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ACCEPTABLE INDOOR THERMAL CONDITIONS AND IMPLICATIONS FOR ENERGY CONSERVATION IN A CONTINENTAL CLIMATE

by

WENTZEL JD, KOK R, LEWIS MI and MEESE GB

ABSTRACT

Discusses the indoor temperature ranges found acceptable by occupants of buildings controlled by passive means, in areas where the influence of land mass dominates the local climate.

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Wentzel, J D; Kok, R; Lewis, M I & Meese, G B.

INTRODUCTION

The current trend in environmental control is to use building design, materials and layout in order to achieve the desired indoor temperatures. This inevitably results in a wider range of indoor conditions than when airconditioning is used, and the tolerance of the occupants to variable indoor temperatures is of considerable interest.

A large proportion of the research into comfort levels has concentrated on steady state conditions close to the neutral comfort region, and on human response at fixed activity levels with prescribed clothing. These findings are not strictly applicable to the more variable conditions which are found in buildings whose indoor temperatures are controlled by passive means.

Because South Africa has a comparatively mild climate and because local custom permits a wide choice of clothing, the population normally adjusts to seasonal changes by varying the type of clothing worn. This largely accounts for the wider temperature ranges which local inhabitants find acceptable, which in turn reduces the need for airconditioning.

For this reason the National Building Research Institute has concentrated on naturally changing indoor environments and the response of normally dressed occupants.

FIELD SURVEYS

(a) Hospital survey

A systematic survey of the thermal response of 1 300 patients and 65 nursing staff was performed in five hospitals in various inland climatic regions (1). At the low humidities which prevail during the summer, the indoor air temperature was found to be a satisfactory measure of the thermal stress imposed on patients in bed. In spite of differences in clothing and the amount of blankets used, 80% of the patients reported an acceptable level of comfort, from a heat point of view (a vote of less than 5 on the Bedford scale) at air temperatures below 28,5°C, (Figure 1).

The corresponding air temperature for nursing staff was 26,5°C. This difference of 2°C could be largely eliminated if nurses were able to wear a lighter summer uniform.

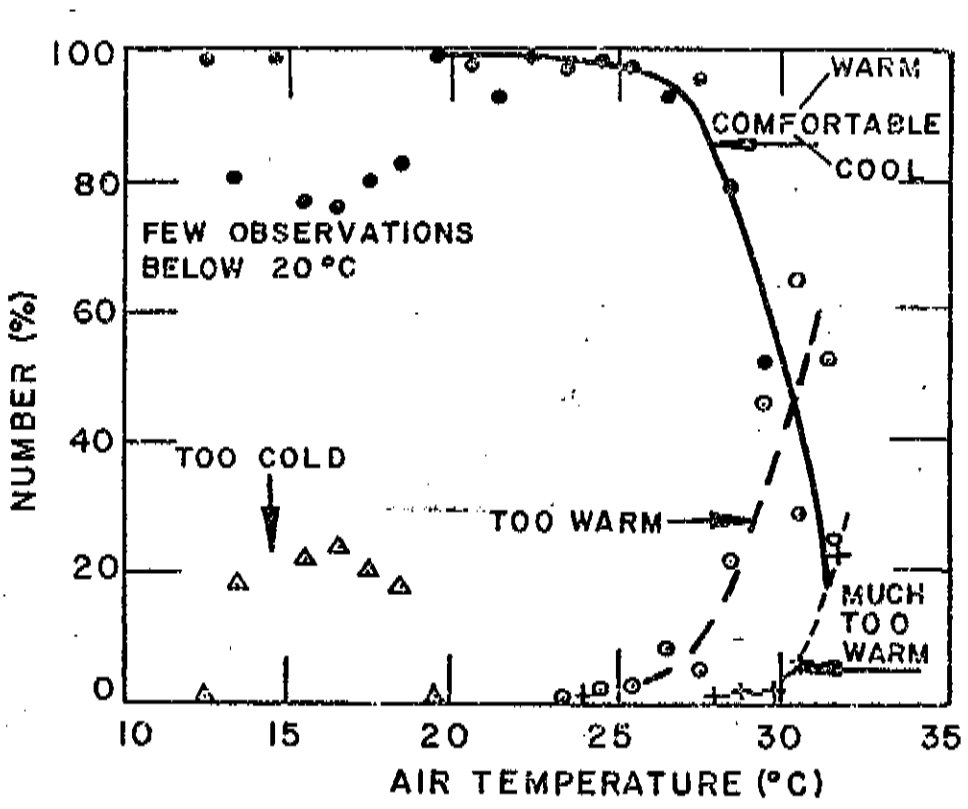

FIGURE 1: Subjective response of patients as a function of the air temperature

(b) Office survey - City centre

A survey of the thermal conditions in offices in the centre of Pretoria was undertaken, involving interviews with 1 200 office workers. The air temperature, humidity and air velocity were measured at the work place and the clothing of each individual noted.

To determine the thermal response of the occupants three approaches were followed in an effort to differentiate between: the acceptability of the thermal environment, the degree of comfort experienced and the temperature sensitivity.

Acceptability of the indoor environment: A questionnaire was used to determine whether office personnel were conscious of the prevailing thermal environment whilst carrying on with their work. If they were distracted by thermal discomfort, they were noted as being "dissatisfied" (Figure 2a).

Comfort: The thermal response of the occupants was also assessed on the 7-point Bedford scale. "Comfortably-warm" was regarded as being the upper limit for an acceptable level of comfort (Figure 2b).

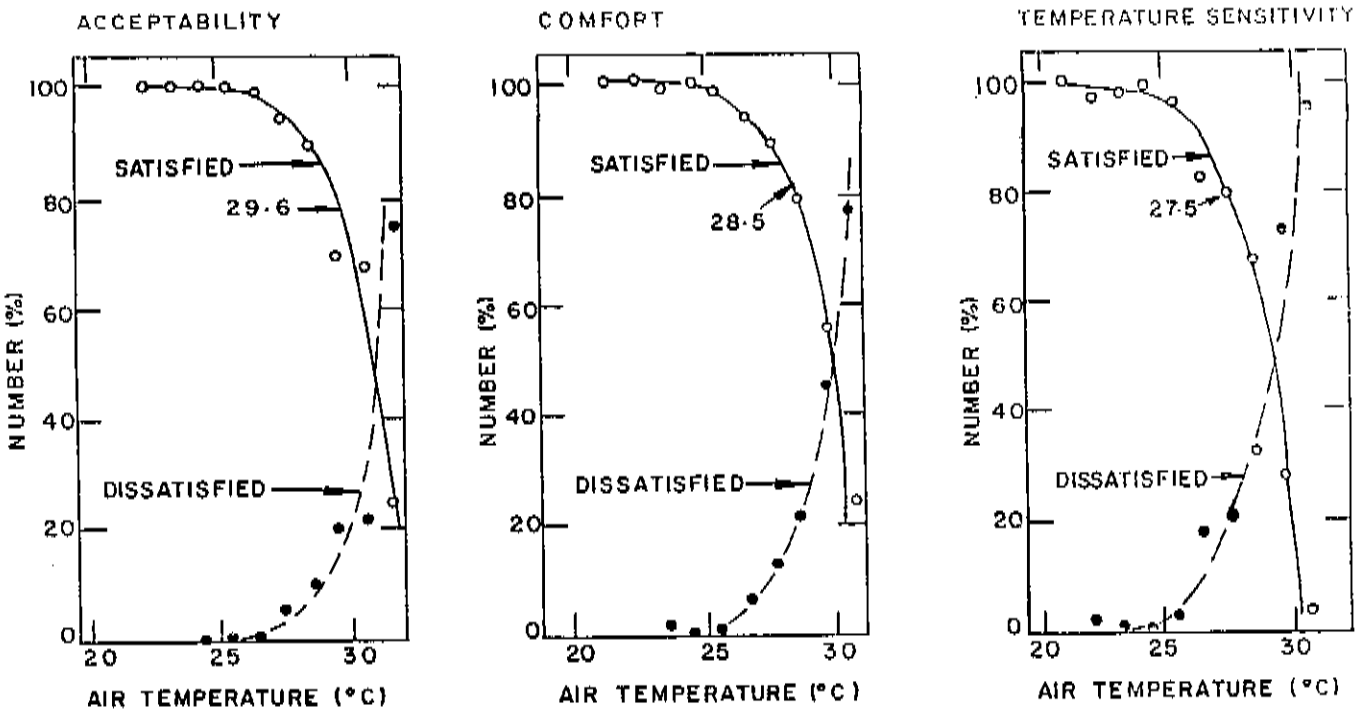

FIGURE 2: Subjective response of office workers as a function of air temperature (°C)

Temperature sensitivity: To measure the thermal sensitivity of office workers a series of questions was asked:

(1) Would you prefer the temperature unchanged or lower?

(2) If you wish the temperature to be lowered, do you want it slightly lower or much lower?

(3) Is much lower sufficient or would you prefer the temperature to be very much lower?

Any vote more extreme than "slightly lower" was deemed to denote dissatisfaction (Figure 2c).

Figures 2a, 2b and 2c show the results of this survey. Eighty percent of the occupants were not distracted by temperatures below 29,6°C. At 28,5°C, 80% of the occupants were comfortable whilst at 27,5°C, 80% of the occupants, although comfortable, would have preferred the temperature to be "slightly lower".

Being employed in a government office, the choice of dress of the office workers was limited, and showed very little adaptation to the prevailing climate. The correlation coefficient between clothing insulation and air temperature was only 0,17. The thermal response of the occupants as a function of air temperature showed a correlation coefficient of 0,66.

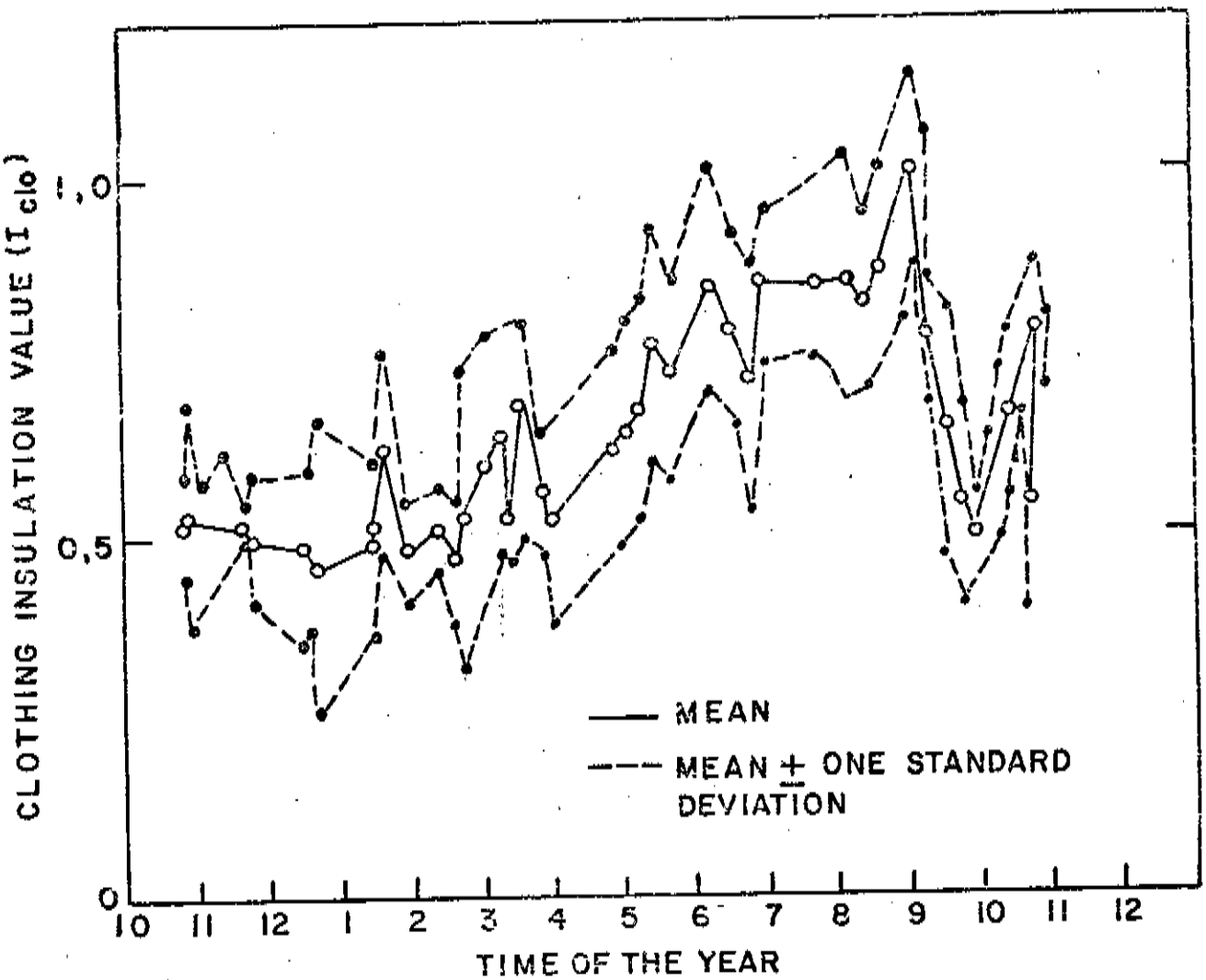

FIGURE 3: Variation in insulation value of clothing in the course of a year

(c) Office survey - NBRI personnel

In the course of a year, 500 interviews were held with members of the NBRI staff. The approach was the same as in the case of the office workers. NBRI staff are free to dress according to their own choice. The adaptation of the staff's dress to changes in air temperature is illustrated in Figure 3 where the mean insulation value of their clothing is shown as a function of the time of the year. (Correlation coefficient 0,65 between clothing and air temperature).

The thermal response of the NBRI staff is shown in Figure 4(a) and (b).

The number of occasions on which the air temperature exceeded 28°C was limited. Nevertheless, with both comfort and temperature sensitivity as bases, the percentage of occupants that were dissatisfied remains acceptably low up to 28°C air temperatures. A negligible number of occupants found the indoor conditions in the NBRI building unacceptable.

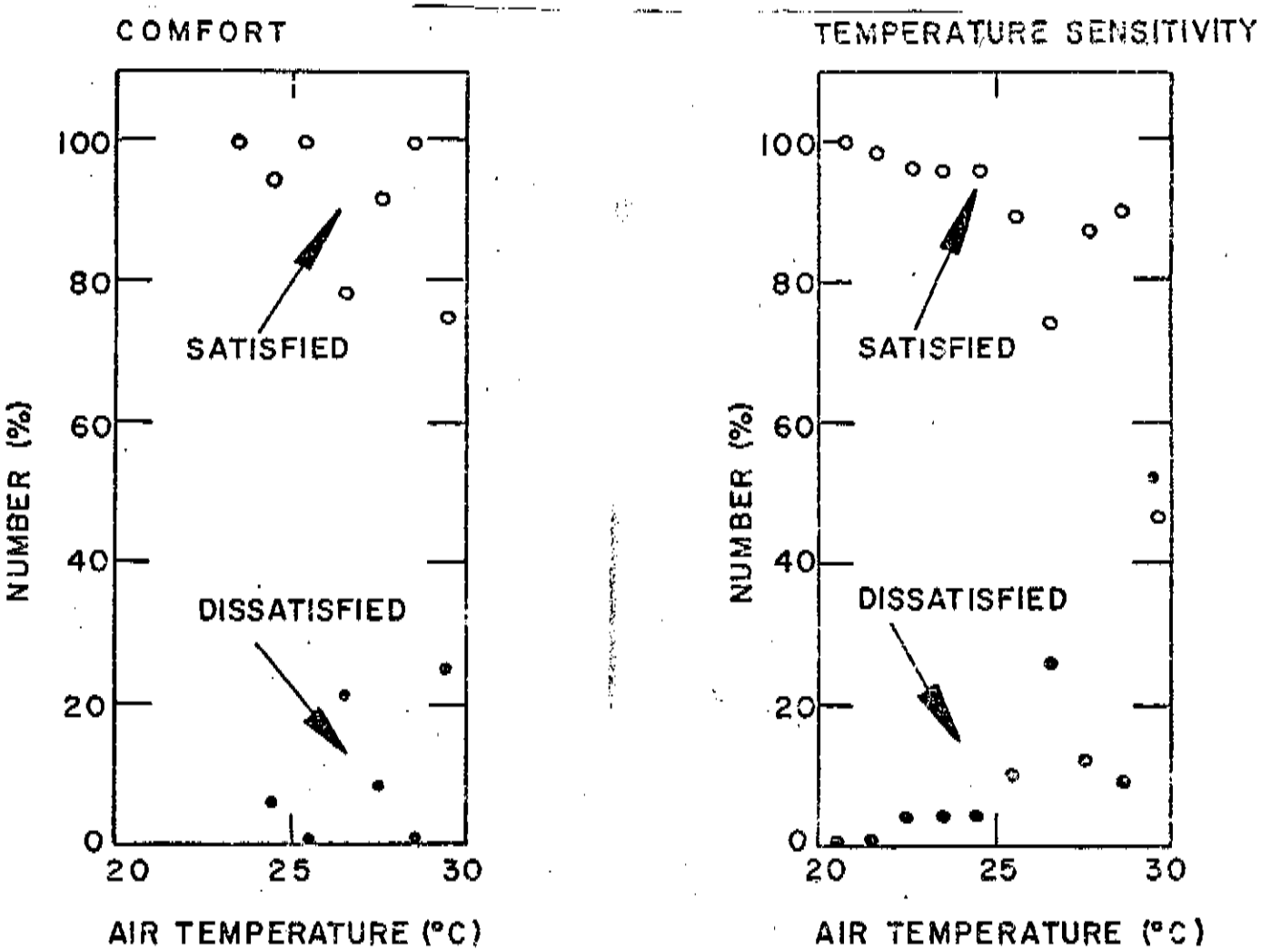

FIGURE 4: Subjective response of NBRI staff as function of air temperature (°C)

In Figure 5 the mean vote (using the 7-point Bedford scale) is shown as a function of the air temperature for the three field surveys. At temperatures above 29°C the occupants of the government office voted approximately one vote warmer than the NBRI staff. Having a free choice of dress thus makes the occupants of the NBRI building more tolerant to higher air temperatures.

The percentage of the occupants that are satisfied is shown as a function of the mean vote in Figure 6. The following equation gives the relationship between mean vote and percentage satisfied with a correlation coefficient of 0,94.

$$PS = 96,4 + 1,6\ (MV) - 20,1\ (MV)^2$$

where

PS = Percentage satisfied
MV = Mean vote

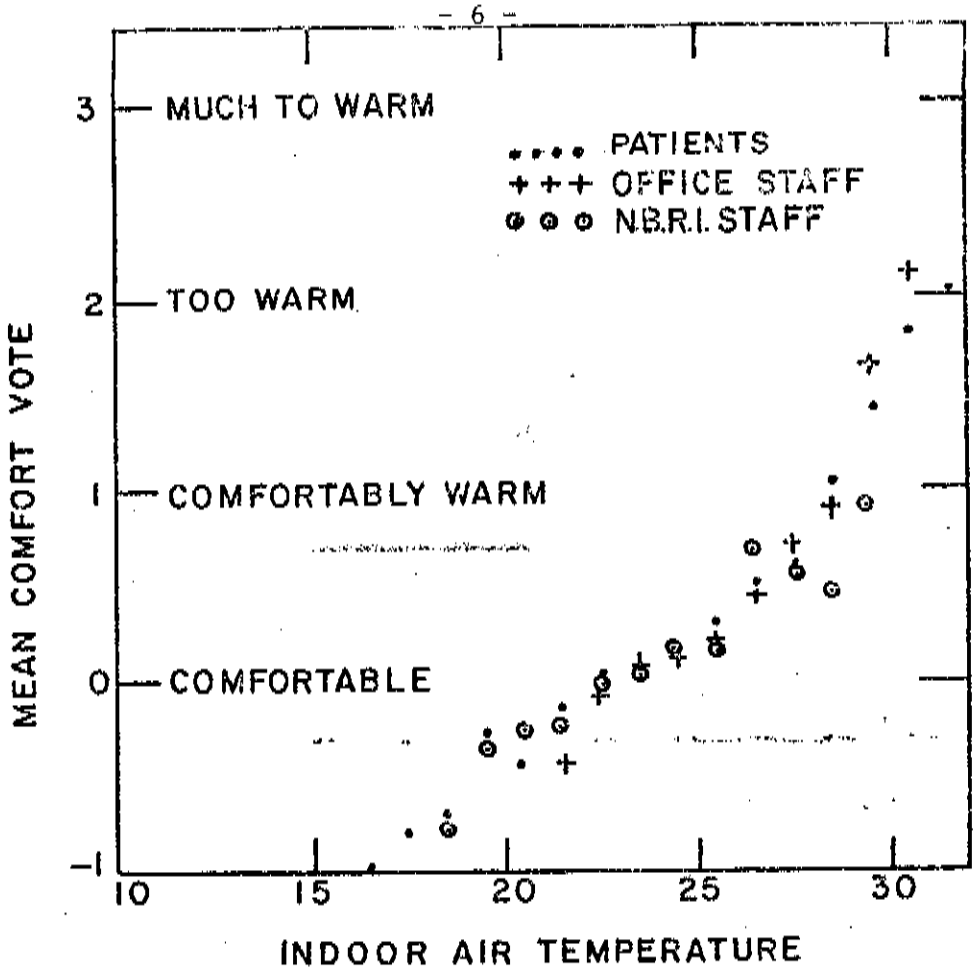

FIGURE 5: Mean comfort vote as a function of air temperature

LABORATORY STUDIES

To complement the field-work, results from a laboratory investigation are presented. Nearly 1 000 subjects (black and white, male and female) have participated in a study to determine the effects of mild thermal stress on the performance of factory workers (2). The experiments were carried out in a mobile climate laboratory comprising two large trailers; a climate chamber and a "control" chamber. The laboratory was sited on factory premises. Temperature could be controlled to within ±0,1°C of the set point over the range 6-40 °C. Humidity control to within 1% relative humidity in the range of 20 to 70% was achieved between 15 and 35°C. Air velocity was below 0,15 m s^{-1} and globe temperatures were within 1°C of air temperature. A total of eight exposures were used, each lasting for a full shift. Results from the "hot series" (20, 26, 32 and 38°C at 1,0 kPa) will be discussed. Approximately 30 subjects of every ethnic/sex group were exposed to each condition.

Four subjects attended each day and after the work had been explained they removed their own clothing and dressed in a standard uniform of insulating value 0,12 K m^2 W^{-1}. The workers remained in the laboratory for the whole day and performed a series of tests designed to simulate factory work.

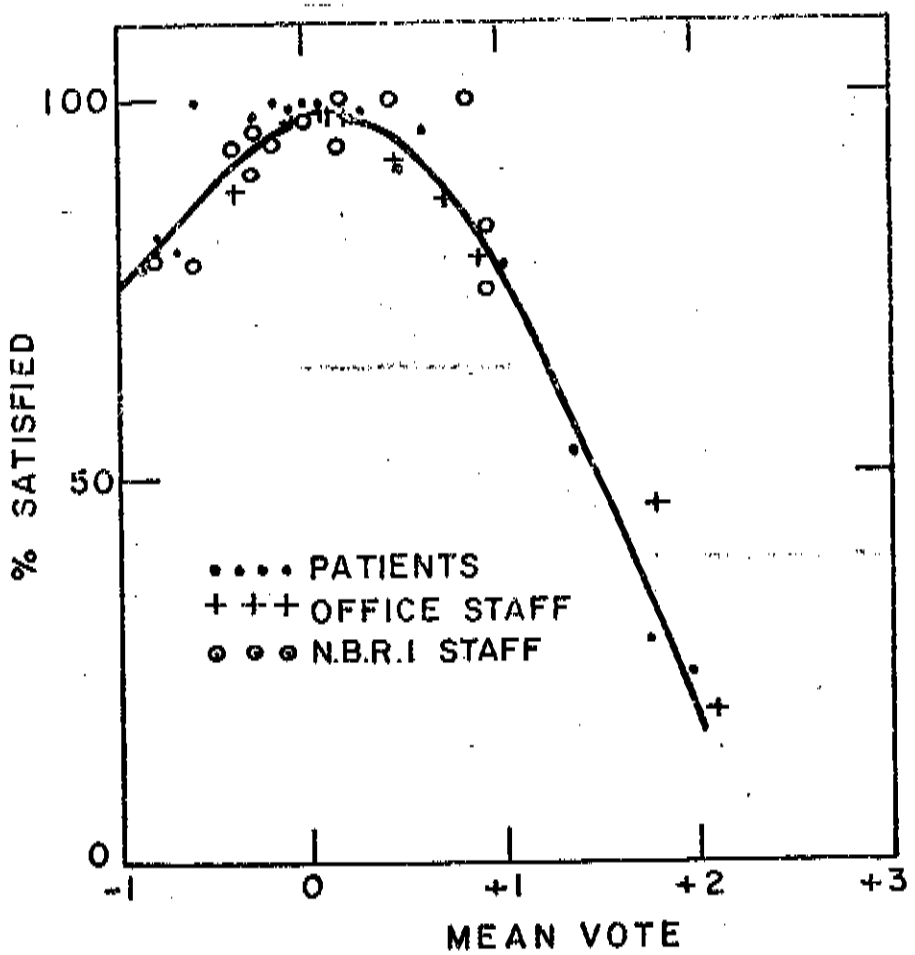

FIGURE 6: Percentage satisfied as a function of the mean comfort vote

Throughout the exposure, skin temperature at four sites, heart-rate and oral temperature were measured at intervals. A subjective comfort vote on the Bedford Scale was obtained every half-hour.

The mean comfort votes recorded at the end of the morning period are shown in Figure 7. In accordance with Fanger's (3) findings, all the groups had a similar neutral temperature, between 20 and 22°C, but diverged considerably at higher temperatures, and at 32°C the females voted significantly ($p<0,001$) warmer than the males. The differences between the sexes were still apparent at 38°C.

The performance trends did not, however, exhibit a simple relationship with the subjective comfort vote. Surprisingly, many of the effects of heat were beneficial to performance. Black factory workers of both sexes tended to work better as the temperature increased from 20 to 32°C and only showed a deterioration at 38°C. At 32°C, by the end of the morning period, 47% of the women and 8% of the men reported feeling "too hot" (vote >5 on the Bedford scale). On these grounds one might have expected performance to either deteriorate or remain unchanged from 20 to 32°C. Of the ten tasks used in this study, nine were significantly affected by temperature, and all showed an improvement at 32°C as compared to 20°C.

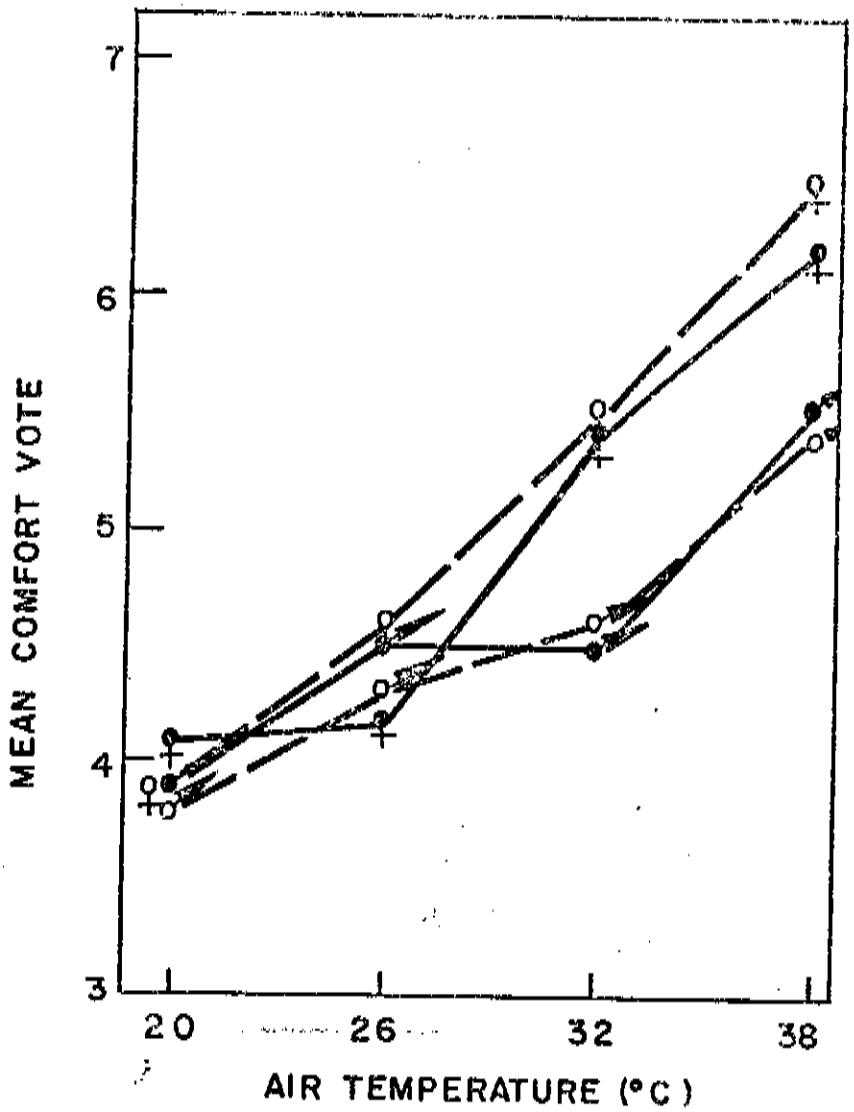

FIGURE 7: Mean comfort vote as a function of air temperature

The white men exhibited a similar pattern and for 48% of the performance criteria they produced their best performance at 32°C, at which temperature, 8% reported feeling thermal discomfort at the end of the morning. In contrast, 41% of the white women expressed discomfort and showed a very different performance pattern; their worst performance was usually at 32°C (Figure 8). It is suggested (4) that this different reaction can be attributed to the poorer sweating response of the white women.

In conclusion, although all the four groups were most comfortable between 20 and 22°C, mild heat stress (32°C) had a beneficial effect on performance for all except the white women. It is clear that cooling factories to below 32°C, for all except the white women (who are not a major factor in local manufacturing industry), would improve subjective comfort but cannot be considered cost-effective in terms of production.

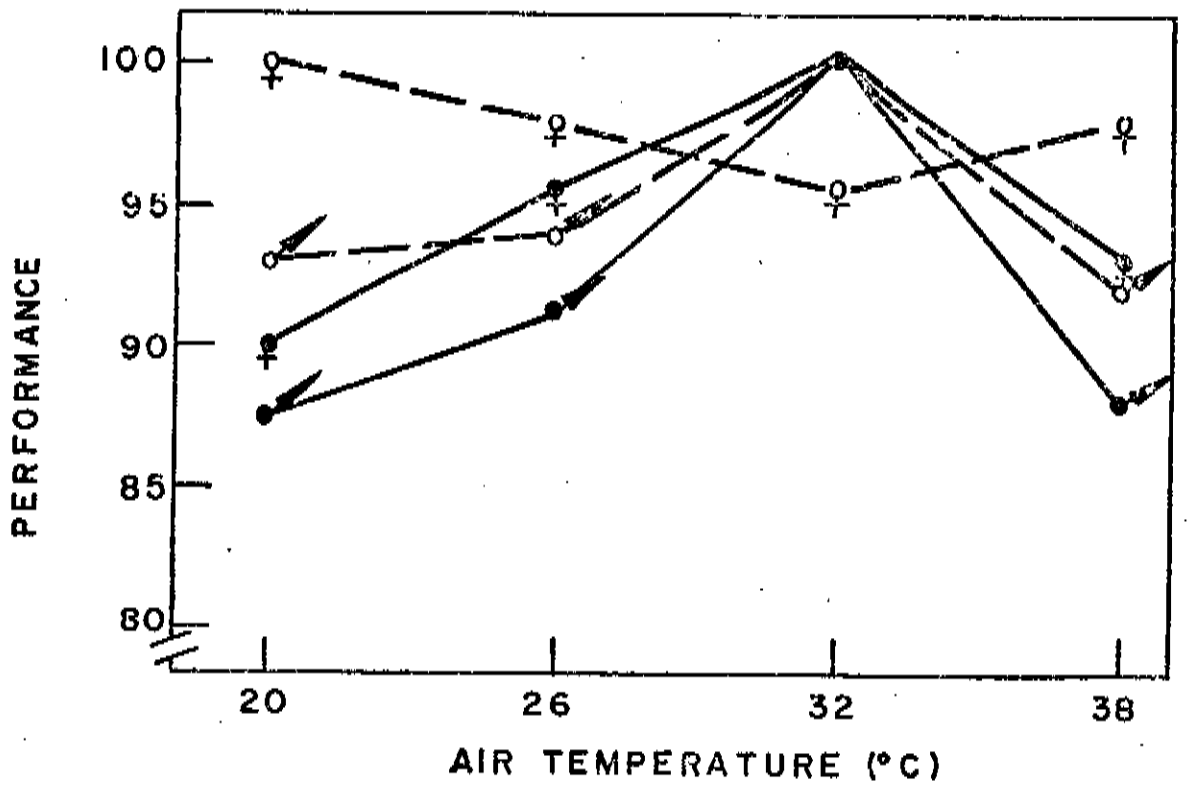

FIGURE 8: Normalised performance as a function of air temperature

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