponding indoor temperature can be calculated with the apparent temperature and relative humidity through equation 2. For example, when relative humidity is equal to 66.9%, the adjustment interval of indoor temperature can be identified (24.3 °C to 26.8 °C) (figure 4d).

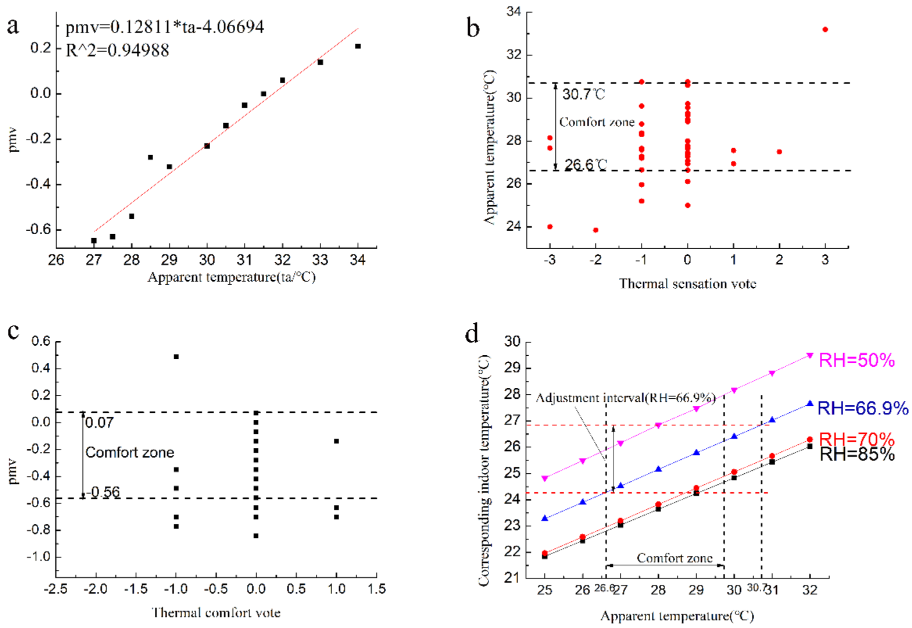

Fig. 4. The comfort zone for air conditioning adjustment: a) Linear relationship between PMV and apparent temperature; b) thermal sensation preference (using apparent temperature as the indicator); c) thermal comfort

preference (using PMV as the indicator); d) suggested value of indoor temperature adjustment based on different relative humidity values.

3.4 The air conditioning adjustment strategy

According to the spatio-temporal distribution of the indoor environment, the 8th floor can be divided into five zones (figure 5). When the air conditioner was initially turned on, we read the temperature of the air inlet displayed on the thermostat in each area of the room. After that, we measured the relative humidity in the room, and the typical indoor relative humidity in the library was 50% – 60%, 60% – 70% and >70% for sunny, cloudy and rainy days, respectively. Through the conditional statements in figure 5, the indoor temperature can be uniformly adjusted in each zone in order to prevent the indoor temperature from increasing due to a sudden rise of outdoor temperature. The indoor and outdoor temperature difference still needs to be input into the program as the judgement value, and the adjustment should be made in advance. The indoor temperature should be maintained at a comfortable level based on the reduction of heat on sunny days and the reduction of moisture on rainy days.

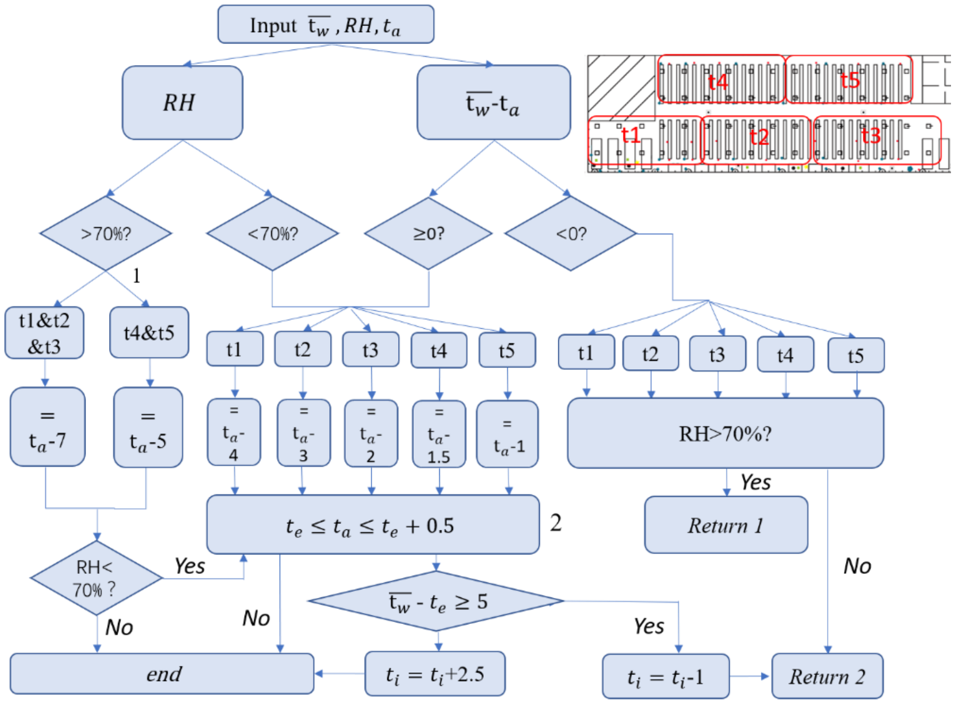

Fig. 5. The air conditioning adjustment strategy (needs to be executed every hour) 'End 'means 'no adjustment need', $\overline{t_w}$ is the cumulative hourly average temperature (from 6 am to the time of measurement), t_a is the indoor air temperature displayed on the thermostat of each air inlet, t1\t2\t3\t4\t5 is the air temperature of five air conditioner adjusting zones(divided manually), RH is the relative humidity of each zone, and t_e is the recommended indoor temperature identified in the adjustment interval according to figure 4d.

4 Discussion

This study identifies the comfortable range (apparent temperature: 26.6 °C – 30.7 °C) for the Sun Yat-sen University Library occupants in Zhuhai. We propose a method to optimize the adjustment of air conditioner, which can be applied to large-scale buildings with glass curtain wall. However, due to our small sample size, the impact of individual differences (e.g. age, gender and homeland) was not analyzed. Our results may be generalizable only to young people aged 20 to 25.

Some studies suggest that the range of 'feeling comfortable' is very personal, but current air conditioning systems rely on a fixed set-point, which is based on the maximum occupancy assumptions that may cause discomfort for occupants [6-8]. By analyzing the predicted comfort in different zones during different weather conditions, the personal thermal comfort preference can be quantified. The optimized range can keep most occupants within a reasonable thermal comfort range [9].

By measuring the main physical parameters influencing indoor thermal comfort, the data calculated from models can assess the impact of behavioral adjustment and control on subjective responses [10]. In addition, some previous studies have included the influence of weather conditions outside to predict thermal comfort [11]. The standard given by the PMV model may not satisfy the thermal comfort requirement of all occupants [8]. In order to identify the comfort range for most people, we can develop a personal thermal preference profile [6]. The method of calculating PMV to convert and obtain the comfort zone has been commonly used in thermal comfort studies [12].

In related studies, computational fluid dynamics (CFD) has been used to evaluate thermal comfort and simulate indoor air flow, offering an intuitive spatial distribution for analysis [9]. Although this study does not involve modelling, we present a basic framework to maximize occupant comfort in different sections of the library using observational approach. This approach is reasonable for a pilot study and can be applied to other library buildings or similar buildings. The main purpose of our air conditioning adjustment strategy is to minimize the thermal comfort complaints [12].

5 Conclusions

This study identifies the comfortable apparent temperature range for the library occupants (26.6 °C to 30.7 °C). In addition, we present a framework to identify the indoor temperature interval for adjusting air conditioning to maintain thermal comfort. By measuring indoor environment variables and conducting thermal comfort survey, we evaluate the data of indoor environment and personal preference of thermal comfort. To compare the difference in individual's thermal comfort, the PMV and apparent temperature model are adopted. Through executing the conditional statements based on indoor temperature, outdoor temperature and relative humidity, they can be used as a basis for adjusting air conditioning in library buildings. Our study approach could enhance the design of automatic air conditioning system to provide a more accurate range for comfort adjustment.

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