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Assessing Ventilation Systems in Hot Building Environments

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The minimisation of energy and operating costs, together with the optimisation of comfort levels must be the aim of any air-conditioning plant. Industrial buildings offer much scope for improvements in the effective operation of air conditioning and ventilation systems. A method of determining the effectiveness of such systems is described—'Thermal Efficacy'. This allows the assessment of total heat removal in hot industrial environments. Summarized results of tests carried out in a synthetic-fibre producing factory are presented. Advantages of using Thermal Efficacy include improved assessment of discomfort levels experienced by workers.

NOMENCLATURE

η ventilation efficiency
η_t temperature efficiency
C concentration of substance in air
T temperature
H enthalpy
ε Thermal Efficacy.

Subscripts
s supply air stream
e extract air stream
i measurement position in building space.

INTRODUCTION

MECHANICAL ventilation and air-conditioning systems for buildings can be split into two main segments. The first might be termed the 'closed' segment consisting of the fan, heating and cooling batteries, humidifier and ductwork; the second, 'open' segment being that which exists between the supply and extract registers in the building space. The prime aim of air-conditioning systems is the provision of satisfactory environments within the open segment, or perhaps more correctly, at particular points within the open segment. Good system design allows the operation of the closed segment to be optimised by suitable sizing and arrangement of the major elements. Optimisation and assessment of performance within the open segment is a more difficult task.

Sandberg [1] introduced the concept of 'ventilation efficiency', initially to investigate contaminant removal. This concept was based on the comparison of a measureable property of incoming and outgoing air streams and of air at a critical position within a building space. Ventilation efficiency was determined from the following expression:

$$\eta = \frac{C_e - C_s}{C_i - C_s}.$$

The use of the word 'efficiency' might be seen as a misnomer since values in excess of 100% are both possible and desirable. Such a beneficial situation can arise by the positioning of air supply and extract systems to take advantage of the varying conditions created by a non-homogenous air mixture in the building space.

VENTILATION FOR HEAT REMOVAL

In situations which involve heat supply or removal rather than contaminant removal, Sandberg [2] (with Svensson) modified his 'ventilation efficiency' to derive an expression termed 'temperature efficiency':

$$\eta_t = \frac{T_e - T_s}{T_i - T_s}.$$

For the particular case of excess heat removal, the ventilation systems should be designed to provide cool supply air to important positions within the space whilst extracting air at as high a temperature as possible. In such cases, convection and stratification effects may be taken advantage of, though problems of 'cold' draughts must be borne in mind.

The temperature efficiency described by Sandberg is quite simple to apply and use, however, by its nature it is deficient in one respect—that being, that it can only take account of sensible heat variations in the state of the air at various points. Latent heat variations indicated as differences in moisture content are not accounted for.

At moderate temperature levels (or approximate conditions of thermal comfort), moisture levels as expressed in terms of relative humidity or percentage saturation have only a small effect on comfort. However, as temperature increases the effect of humidity on discomfort

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BAE 21:3/4-B

becomes progressively more important. The reason for this lies in the fact that in the 'comfort zone', evaporative heat loss from the human body is only about 25% of the total [3]. As the temperature of the environment rises towards skin temperature (at about 35°C), and above, the proportion of heat loss due to evaporation increases towards 100%. If the 'New' Effective Temperature Scale (ET*) as described by the American Society of Heating, Refrigerating and Air-conditioning Engineers [3] is considered, then at high and humid temperatures lines of equivalent comfort (or discomfort) levels plotted on a psychrometric chart are almost parallel to wet-bulb temperature [4] (see Fig. 1).

Thus in hot environments, simple dry-bulb temperature measurements not only neglect the heat content of air ascribable to moisture levels, but also the important influence of humidity on comfort. As a result a new method of assessment of ventilation is proposed which encompasses both temperature and moisture level variations for those types of environments.

THERMAL EFFICACY OF HEAT REMOVAL

The property of moist air which accounts for variations in both temperature levels and water vapour content is specific enthalpy. It would seem sensible therefore to use this property in order to derive an efficiency, or perhaps an 'efficacy' of total heat removal. The additional benefit of using specific enthalpy lies in the fact that in terms of the psychrometric chart and comfort levels, lines of constant enthalpy are very nearly parallel to lines of constant wet-bulb temperature, and as has already been stated, wet-bulb temperature is a very good indication of thermal comfort in hot environments. This close association indicates that specific enthalpy is a much more accurate predictor of comfort in such environments than simple dry-bulb air temperature. However, this scale in its simplest form does not take into account relative air velocity or mean radiant temperature.

'Thermal Efficacy', using specific enthalpy can be defined for heat removal thus:

$$\varepsilon_h = \frac{H_e - H_s}{H_i - H_s}.$$

DETERMINATION OF THERMAL EFFICACY

In order to calculate values of this efficacy, the specific enthalpy of air for at least three points must be found (one point in the supply air stream, one point in the extract air stream, and one or more points of interest within the building space). Since enthalpy cannot be measured directly, two other independent properties of air must be used. Wet- and dry-bulb temperature measurements are those most commonly used, however, for ease of incorporation into a data acquisition system, an alternative is suggested—dry-bulb (or air) temperature and relative humidity. A number of electronic probes are now available which can provide such measurements, though careful calibration of the humidity sensor is required and care must be taken when humidity levels are likely to vary quickly or by large amounts.

Algorithms [5] relating the properties of moist air can then be used to determine specific enthalpy values and hence thermal efficacy.

So that the potential for using this assessment method could be investigated and evaluated, a series of experiments were designed and carried out within an industrial environment.

EXPERIMENTAL WORK

Measurements of air temperature and humidity were made over an extended period within the air-conditioned environment of a synthetic-fibre producing factory. In one section of the process, nylon polymer 'chips' are

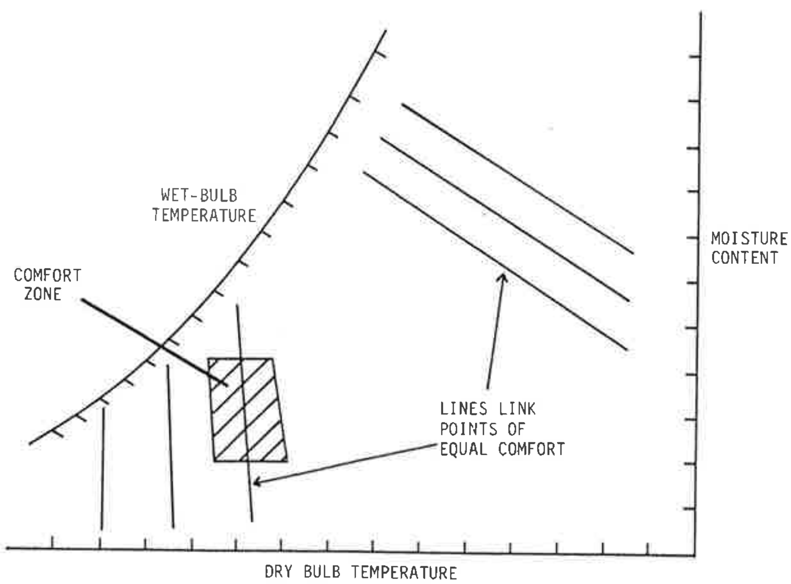

Fig. 1. Psychometric chart showing comfort zone and lines of equal comfort.

melted and extruded. The environment adjacent to the machines carrying out this process is very warm and it is made more uncomfortable since amounts of steam are also liberated into the area.

In order to try to alleviate the thermal discomfort for the workforce, crude air-conditioning is employed. This attempts to deliver (cooled) outside air to the area where workers may be located, whilst extracting hot air from above the production machines. To assess the effectiveness of the system, measurements were made in the supply air, extract air and at a position approximating to the head height of the workers. A sketch showing the machine and measurement position layout is given in Fig. 2.

Recording of data was carried out at different times of the year to enable external climatic variations and differences in air-conditioning system operation to be taken into account. It was possible to use the data to determine values of Sandberg's temperature efficiency of ventilation as well as thermal efficacy. The results given below are based upon several days records of hourly means of measurements taken at 10-min intervals; also given are the 95% confidence limits.

RESULTS

Winter (Typical environmental conditions 34°C, 40% r.h.)

Temperature Efficiency	99.2% (±8.4%)
Thermal Efficacy	87.6% (±4.3%).

Summer (Typical environmental conditions 37°C, 50% r.h.)

Temperature Efficiency	87.8% (±9%)
Thermal Efficacy	65.4% (±14.7%).

(The differences between winter and summer results and between temperature efficiency and thermal efficacy are statistically significant at the 95% confidence level.)

Two important facts emerge from the results—first, that neither the temperature efficiency nor the thermal efficacy of the systems is very great; and secondly, that thermal efficacy allows better identification of poor performance. This is especially true for the summer period when the systems were operated in a different manner and when complaints from workers were most prevalent. A more detailed study of the environment and air movement, carried out in parallel with the measurement of total thermal efficacy supported the low values found and enabled modifications to be suggested to improve the overall performance. These modifications related to the position of the air supply and extract registers and control of the air movement within the space giving better directional quality.

CONCLUSIONS

Specific enthalpy is an important property of moist air since it represents total heat content (taking into account both sensible and latent heat fractions) and for hot environments it gives a better indication of relative comfort/discomfort than simple air temperature. This property, therefore, suggests itself for use in the evaluation of the effectiveness of ventilation and air-conditioning systems for hot environments or those environments in which moisture levels are likely to vary.

Comparison of thermal efficacy (based upon specific

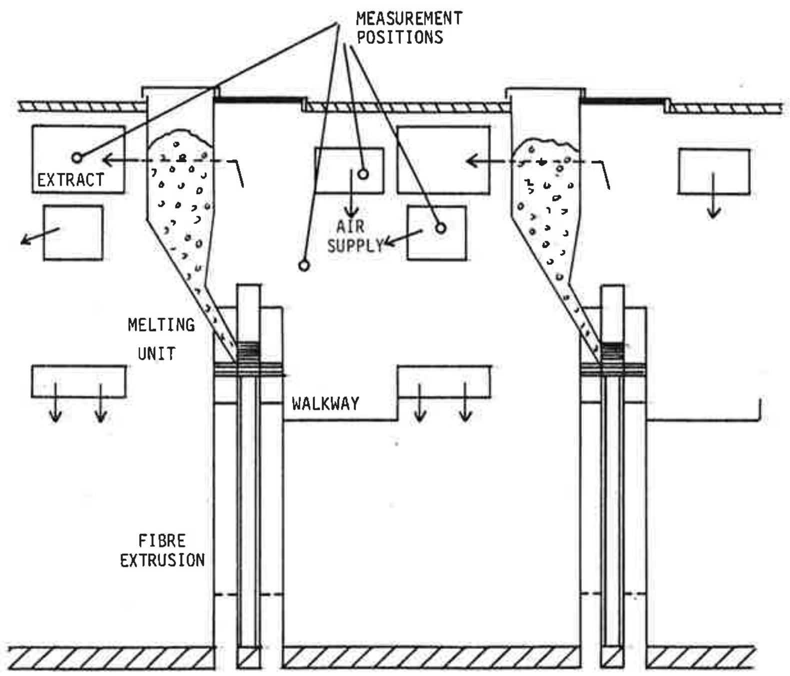

Fig. 2. Cross-sectional sketch showing temperature and humidity measurement positions in factory.

enthalpy values) and the simpler scale of temperature efficiency have indicated that additional information is provided by the thermal efficiency value. This can help with the evaluation of comfort and with the determination of system improvements necessary.

REFERENCES

1. M. Sandberg, What is ventilation efficiency. *Bldg Envir.* **16**, No. 2 (1981).
2. M. Sandberg and A. Svensson, The ventilation and temperature efficiency of mechanical ventilation systems. *Proc. CIB W67 Third International. Symposium—Energy Conservation in the Built Environment*, Dublin, Vol. 6 (1982).
3. ASHRAE, Chap. 8, *Physiological Principles, Comfort and Health Handbook of Fundamentals* (1981).
4. A. P. Gagge, J. A. J. Stolwijk and Y. Nishi, An effective temperature scale based on a simple model of human physiological thermoregulatory response. *ASHRAE Trans.* 77, 247 (1971).
5. CIBS Working Group, *Psychrometric Data.* (Basis of the psychrometric tables presented in Book C of the Guide.) (1970).