THERMAL COMFORT IN BED

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Résumé

Puisque nous passons un tiers de notre vie au lit, il parait normal de s'intéresser particulierèment aux conditions thermiques qui règnent durant le sommeil.

Cet article présente une série de mesures effectuées en partie au laboratoire et d'autre part dans un nouvel hospital Danois ou l'on s'est efforcé de créer un environnement thermique idéal pour tout le monde, c'est à dire à la fois pour les malades et le personnel. Cela s'est avéré impossible à réaliser avec les édredons normalement utilisés car alors la température de la pièce correspondant aux conditions de confort pour le malade alité est de 12 à 16°C, ce qui est une température trop basse pour le personnel. (au Danemark, d'habitude, les couvertures sont faites d'un édredon leger et doux entouré d'une envelope de coton).

Cela nous a amené à effectuer des mesures en laboratoire sur un certain nombre d'édredons remplis de matières naturelles ou synthétiques. A partir des résultats on peut maintenant établir la corrélation entre la température de la pièce d'une part et le poids et le contenu de l'édredon d'autre part assurant le confort thermique durant le sommeil.

Les mesures ont été effectuées à l'aide d'un mannequin de taille humaine dont le comportement thermique est celui d'un homme en bonne santé. De la mesure des réactions du mannequin ainsi que de la mesure de la température de la pièce on peut déduire la valeur de l'isolation thermique (valeur en clo) de l'édredon et fixer la température de la pièce lorsque l'on dort sous l'édredon.

Introduction

A great deal of the total energy consumption - in some countries as much as half - is spent on maintaining an acceptable indoor climate in dwellings as well as in workplaces. It is therefore reasonable to concentrate on this aspect in any effort to conserve energy, and the last few years have shown that people are willing to save when given appropriate instructions on how they should set about it.

The sole aim in heating or cooling our surroundings is to create a comfortable heat balance between the human body and the environment. The following climate parameters are essential for this heat balance:

air temperature } convective heat loss
air velocity }
mean radiant temperature
air humidity

clothing
activity level

The first four parameters are determined by the environment, and at the moment considerable efforts are being made to optimize these parameters by keeping the energy consumption as low as possible, e.g. by means of solar energy, insulation, heat recovery, heat pumps, etc. Mean radiant temperature and air humidity can to a large extent be determined by the individual. The metabolism is determined by the occupation in which the individual is engaged and this cannot be changed. In most daily situations clothing is set by habit and fashion, and it should thus be possible to alter this to some extent.

Fig. 1 shows the connection between the optimal room temperature and the individual's own parameters, activity level and clothing. It appears from this that it is at the low activity levels, which are typical indoors, that the insulating capacity of the clothing is a decisive parameter.

However, this paper will deal with the significance of clothing in one particular, very common and well-defined situation, namely, during sleep.

Definition of the term "insulating capacity of the clothing"

The main physiological purpose of wearing clothes is to reduce the heat loss from the body just enough so that the body's internal heat production can be emitted to the environment while still maintaining thermal comfort.

The unit most frequently used in indicating the heat insulating capacity of the clothing is clo, introduced in 1941 by Gagge et al [1].

$$1 \text{ clo} = 0.155\ {}^{o}\text{C m}^2/\text{W} \quad (= 0.18\ \text{C m}^2\ \text{h/kcal})$$

The figures are not round because 1 clo was taken to mean the

insulating capacity of a man's office clothing as it was in USA (and Europe) in the 1940s.

Clothing amounting to 1 clo will maintain a sedentary person (metabolism: 60 W/m^2) in thermal comfort, the resulting temperature being 23^{o}C and the air velocity < 0.1 m/s.

Measuring method

In determining the insulating capacity (clo-value) of a given clothing, it is useful to employ a full-size, heated mainkin. Such a thermal manikin (TM2), see fig. 2, has been developed at the laboratory, and is briefly described below.

As a starting point in the construction of TM2, a nearly anatomically correct display model was chosen. This consists of a shell of approx. 2 mm fibreglass reinforced polyester, a construction both light and robust. The model is divided into 16 sections (see fig. 2), each with its own heating system. Individual measuring of the heat loss from each of the 16 sections is thus possible. The actual heating system, as regards the limbs and head, consists of a tubular heating element with inbuilt, powerful axial blowers, which create a good convective heat transfer to the fibreglass shell and thus a uniform temperature on its surface. The trunk is heated by means of resistance wires which are glued to the inner side of the fibreglass shell at distances of 5 mm. The heat conveyance to each section is controlled by four Ni-wire-resistors distributed evenly along the inner side of the shell. On the neck, 36 contacts multiple plugs are built in, one each for parts I and II. By using these, TM2 can, by means of two 7 m long multicables, be coupled to the joint control and measuring aggregate (fig. 2).

Measuring the clo-value

By means of P.O. Fanger's comfort equation [2], it is possible to state the connection between skin temperature (t_s) and the dry heat loss (ϕ_d) in the comfort condition. For a water vapour pressure of 15 mbar (equal to 24^{o}C and 50% RF) the following is obtained:

$$t_s = 36.4 - 0.054 \cdot \phi_d \quad ({}^{o}\text{C})$$

The surface temperature of TM2 follows this expression, the thermostats for each of the 16 sections seeking to maintain a surface temperature of 36.4^{o}C, and at the same time having a constant and well-defined load deviation (offset) of 0.054°C/Wm^2. If, for instance, TM2 har a dry heat loss of 100 W/m^2,

$$t_s = 36.4 - 5.4 = 31°C$$

To gain an overall view of the thermal system: TM - clothing - environment, the electrical analogy should be considered. From fig. 3, and with the aid of Ohms law, we obtain

$$m_{clo} = \frac{t_s - t_{clo}}{\phi_d} \left(\frac{m^2C}{W}\right) = \frac{t_s - t_{clo}}{\phi_d \cdot 0.155} \quad (clo)$$

where t_s is the mean skin temperature
t_{clo} is the mean surface temperature with clothing
ϕ_d is the heat loss by radiation, conducting and convection.

When corresponding values of these parameters have been measured, the clo-value can be calculated.

Measuring in a hospital

In connection with the construction of Denmark's most expensive and most modern hospital,
it was natural to attempt to optimize the thermal indoor climate so that both patients and personnel could be in thermal comfort. The laboratory's thermal manikin was used for this purpose. Taking as a starting point the uniform and occupation of the nursing personnel, the optimal temperature in the bedrooms was established as 22°C.

It is possible, still by using fig. 1, to determine the clo-value for all the other users of the bedrooms. For patients confined to bed, the activity level was during the day 50 W/m^2 ~ 1.75 clo and at night 40 W/m^2 ~ 2.4 clo, and for patients allowed up, 70 W/m^2 ~ 0.9 clo.

It soon became apparent that the group presenting thermal comfort problems was that of the patients confined to bed. The main task, therefore, was to analyse the thermal conditions of this group.

By means of TM , two analyses were performed:

1. the dependence of the clo-value on the patient's position
2. the dependence of the clo-value on the weight and material of the eiderdown.

In fig. 5, TM's heat loss is indicated, dependent of the resulting temperature, when lying under a typical Danish hospital eiderdown in various positions. It will be seen that the position is of definite significance for the heat loss. This is why the same eiderdown can be used, if at all, in summer and winter, in both heated and non-heated bedrooms. But it does not mean that it is the ideal solution. Especially for patients who are very ill, it is important that they can attain thermal comfort in a position which they are themselves perhaps unable to alter.

In fig. 6, TM's heat loss is shown, dependent of the resulting temperature, for various eiderdowns and blankets. Using figs. 5 and 6, it is possible to calculate the clo-values for all eiderdowns, in the various positions.

The result of the investigation was that the light terylene eiderdown was chosen.

Laboratory measurements

As a result of the hospital measurements, some Danish eiderdown manufacturers expressed an interest in having the insulating capacity of their products determined. These measurements were made in the laboratory's temperature-constant chamber. This is a heavy room situated in the cellar and surrounded by extra insulation on all sides. Thus the air temperature is equal to the mean radiant temperature and the air velocity is ~ 0.0 m/s.

TM2 was placed on the back, on a 100 mm polyether mattress without sheet or pillow. The eiderdown was placed lightly over the model so that it barely reached the chin (fig. 7). The eiderdown was not tucked in around the figure for the ligther it is, the better it falls around the body, thus reducing the heat loss.

Each time TM2's heat loss became constant with a new eiderdown, the corresponding values of t_r and ϕ_d were read, after which the clo-value of the eiderdown could be determined with the aid of the diagram (fig. 4). Line A indicates the connection between ϕ_d and t_r for TM2 lying on a mattress without an eiderdown. This corresponds to an eiderdown with a clo-value of 0. When the corresponding lines are drawn in for the eiderdown in question, the clo-values can be determined from the formula:

$$m_{eiderdown} = \frac{\Delta t}{\phi_d \cdot 0.155} \quad (clo)$$

where Δt (°C) is the difference between the optimal room temperature with and without eiderdown, at a heat loss of ϕ_d (W/m²).

0.155 (m²C/W) is the conversion factor from SI-units to clo-value.

As mentioned earlier, people have during sleep a metabolism of approximately 40 W/m². Of this, by far the greater part, i.e. approx. 32 W/m², is emitted to the environment as dry heat, ϕ_d (radiation, conduction and convection).

The optimal bedroom temperature for a particular eiderdown can be found from the diagram by intersecting the lines for each eiderdown with the line corresponding to ϕ_d = 32 W/m².

Index for the classification of eiderdowns

Although the original purpose of clothing was to insulate the body against the environment, no index is as yet used to inform the buyer of the degree to which this purpose can be expected to be fulfilled. As far as eiderdowns are concerned, the clo-value could be given. However, this demands that people become accustomed to it before they can understand what it means. Moreover, as eiderdowns are primarily used during sleep, i.e. at an activity level of 40 W/m², the eiderdown's insulating capacity can be characterized quite simply by the room temperature which gives thermal comfort during sleep under the eiderdown in question.

Apart from the actual insulating capacity, a form of comfort index would be desirable; eiderdowns are by no means uniformly comfortable, even though they may insulate equally well. A good eiderdown must be light and soft so that it falls well around the user, a factor which is included in the laboratory measuring. The softer the eiderdown, the better will it fall of its own accord around the manikin, and the greater will be the clo-value measured. The weight of the eiderdown depends on the type and quality of the material used to fill it. The higher the material's heat resistance per weight unit, the better. A reasonable comfort index could thus be:

$$E_c = \frac{clo \cdot m^2}{kg}$$

The area unit is included partly because of children's eiderdowns, and partly so that manufacturers will not be tempted to produce eiderdowns with a smaller surface area and consequently less weight. Without the area unit, this will give a greater E_c at a lower price, but at the same time perhaps an eiderdown affording less comfort because it is too small.
Table 1 gives the clo-value, the bedroom temperature and the comfort index for the eiderdowns tested in the laboratory.
It is not unreasonable to demand that these data be declared when purchasing an eiderdown. Both the manufacturer and the user would benefit from this information. The manufacturer because with a more well-defined and differentiated stock, sales would increase, and the user because, based on his own personal requirement (bedroom temperature), he can choose an eiderdown which suits him, and it will not always be the expensive eiderdown with the high insulating capacity.

References

[1] Gagge, Burton and Bazett: A Practical System of Units for the Description of the Heat Exchange of Man with his Environment. Science, 94 (1941).

[2] Fanger, P.O.: Thermal Comfort. Danish Technical Press, Copenhagen 1970.

Optimal temperature in bedroom, clo-value and comfort index (E_c), measured in the laboratory. The bedroom temperature corresponds to a nude sleeping person

Table 1

	weight, gr.		comf.temp. in bedroom	clo-value	E_c
	filling material	cover			$\frac{clo\ m^2}{kg}$
White goose down	700	800	18	2.5	4.0
Grey duck down	800	800	17	2.6	3.9
White duck down	750	800	19	2.4	3.7
Down/feather	1100	800	18	2.5	3.3
Mixed feather	1700	800	20	2.2	2.9
Longfiber diolen polyester	1100	800	19	2.3	3.0
Synthetic material	1500	800	20	2.1	2.3

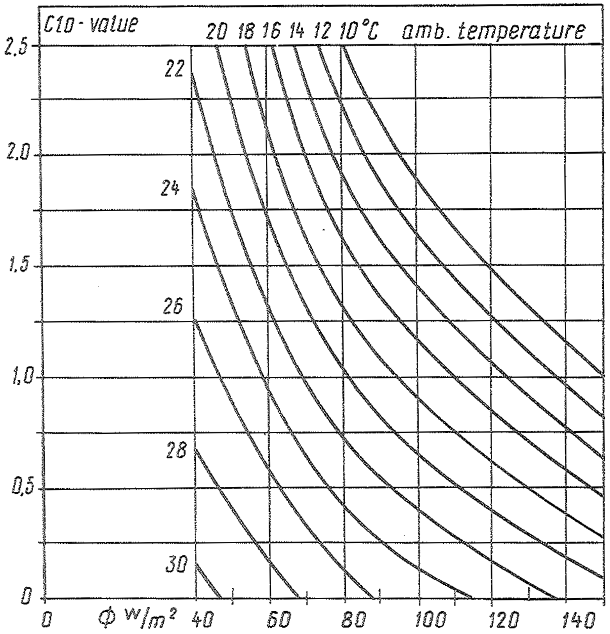

Fig. 1. The optimal clothing (clo-value) as a function of room temperature and activity level

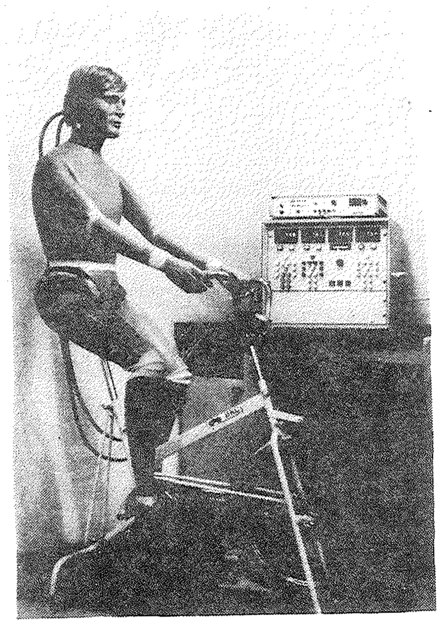

Fig. 2. Thermal manikin (TM2) and measuring aggregate

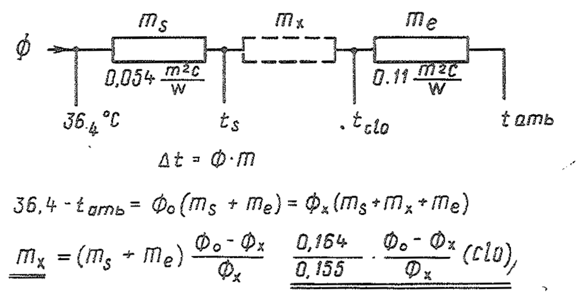

Fig. 3. Electrical analogy to the thermal system: man - clothing - environment

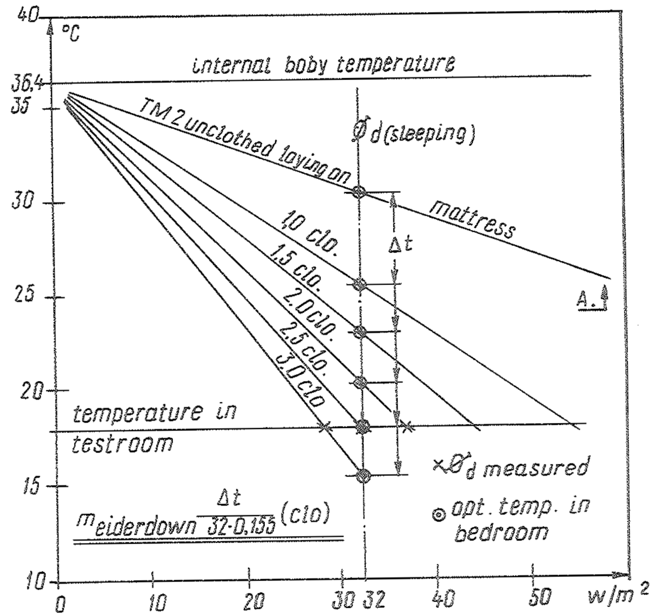

Fig. 4. Graphical method for calculating m (eiderdown) when the heat loss and test room temperature are known

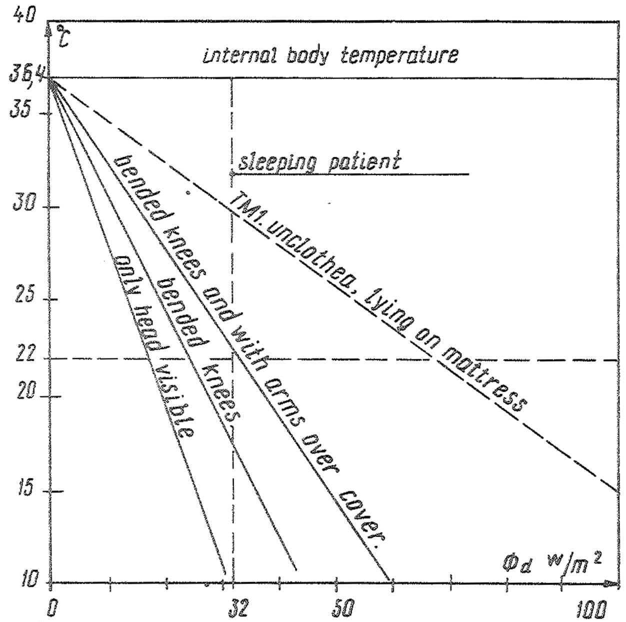

Fig. 5. The significance of position for heat loss at a given temperature and with a given heavy eiderdown

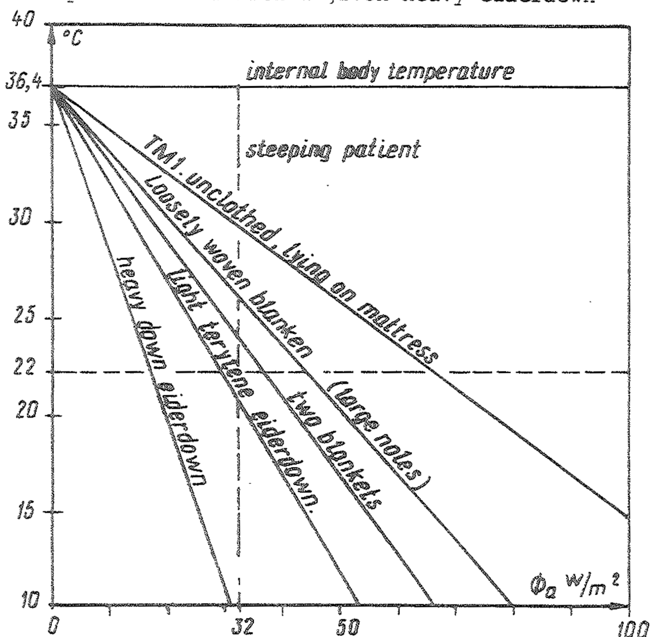

Fig. 6. The significance of the eiderdown for heat loss at a given temperature and a given position (only head visible)

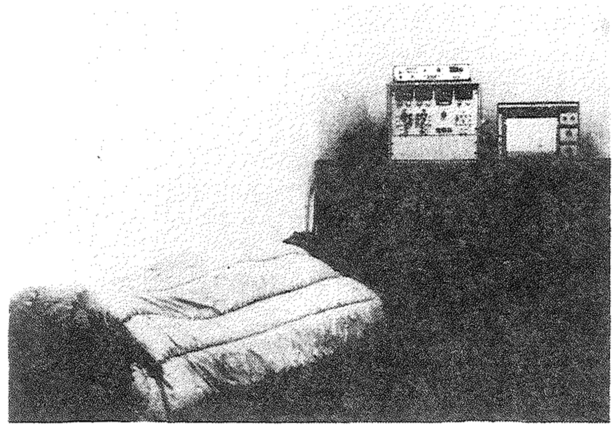

Fig. 7. TM2 in measuring position