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An unconventional method for reduction of the energy consumption for heating of buildings.

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A quite ordinary thermal comfort problem is that you cannot expect to establish optimal thermal comfort for everyone in rooms where several persons are supposed to stay.

As seated persons are the most thermally sensitive ones and at the same time those who want the highest temperature, it is obvious to give these persons a reasonable local heat supply, and in return keep the general indoor temperature at a level that establish thermal comfort for the persons having a higher activity level.

Investigations have been carried out on some electrically heated office chairs supplied with individual temperature control. These investigations indicate that it will be possible at the same time to reduce the temperature by 3^{o}C as well as to bring more persons in thermal comfort.

Une méthode peu conventionelle pour reduire la consommation d'énergie pour le chauffage des batiments.

Un probleme ordinaire c'est qu'il est à peu près impossible d'établir l'optimum d'un confort thermique pour tout le monde dans des pièces aù plusieurs personnes doivent se tenir.

Les personnes assises sont thermiquement les plus sensibles et par conséquent ce sont aussi celles-ci qui demandent la température la plus elevée. Une idée évidente c'est de donner localement à ces personnes un chauffage supplémentaire, et en retour de tenir la température en général à un niveau qui donne confort thermique aux personnes qui déploient le plus d'activité.

On a fait des études de quelques chaises de bureau qui sont chauffées éléctriquement et individuellement controllées. Ces études indiquent qu'il serait possible de baisser la température de 3^{o}C et en meme temps de donner confort thermique à un plus grand nombre de personnes.

An unconventional method for reduction of the energy consumption for heating of buildings.

Thomas Lund Madsen and Bjarne Saxhof, Thermal Insulation Laboratory, Technical University of Denmark.

The energy crisis in 1973 caused a sudden intensification in research into the use of the so-called alternative and lasting energy sources and, furthermore, the requirements to maximum heat loss in buildings were tightened in many countries.

There is every indication that several years will pass before lasting energy sources will form a significant part of the energy consumption in modern society.

A long time will probably pass before all existing buildings are sufficiently insulated and the heat loss is reduced to a level corresponding to the requirements for houses built in 1979.

The energy consumption for heating of buildings represents a signigicant part of the total energy consumption in many countries - in Denmark it amounts to approx. 45% - it therefore makes good sense to search for other methods for a quick reduction of this energy consumption.

The possible saving of energy by lowering of the indoor temperature

The easiest method to reduce energy consumption quickly is a general lowering of the operative temperature (t_o)+ during the winter. A temperature lowering of this kind has often been made during the acute phases of an energy crisis. However, these have not been sufficiently serious to maintain this

+operative temperature is defined as the uniform temperature of an imaginary enclosure by which it is possible to exchange the same dry heat by radiation and convection as in the actual invironment.

lowering of temperature for longer periods.

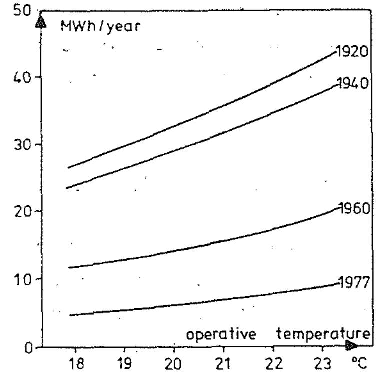

Fig. 1. The correlation between mean operative temperature and the average annual energy consumption for heating of the typical 120 m^2 Danish one-family houses of various ages (1).

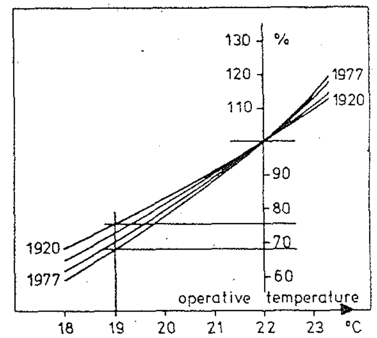

Fig. 2. The percentage of energy conservation obtained by a given lowering of the operative temperature from 22°C in the four examples from fig. 1.

As it appears from fig. 1 this method is very efficient. The figure shows the relationship between operative temperature and the average annual energy consumption for heating of a typical Danish 120 m^2 one-family house constructed in 1920, 1940, 1960 and 1977 respectively. In fig. 2 is shown the percentage savings obtained by a given lowering of the operative temperature in all four cases. (from 1).

As seen from the two figures, the absolute saving of energy by lowering the operative temperature is most considerable in old houses while the percentage saving is largest in the new low-energy houses. The first is obvious while the second is due to the so-called free heating - (radiation from the sun, emission of heat from persons etc.) - which forms a larger percentage of the smaller than of the larger heat loss. The average operative temperature without heating is higher the better a house is insulated. Thus one degree makes a larger percentage of the difference between the desired temperature and the temperature obtained without heating. Fig. 2 shows that even in a 1920 house the saving amounts to 25% of the existing energy used for heating if the operative temperature is generally lowered from 22° to 19°C (1).

Thermal discomfort caused by lowering of the operative temperature.

Besides the thermal environment the human feeling of thermal comfort also depends upon the activity level and the clothing of an individual. Fig. 3 shows some typical examples of the relationship between the percentage of the thermally dissatisfied persons and the change of temperature from the optimum value (2).

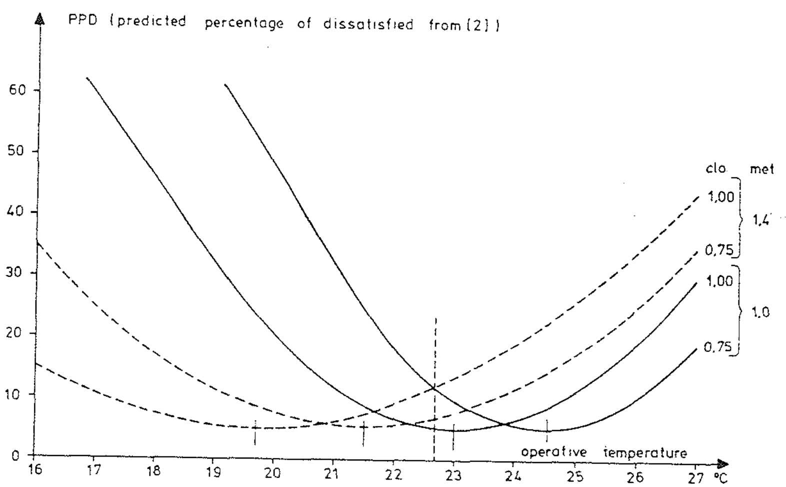

Fig. 3. The correlation between the operative temperature and the expected percentage of thermally dissatisfied persons at four typical combinations of activity level and clothing. (2).

For seated persons (1.0 met) the comfort temperature is 23 - 24.5°C with a clothing of 1.0 - 0.75 clo. The corresponding comfort temperature for standing persons performing light

activities (1.4 met) is 20.0 and 21.5°C. This example shows that there will normally be different wishes to the operative temperature if several persons with different activities are using a given room simultaneously. The common operative temperature, which gives the smallest amount of dissatisfied persons , is 22.7°C, and the percentage of thermally dissatisfied persons increases at a faster rate when the temperature is lowered in relation to 22.7°C than if the temperature is increased. Thus there is an objective physical reason for maintaining a high temperature if complaints are to be avoided.

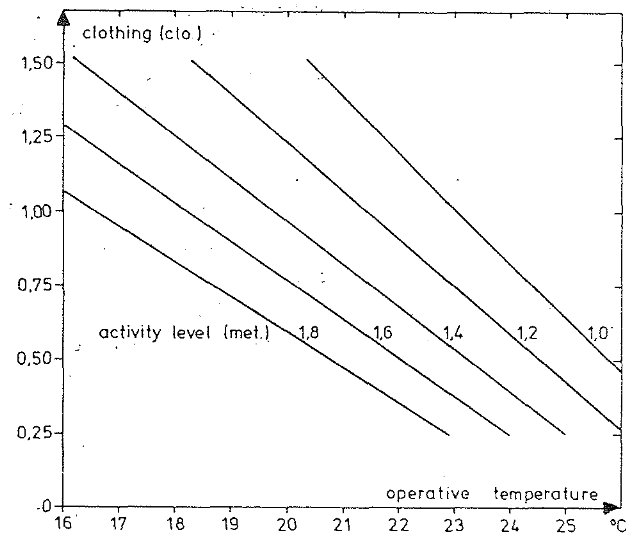

Fig. 4. The correlation between operative temperature and clothing for persons in thermal comfort at different activity levels. Air velocity <0.1 m/s, relative humidity = 50% (2).

Fig. 4 shows how much a person with a given activity level should increase the insulation of his clothing in order to maintain thermal comfort when the operative temperature is lowered. If the operative temperature is lowered from 22°C to 19°C in order to save energy for heating, it is necessary to increased the clothing to 0.5 clo in order to maintain thermal comfort at an activity level of 1.2 met. It is hardly possible to motivate people to increase the clo value voluntarily so drastically considering the existing prices for energy (February 1979). The only possibility to obtain a general change in the insulating capability of every day clothing within a relatively short period of time is probably in the hands of the leading fashion designers of the international clothing industry.

Heated chairs.

An additional practical possibility seems to exist for maintaining thermal comfort even at low activity levels and low operative temperatures. This possibility consists of individual local heating of chairs. Analyzing the situation quite a lot of aspects are in favour of a solution of this kind:

1. Considerable energy savings can be obtained if buildings are equipped with heated chairs,
2. Improved possibility for thermal comfort among people with individual levels of activity caused by the fact that seated persons normally have a lower activity level than standing or walking persons.
3. A possibility is established for the control of the individual "climate" without change of clothing.
4. This solution can be used in new as well as in old houses.
5. The price of electronic components is dropping almost as quickly as the price of energy is increasing, so possibly the point when it is economically feasible to buy and sell heated chairs has already been passed.
6. A lowering ot the air temperature of f.inst. 3°C will, if the other parameters are kept constant, cause an increase in the relative humidity of 20% which will reduce the inconveniences caused by static electricity.
7. The efficiency of heat pump systems as well as solar energy systems is increased when the necessary heating is performed at lower temperature levels. This fact is met by the lower energy requirements as well as by the lower operative temperature.

Can a heated chair compensate for a lower indoor temperature in practice?

A number of investigations have already been made in order to find what degree of asymmetrical heating can be accepted without thermal discomfort. Gagge et al. (3) used 2 high temperature radiation panels placed above a seated person. The air temperature was changed during the experiment while the person was allowed to adjust the radiation to the desired amount necessary to obtain thermal comfort. All four persons involved in the experiment could remain in thermal comfort at air temperatures down to 15°C even when they were naked, and down to 10°C when they were wearing a clothing corresponding to approx. 0.6 clo. Of the total surface of these persons only 28% were exposed to the radiation. It also appears that the radiated area must receive 6.9 W/m² per °C the air temperature is lowered below the comfort temperature.

A nude person will at an air temperature of 15°C receive the following amount of radiant heat:

$$\Phi_{R_{nude}} = 6.9\ (28.6 - 15) = 93\ W/m^2$$

and a person wearing o.6 clo will at 10°C receive:

$$\Phi_{R_{0.6\ clo}} = 6.9\ (24.6 - 10) = 101\ W/m^2$$

Olesen et al. (4) have investigated a thermal situation similar to the one which can be expected in a locally heated chair.

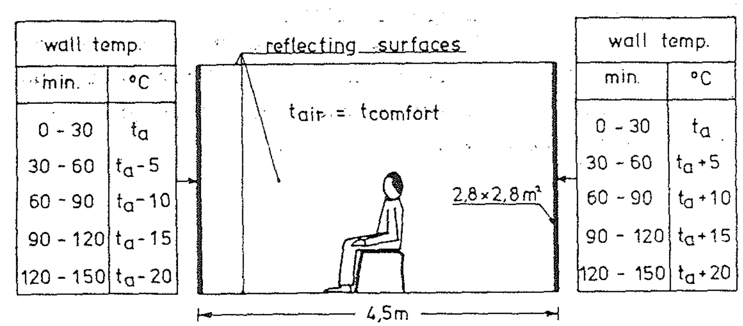

Fig. 5. Sketch of the asymmetric thermal situation (from 4).

14 persons were exposed to a situation outlined in fig. 5. In the environmental chamber the subjects are placed so that they face the end wall of the chamber consisting of a large cooling surface, and with their back to the other end wall consisting of a heated surface of the same size. The 4 remaining surfaces of the room consist of heat reflecting aluminium plates. First the optimal operative temperature is found for each subject in a seated and almost nude position (0.05 clo), then the temperature of the 2 end walls is changed 5°C every half hour upwards and downwards respectively. In this way the heat balance of the subjects remain unchanged while the thermal field becomes more and more asymmetrical. The main result of this investigation was that none of the 14 subjects found temperature differences between the end walls of 10, 20 and 30°C to be uncomfortable while 2 subjects found that 40°C was uncomfortable.

Calculating the heat exchange between chest and back and the corresponding end walls -15/+15°C indicates that the back of the person is in balance at a skin temperature of approx. 36°C and a heat loss of approx. 0 W/m^2 while the chest temperature is approx. 31°C corresponding to a dry heat loss of approx. 90 W/m^2.

Both examples indicate that a person can accept signigicant asymmetry in heat loss as long as the total heat balance is acceptable.

Practical arrangement of a heated chair.

The starting point when designing a heated chair must be a knowledge of the distribution of heat loss of the individual parts of the body. The surface of the body can roughly be divided in the following way:

	Percentage of the total skin area	Percentage which can be heated by a chair	Percentage of the total skin area which can be heated by a chair
Head	7	0	0
Body	37	0.33	12.2
Thigh	20	0.33	6.6
Legs	14	0.25	3.5
Feet	7	0	0
Arms	11	0.20	2.2
Hands	5	0	0
Total	100%		24.5%

To the right is shown the percentage of the total skin area which at a first glance can be expected to be heated by a chair. If it is assumed that,in accordance with the results from (4),there will be no heat loss from the heated area of the body.For a person with an activity level of 1.2 met and a clothing of 0.75 clo, and where thermal comfort is expected at 22.9°C, it is then possible to lower the operative temperature to:

$$t_{op} = 22.9 - \frac{0.245}{0.755}(36.5 - 22.9) = 18.5^{o}C$$

where 36.5^0 is the internal temperature of the body and $\frac{0.245}{0.755}$ is the relationship between the heated and the unheated body area.

The chair should be made with a high back so that the person's back, neck and shoulders can be kept warm. It will, probably, also be appropriate to apply a suitable radiant heat source under the seat so that the legs and feet will receive a certain amount of heat. In fig. 6 a sketch of such a chair is outlined.

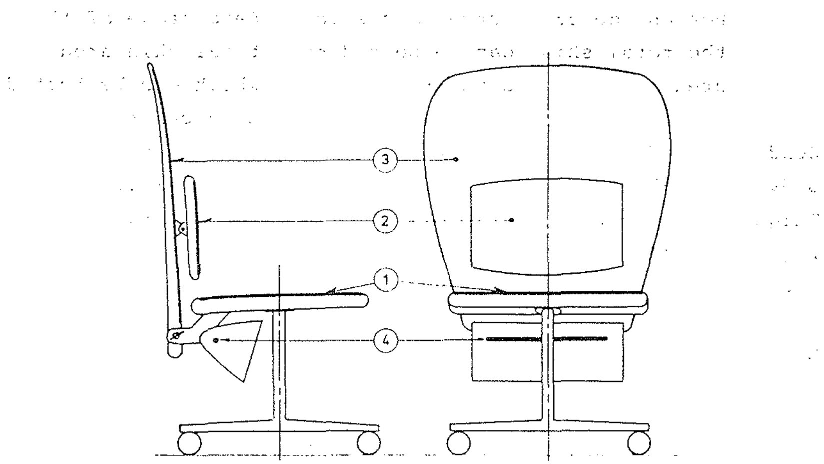

Fig. 6. Principle shetch for a heated chair. Each of the four elements can be controlled separately to a wanted effect.

1. heating element in seat.
2. heating element in back
3. radiation heating element behind the back
4. radiation heating element for legs and feet

Initial Measurements.

Using a thermal mannequin developed at the laboratory (5,6) a number of initial measurements has been made of the thermal effect of a heated chair upon a seated person. The mannequin is designed in such a way that its surface temperature will always be the same as the skin temperature of a person exposed to the same thermal environment as the mannequin. By measuring the heat loss of the mannequin, you can obtain a direct measurement of the expected dry heat loss of a person in the mannequin's situation.

For the initial measurements an ordinary office chair was used with 2 built-in heating elements ($A = 0.3 \times 0.3\ m^2$, effect = 4 W), one in the seat and one in the back. The area of the heating elements is only 0.18 m^2 corresponding to approx. 10% of the total surface of a person. It is thus rather limited how large a reduction in heat loss to the environment the elements can provide.

Therefore the chair was supplied with an extra heat source under the seat. This has two purposes:

1. to supply radiant heat to legs and feet
2. to increase the total convection from the heating sources in order to reduce the person's convective heat loss to the surrounding air.

The main results of these initial measurements are shown in fig. 7.

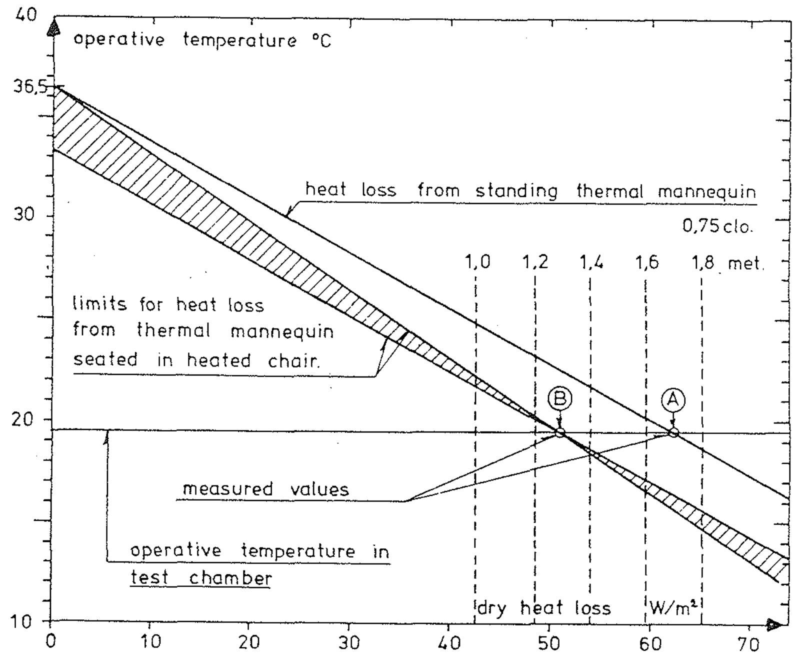

Fig. 7. Main results from the initial measurements. The five vertically dotted lines indicate the dry heat loss from persons in thermal comfort at the shown activity levels. The figure indicates that it will be possible, by use of a heated chair to decrease the operative temperature approximately 3°C and still maintain the degree of thermal comfort, and, furthermore, that it will be possible to establish thermal comfort for seated as well as standing persons with the same clothing and with activity levels differing approx. 0.4 met.

A chair with the thermal mannequin was placed in a room where as well t_a as t_{mrt} were kept at 19°C. The standing mannequin with a simulated clothing of 0.75 clo had a heat loss of 62.4 W/m^2 (point A). Seated on the chair with 4 Watt of electric heating in the seat plus 4 Watt in the back and a 70 W lamp under the seat, the heat loss in the same environment was 51 W/m^2 (point B). The declining line through point A indicates the relationship between the heat loss from the mannequin and the operative temperature of the environment. It also indicates the expected relationship between the dry heat loss of a person and the comfort temperature at a clothing of 0.75 clo. The corresponding relationship for a person in the heated chair is to be found within the shaded area in the figure. A better estimation of this relationship will require more measurements at different operative temperatures.

The vertical lines in the figure indicate the dry heat loss corresponding to 5 typical indoor activity levels. From fig. 7 it is read directly what lowering of the temperature will be acceptable at the various levels af activity, if thermal comfort is to remain unchanged. The lowering of temperature is approx. 3°C. According to fig. 7 the heated chair will make it possible to maintain optimal thermal comfort for seated persons with an activity level which is approx. 0.4 met lower than the level of standing or walking persons if the temperature is correctly chosen.

It is now intended to build a chair in accordance with the indications obtained from fig. 6 and to continue the experiments. First with the thermal mannequin and hopefully later on with human beings.

Conclusion.

The theoretical considerations as well as the initial experiments indicate that it is possible to lower the room temperature significantly if seated persons are supplied with possibilities for local heating of their immediate environment by a heated chair. To obtain a reasonably accurate indication of how large the lowering in temperature may be in practice will require a development period to optimize the form, the heat

loss and the regulating system of various chairs, and next a testing period of such chairs with a suitable number of persons in an environmental chamber under well-defined thermal conditions.

If the idea is still considered good after such testings, it will be possible at the same time to obtain thermal comfort for more people and to save considerable amounts of energy for the heating of houses, new as well as old ones.

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