7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient Buildings and Urban Environments

ibpc2018.org | #ibpc2018

Research for the Optimization of Air Conditioner Sensor Position Based on the Room Spatial Parameter

Kuixing Liu[1], Gang Liu[1,*], and Yueqiang Di[1]

[1]School of Architecture, Tianjin University, China

[*]*Corresponding email: diyueqiang@tju.edu.cn*

ABSTRACT

The indoor temperature measured by the sensor is an important basis of air conditioner control strategy. Accordingly, the position of the sensor influences power consumption and the stability of indoor temperature control. This paper aims to study the influence of different sensor positions on air conditioner power consumption and indoor temperature stability. An experiment is conducted, which has 20-position circumstances, including different height, horizontal distance, and vertical distance from the air conditioner. Furthermore, Fluent is used to simulate the situation that sensor is in rooms with different sizes and air conditioner direction. An optimal sensor position searching model is developed, and an ideal position is proposed. A correction parameter is presented to adjust the sensor in original position. This study provides theoretical and practical support for improvement of the operation of air conditioners.

KEYWORDS

Air conditioner; Thermal comfort; Indoor temperature; Temperature sensor

INTRODUCTION

With the advancement of science and technology, the living condition of people is becoming increasingly comfortable, and the air conditioner plays an important role in creating such a comfortable condition. As the demand for indoor comfort continues to increase, higher requirements have been placed on the air conditioner (Jani et al. 2017). Moreover, efficient operation of an air conditioner is necessary under the energy conservation trend.

One study focuses on the heat pump inside the air conditioner (Waheed et al. 2014). However, as a key input for the operation of the air conditioner, the temperature measured by temperature sensor cannot be neglected. The temperature of the sensor position directly affects the air conditioner start–stop control, which eventually affects energy consumption and indoor temperature. If comfort and efficiency can be improved by optimizing this input, then low-cost optimization can be achieved. The conventional air conditioner contains a temperature sensor positioned on the return air grill, which measures the temperature of the return air. This is due to the closed control link of the air conditioner. However, as technology advances, information interconnection makes it possible for an open control link of the air conditioner operation. The temperature data from other sensors, and even the humidity and velocity, could be the input of the air conditioner. When the sensor position is not confined inside the air conditioner, it is necessary to study the ideal position of the sensor. In this paper, cool mode, rather than dehumidification mode or others, will be focused on, thus only temperature would be used as an input.

Yang (2009) put forward a method to find a proper position that can represent the sectional environment of the air conditioner. Liu et al. (2013) studied the influence of three different sensor positions on an indoor PMV. These studies focus on the indoor average temperature, which is affected by the average temperature of the position of the sensor. But the initiative of people could eliminate the bias of the average temperature because people can change the target temperature of the air conditioner. Meanwhile, Nevins (1971) found that people are sensitive to the fluctuation of temperature, and the fluctuation cannot be directly controlled by changing the target temperature.

In this article, the domestic air conditioner is chosen as the experiment object, and the stability of indoor temperature and power consumption are the criteria to evaluate the air conditioner operation. By analyzing the characteristic of the temperature of different position using clustering and classification method, an ideal measurement position could be indicated.

METHODS

Experiment

The experiment is in a 5 m x 3.5 m room on the fourth floor of a six-story residential building in Tianjin, China (as shown in Figure 1). The air conditioner is located 2.7 m high at the southwest corner, which faces east. The temperature monitor device is a HOBO thermocouple data logger. Several pre-experiments are conducted and show that when the distance between two HOBO loggers is bigger than 1.5 m, the measurement error would be insignificant.

The measurement positions fill the room with a 1.5 m interval distance, and there are 20 measurement positions in total, including one at the return air grill. Except for the return air position, all 19 positions are distributed in a grid that has 2 layers (0.3 m high and 1.8 m high), 3 rows with a 1.5 m interval in an east–west direction, and 4 columns with a 1.5 m interval in a north–south direction. In the grid, 5 positions in a 0.3 m high layer are unreachable because of furniture and thus are ignored. HOBO loggers are placed at all 20 positions to monitor the temperature change (as shown in Figure 2).

There is only one adjacent room with an exterior wall, which is installed using a smart heater to be constant 30° C, according to the local summer outdoor design temperature. The air conditioner mode is cool, and the target temperature is set at 24° C, which is accordant with the adjacent room to avoid external factors. Other settings are set at default. By modifying the circuit, the sensor inside air conditioner is extended to reach all the positions. During the experiment, the sensor will be at one of the 20 positions, and the air conditioner will operate using the temperature of that position. The moving of the air conditioner temperature sensor only happens during the stopped period of the air conditioner's intermittent operation.

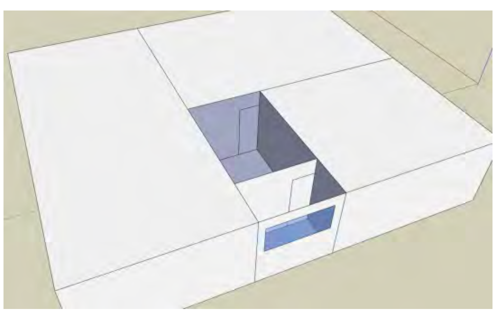

Figure 1. Experiment environment

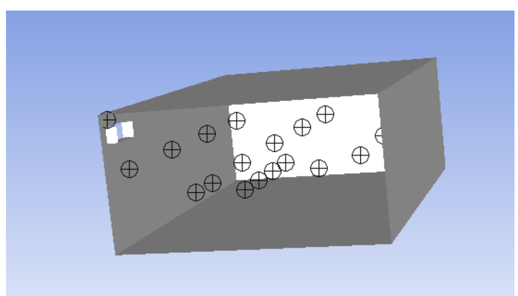

Figure 2. Measurement positions

Data analysis outline

The 20-position temperature is clustered using two key factors, and the influence of sensors located at positions of different cluster is analyzed. Thus, the clustering result and the cluster to which the ideal sensor measurement position belongs are obtained. The clustering result would be used to train a classifier. Afterwards, ANSYS is used to simulate the indoor temperature of rooms with different parameters, and the trained classifier is used to classify the temperature. Then, the recommended measurement position for rooms with different parameters could be drawn. In this project, clustering and classification algorithms run in the Ubuntu operating system, and the algorithm program is written in Python.

Simulation

ANSYS is used to simulate three different conditions, including a verification condition and two generalization conditions (GCs). In the verification condition, all parameters are accordant with the experiment to verify. In GC I, the room is changed to 10 m x 7 m. In GC II, the room is changed to 10 m x 7 m, and the air conditioner direction is changed to northeast. DesignModeler is used to build models, and ICEM-CFD is used to generate the mesh. Fluent is used to perform the transient simulation calculation, and the time step is set to 2 s.

Data analysis method

Min–Max Normalization is used before the analysis algorithm to normalize the data with different ranges or units. The clustering method is K-means, which has better performance (Milligan and Cooper, 1980), and the silhouette coefficient is used to select the clustering number. The Bayesian classifier is used for classification, which is not sensitive to data deficiency. The temperature of the 20 positions is recorded using a time–domain curve, which is not compatible with the clustering or classification methods. Therefore, two key factors—temperature fluctuation amplitude and delay—are extracted from the original data to represent the characteristic of the temperature curve. Because the average indoor temperature is not the evaluation quota, the average temperature is not chosen to be the key factor.

RESULTS

Experiment and clustering result

Figure 3 show a 20-position temperature curve controlled by the air conditioner from one day of the experiment. It is obvious that the temperature of every position fluctuates together but has different amplitudes. For the following discussion, a position named α position is defined as the position that is 2 m high, along the same wall as the air conditioner but 1 m away from the air conditioner. In the experiment, α position is position 2. The experiment lasted for 19 days, and all the data is used for following analysis. When the clustering number is 3, the silhouette coefficient reaches best, which indicates the proper clustering number. By using amplitude and delay, the clustering result could be calculated (as shown in the Table 1).

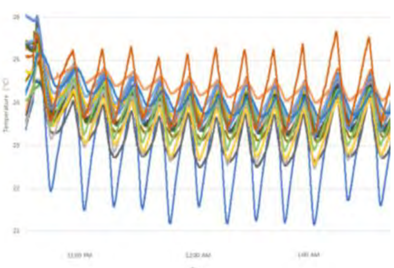

Figure 3. 20-position temperature

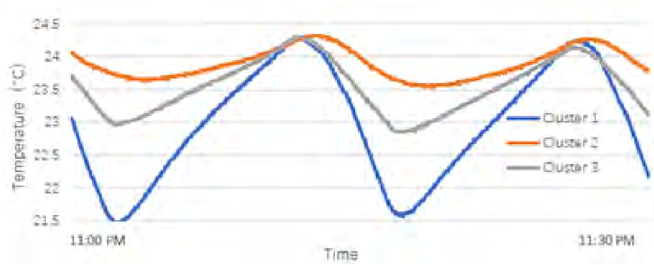

Figure 4. Typical curves

Table 1. Clustering result: experiment

Cluster	Measurement Position
Cluster 1	5, 9, 10, 13, 20
Cluster 2	4, 7, 8, 12, 14, 17, 19
Cluster 3	1, 2(α), 3, 6, 11, 15, 16, 18

Difference between clusters

The typical temperature curves of three clusters are shown in Figure 4. It is obvious that the temperature of positions in cluster 1 fluctuates significantly, of which the amplitude is the largest. In cluster 2, it fluctuates softly with an obvious delay. Cluster 3 performances between two other clusters. The average parameter of three clusters is shown in Table 2.

Table 2. Parameter of three clusters

Cluster	Average Temperature (℃)	Amplitude (℃)	Delay (s)
Cluster 1	23.54	2.43	32
Cluster 2	23.93	1.13	81
Cluster 3	23.79	1.6	55

Runtime difference

The temperature of the different clusters behaves variously, which will cause diversity in the air conditioner operation if the sensor is placed at positions of different clusters. When the sensor is changed from one cluster to another one, the air conditioner will perform differently, which leads to the change of both indoor temperature and power consumption. By using 20-position temperature to represent the indoor temperature, the alteration is clear. It can be seen in Figure 5 that when the sensor is changed to the position in cluster 1, the indoor temperature fluctuates gently and is more agglomerative. The period of air conditioner operation shortens obviously but the temperature changes as almost straight lines. In Figure 6, compared with that of cluster 3, the period is stretched and the temperature in cluster 2 changes in a bent way.

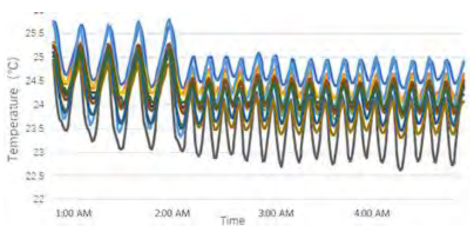

Figure 5. Cluster 3 to 1

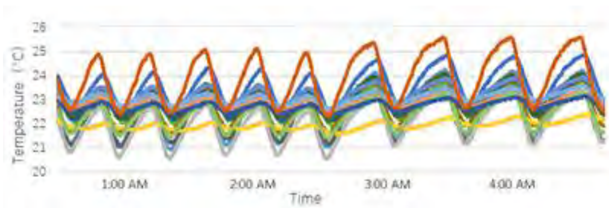

Figure 6. Cluster 3 to 2

Three parameters are used to evaluate the air conditioner operation caused by different sensor position. Temperature fluctuation variance is the temporal variance. Temperature distribution variance is the spatial variance. Power consumption is the electricity used in a unit time. The former two represent the stability of indoor temperature, which is directly related to indoor comfort. For better comparison, three parameters are converted to three indexes: temperature fluctuation variance index (TTVI), temperature distribution variance index (TDVI), and power consumption index (PCI). These three indexes are three parameters divided by the respective average value. For example, the TTVI is the temperature fluctuation variance divided by the 20-position average value. A comparison is shown in Table 3.

Table 3. Run-time difference of the three clusters.

Cluster	TTVI	TDVI	PCI
Cluster 1	0.88	0.93	1.14
Cluster 2	1.37	1.19	0.81
Cluster 3	0.99	1.02	0.98

Simulation

Figure 7 is the temperature distribution of a 2 m high layer in vilification condition; the general boundary of three clusters at 2 m high is also shown by blue lines: the left part is cluster 2, the middle part is cluster 3, and the right part is cluster 1. In Figure 8, the normalized value of the temperature fluctuation amplitude is shown, where the average temperature is 23.8° C, and the min/max value of temperature fluctuation is 0.9/2.6° C. In verification condition, though there is a visible bias from position 13 to position 19, which is because of the unconsidered furniture in simulation, the simulation result shows a high accordance with the experiment. In two GCs, by using the classifier trained by the clustering result, the positions could be classified as the previous three clusters according to their temperature amplitude and delay. The classification result is shown in Table 4. As the size of room becomes larger, the airflow has a weaker return trend, which leads to a weak response for every position. Because the characteristic of positions changes, the clustering result alters.

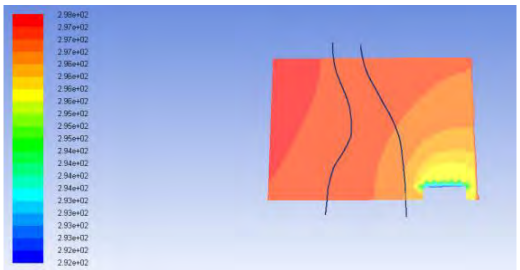

Figure 7. Temperature distribution

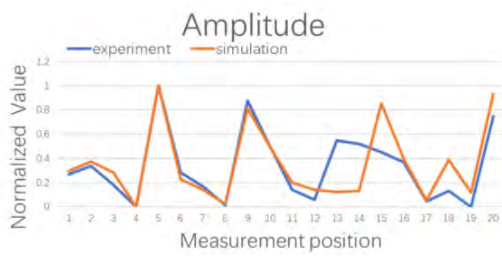

Figure 8. Verification

Table 4. Clustering result: simulation.

Cluster	Measurement Position-GC 1	Measurement Position-GC 2
Cluster 1	1, 5, 20	5, 20
Cluster 2	3, 4, 6, 7, 8, 11, 12, 14, 15, 16, 17, 18, 19	3, 4, 7, 8, 10, 11, 12, 14, 15, 16, 17, 18, 19
Cluster 3	2(α), 9, 10, 13	1, 2(α), 6, 9, 13

DISCUSSIONS

Evaluation index

To compare the performance of the air conditioner operation, an evaluation index (EI), as a comprehensive consideration of indoor comfort and power consumption, is defined as:

$$EI = \frac{2}{\frac{2}{TTVI + TDVI} + \frac{1}{PCI}} \qquad (1)$$

where *TTVI* is the temperature fluctuation variance index, *TDVI* is the temperature distribution variance index, and *PCI* is the power consumption index. A lower EI is better. As shown in Table 5, cluster 3 shows a better performance than the two other clusters.

Table 5. EI of three clusters

Cluster	EI (lower is better)
Cluster 1	0.981
Cluster 2	0.986
Cluster 3	0.973

Suggested position

After analyzing the characteristics of the three clusters, it can be drawn that three clusters can be named as Direct Zone, Inert Zone, and Reasonable Zone, respectively.

Direct Zone: The positions are close to the air conditioner, and are directly blown by the air conditioner, so the temperature fluctuates greatly; the response is quick; and the feedback to

the air conditioner is intense. In general, this zone is within 3.2 m of the wind path of the air conditioner, and the boundary varies around 3 m when the wind speed or room size changes.
Inert Zone: The positions are located far away from the air conditioner or in the corner of the room. Obviously, due to the stagnant airflow, the temperature fluctuation is weak, and the feedback to the air conditioner is weak. The boundary of this zone varies significantly.
Reasonable Zone: The measurement points in this cluster are in the middle of two other clusters. They are in a relatively open position with moderate temperature fluctuations. The reasonable zone is an ideal choice of air conditioner sensor measurement position, which considers both indoor comfort and energy conservation. The clustering stability, the accordance in different condition clustering, of the position should also be considered. The distance from the center of the cluster represents the clustering stability, and positions that are closer to the center would be clustered in the same cluster and perform more like the expect performance. The location of air conditioner temperature sensor recommended in this paper is position α, defined previously as located on the same wall as the air conditioner, 1.8 m high and 1 m away from the air conditioner. This measurement position is not only good in theoretical performance but also in application because it is located on the wall surface, which is convenient for placement. It is not in the center of the room or in the place where people pass by, which is less influenced by human activities, ensuring stable and efficient operation.

Sensor correction

The original position of the temperature sensor is at the return air grill, which belongs to the Direct Zone. By analyzing and comparing the characteristic of the temperature curve of the recommended measuring position and that of the original position, which is the fluctuation amplitude and delay, it can be found that the delay is 25 s shorter and the fluctuation amplitude is 35% higher. It can be adjusted simply by adding an RC circuit.

CONCLUSIONS

This paper proposes the following method to find the ideal air conditioner sensor position of different parameters of the room: by clustering and classification after simulation to obtain the proper and stable position. This method does not require the actual measurement of different rooms, as different circumstances can be achieved through simulation. Therefore, it is applicable not only to the actual construction but also to the design stage. Meanwhile, this article gives the recommended air conditioner temperature sensor position, α position, which can make the air conditioner run at the balance point of energy-saving and indoor comfort.
More kinds of room conditions, including different return air forms and room shapes, may produce different ideal measuring positions, which could be studied in the future. Moreover, due to the distance between measuring points, the precise α position needs further study.

REFERENCES

Jani DB, Mishra M, Sahoo PK. A critical review on solid desiccant-based hybrid cooling systems. *Int J Air-Cond Refrig*. 2017;25(3):1730002.

Waheed MA, Oni AO, Adejuyigbe SB, Adewumi BA, Fadare DA. Performance enhancement of vapor recompression heat pump. *Appl Energy*. 2014;114:69-79.

Yang B. The analysis of improving the comfortable performance of multi A/C from sensor’s position design and fan speed design. *Chin Assoc of Refrig*. 2009:4.

Liu Q-l, Du Z-m, Jin X-q. A study on the effect of location of indoor temperature sensor’s of VAV air conditioning system. *Build Energy & Environ*. 2013;32(01):11-14.

Nevins RG. Thermal comfort and draughts. *J Physiol*. 1971;13:356-358.

Milligan GW, Cooper MC. An examination of the effect of six types of error perturbation on fifteen clustering algorithms. *Psychometrika*. 1980;45(3): 159-179.