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A Guide to Thermal Comfort Environment

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ABSTRACT

This paper presents a simple design procedure for dealing with the requirements for a comfortable thermal environment. From the expected activity level and clothing insulation of the people concerned, a subjective temperature is calculated which will provide thermal comfort. This subjective temperature is a combination of physical parameters of the environment, i.e., air and mean radiant temperatures, and air speed.

Consequently a heating system must be designed so that the parameters would combine to give the optimum subjective temperature. This proposed procedure also considers other possible sources of discomfort, and gives an acceptable limits for them.

دليل البيئة المريحة حرارياً

الملخص

يقدم هذا البحث طريقة تصميم بسيطة للتعامل مع متطلبات البيئة المريحة حرارياً. اعتماداً على مستوى الفعالية المتوقع وطبيعة الملابس للاشخاص المعنيين، يتم حساب حرارة موضوعية وواقعية والتي توفر شروط الراحة الحرارية.

ان درجة الحرارة الموضوعية هذه هي ناتجة عن اندماج العوامل الفيزيائية للبيئة وهي درجات حرارة الهواء المتوسطة والاشعاعية اضافة الى سرعة الهواء.

بناء على ذلك فلابد ان يؤخذ بنظر الاعتبار عند تصميم انظمة التدفئة والتبريد العوامل المذكورة آنفاً بهدف الحصول على امثل درجة حرارة موضوعية.

ان هذه الطريقة المقترحة تأخذ بنظر الاعتبار ايضاً مسببات اخرى لعدم الراحة وتعطي حدود مقبولة لهذه المسببات.

INTRODUCTION

A designer is required to produce a thermal environment which is optimum for the occupants of the conditioned space. He designs the services to give a set of values of the appropriate physical variables, i.e., air and radiant temperature, relative humidity and air velocity. The design values of these parameters are obtained from our knowledge of human requirements for thermal comfort. This gives a simple procedure to enable this to be done.

The variables which affect a man's thermal balance are here divided into two group, physical and personal variables. It is the job of the heating engineer, in association with the architect, to control the physical variables of the thermal environment, i.e., air and radiant temperature, air velocity and humidity. The personal variables, i.e., metabolic rate and the insulation value of the clothing worn by the building's occupants, are outside the engineer's control, but affect the optimum set of physical conditions.

METABOLIC RATE Ms, (W/m2)

The heat produced in the body by the metabolic processes must be lost to the outside if thermal equilibrium is to be maintained. The rate of heat production varies with the activity of the person, so that an active person producing heat at a greater rate requires a cooler environment to enable him to dissipate the extra heat. The metabolic rate is normally expressed as a function of activities and body surface area and is denoted by Ms (W/m^2). The temperature required for comfort is therefore a function of metabolic rate, and an estimate of a person's heat production is required to predict his comfort temperature. A table of metabolic rates for different activities is given in Table (1). The rates are quoted as power per unit body surface area, which is the appropriate unit since heat transfer takes place at the body surface. The variation from person to person due to height and weight is not greater than the uncertainty in predicting the activity of a person, and need not be taken into account.

Table 1: Metabolic rate for different activities

Activity	**Metabolic rate of heat Production per Unit surface area W/m^2**
Basal metabolic rate	45
Seated at rest	60
Standing at rest	65
Office work	75
Light work standing	90
Walking on level ground at 3.2 km/h (2Mile/h)	115
4-8km/h (3Mile/h)	170
6-4 km/h (4Mile/h)	240
8-0 km/h (5Mile/h)	340
Heavy manual work	250
Playing tennis	260
Digging	320

CLOTHING

The insulation value of a clothing is normally expressed in do units, where an insulation value of one CLO corresponds to a thermal resistance of 0.16 $m^2\ C^o/W$. Note that this is the surface-to-surface resistance, and is independent of the resistance of the outer air film. CLO values are difficult to predict from measurements on the component fabrics, and it is necessary to use a heated manikin. Table (2) lists examples of CLO values, from which the insulation value may be estimated with reasonable accuracy.

Table 2: Insulation values of some clothing outfits

Components of clothing ensemble	Insulation (CLO)
Nude	0
Light sleeveless dress, cotton underwear	0.2
Light trousers, short sleeve shirt	0.5
Warm long sleeve dress, full length slip	0.7
Light trousers, vest, long sleeve shirt	0.7
Light trousers, vest, long sleeve shirt, jacket	0.9
Heavy three piece suit, long underwear	1.5

Newburgh (1968), Fanger (1970).

Physical variables:

The physical variables of the thermal environment are those which affect the heat loss of a person. Heat is lost by radiation directly to surrounding surfaces, by convection to the air, and by evaporation from the skin and lungs. In the comfort region, the heat loss by sweating is small and little affected by the physical variables. The convective loss depends on both air temperature and air speed; and the radiation loss depends on the mean radiant temperature of the surroundings. In a typical indoor environment, the convective and radiation losses are similar in magnitude.

Air temperature T_a (°C):

Air temperature may be measured with almost any type of thermometer. Where an accurate air temperature is required in the presence of thermal radiation it is necessary to use an aspirated thermometer with a radiation shield.

Mean radiant temperature T_r (°C)

The mean radiant temperature (mrt) at a point is the temperature of a hypothetical uniform enclosure with which a black sphere at the test point would have the same radiation exchange as it does with the actual environment. It may be measured using a black globe thermometer (Hey, 1968) or, more accurately, with a thermopile. It may be estimated from the surface temperatures by

$$T_r = \sum \phi_i T_i / (4\pi) \quad (1)$$

where ϕ_i is the solid angle subtended at the test point by the surface of temperature T_i. This equation is an approximation to the true fourth power law, but is accurate enough for low surface temperatures. The mrt is a function of position within the room, but an average value may be obtained from the mean of the surface temperatures weighted by area

$$T_r = \sum A_i T_i / \sum A_i \quad (2)$$

Where sources of high temperature radiation are present, it is necessary to know the radiation flux density R(W/m^2) produced at the test point by each source. The mrt is then (Spurrow and Cess. 1966)

$$T_r = \sum \phi_i T_i / (4\pi) + \sum R_j / (16\sigma T^3) \quad (3)$$

Where Tr (K) is an approximation to the (mrt) and σ is the Stefan Boltzmann constant (5.67 x 10^{-8} W/m^2 K^4). At normal room temperature

$$T_r = \sum \phi_i T_i / (4\pi) + \sum 0.043 R_j \quad (4)$$

Air speed (ν m/s):

For the purpose in defining a comfort criterion, a non-directional magnitude of the air speed is all that required. This is most easily obtained using a Kata thermometer (Bedford 1964). Smoke trails may be used to give a quick visual indication of flow. Where a detailed knowledge of air velocity is needed, a hot wire anemometer can be used, preferably of the low velocity type, which uses a vibrating head to maintain sensitivity at low speeds.

Air movement:

The cooling effect of increased air speed may be compensated by increasing the air and radiant temperatures according to equation (6). The upper limit of a uniform air velocity has not been established.

The presence of occasional increases in air velocity or drops in air temperature may give rise to complaints of draughts, which are defined as unwanted local cooling of the body.

Radiation to a local cold surface, e.g., windows, is perceptually indistinguishable from a draught caused by air movement.

Humidity:

Humidity is a measure of the amount of water vapour in the air. The relative humidity (RH) is the ratio of the vapour pressure of water in the air to the vapour pressure in saturated air at the same temperature. It is best measured with an aspirated wet and dry bulb thermometer. Relative humidity affects both feelings of comfort *and* warmth at high temperatures; if a person is too warm, increasing humidity will make him feel warmer and more uncomfortable (Nevins, Rohles, Springer and Feyerherm 1966; Mclntyre and Griffilhs, 1973). At a thermally neutral temperature, variation of humidity in the range 20 to 75% has little effect on warmth. However, people can detect this change in humidity, and both the 20 and 75% levels are less comfortable than a value of 50% (Mclntyre and Grifiths 1973).

There are also practical reasons for restricting the range of RH in a building. The moisture pick up of materials depends on the RH of the atmosphere; low humidities may give problems with shrinkage of wood, and with static electricity. Prolonged periods of humidities greater than 70% encourage mould growth, and may give condensation on cool surfaces. While it is difficult to set exact limits, a relative humidity in the range 35 to 65% should be satisfactory from both the comfort and structural aspects.

Floor temperature:

The temperature of a heated floor should not exceed 25°C for prolonged periods of occupation/Excursions up to 27°C are permissible. At the other end of the range, Nevins and Feyerherm (1967) have established that floor temperatures down to 18°C were acceptable to seated persons.

Subjective temperature T_{Sub} (°C)

It is advantageous to be able to combine the physical variables into a single index which describes the warmth of the environment. This index is termed the “Subjective Temperature” (T_{sub}) and is defined as:

"The subjective temperature of an environment is the temperature of a uniform enclosure, with T_a=T_r, v=0.1 m/s and RH=50% which would produce the same feeling of warmth as the actual environment under consideration" Parczewski and Berans (1965).

This concept was introduced by Parczewski and Berans (1965) in term of environmental temperature which is now is used is another context subjective temperature is therefore suggested as a suitable.

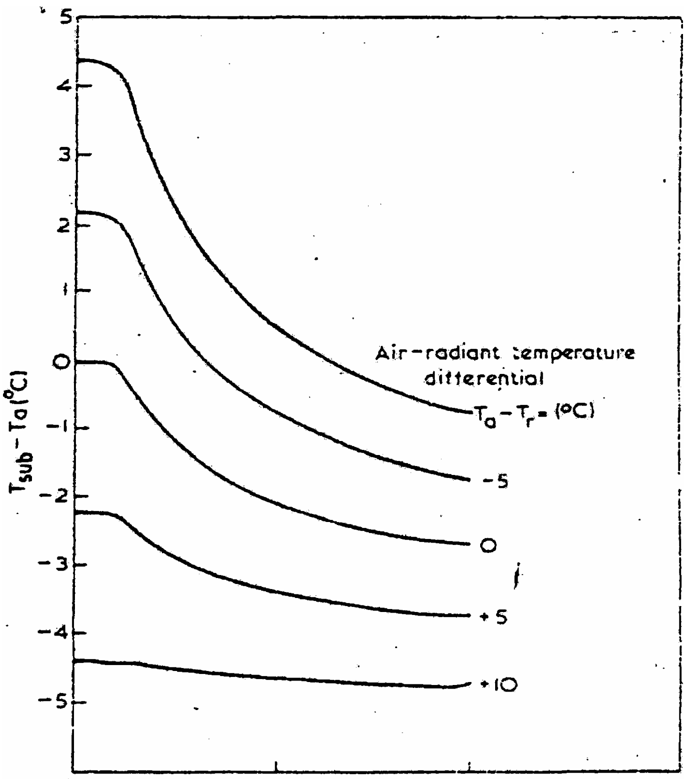
The expression of subjective temperature in terms of the physical parameters of the environment must compromise between simplicity and accuracy. The following expressions have been derived (Mclntyre and Griffiths 1972):

$T_{sub} = 0.56T_a + 0.44\ T_r$ for $v < 0.1$ m/s (5)

$T_{sub} = \{0.44\ T_r + 0.56\ (5\sqrt{10v}\ (5\ T_a))\}\ /\ (0.44 + 0.56\ \sqrt{10v}\,)$

for v> 0.1 m/s (6)

The expression for T_{sub} is displayed graphically in Fig 1, which shows the difference between T_{sub} and T_a as a function of air speed and of the temperature difference (T_a-T_r) eg, a combination of variables T_a=20 ^oC, T_r=15 ^oC, v=0.3 m/sec requires a correction of 3°C the air temperature, i.e., T_{sub} = 17°C. Note that equation (5) and (6) and Fig 1 strictly apply to comfort conditions only.



Air speed (m/sec)

Fig 1: The difference between subjective temperature and air temperature as a function of air speed, for different values of the differential (T_a-T_r) (Mclntyre and Griffiths 1972).

Comfort equation:

For a given combination of metabolic rate and clothing insulation, it is possible to predict the subjective temperature of the environment which is required for comfort. The comfort temperature has been established experimentally for light clothing and sedentary activity. It is possible to extrapolate to the full range of activities and clothing insulation by using the physical laws of heat transfer together with other physiological data.

This has been studied in great detail by Fanger (1970) and his results have been simplified to produce Fig. (2) which relates subjective temperature for comfort to metabolic rate and clothing.

This results may also be expressed in the equation

$T_{sub} = 33.5 - 31_{cl} - (0.08+0.051_{cl})M_s$

It must be remembered that when using this equation it requires the estimation of two quantities, metabolic rate clothing insulation, which is unlikely to be known with any great accuracy. Where field data exit for thermal conditions and preferences in the building type in question, this should be used in conjunction with equation (7) when choosing the design value of T_{sub}.

As an example of the use of the equation we may take the case of clerical work in an office. The typical metabolic rate is about 75 W/m^2, and the clothing insulation is about 0.8 do. Putting these values in equation (7) gives a value for T_{gub} of 22°C.

Figure (2) has been derived for steady state conditions, but when using the metabolic rates in Table (1) to predict comfort, it must be remembered that it is rare for high metabolic rates to be maintained for an extended period, and the metabolic rate corresponding to average, rather than peak, activity should be chosen. In this context it may be pointed out that an individual will find it easier to cope with a range of activities of varying metabolic rate if he is lightly dressed in a warm environment, rather than heavily dressed in a cool one. (Humpheys and Nicol, 1971).

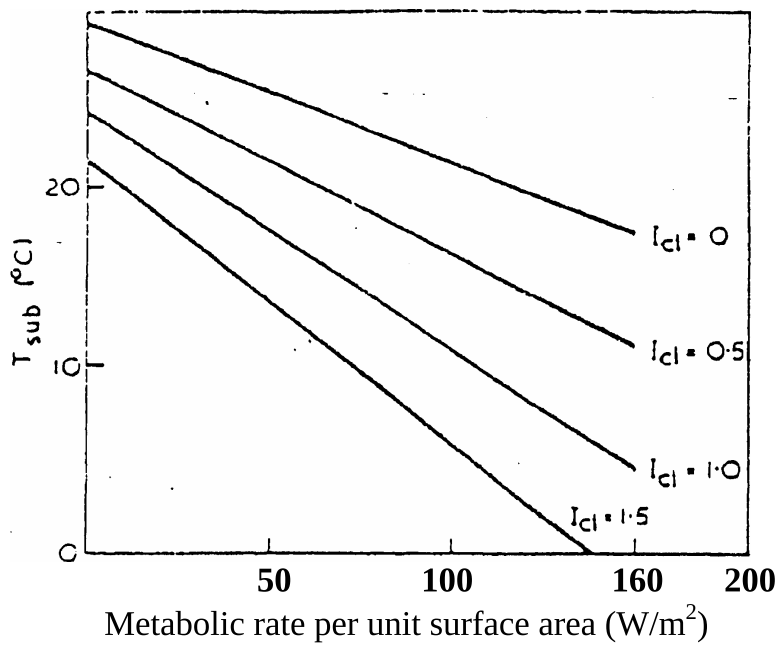


Fig 2: has been derived for steady state conditions. When using the metabolic rates in Table 1 to predict comfort (Fanger 1970).

Design procedure:

The information given allows the designer to select the optimum thermal conditions to suit the occupants of building. The procedure is as follows:

1. From the known or intended use of the building, estimate the average metabolic rate of the occupants from Table (1).
2. Estimate the insulation value of the clothing likely to be worn from Table (1).
3. From Fig. (2) or equation (7) find the required subjective temperature.
4. The heating system must then be designed to provide a combination of air temperature, MRT and air speed which will combine according to equations (5) and (6) give the correct subjective temperature.
5. Check that other criteria are met.

REFERENCES

Bedford, T., 1964. Basic Principles of ventilation and Heating, H. K. Lewis Ltd., London, Vol. 2, pp. 62-65.

Chrenko, F. A., 1957. Brit, J Industr Med 14. 13-et seq. The effects of the temperature of the floor surface and of the air on the thermal sensations and the skin temperature of the feet, Vol 4, pp27-30.

Fanger, P. O., 1970. Thermal Comfort, Danish Technical Press, Copenhagen.

Hey, E. N., 1968. J Sci Inst 1, (ser 2), 955-957 and 1260 small globe thermometer.

Humphreys, M. A. and Nicol, J. F., 1971. Theoretical and Practical Aspects of Thermal CoMfront, BRS cp 14/17, Building Research Establishment, Watrford, England.

Mclntyre, D. A. and Griffilhs, I. D., 1972. Subjective Responses to Radiant and convective environments, Vol 12, pp. 672-677.

Mclntyre, D. A. and Griffilhs, I. D., 1973. Subjective Responses to Atmospheric Humidity, Electricity Council Research Center ECRC M600.

Newburgh, L. H., 1968. Physiology of Human Regulation and the science of clothing: Hafner, New York, Vol. 7, pp. 213-216.

Parczewski, K. I. and Bevans, R. S., 1965. ASHRAE J June, 80-86 A new method of rating the quality of the environment in heated space.

Sepanen, O.; McNall, P. E.; Munson, D. M. and spragne, C. H., 1972. A Shrae Trans No. 2219, 78.1, 120-130 Thermal Insulating values for typical clothing ensembles.

Sparrow, E. M. and Cess, R. D., 1966. Radiation Heat Transfer, Brookes l Cole, Clif.