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The new ASHRAE Standard 55 *provides information on appropriate indoor air velocities for occupant comfort*

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Recent HVAC design innovations, energy conservation concerns and new laboratory data on drafts have brought substantial attention to the issue of acceptable levels of air movement in office environments.

Air movement may provide desirable cooling in warm conditions, but it may also increase the risk of unacceptably cool drafts. Detectable air movement may be perceived by the occupants as providing freshness and pleasantness to the breathing air, yet it may also be perceived as annoying.

Clearly, a specific air speed has many possible physiological and subjective consequences. These range from a pleasant sense of coolness to an unpleasant sense of draft, depending on the air temperature, mean radiant temperature, humidity, clothing, metabolic rate and air movement preference of the occupant.

Since the turn of the century, ASHRAE and thermal comfort researchers have worked to define levels of air movement that are acceptable to the widest possible group of individuals within an evolving architectural setting, and to incorporate these results into an indoor environmental standard.

This article outlines the current state of this discussion. Reference is also made to research investigating the effect of air movement on thermal comfort and the development of air velocity limits in the latest ASHRAE thermal comfort standard.

Why is air velocity important?

HVAC engineers design systems to move energy and ventilating air through buildings. Many, if not most, commercial buildings built since the middle of this century use air distribution systems to deliver heated and/or cooled air to occupied spaces.

Accordingly, ASHRAE and other organizations have produced standards and guidelines for distributing this air. Included in these documents are specifics such as: volume of air per unit time, percentage of outdoor air, and type and location of duct outlets.

In general, design recommendations have favored specifying delivered cfm per square foot of occupied space rather than specifying air velocity for achieving thermal comfort. However, the desired end-product of HVAC systems is not cfm per square foot, a cooled building interior or air movement per se; it is the comfort, health and satisfaction of building occupants.

Beyond special cases such as laboratories and clean rooms, efforts in HVAC are primarily directed at producing thermal comfort and air quality that are acceptable for breathing. The focus of this article is the influence of the air movement (created by an HVAC system) on thermal comfort.

Air velocity is one of six main variables affecting human thermal comfort. The other five include three physical variables (air temperature, mean radiant temperature and relative humidity) and two behaviorally regulated variables (metabolic rate and clothing insulation).

In humans, the thermoregulatory system is responsible for maintaining the heat balance of the body using a core setpoint of 98.6°F (37°C) within the constraints of the six variables given above. This system controls the release of metabolic heat by regulating skin temperature, primarily by varying skin blood supply and sweating at the skin surface.

Convective heat transfer at the skin varies with surface temperature and local air motion across the skin surface. Extensive laboratory studies have shown that thermal sensation vote (an important method for measuring thermal comfort) is closely related to skin temperature in cool and comfortable conditions. In warm and warm-humid conditions, moisture on the skin has a strong effect on thermal sensation, particularly after sweating mechanisms have been triggered.

About the authors

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Because heat loss, skin temperature, skin wettedness and thermal sensation are interdependent, local air movement is an important factor in thermal comfort. Accordingly, it has been incorporated in comfort standards from their inception.

Research efforts

With the advent of HVAC systems in the earlier half of this century, the issue of suitable thermal conditions for human occupancy needed attention.

ASHRAE's precursor (ASHVE) began a program of determining suitable indoor thermal environments at its laboratory in Pittsburgh. This effort was spurred by the experience that drafts were the most frequent cause for criticism in the heating systems of that time.

In 1912, Houghten made the first study of air movement and thermal comfort by quantitatively examining the cooling effects of air motion at different temperatures. An initial side-by-side experiment[1] contrasted a condition of air movement up to 500 fpm (2.5 m/s) to a "still-air" condition, both at elevated air temperatures.

A subsequent experiment[2] focused specifically on drafts experienced at the back of the neck and the ankles. Elaborate ductwork was constructed to deliver air directly to the back of the subjects' necks. From this experiment, draft limits were proposed to ensure that 90% of the persons exposed to certain temperature/ velocity combinations on the back of their necks would not feel a draft.

In the late 1950s, ASHVE became ASHRAE and the ASHRAE laboratory equipment was moved to Kansas State University (KSU). At KSU, Rohles[3] exposed subjects to nine experimental combinations of air temperature and air movement within the ranges of 72° to 85.2°F (22.2° to 29.5°C) and 40 to 160 fpm (0.2 to 0.8 m/s).

Rohles found strong relationships between air velocity, air temperature, skin temperature and thermal sensation. Draft discomfort was not observed. Based on this, Rohles recommended an extended summer comfort zone in which air movement up to 157 fpm (0.8 m/s) compensated for elevated temperature. This extended zone was incorporated into *ASHRAE Standard 55-81*.[4]

A later study[5] was motivated by the question of whether the 157 fpm (0.8 m/s) limit was still applicable under the turbulent flow of a ceiling fan. The experimenters found that the subjects considered air movement pleasant at levels beyond what had been previously considered reasonable: up to 196 fpm (1 m/s) at 85°F (29.5°C). The subjects considered the turbulence of the flow a beneficial aspect.

A further fan study[6] compared fixed fans to oscillating fans. It was found that, for the same mean velocity, oscillating fans were preferred.

In another fan study,[7] subjects more active than the sedentary levels of the other studies (standing and moving about at a moderate pace) found that air velocities up to 235 fpm (1.2 m/s) improved comfort.

Yet another fan study[8] concluded that fan cooling with velocities up to 196 fpm (1.0 m/s) at temperatures up to 88°F (31°C) produced comfortable conditions. Similar results have been found in naturally ventilated buildings in the field.[9]

Two important studies were done in the late 1970s by McIntyre in the United Kingdom. The first study examined the subjects' sense of acceptability resulting from higher air velocities at higher temperatures.[10] McIntyre found that the subjects chose fans speeds lower than what was required to maintain their bodies' thermal neutrality, but that air movement could compensate for air temperature up to 82.5°F (28°C).

The second study looked at drafts directed at the face.[11] The conclusions were that people who felt cool found the air movement unpleasant, while people who felt warm found the air movement pleasant. Also, initial cool sensations from drafts lessened over time.

During the last decade in Japan, several experiments have looked specifically at the ability of air motion to compensate for higher summer temperatures. Tanabe and Kimura[12] found subjects regularly preferred air movement of 196 fpm (1 m/s) at an air temperature of 82°F (28°C) and very few regarded the air movement unpleasant under the conditions studied.

Another study by Tanabe and Kimura[13] found that sinusoidally fluctuating air movement resulted in a greater perceived cooling effect than random, constant or pulsed air movement. It also had a greater effect on mean skin temperature.

Meanwhile, in Denmark, a large program in thermal comfort research has been ongoing since the late 1960s. Included are several very extensive studies of the effects of air movement.

In one study, Fanger[14] found that a thermally comfortable subject has a skin temperature that is independent of air velocity. This suggests that any combination of temperature and velocity yielding that skin temperature will produce comfort.

In another study, Fanger and Pedersen[15] exposed subjects to well-defined turbulent air flow directed at the back of the neck and the ankles. They determined that turbulent flow is less comfortable than uniform flow with the same mean velocity, and that certain frequencies of turbulence are more uncomfortable than other frequencies.

Fanger and Christensen[16] measured the sensitivity of the back of the neck with a horizontal diffuser on the ceiling directed slightly downward. This study produced a draft chart predicting the percentage of people feeling a draft at a given air velocity and air temperature.

Table 1. Evolving Air Velocity Limits in Thermal Comfort Standards

Year	Issuer	Mid-Zone Air Temp. °F	(°C)	Maximum Air Velocity, fpm	(m/s)	Comments
1896	ASHVE	N/A		30 cfm, no air velocity recommended		ASHVE committee reviews European ventilation standards
1915	ASHVE	66°	(19°)	30 cfm, no air velocity recommended		Code of Minimum Requirements for Ventilation
1920	ASHVE	66°	(19°)	160	(0.81)	Synthetic Air Chart
1932	ASHVE	70°	(21°)	50	(0.25)	ASHVE Ventilation Standard
1938	ASHVE	70°	(21°)	50	(0.25)	Code of Minimum Requirements for Comfort
1966	ASHRAE	74.8°	(24°)	45	(0.23)	First Standard 55
1974	ASHRAE	74.8°	(24°)	(70)	(0.36)	Comfort velocity = 30 fpm (0.15 m/s)
1981	ASHRAE	74.8°	(24°)	50	(0.25)	Extended summer zone to 155 fpm (0.79 m/s)
1984	ISO	71.5°	(22°)	30	(0.15)	Extended summer zone to 50 fpm (0.25 m/s)
1993	ASHRAE	74.8°	(24°)	30	(0.15)	Tu=40% at 74.8°F (24°C)

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A subsequent study[17] focused on turbulence intensity as a controlled variable. In this study, the researchers found increased discomfort with increased turbulence. They also present a modified draft risk chart for inclusion in future thermal comfort standards. The results from this study are incorporated into *ASHRAE Standard 55-92*.[18]

Of necessity, each experiment can only examine a subset of the variables influencing thermal comfort. The method each researcher uses to bound the experiment and present the subjects with the experimental conditions can have a significant effect on the results.

Fountain[19] raised numerous issues concerning the above laboratory experiments in this regard. One important conclusion was that existing laboratory studies do not present a clear picture concerning the levels of air velocity that produce comfort.

Variations in methods between experimenters can produce widely differing recommendations. The next section of this article discusses how the results of these experiments have been used to develop *ASHRAE Standard 55*.

Air velocity and ASHRAE standards

Limits in ASHVE and ASHRAE standards for indoor air temperature have steadily risen while air velocities have steadily dropped since the turn of the century (see *Table 1*).

More recently, the ASHRAE standards[4,18] have followed the DIN and ISO standards[20, 21] in terms of more stringent air movement restrictions. The current *ASHRAE Standard 55-92* contains two figures for air velocity and comfort that are complementary but may be difficult to apply in engineering practice.

Figure 3 in this standard (reproduced here as *Figure 1*) allows higher air velocities under occupant control to offset the effect of higher operative temperatures. (Operative temperatures are approximately equal to air temperature plus mean radiant temperature divided by two.)

It is applied in practice by selecting the operative temperature rise of the environment and then choosing the air velocity needed for comfort along the appropriate temperature difference curve.

Figure 4 in the *Standard 55-92* (reproduced here as *Figure 2*) has the objective of eliminating drafts, defining the effects of different levels of air velocity and turbulence intensity on comfort. Turbulence intensity is defined as the standard deviation of fluctuating velocities divided by their mean for the measuring period.

Together, the figures are designed to be applied within the combined temperature range of 68° to 84°F (20° to 29°C). The curves represent percent discomfort curves, with 15% discomfort being used for the draft figure and 20% for the increased air movement figure.

The curves in *Figure 1* are computed values representing constant heat loss at the skin surface under various combinations of thermal conditions. Constant heat loss approximates equal comfort, and the predictions of these curves are consistent with the results of several laboratory studies.[5,6,7,8,10,12,13]

As incorporated in *ASHRAE Standard 55-92*, this figure can only be used if the local air movement is under the control of the occupant, with *Figure 2* covering all other situations.

The draft risk curves in *Figure 2* are solidly based on laboratory data at the lower end of their temperature range.[17] However, in the higher temperature range above 73.5°F (23°C), the draft curves are extrapolations to conditions where data were not collected and where other research is in disagreement.[3,8,22]

If this part of the curve is too restrictive, several possibly effective environmental conditioning strategies involving air movement may be excluded by the standard.

Figure 3 shows air velocity requirements suggested by the standard, and by various studies discussed in this article. The range of supposedly acceptable conditions is considerable.

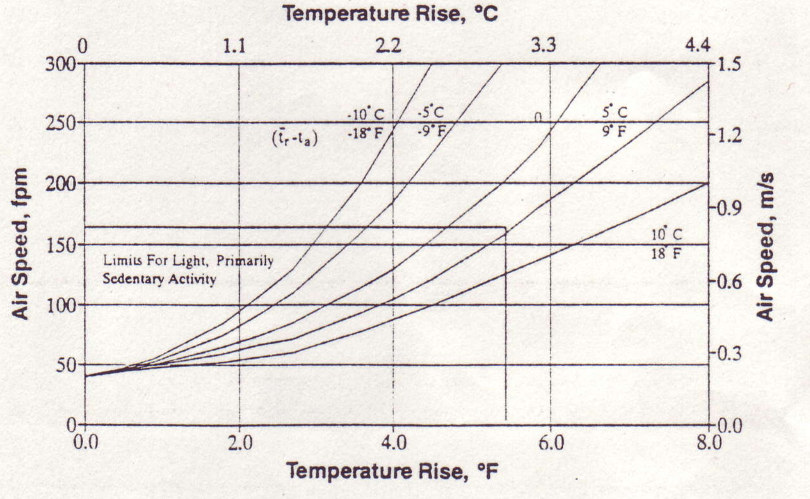

Figure 1. Air speed required to offset increased temperature.

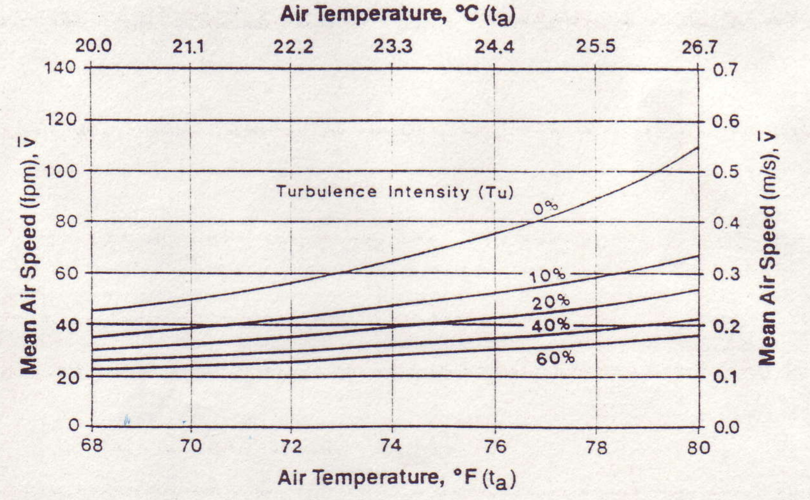

Figure 2. Allowable mean air speed as a function of air temperature and turbulence intensity.

Draft risk data for a turbulence intensity of 40% (typical of indoor office environments) are applied in the standard between 68° to 78.8°F (20° to 26°C). Using this draft risk curve, air movement is restricted to 24 fpm (0.12 m/s) at 68°F (20°C) and 40 fpm (0.2 m/s) at 78.8°F (26°C).

On the other hand, the (Ta = Tr) curve from *Figure 1* starts at the point 40 fpm, 78.8°F (0.2 m/s, 26°C) and extends to 160 fpm, 84.2°F (0.8 m/s, 29°C). Although the curves in *Figure 1* were developed for 78.8°F (26°C) and above, they can be shown to apply as well in the range of 73.5° to 78.8°F (23° to 26°C). Thus, they can be used to produce the zone of occupant-controlled comfortable conditions shown in *Figure 3*.

This figure also presents data from three experiments,[5,8,12] the Fanger draft risk zone and *ASHRAE Standard 55-81* air velocity limits. They are in broad agreement about the ability of the occupant-controlled air movement zone to provide comfort.

On the other hand, the new draft risk limit represents a significant air movement restriction over the previous *Standard 55* zone. The difference in the ranges of the acceptable conditions in *Figure 1* and *Figure 2* is obvious and should be investigated in the future.

Conclusion

It is not clear today what air velocity levels are appropriate for the range of temperatures found indoors. Two important aspects of moving air—draft risk and desirable occupant cooling—are addressed as separate issues in the new *ASHRAE Standard 55-92* because a single recommendation cannot be produced from the existing research.

The velocity limits prescribed in the standard clearly have an impact on the various ventilative cooling strategies that are possible in buildings. These strategies include fan ventilation, direct evaporative cooling, operable windows and task conditioning systems using locally controlled air outlets.

It is important that HVAC standards such as *Standard 55-92* encourage and not restrict the potential for new designs to improve comfort and conserve energy. ASHRAE research could usefully undertake a comprehensive examination of the influence of air movement on human thermal comfort aimed specifically at providing recommendations for the next standard revision.

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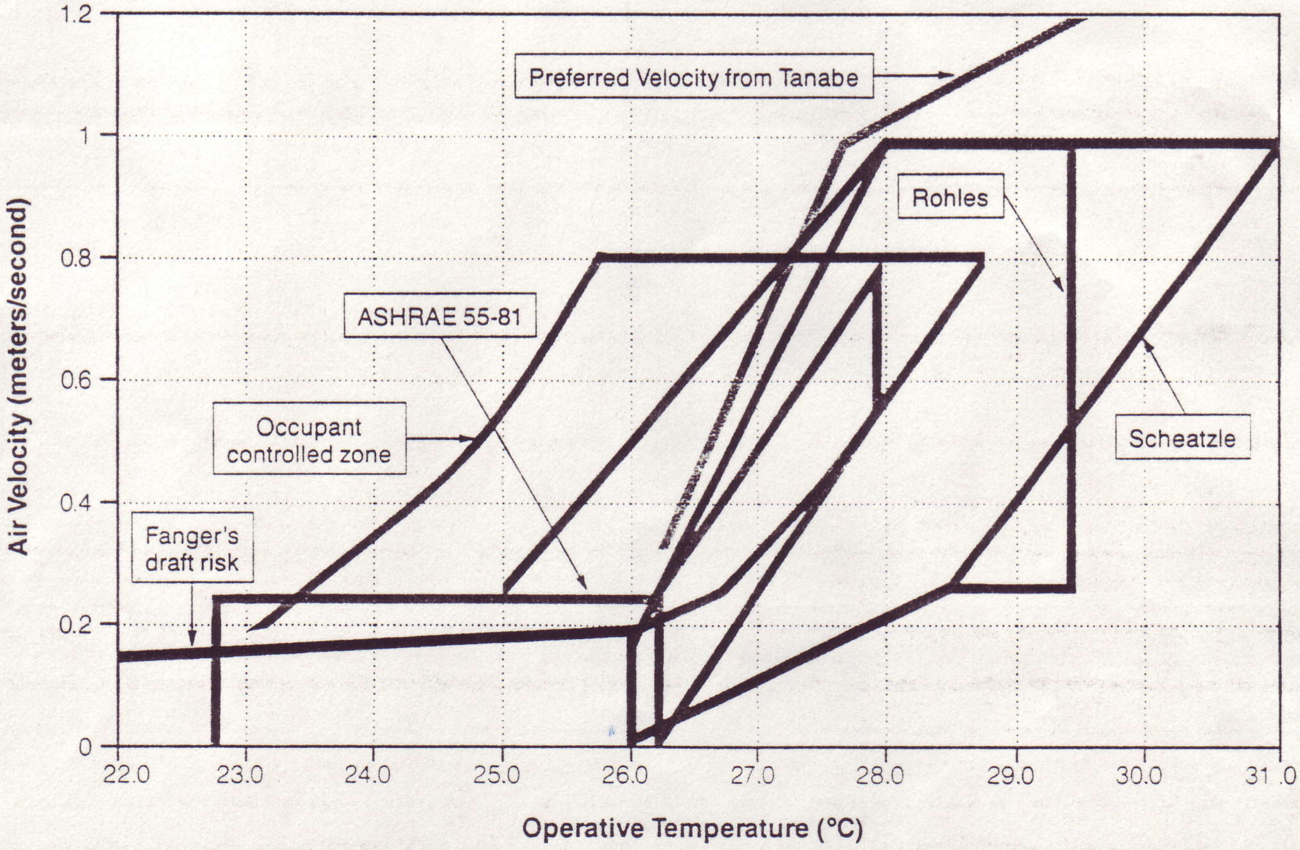

Figure 3. Range of velocity requirements.

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