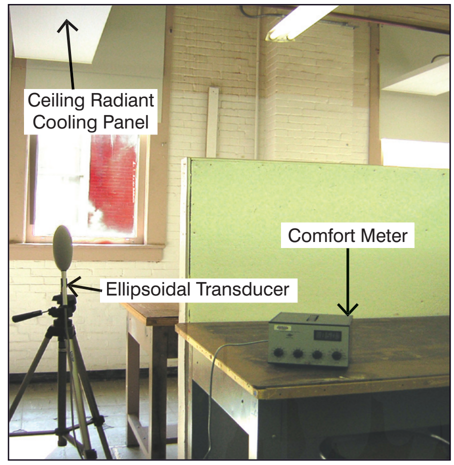
Dedicated Outdoor Air Systems

Comfort With DOAS Radiant Cooling System



Test space with thermal comfort meter.

By S.A. Mumma, Ph.D., P.E., Fellow ASHRAE

Thermal comfort is a central design/operational theme of HVAC systems serving human occupants. This topic is central to ASHRAE Technical Committee 2.1, Physiology and Human Environment, and is addressed by ASHRAE Standard 55-2004 *Thermal Environmental Conditions for Human Occupancy*.

This column presents measured thermal comfort data for a hybrid dedicated outdoor air (DOAS) ceiling radiant cooling panel (CRCP) system.

In past editions of IAQ Applications, the author addressed the following DOAS-CRCP topics: preconditioning outside air, CRCP condensation control, environmental safety, economics, demand-controlled ventilation, meeting air-change criteria with DOAS, and air diffusion performance with DOAS.

Thermal Comfort

A person who is thermally neutral does not know whether they would like to be warmer or cooler. The subjective and physiological reaction of a person to the thermal environment is determined by the rates of bodily heat generation and heat emission. These, in turn, are functions of the following six parameters:

- Air temperature,
- Mean radiant temperature,
- Local air velocity,
- Water vapor pressure (or dew-point temperature),
- Metabolic rate of the subject, and
- Thermal insulation of the subject's clothing.

All of these factors can be measured and used to predict the human subjective response to any given combination of environment, clothing, and activity level. These reactions follow a normal distribution about a mean, which is termed the predicted mean vote (PMV). While not everyone has identical thermal comfort preferences, no more than 95% of the occupants of any given thermal environment will be satisfied. Satisfying 80% of the occupants is a more realistic and more common goal.

Terminology of Thermal Comfort

The *Predicted Mean Vote* is an index that predicts the mean value of the subjective ratings of a large group of people on a seven-point thermal-sensation scale as follows: +3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, –1 = slightly cool, –2 = cool, and –3 = cold.

The predicted percent dissatisfied (PPD) is an index that predicts the percentage of a large group of people likely to feel thermally uncomfortable, i.e., voting +3 or +2. The functional relationship between PMV and PPD is:

$$PPD = 100 - 95 \times e^{-\left(0.03353 \times PMV^4 + 0.2179 \times PMV^2\right)}$$

The minimum PPD is 5%, even when the PMV is zero. This relationship is presented in *Figure 1*.

The *operative temperature* is an air temperature that would result in the same heat loss from a person by convection and radiation as in the actual environment if the air temperature and mean radiant temperature were equal. It integrates the influence of the air and mean radiant temperatures.

The *equivalent temperature* is the temperature of the air and all the interior surfaces in a reference environment in which the air is still and the temperature has been adjusted to obtain the same heat loss from a person by convection and radiation as that person experiences in the actual environment. When this condition is satisfied, then the equivalent temperature of the actual environment is the same as the air temperature in the reference environment. Equivalent temperature integrates the influence of air temperature, mean radiant temperature, and air velocity. The cooling effect of air movement is measured as a decrease in temperature.

The *comfort temperature* is the equivalent temperature required to achieve thermal comfort when the cooling, activity level and humidity are given. Instrumentation exists, and was used in the experimental results to be presented later, to automatically compute the comfort temperature given the level of activity, clothing, and space water-vapor pressure.

The *difference temperature,* or the comfort temperature minus the equivalent temperature, is the amount by which the equivalent temperature of the measured environment should be altered to achieve thermal comfort.

Thermal Comfort Measurement Instrumentation

A thermal comfort meter can measure the influence of air motion, temperature, and mean radiant temperature on thermal comfort for prescribed values of clothing, activity level, and space humidity. The instrument uses a heated ellipsoidal (6.25 in. × 2.25 in.* major and minor axis) transducer designed to simulate the thermal pattern of a human being. It contains a surface temperature sensor, and a surface-heating element whose power is adjusted automatically by the thermal comfort meter to bring the surface to a temperature similar to that of a thermally comfortable human. The rate of heat production needed to attain this temperature is used as a measure of the environmental conditions.

The shape of the transducer is determined by the need to obtain the same ratio of horizontal and vertical projected radiant surface areas as for a human being. This is important where significant difference between horizontal and vertical radiation temperature can occur, as with overhead lighting or when CRCPs are used.

With the experimental results reported here, the occupants were assumed to have a clothing insulation value of 1 clo.* This corresponds to an office worker dressed in slacks, shirt, shoes and socks. The occupants were also assumed to be doing sedentary work, with a metabolic rate of 1.2 met.*

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Test Space Conditions

The tests were conducted in a 3,200 ft^2* academic space served with a DOAS-CRCP system. The space has a 14 ft* ceiling, with the illumination and the CRCPs at the 9 ft elevation. The eight 2 ft wide CRCPs are spaced approximately 10 ft apart. Air from the DOAS is introduced via high induction diffusers, also 9 ft above the floor, adjacent to and parallel to each CRCP. Test thermal conditions were: space water vapor pressure = 6 in. w.g.;* room dry-bulb temperature = 73°F;* room dew-point temperature = 53°F; average CRCP surface temperature = 60°F; DOAS supply air-temperature = 62°F; and average temperature of the ceiling at 14 ft = 74°F.

Thermal Comfort Measurements

Measurements were taken systematically throughout the space, directly under the radiant panels, directly under the illumination, near the exterior windows, near interior walls, and interstitially. *Figure 1* is an illustration of the thermal comfort meter in use in the space evaluated. The variations in measurements were very modest, and can be summarized as follows:

- Operative Temperature: 73.9°F
- Comfort Temperature: 70.2 to 71°F
- Equivalent Temperature: 70.2 to 71°F

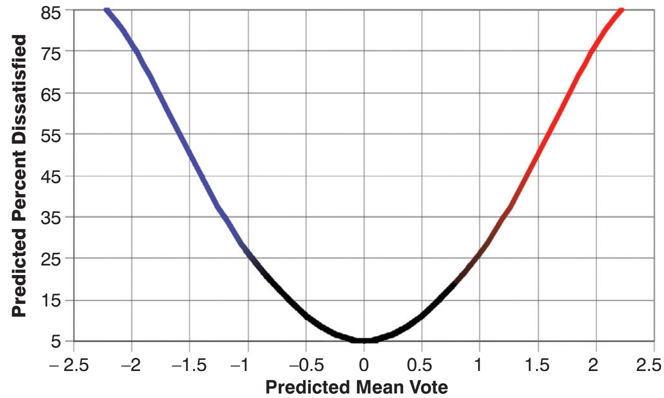

Figure 1: Thermal comfort index.

- Temperature Difference: –0.9 to 0.2°F
- PMV: –0.01 to +0.07
- PPD: 5.1 to 5.4%

Discussion of Results

The variation in the thermal conditions was minimal. For the assumed clothing and metabolism, a remarkably low PPD was measured. ASHRAE's accepted thermal comfort design guidelines permits PPD to be as high as 20%. Satisfying nearly 95% of the occupants is certainly far superior to the ASHRAE target of 80% satisfied. The DOAS-CRCP system offers extremely fine control of both the temperature and relative humidity of the space while maintaining good air circulation. Therefore, other levels of clothing and activity levels can be accommodated easily with the system to produce the same PPD.

Conclusions

The high level of thermal comfort expressed during the past three years by the students and faculty quartered in the DOAS-CRCP space has been confirmed by the measurements reported here. When these results are combined with the other DOAS-CRCP benefits (e.g., improved IAQ, improved environment safety, tight humidity control, a nearly 50% reduction in energy use compared to a conventional all-air VAV system, equal or lower first cost in new construction, and that the system overcomes all of the inherent problems of VAV systems) one may wonder if the time has come for its widespread adoption in the U.S.

Acknowledgments

P.O. Fanger, Ph.D., Fellow/Life Member ASHRAE, is the international leader in this research and credited with developing the thermal comfort terminology used here. His work is documented in technical literature and his book, "Thermal Comfort: Analysis and Applications in Environmental Engineering."

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* in. × 25.4 = mm; clo ×0.155 = $m^2 \cdot K/W$; met × 58.15 = W/m^2; ft ×0.3048 = m; in. w.g. × 249 = Pa; (°F – 32) ÷ 1.8 = °C