Research on Indoor Thermal Environment Control and Thermal Sensation Prediction

Wenhong Yu, Nana Dong, Hui Li
North China University of Technology, 100144, Beijing, China

Abstract: Most of indoor thermal environment are controlled based on given values. Researchers have proposed a new indoor thermal environment control method based on thermal sensation. Thermal sensation means human body thermal sensation to indoor thermal environment such as cold and hot. This method can not only avoids the unreasonable setting points, but also satisfies the demand of dynamic thermal comfort. At the same time, it benefits to thermal comfort and energy saving of building. Since there are many factors influencing human body thermal comfort, this method needs to be supported by more experiments. This article discusses on the thermal sensation influence factor of this new method, which will make more energy saving.

1. Introduction
Nowadays, the temperature and humidity control of rooms is usually given a set value manually, and then the air conditioning system adjusts the temperature and humidity of the room according to the set value. However, there are some problems to this control method. To this end, some scholars have proposed an indoor thermal environment control method based on thermal sensation. In order to achieve better automatic control of indoor thermal environment, a control method based on thermal sensation prediction is proposed in this paper. The user’s skin temperature is detected by infrared probe, and the indoor thermal environment is adjusted according to the skin temperature prediction. Compared with other methods, this method can directly detect human physiological information so as to predict human body thermal comfort, and reduce the interference of detection to human body through non-contact detection.

2. Control system research
By setting up an experimental platform based on thermal sensation control and recruiting volunteers to carry out experiment, the author has analyzed the behavior characteristics of room users expressing their complaints after using thermal sensation control. The room has a desk, an computer on the desk, a HMI that can input hot and cold complaints, an infrared camera (detecting the skin temperature of human face and neck), and an indoor air temperature sensor with an exhaust fan on the window. Sensors are used to measure indoor and outdoor temperature, humidity, air speed and other environmental parameters. The layout of the experimental equipment is shown in Figure 1, and the photo of the laboratory site is shown in Figure 2.
Figure 1. Layout of laboratory equipment. Figure 2. Field photo of the laboratory.

When the preparation is completed, the system is turned on and the infrared probe detects the skin temperature of the volunteers. The skin temperature includes the temperature of the face and the neck, and the detected temperature will be sent to the computer database at a data transmission rate of 10 per second. According to the current average skin temperature of the volunteers, the computer adjusts the air conditioning system to control the indoor thermal environment of the room and make it reach the user's comfort zone. At the same time, HMI will be provided as a man-machine interface during the experiment. When volunteers feel cold or hot, they can "complain" to HMI. The system will record this complaint and make corresponding adjustments to the air conditioning system.

The main interface of the human-machine interface is shown in Figure 3. The control logic of indoor thermal environment based on thermal sensation is shown in Figure 4. In the control method based on thermal sensation prediction (Figure 4), the set value is given by the system through learning the user's thermal comfort zone, measuring the user's skin temperature and running a series of algorithms. " - "represents negative feedback of room temperature and humidity.

Figure 3. Human-machine interface for entering thermal sensation.
The online self-learning algorithm is a machine learning method often used in the field of artificial intelligence. According to the person's hot and cold feeling and the corresponding skin temperature, the volunteer's skin temperature comfort domain range is gradually learned. The flow of the control method based on thermal sensory prediction is shown as following: First, the person expresses the feeling of hot and cold in the room, and the infrared camera detects the skin temperature when the person expresses the feeling of hot and cold, and after obtaining a certain amount of data, the system according to the online self-learning method draw a comfortable temperature range (the skin of the comfort range is changing with the updated). Then, after learning the comfortable range of skin temperature, it determine the user's "hot and cold feeling" and get the room temperature setting value according to the current skin temperature based on the fuzzy logic. At last, through the action of the controller and air conditioning equipment, the indoor temperature would reach a comfortable range. The thermal sensory prediction control flow chart is shown in Figure 5.

Figure 4. Control logic of indoor thermal environment.

Figure 5. Flow chart of thermal sensation predictive control
3. Limitations and improvements of the experimental device

As a thermostatic animal, the human body temperature under normal circumstances is maintained in a constant range, and the body to maintain a constant temperature mainly depends on the body’s autonomic temperature regulation, the body’s autonomic temperature regulation mainly includes these three ways: vasoconstriction and vasodilation, shivering, sweating.

When the temperature in the human body is higher than the temperature setting point, the skin blood vessels will expand, so that the blood vessel flow increases, more heat in the human body is discharged into the external environment through the skin. Conversely, when the temperature inside the body is lower than the temperature setting point, the skin blood vessels will contract, so that the blood vessel flow is reduced, the body to the outside heat loss is also reduced. Human skin vascular contraction and expansion, can cause skin temperature of the lower and higher, so the skin temperature can reflect the degree of thermal comfort of human body.

Lan, ect. [8] measured the local skin temperature of the volunteers at different air conditioning temperatures (21, 24, 26 and 29 °C) and calculated the average skin temperature. Figure 5 shows the relationship between the average skin temperature and thermal comfort of the volunteers in the experiment.

![Figure 6. The relationship between average skin temperature and thermal comfort](image)

Figure 6 shows that when the human body is in an uncomfortable “cold” state, the average skin temperature is lower than that in a comfortable hot state. When the human body is in an uncomfortable “warm” state, the average skin temperature is higher than the thermal comfort state. The average skin temperature of the human body under the three states (cold discomfort, comfort, warm discomfort) is significantly different, and the measurement of the average skin temperature of the human body can reflect the thermal comfort degree of the human body to some extent.

It should be pointed out that, there are many factors affecting the human body thermal comfort such as human skin temperature, sweat rate, metabolic rate degeneration, brain waves, heart rate, indoor air temperature, humidity, air speed, clothing, etc. These all have a bigger relevance and human thermal comfort degree. There are some limitations in judging a person's thermal comfort degree only by the main factor of skin temperature on the human body surface, as shown in table 1.

|   | The analysis of limitation factors |
|---|----------------------------------|
| 1 | The number of infrared detectors  |
| 2 | The part of the body that is being detected |
| 3 | Perspiration of human skin       |
| 4 | Gender, age, height, and weight of the volunteers |
| 5 | The health of the volunteers     |
6 Amount of work activity
7 Clothing of the volunteers
8 Building environment factors (air temperature, humidity, air speed, etc.)

However, from the perspective of practicality and popularization about intelligent control of air conditioning equipment, it is not good to have too many types and quantities of detectors reflecting human thermal comfort. The method of selecting local surface temperature detection of human body to reflect the thermal comfort degree of human body is relatively simple and convenient from the perspective of measurement method and calculation method, and has good popularization and application value. Therefore, a larger number of personnel experiments are needed to verify this method and a larger number of samples are needed for this online self-learning.

4. Summary
Based on a control method for prediction of thermal sensation is a kind of new thermal environment intelligent control method, the traditional control mode is not reasonable and lead to the waste of energy, carbon emissions and air pollution, at the same time, unable to realize the personalized dynamic thermal comfort. The control method based on thermal sensation prediction can not only avoid the waste of energy, but also automatically adjust the indoor thermal environment to make it comfortable. This method is a new personalized micro-environment control method, which can directly detect human physiological information to predict individual thermal comfort, and reduce the impact of detection on human body through non-contact detection.

References
[1] Wang Fulin, Chen Zheliang, Jiang Yi, et al. Preliminary study on perception-based indoor thermal environment control [C], In: The 13th International Conference on Indoor Air Quality and Climate, Hong Kong, China, 2014.
[2] ASHRAE, Standard 55a-1995. Thermal Environmental Conditions for Human Occupancy [S], American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, 1995.
[3] Wang Fulin, Chen Zheliang, Jiang Yi, et al. Indoor thermal environment control based on thermal sensations [J], HVAC. 2015, 45 (10): 72-75.
[4] Zhao Qianchuan, Yin, Zhao Yin, Wang Fulin et al. Preliminary study of learning individual thermal complaint behavior using one-class classifier for indoor environment control [J], Build. Environ. 72 (2014): 201-211.
[5] Zhao Qianchuan, Cheng Zhijin, Wang Fulin et al. Experimental Assessment of a Satisfaction Based Thermal Comfort Control for a Group of Occupants [C], The IEEE International Conference on Automation Science and Engineering 2015, Gothenburg, Sweden, 2015.
[6] Chen Zheliang, Xue Fei, Wang Fulin. A novel control logic for fan coil unit considering both room temperature and humidity control [J], Build. Simulation. 8 (2015): 27-37.
[7] Karlin B, Ford R, Squiers C. Energy feedback technology: a review and taxonomy of products and platforms [J], Energy Efficiency, 2014, 7(3): 377-399.
[8] Lan L, Lian Z W, Liu W W, et al. Investigation of gender difference in thermal comfort for Chinese people [J]. European Journal of Applied Physiology, 2008, 102(4): 471-480