# CEILING FAN SPEED CONTROLS FOR COMFORT IN WARM ENVIRONMENTS

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*ABSTRACT Human thermal comfort in warm conditions can often be improved inexpensively by increased air movement. Two automatic ceiling fan systems are described that regulate air speed to maintain comfort in changing conditions. One system is based on the ASHRAE comfort standard and the other uses the PMV comfort model. In comfort tests at 29°C and 50% RH both automatic systems provided the same level of comfort at steady state conditions as manual control. However the automatic systems were faster in bringing the subjects to comfort. The comfort performance of the two automatic systems were also compared during a temperature down drift from 29°C to 25°C.*

## 1 Introduction

Ceiling fans are a particularly good low energy method to reduce warm discomfort in buildings. If the fan's operation was more automatic so that the air speed in the space increased and decreased with the conditions to keep occupant comfort constant, the fan's operation may become more invisible to the occupant and accepted in the modern architectural setting. Such fans could permit the raising of set point temperatures above which mechanical cooling is necessary and thereby decrease the building's cooling budget.

How can ceiling fans be made to automatically provide a constant level of comfort with changing conditions? One way, is to use accepted comfort, temperature and air speed information to guide the speed controller. This paper explores how two such guidance systems perform in providing comfort with ceiling fans. One system simply uses the air speeds for comfort specified in ASHRAE Standard 55 for temperatures above the traditional still air comfort zone (ASHRAE, 1992). The second system predicts the comfort level in the space with a human simulation model and then adjusts the air speed to bring or maintain the predicted comfort to some desired set level (Berglund, 1994). Many prediction models are applicable, for this paper the PMV comfort model (Fanger, 1972) was used because it is well accepted and short in terms of necessary microprocessor code.

## 2 Control systems

The layout of the ceiling fan and its control system is illustrated in Fig.1. The automatic control was done by computer with analog to digital signal conversion and multiple digital output switches (Ronnheim, 1994). The system monitored the environment and made air speed adjustments every 10 seconds.

### 2.1 Control with ASHRAE Standard 55

The speed control system based on the ASHRAE comfort standard uses the following algorithm to adjust the air speed(V):

$$V = 0.19*\exp[0.56*(T-Tcomf)] \quad m/s \qquad (1)$$

where T is the measured air temperature and Tcomf is the comfort temperature in a still air condition. Equation 1 is a curve fit to the comfort air speed graph of Standard 55 for uniform thermal conditions, that is, for conditions where air and mean radiant temperatures are equal. With equation 1, a person in a uniform environment of temperature T and air speed V will have the same comfort level as the person would have at Tcomf with $V \approx 0.2$ m/s. Tcomf in turn depends on the occupant's clothing and activity level.

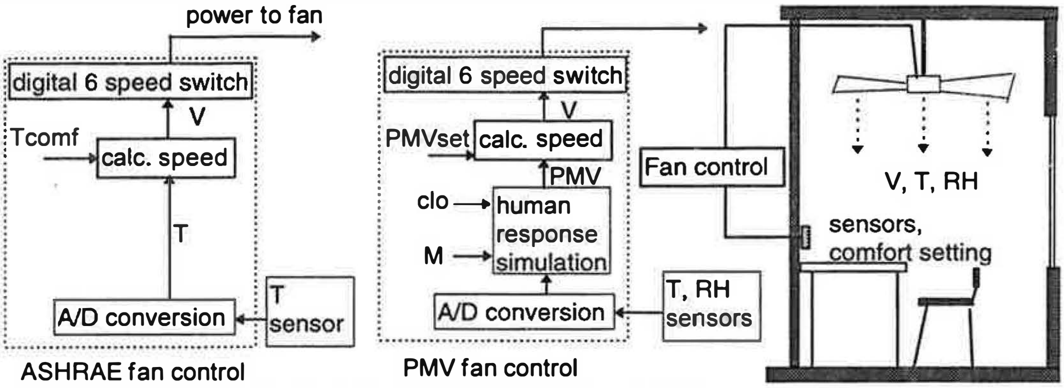


**Fig.1 Schematic of ceiling fan in the perimeter office as tested with its two automatic control systems**

## 2.2 PMV control

The PMV model is more rigorous and considers more than air temperature. It starts by assuming the person wearing clothing(clo) has the skin temperature and sweat rate of a comfortable person with a metabolic rate(M) that corresponds the person's activity. It then calculates the person's heat loss (L) in the actual environment from measured parameters T, MRT, V and RH. How the person actually feels in the environment by this model depends on the difference between M and L. If M = L the person would be expected to feel comfortable with a neutral thermal sensation. If M > L the person would be expected to store heat and feel warm. If M < L the person would be loosing stored energy and feel cool. The model is based on the responses of about 1400 test subjects and is generally a good predictor of the mean thermal sensation or predicted mean vote (PMV) of a group of people. The prediction equation is:

$$PMV = [0.303*\exp(-0.026*M) + 0.0276] * (M-L) \qquad (2)$$

where M and L are in $W/m^2$ and the PMV values correspond to whole body thermal sensations of: 3 = hot, 2 = warm, 1 = slightly warm, 0 = neutral, -1 = slightly cool, -2 = cool and 3 = cold.

In these experiments MRT was calculated from globe and air temperature measured at the 1.1.m elevation behind the chair in Fig.1. Without the subject present air and globe temperatures were always essentially equal in this north side perimeter office without solar radiation. The air speed under the fan at the subject level was very uniform. The ceiling fan used had 6 distinct speeds. Thus by prior calibration of measured air speed with fan setting it was possible to eliminate air speed input measurement from the control operation.

## 3 Performance tests

To have a repeatable environment for the performance tests the air temperature and humidity of the space was artificially raised with multiple small electric convective heaters on the floor and a steam humidifier. The six college age men who participated wore their own clothing whose insulation value averaged 0.44 clo as determined by the ASHRAE estimation method(ASHRAE,1992). The insulation effect of the chair was neglected. During the tests, the subjects indicated their subjective responses by marking category scales on a paper ballots administered at regular intervals.

The first set of tests concerned responses to a steady state environment of 29°C and 50% RH with: a) no fan, b) fan speed controlled manually by the subject, c) air speed automatically controlled using the ASHRAE comfort standard algorithm, and d) with air speed automatically controlled using the PMV comfort model. The results are shown in Figs. 2 and 3. Without the fan under these conditions the subjects felt warm with a steady state thermal sensation value of 2. With the fan operating, all of the control systems both manual and automatic were successful in maintaining steady state thermal sensation levels near neutral (Fig.3). It is interesting that with the PMV control the subjects' thermal sensations reached neutral much sooner than with manual control.

Fig.2 shows that the PMV control initially increased air speed more than when it was controlled manually by the subjects. This may explain the faster cooling response of the subjects with the PMV control. In terms of air speed at steady state conditions, it was higher with manual control than with the automatic systems.

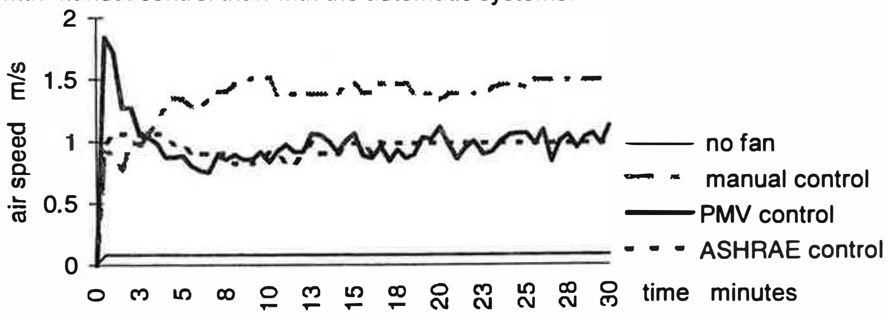


**Fig.2 Air speeds at 29°C and 50% RH from various methods of fan control**

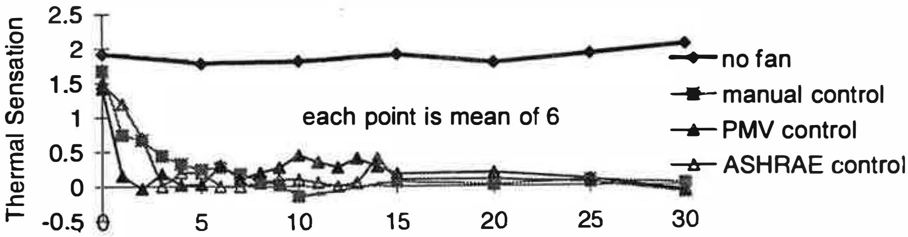


**Fig.3 Thermal sensations at 29°C and 50% RH with various methods of fan control**

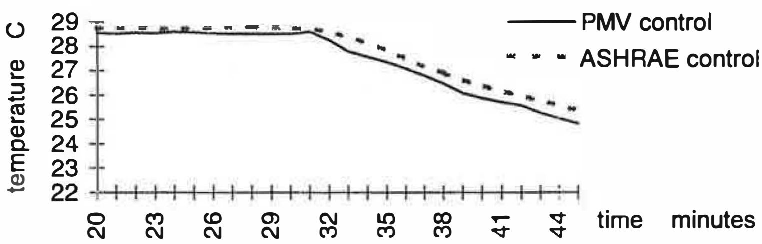


**Fig.4 Air temperatures during the temperature down ramp**

The second set of tests concerned the response to a temperature decrease. After 30 minutes at 29°C and 50 % RH the temperature steadily decreased to about 25 over a 15 minute period (Fig.4). During the down drift the dew point was maintained constant at 17°C. The ASHRAE standard based control decreased the air speed less rapidly than the PMV control did and this probably caused the subjects to feel consistently cooler during the temperature decrease (Figs.5 and 6). Fig.6 also shows that with PMV control the subjects felt warmer than the predicted PMV initially but cooler near the end of the temperature down ramp. Some of these differences may be due to the small sample size of 6 subjects.

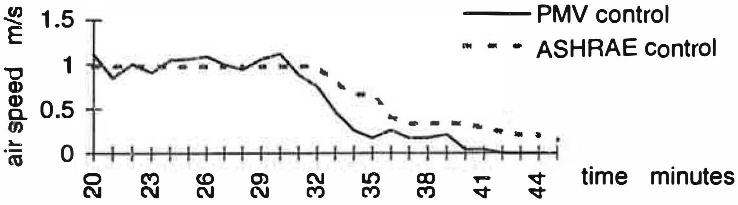


**Fig.5 Air speeds under automatic control during the temperature down ramp**

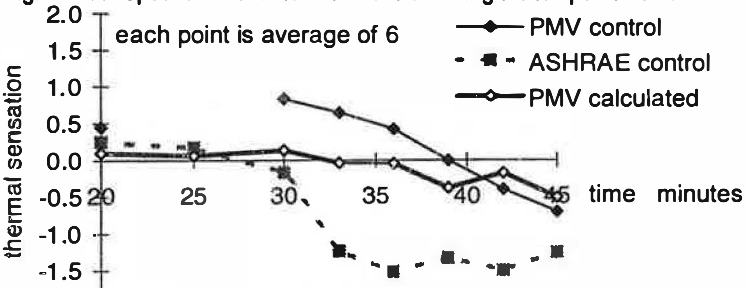


**Fig.6 Thermal sensations during the temperature down ramp**

Throughout both sets of test the subjects rated their feelings of draft and noise. The results indicate that these subjects where not dissatisfied with either the draft (Fig.7) or noise (Fig.8) conditions at air speeds below about 1 m/s.

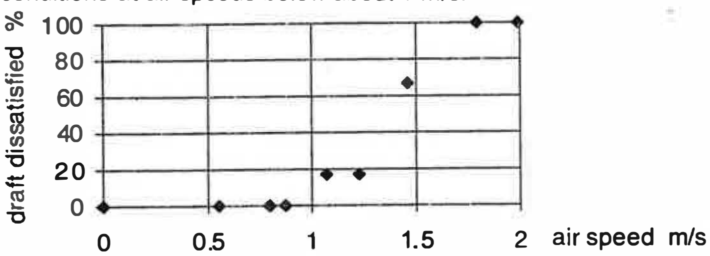


**Fig.7 Draft dissatisfaction from air speed (each point is average of 6 or more responses)**

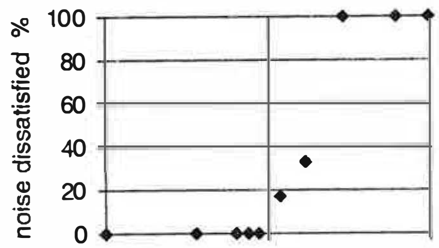


**Fig.8 Noise dissatisfaction with fan**

**Table 1 Measured noise levels**

| air speed m/s | sound dbA |
|---|---|
| 0 | 40.2 |
| 0.43 | 41 |
| 0.75 | 41.5 |
| 1.07 | 42.6 |
| 1.46 | 44.6 |
| 1.79 | 48.2 |
| 1.99 | 50.4 |

## 4 Conclusion

The ceiling fans improved the comfort of the warm conditions of these tests. The automatic fan speed control systems tested did about as well in providing comfort as when the fan was manually controlled by the subject.

## References


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