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EFFECT OF VENTILATIVE COOLING ON INDOOR THERMAL ENVIRONMENT

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ABSTRACT. Problems on the various effects of ventilative cooling on thermal comfort in indoor spaces based on recent studies are discussed. The ventilative cooling effects on thermal comfort can be found in the literatures, but clear boundaries between comfort and discomfort are not given. This paper presents such boundaries in more definitive expression both in a specific chart and in an equation form, based on the analysis of the data from our past experiments with different patterns of air velocity. From the results of these studies a weak jet system for personal air conditioning is proposed to provide cooling effect so that nice and healthy air distribution around the body could be maintained.

KEYWORDS Ventilative Cooling, Thermal Comfort, Air Velocity, Personal Air Conditioning, Weak Jet

INTRODUCTION. Under the summer conditions especially in hot and humid regions the effects of air movement as can be seen in traditional houses are often pronounced from the viewpoint of energy conservation in air conditioning of modern buildings. In fact in the air tight office buildings the air conditioning is capable of providing thermal comfort for occupants where air movement may be kept minimum by having the temperature and humidity maintained lower. It is generally known that 1°C higher room air temperature will result in about 10% reduction in energy consumption for cooling. It is advisable, therefore, to set higher indoor air temperature and humidity with increased air movement for providing thermal comfort under hot and humid conditions. For this purpose the boundary between comfort and discomfort in the psychrometric chart depending on air movement must be informed. The ventilative cooling effects on thermal comfort have been given in the literatures by Olgyay(1963) and Givoni(1969) under higher temperature conditions based on their earlier studies, showing extensions of the comfort range by air movement in their bioclimatic chart and psychrometric chart, but clear boundaries between comfort and discomfort are not given.

VENTILATIVE COOLING. Excessive air movement gives discomfort by draft under winter conditions, while higher air velocity up to a certain limit may be acceptable for office workers under summer conditions. This is being called ventilative cooling and the effect is found more pronounced than explained by Predicted Mean Vote (PMV) according to the subjective experiments by Tanabe & Kimura (1987). Figure 1 shows the results with six different air velocities from 0.13 to 1.63 m/s for four conditions of modified temperature and humidity 27°C 50% rh, 29°C 50% rh, 29°C 80% rh and 31°C 50% rh, where the modified temperature MT is defined as the air temperature equivalent to the condition of 50%rh, air velocity of 0.1 m/s, mean radiant temperature equal to room air temperature, for a subject in 0.6 clo clothing with 1 met activity. The difference between these results and predicted values by the comfort equation(Fanger, 1970) may possibly be attributed to the decrease in clo value caused by higher air movement, which is reported by Seppanen et al (1973) from the measurement and an increase in skin diffusion with the thermal manekin.

The experimental results with a thermal manekin in a clothing of 0.5 clo under varied air velocity showed a gradual decrease in clo value down to 0.4 at 1.5 m/s of air velocity (Haga et al 1990). The relationship based on further studies can be expressed by

$$Iclov = Iclo\ e^{-0.15v} \qquad (1)$$

where Iclo is nominal clo value of 0.5 and Iclov is clo value with air velocity of v[m/s].

Figure 1 Subjective Experimental Results of Thermal Sensation Vote against Modified Temperature under Different Air Movements

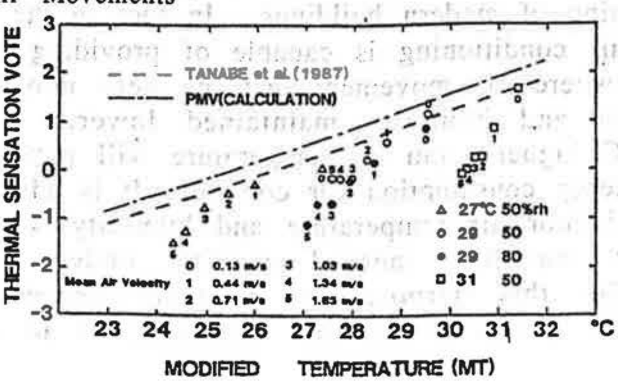
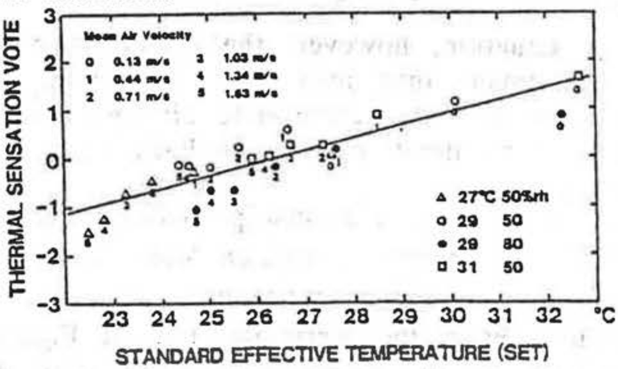


Figure 2 shows the same experimental results as shown in Figure 1 compared with Standard Effective Temperature(SET), where closer relationship between these can be found. The reason may be explained by the fact that SET takes account of increase in sweat diffusion due to an increase in air velocity, while PMV equation does not.

Figure 2 Subjective Experimental Results of Thermal Sensation Vote against Standard Temperature under Different Air Movements



These effects of ventilative cooling must be incorporated in presenting the boundaries between comfort and discomfort against air velocity under the summer conditions. As the criteria for determining such boundaries the percentage of dissatisfied occupants of 20% may be taken and it corresponds to PMV of 0.8 in reference to ISO 7730(1984).

THEORETICAL CONSIDERATIONS. From the relationship between PMV and thermal load of human body referring to Fanger's comfort equation (Fanger, 1970), it can be understood that a decrease in PMV due to an increase in air velocity ΔPMV is equivalent to an increase in thermal load ΔL attributable to an increase in heat loss by convection and radiation. Thus, under the condition of 1 met activity level,

$$\Delta PMV=0.32\ \Delta L \qquad (2)$$

If the heat loss by convection and radiation can be combined and expressed by the overall thermal transmittance from skin surface to ambient air multipled by the difference between skin surface temperature t_{sk}[°C] and ambient operative temperature t_o[°C] the increase in heat loss is expressed by

$$\Delta L= (t_{sk} - t_o)/\Delta R \qquad (3)$$

where ΔR is a decrease in overall thermal resisitance [m^2K/W] from skin surface to ambient air to be expressed by

$$\Delta R = I_{clo} - I_{clov} + 1/(\alpha_c + \alpha_r) - 1/(\alpha'_c + \alpha_r) \qquad (4)$$

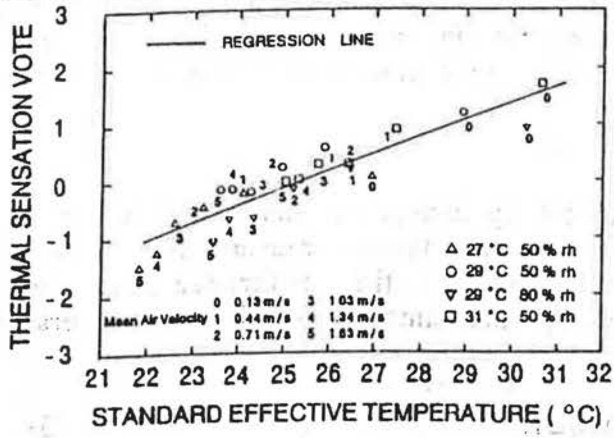
where α_c and α'_c [W/(m^{2}K)] are convective heat transfer coefficients when air velocity is 0.1 m/s and v [m/s] respectively, whose values may be obtained from literatures. It is assumed that radiative heat transfer coefficient α_r[W/(m^{2}K)] from clothing surface to the room enclosure remains constant irrespective of different air velocities.

Thus ΔR in equation (4) may be obtained. As skin surface temperature does not change when air velocity changes, the increase in heat loss ΔL can be obtained from equation (3) and consequently the decrease in PMV from equation (2).

In such an equation, however, the effect of evaporation by air movement is not taken into account. Conversely for any given temperature and humidity, the appropriate air velocity can be obtained from these equations by iteration to make PMV value +0.8 for 20% of dissatisfied percentage.

Figure 3 shows the relationship between Standard Effective Temperature (SET) and Thermal Sensation Vote (TSV) when a decrease in clo value and an increase in wettedness due to air movement are taken into account. From the regression line of Figure 3, the results with four conditions in the experiment would give the temperature-humidity relationshp with respect to air velocity may be obtained as shown in Figure 4 for the region of ambient temperature above 27°C. This is a tentative chart based on the criteria with which thermal sensation vote of +0.3 could be satisfied.

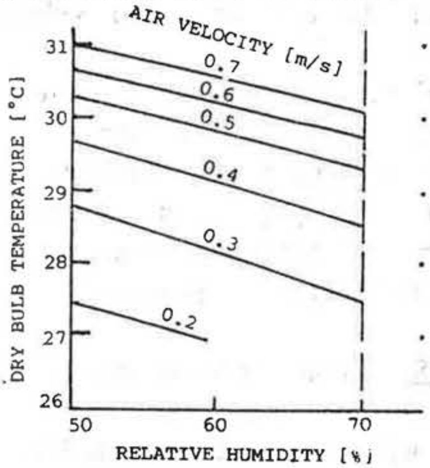
Figure 3 Thermal Sensation Vote against Standard EffectiveTemperature under Different Air Movements where Plots were Changed Taking into Account of a Decrease in clo Value and an Increase in Skin Wettedness with Air Velocities.



<u>WEEK JET SYSTEM.</u> In compliance with the criteria as clarified by the preceding results a week jet system may be considered desirable for

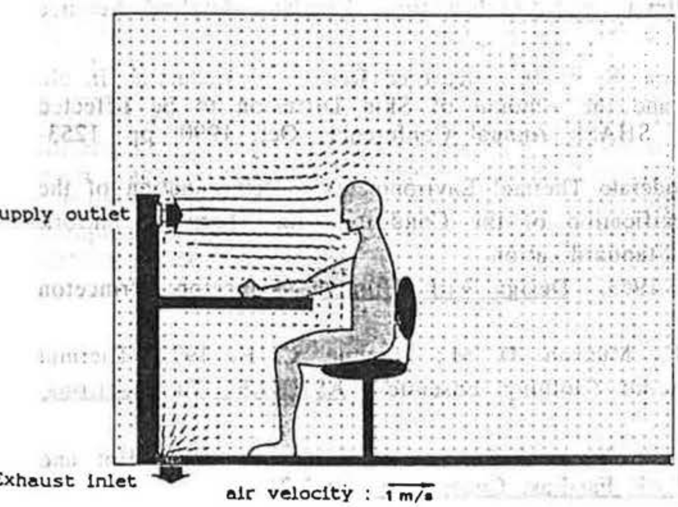
office spaces with heat generating office machines. This may be equivalent with hand fans under natural air conditions of rather high temperature. As the temperature level is to be set as high as 31°C and above 27°C with different humidity level as shown in the chart of Figure 4, dissatisfaction by the cold air stagnant around feet can be eliminated as often claimed in the offices with heat generating machines.

Figure 4 Tentative Recommendation of Air Velocity for Ventilative Cooling against the Combination of Temperature and Humidity for 0.6 clo and 1 met Activity



Predicted air distribution for personal air conditioning with week get system in the case of discharge temperature equal to room air

Figure 5 Example Air Distribution for a Personal Working Space with a Week Jet Sytem Based on Numerical Calculation by Suyama



Conditions of numerical calculation

- Isothermal 3-D numerical simulation
- Calculated region (2.5m(L)×2.5m(W)×2m(H)) is divided into about 100,000 cells.
- k-ε two equation model is adopted.
- Supply outlet is on the front wall. (air velocity : 0.7 m/s)
- Exhaust inlet is on the floor. (air velocity : 0.7 m/s)
- Pressure 0 is assumed at boundaries except floor surface.
- Air velocity near the face is 0.4~0.5 m/s.

temperature is shown in Figure 5. This graphical presentation is made by Suyama from the results of numerical computation.

CONCLUSION. Quantitative estimation on the effect of ventilative cooling on indoor thermal environment is attempted on the basis of subjective experiments made in the past studies.

Theoretical consideration is made to modify the comfort equation where a decrease in clo value with air velocity is taken into account. The procedure to obtain the appropriate air velocity is presented for given temperature and humidity.

Taking account of the decrease in clo value and an increase in wettedness due to air velocity in SET, a chart to obtain the appropriate air velocity for a given temperature and humidity is presented.

In consequence a weak jet system is considered desirable for offices under rather higher temperature-humidity conditions and an example pettern of air distribution is presented.

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