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PREDICTING HUMAN PERFORMANCE DECREMENT FROM THERMAL DISCOMFORT AND ET*

L.G. Berglund, R.R. Gonzalez* and A.P. Gagge
John B. Pierce Foundation Laboratory and
Yale University
290 Congress Avenue
New Haven, CT 06519 U.S.A.

* U.S. Army Research Institute of
Environmental Medicine, Natick, MA

INTRODUCTION

Conservation of energy and/or conservation of capital for HVAC systems may compromise the thermal quality and acceptability of the built environment. If by design or accident, deviations in the thermal level of a space may lead to discomfort, physiological strain and affect the productivity of its occupants. While human performance and productivity depend on a great many factors (1,2), thermal discomfort and physiological strain can decrease it. Human physiological response and discomfort from environmental challenges can be predicted with some accuracy with thermoregulatory models (3,4,5). Combining experimental performance results with the regulatory models provides a rational method to estimate performance decrements caused by thermal parameters.

PERFORMANCE MEASUREMENT

Some years ago the British Navy was concerned about whether and to what extent air conditioning should be provided for its ships in service in tropical waters to improve or maintain human performance. Many excellent studies were conducted. One of these, conducted by Mackworth (2), is particularly applicable for use with models of thermoregulation and for transfer to the commercial work place. Mackworth measured the errors made by wireless telegraph operators in receiving morse code messages in a wide range of thermal conditions from comfortable to very hot. The difficult mental task required concentration and alertness similar to that desired in current offices and industry.

The study was done under laboratory conditions with experienced wireless operators 18 to 34 years of age. Prior to this study each of the eleven male volunteers had been acclimatized to heat at 35°C for six weeks. The tests were conducted at five air temperatures (Ta) from 29 to 41°C with the corresponding wet bulb temperatures 6°C lower (Table 1). Each test lasted 3 hours during which nine messages of 250 five character words (random mixed letters and numbers) were sent at the rate of 22 words per minute. Each message took sixteen minutes to transmit with three minutes between messages. The subjects were dressed in gym shorts and the air speed was 0.5 m/s.

Table 1. Conditions and results of telegraph tests

measured by Mackworth				predicted by 2NM model	
Ta C	Tdp C	Av. mistakes/subj. per hour	performance decrement %	SET* C	Discomfort
29.4	21.7	12.0	0.	23.7	0.14
32.2	24.8	11.5	0.	27.2	0.79
35.0	27.8	15.3	27.5	30.5	1.49
37.8	30.9	17.3	44.	37.0	3.77
40.6	34.0	94.7	689.	42.1	11.4

The average number of mistakes per subject per hour increased with temperature (Table 1). Individual performance levels depended on skill and experience. Very skilled morse code receivers showed no significant decrements until air temperatures exceeded 38°C.

THERMAL RESPONSE

Using the (two node) subjective and thermoregulatory model developed by Gagge, Stolwijk and Nishi (3) the corresponding standard effective temperatures and discomfort levels midway thru each test were determined (Table 1). The model as used is described by Gagge (5). The standard effective temperature (SET*) is the temperature of an isothermal still air (<.1m/s) environment at 50% relative humidity in which for this case a sedentary person wearing 0.6 clo of insulation (trousers and long sleeved shirt) would have the same heat stress (skin temperature) and thermoregulatory strain (skin wettedness) as in the actual environment and clothing. The discomfort prediction is based on physiological strain and is related to deviations in the mean body temperature and skin wettedness level from those necessary for comfort. The numbers of the discomfort scale correspond as follows: 0-comfortable, 1-slightly uncomfortable, 2-uncomfortable, 3-very uncomfortable, and 4-intolerable. Discomfort levels determined by the model in other experiments have agreed well with actual discomfort responses of subjects (6).

The measured performance decrement results of the wireless operators are plotted against their predicted discomfort levels in Figure 1. Performance decreased with increasing discomfort.

PERFORMANCE PREDICTION

Assuming the performance-discomfort relationship is valid for warm and cool discomfort, the two node model can be used to estimate the performance of difficult mental tasks in other situations. For example, in office conditions the model predicts that performance is unaffected by temperature over a 4°C interval (Figure 2). Langkilde (7,8) found mental performance unaffected over an 8°C interval and Vernon (9) found the frequency of accidents in a munitions factory was a minimum over a 2.5°C interval. On the cool side of the interval performance decrement increased steeper with temperature than on the warm side. Predicted discomfort levels had a similar response (Figure 2).

The effect of air speed and humidity on performance can also be predicted. Increasing the air speed to 0.3 and 0.5 m/s shifts the zero performance

Figure 1. Performance decrement measured by Mackworth compared to predicted discomfort of 2NM model

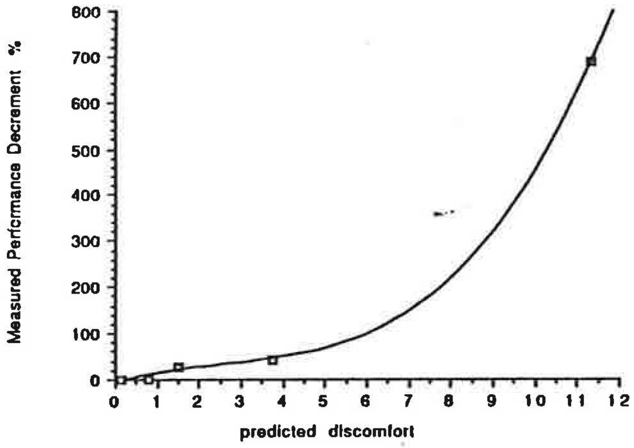
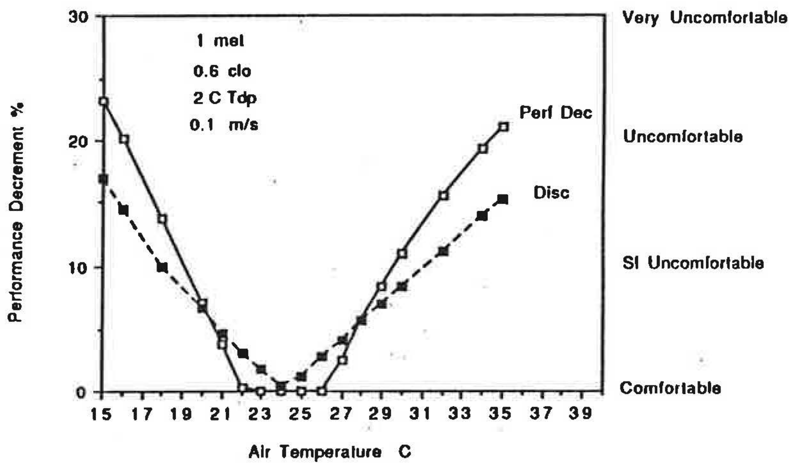


Figure 2. Predicted thermal discomfort and performance decrement over a range of indoor temperatures



decrement interval to warmer temperatures by two and three degrees, respectively (Figure 3). Portable desk fans and ceiling fans can economically provide these levels of local air speeds.

Humidity effects evaporative heat loss, skin moisture, thermal balance and discomfort. Increasing humidity shifts the zero decrement interval to lower temperatures and may be helpful in winter when humidity levels are normally low (Figure 4). However, in summer with high dew point (Tdp) conditions outside, economizer cycle cooling with outside air may raise the humidity level in the space and degrade comfort and the performance of mental tasks. The effects of other thermal parameters on performance could be similarly studied such as clothing level, solar radiation, and activity or metabolic rate.

CONCLUSION

The method of relating performance decrement to thermal strain and discomfort is useful for estimating the effects of temperature and other thermal parameters on performance. Performance measurements made at one set of thermal conditions can be rationally extrapolated to other conditions. The prediction techniques presented suggest a method (previously unpublished) for quantifying the cost in human performance from deviations in the thermal parameters of the environment and provide a rational basis and guide for further studies.

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Figure 3. Predicted effect of air speed on performance decrement.

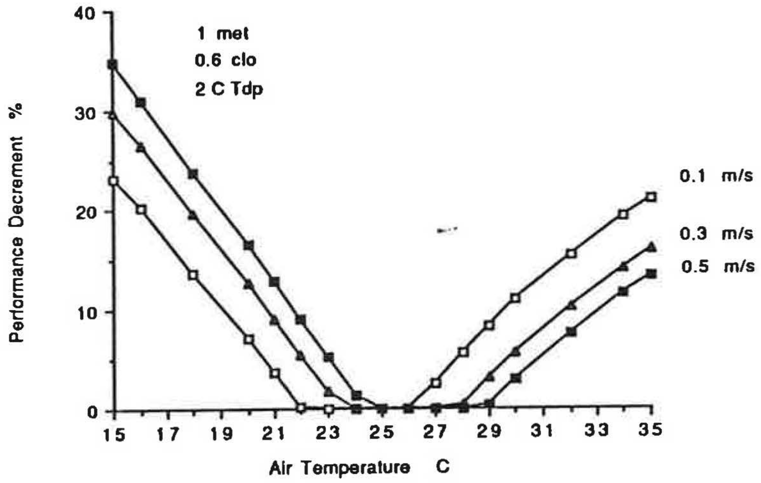
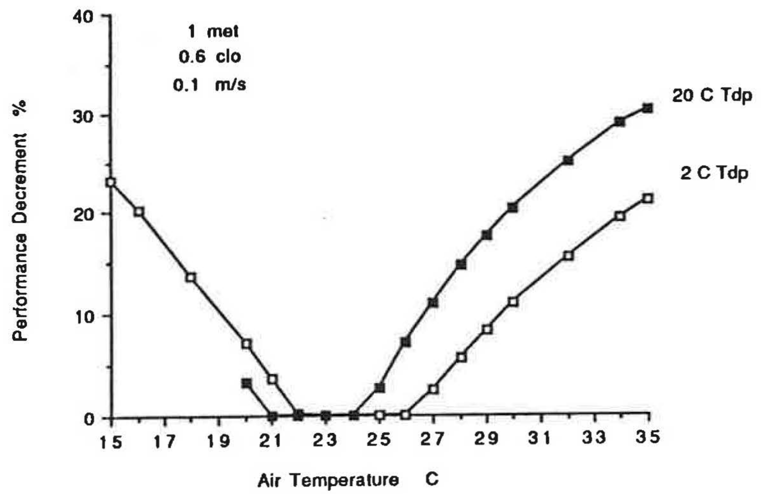


Figure 4. Predicted effect of humidity on performance decrement.



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