Thermal Comfort Characteristics Using An Automatic Fan Speed Control And 360° Object Tracking Based On Microcontroller

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Abstract.

Energy saving in residential buildings and global warming situations has a potential to interest of thermal comfort. ASHRAE thermal sensation scale (ASH) is considered the thermal comfort in this work. An automatic speed control and object tracking fan was developed and tested. Field thermal comfort tests both of natural ventilation and air conditioning rooms were also assessed. The results revealed that an automatic fan can function both of speed control and object motion capture with 100% accuracy. This is helpful to enhance thermal comfort for sedentary and non-sedentary activities in daily life. Occupants satisfied in distance not over 1.5 meters and ASH was almost in the neutral zone.

Keywords. object capture, thermal sensation scale, sedentary activity, variable fan speed, Arduino.

1. INTRODUCTION

Thailand is a country in Southeast Asia, located at the northern hemisphere. The average maximum temperature in the hot season can be reach to 35ºC. Especially, the northeast region of Thailand climate all year round is almost hot and humid, except between mid-November and mid-February. The people feel bad in this time interval. A solution of more comfortable feeling is always turning on a fan.

The fan evolution is now happened in many versions. It is designed by criteria of air flow rate, air pressure, and user purposes, e.g., centrifugal, axial, pedestal, ceiling, table, tower, misting, and evaporative cooling fans. A kind of fan, pedestal fan, is often seen in household appliances.

Recently tropical climate researches mostly studied the effect of air movement by fan assisted air conditioning on thermal comfort for many activities, e.g., classrooms, laboratories, sedentary and non-sedentary office activity levels, living room and bedroom [1-7].

The experimental airflow is classified as three main patterns: constant mechanical, pulsating, and sinusoidal. Increased airflow in indoor space led to increased mean and standard deviation of air speed but decreased mean and standard deviation of turbulence intensity when compared to without sources of increased airflow or natural ventilation [8]. The sinusoidal pattern at more than 40% turbulence intensity, the 0.5-1.0 Hz fluctuation frequency and a constant 0.6 m/s average air speed under condition of 28-30°C and a constant 35% RH, is studied in 2012 [9]. The thermal sensation vote (TSV) showed that human feel cool at the 28°C air temperature whilst, feel hot at the 30°C air temperature with a range of 0.5-1.0 Hz frequency. Later in 2018, intensified global warming periods, human feel cool at lower than 25°C (air temperature decreased around 3°C from 2012) while feel comfort at 25°C under condition of 50-70% RH, 0.2-0.6 m/s and 0.016-0.1 Hz [10].

Additionally, the constant mechanical and pulsating patterns (turbulence intensity < 40%) and sinusoidal pattern (turbulence intensity > 40%) at a constant condition: 27.5°C, 50% RH, and 0.65 m/s is compared on thermal comfort. TSV vote of the constant mechanical and sinusoidal patterns are positive (slightly hot) and negative (slightly cool) for pulsating pattern [11].

The people would like decrease the air velocity after 30 minutes exposure in variable airflow direction [12]. The comfortable air speeds are between 0.25 m/s (at 27°C and 40%-60% RH) and 1.17 m/s (at 30°C and 60%-80% RH) and between 0.12 m/s and 1.31 m/s for 2 beds of healthy young people in the 20 m^2 bedroom area with pedestal fan coupled with 3500 W air conditioner [7]. The optimized air movement in University classroom can enhance the thermal comfort satisfaction from 62% to 94% of totally 34 persons [13].

The current deteriorated developing global recession resulted in the reduction of net income. Many undergraduate students necessary to select the lowest cost of accommodation by renting fan room with natural ventilation (no air conditioner). They feel hot in summer season, therefore, this study aims to develop and build a 360° object tracking fan to enhance thermal comfort of student's accommodation. The thermal comfort under pedestal fan speed control complied with air temperature and relative humidity was also studied in student's accommodation and air conditioning faculty office.

2. MATERIALS AND METHODOLOGY

2.1 *Design Principles*

A pedestal fan is design by using 6 sets of ultrasonic sensor HC-RS04 (working temperature: -15°C to 70°C, sensing angle: 30° cone, angle of effect: 15° cone, and ultrasonic frequency: 40kHz) for detecting the object tracking and a sensor module DHT22 (measured temperature range of -40 to 80°C with ± 0.5°C accuracy) for measuring and displaying the air temperature and humidity. We used the Arduino Uno R3 microcontroller board for controlling the operation of 360° object tracking by stepping motor and variable air velocity with air temperature and relative humidity.

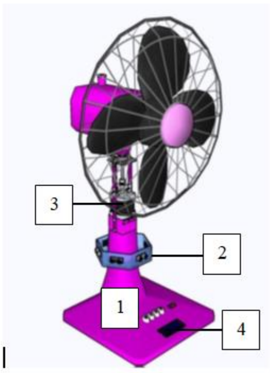
2.2 *Accuracy Test*

A prototype of 360° object tracking fan as Fig. 1 is tested in 6 different directions of ultrasonic sensor and 3 different levels of distance between sensor and object: 0.5, 1.0, and 1.5 meters.

The variable air speed testing, fan speed level is adjusted corresponding to air temperature and relative humidity condition as shown in Table 1.

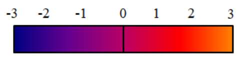
2.3 *Field thermal comfort*

The operation testing of 360° object tracking and variable fan speed starts from 2 students came in their accommodation (2 beds fan room size: 20 m^2 and opening space for 2 windows with natural ventilation) and fill thermal sensation scale questionnaire. Each student was done for 3 time intervals: morning (9 AM-11 AM), afternoon (12 PM-2 PM), and evening (4 PM-6 PM) in the same day. The temperature and relative humidity of air in tested room and fan speed number is recorded in every 10 minutes for each time interval. At a 64 m^2 equipped 2 sets of 1 tons air conditioning faculty office, we have test in the morning and afternoon. Thermal comfort is assessed by ASHRAE thermal sensation scale (ASH). This scale is divided into 7 levels of -3 to 3 as presented in Fig. 2.



1 : microcontroller
2 : ultrasonic sensor
3 : stepping motor
4 : temperature and humidity sensor and LCD display

Figure 1 A fan speed control and 360° object tracking based on microcontroller.



Scale	Sensation
-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
1	Slightly warm
2	Warm
3	Hot

Figure 2 ASHRAE thermal sensation scale.

Table 1 Criteria for adjusting fan speed level

Room condition	fan speed level
T < 25°C, RH<70%	No. 0
T 25-29.9°C and RH<70%	No. 1
T 30-33.9°C and RH< 70%	No. 2
T ≥ 34°C and RH< 70%	No. 3
T 25-27.9°C and RH≥70%	No. 2
T 28-32°C and RH≥70%	No. 3

3. RESULTS AND DISCUSSION

3.1 *Accuracy test of the direction sensor*

Ultrasonic sensor was turned towards 6 different directions to detect moving and static objects at the radii of 0.5, 1.0 and 1.5 m. The accuracy tests of the direction sensor showed that 100% accuracy was achieved at the distance of 0.5 and 1.0 m. However, the accuracy slightly dropped at 1.5 m.

3.2 *Accuracy test of the temperature and relative humidity sensor*

DHT22 Temperature & Relative Humidity Sensor was used as a key component of the developed automatic fan. It could automatically change the fan speed according to the set temperature and relative humidity. The accuracy tests of the sensors were conducted in triplicate. The test results were tabulated in Table 2. It is clearly seen that the sensors could completely control the fan speed level in accordance with the specific conditions.

3.3 *Thermal comfort via thermal sensation scale (ASH)*

The ASHRAE thermal sensation scale was developed for use in quantifying people’s thermal sensation. The sensation scale expressed from –3 to +3 corresponding to the categories “cold (-3),” “cool (-2),” “slightly cool (-1),” “neutral (0),” “slightly warm (1),” “warm (2),” and “hot (3).” [14]. People voting +2, +3, –2, or –3 on the thermal sensation scale are assumed that they feel uncomfortable.

The experiments were performed in the summer of Thailand (March – April 2020) at three time intervals viz. in the morning (9 AM – 11 AM), in the afternoon (12 PM – 2 PM), and in the evening (4 PM – 6 PM). During the day, air temperature tended to increase whilst the relative humidity tended to decrease. At 9 AM to 11 AM, air temperature gradually increased from 29°C to 33°C and relative humidity drastically decreased from 72% to 62%. Mean value of ASH (ASHRAE thermal sensation scale) in Fig. 3 illustrated that at the beginning of the experiment, the occupants felt slightly warm and then they felt indifferent. Generally, tropical climatic regions have high temperature and humidity levels in the summer season. However, in the morning interval of this research work, the level ranges are not an extreme condition therefore the feeling is mostly in neutral sensation. Most of temperature and relative humidity are in the air conditioned zone [15].

Additionally, it was depicted in Fig. 4 that at 12.00 PM to 12.20 PM the thermal sensation scale was 1 (Slight warm). After that, the fan speed level was automatically elevated from 2 to 3. This led to the neutral preference during 12.30 PM – 12.50 PM. Nevertheless, after 01.00 PM the temperature gradually increased and reached 35°C at 01.20 PM. Such a relatively high temperature resulted in the positive side of thermal sensation scale.

As depicted in Fig. 5, during 4 PM – 4.30 PM, thermal sensation was considered slightly warm (1) and warm (2). Thereafter, the air temperature seemed to be maintained at 34°C. Although the air temperature is rather high, thermal sensation was still in the neutral zone. This was because the fan speed level was automatically changed from speed level 2 to speed level 3. The increased air velocity resulted in the pleasant feeling. Furthermore, occupants felt more comfort for an automatic fan than the general electric fan, especially in case of non-sedentary activities in fan room.

The experiments of variable fan speed in air conditioning faculty office were executed in the summer of Thailand (mid-April 2020) in the morning (9 AM – 11 AM) and in the afternoon (12 PM – 2 PM) as shown in Fig. 6-7. The ambient air temperature tended to increase whilst the relative humidity tended to decrease during the day. At 9 AM to 11 AM, room temperature gradually decreased from 30°C to 25°C (set point temperature of air conditioner) and room relative humidity drastically decreased from 70% to 46%. Mean value of ASH at the beginning, the occupants felt slightly warm and then they felt comfort - slightly cool - cool at 30, 50, and 60 minutes, respectively

In the afternoon 12.00 PM to 12.20 PM, the thermal sensation scale was 1 (Slight warm) and then the fan speed level was automatically stepdown from 2 to 1. This led to the neutral preference during 12.30 PM – 02.00 PM. Nevertheless, the room temperature gradually decreased and reached 25°C at 01.00 PM. Such a relatively mild temperature resulted in the comfortable thermal sensation scale.

Table 2 Accuracy of the fan speed level according to the specific conditions

The given conditions	Fan speed level	Accuracy
T < 25°C, RH < 70%	No. 0	100%
T= 25-29.9°C, RH < 70%	No. 1	100%
T= 30-33.9°C, RH < 70%	No. 2	100%
T > 34°C, RH < 70%	No. 3	100%
T = 25-27.9°C, RH ≥ 70%	No. 2	100%
T = 28-32°C, RH ≥ 70%	No. 3	100%

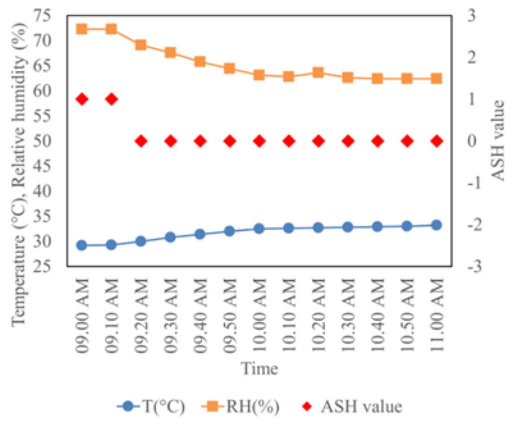


Figure 3 Temperature and relative humidity of the air and thermal sensation scale voted by occupants in the morning period of fan room student's accommodation

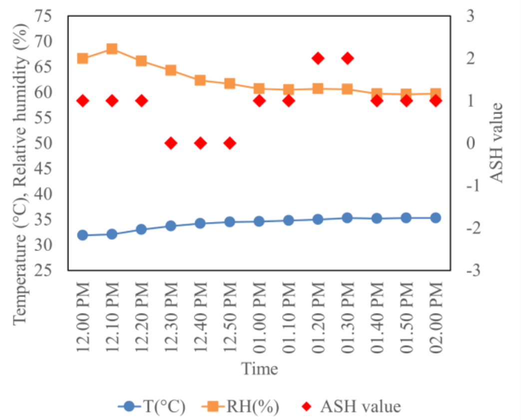


Figure 4 Temperature and relative humidity of the air and thermal sensation scale voted by occupants in the afternoon period of fan room student's accommodation.

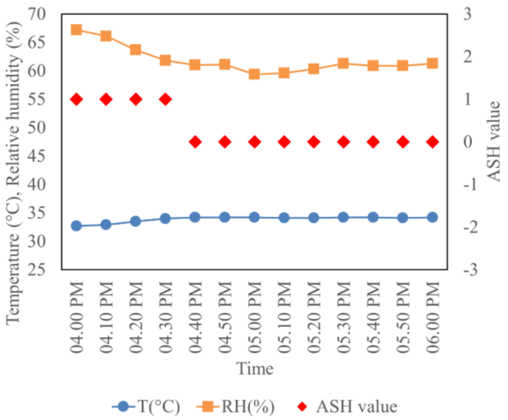


Figure 5 Temperature and relative humidity of the air and thermal sensation scale voted by occupants in the evening period of fan room student's accommodation.

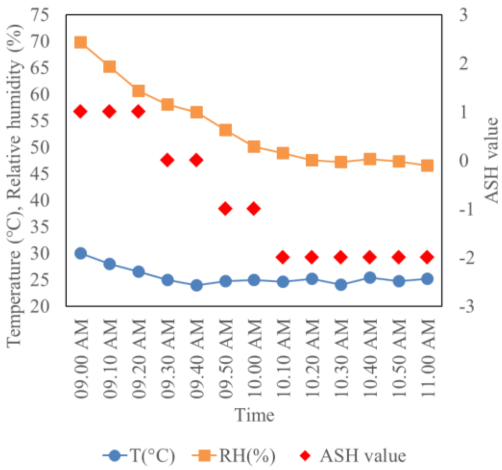


Figure 6 Temperature and relative humidity of the air and thermal sensation scale voted by occupants in the morning period of air conditioning faculty office.

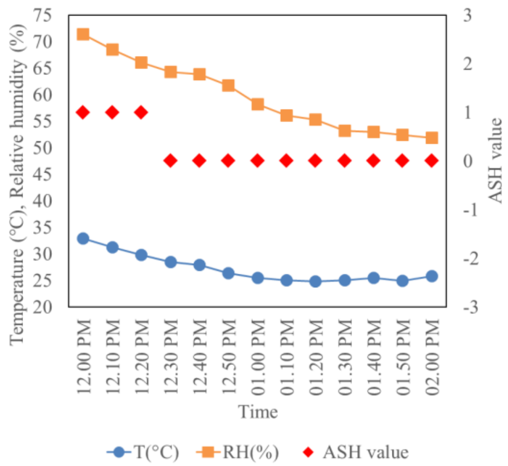


Figure 7 Temperature and relative humidity of the air and thermal sensation scale voted by occupants in the afternoon period of air conditioning faculty office

4. Conclusions

An automatic fan was developed and tested in this research work. The fan could automatically turn to the direction of object existence with almost 100% accuracy. In addition, it could automatically adjust the speed level according to the temperature and humidity of the surrounding air. Thermal comfort via thermal sensation scale indicated that when temperature and relative humidity were in the uncomfortable condition, the fan would automatically speed up. Consequently, thermal sensation scale were mostly in the neutral zone. The tests in other case, air conditioning faculty office, this developed fan could help to enhance the airflow movement and comfortable preference.

5. Acknowledgment

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6. References

[1] N. Puangmalee, K. Hussaro, V. Boonyayothin, and J. Khedari, “A Field of the Thermal Comfort in University Buildings in Thailand under Air Condition Room,” Energy Procedia, vol. 79, 2015, pp. 480-485.

[2] A. Lipczynska, S. Schiavon, and L.T. Graham, “Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics,” Build Environ., vol. 135, 2018, pp. 202-212.

[3] Y. Zhai, E. Arens, K. Elsworth, and H. Zhang, "Selecting air speeds for cooling at sedentary and non-sedentary office activity levels," Build Environ., vol. 122, 2017, pp. 247-257.

[4] S. Tadepalli, T.K. Jayasree, V.V. Lakshmi, and S. Chelliah, "Influence of ceiling fan induced non-uniform thermal environment on thermal comfort and spatial adaptation in living room seat layout," Build Environ., vol. 205, 2021, 108232.

[5] R. Rissetto, M. Schweiker, and A. Wagner, "Personalized ceiling fans: Effects of air motion, air direction and personal control on thermal comfort," Energy Build., vol. 235, 2021, 110721.

[6] A.K. Mishra and M. Ramgopal, "Thermal comfort field study in undergraduate laboratories - an analysis of occupant perceptions," Build Environ., vol. 76, 2014, pp. 62–72.

[7] Y. Chen, Y. Zhang, and H. Tang, "Comfortable air speeds for young people lying at rest in the hot-humid area of China in summer," Build Environ., vol. 124, 2017, pp. 402–411.

[8] Y. Zhang, Q. Liu, and Q. Meng, "Airflow utilization in buildings in hot and humid areas of China," Build Environ., vol. 87, 2015, pp. 207–21.

[9] L. Huang, Q. Ouyang, and Y. Zhu, "Perceptible airflow fluctuation frequency and human thermal response," Build Environ., vol. 54, 2012, pp.14–19.

[10] Y. Xie, S. Fu, C. Wu, and C.Y.H.H. Chao, "Influence of sinusoidal airflow and airflow distance on human thermal response to a personalized ventilation system," Indoor Built Environ., vol. 27, 2018, pp. 317–330.

[11] T. Parkinson and R. de Dear, "Thermal pleasure in built environments: spatial alliesthesia from air movement," Build Res. Inf., vol. 45, 2017, pp.320–335.

[12] F. Kalm´ar, "Impact of elevated air velocity on subjective thermal comfort sensation under asymmetric radiation and variable airflow direction," J. Build Phys., vol. 42, 2018, pp. 173–193.

[13] S. Liu, L. Yin, S. Schiavon, W. Khuen, and K.V. Ling, "Coordinate control of air movement for optimal thermal comfort," Sci. Technol. Built Environ., vol. 24, 2018, pp. 886–896.

[14] ANSI/ASHRAE Standard 55-2017, Thermal Environmental Conditions for Human Occupancy.

[15] G. Baruch, "Comfort, Climate Analysis and Building Design Guidelines." Energy Build., vol. 18(1), 1992, pp. 11–23.