THERMAL COMFORT REQUIREMENTS FOR FLOORS

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This paper deals with the establishment of thermal comfort limits for the temperature of floors occupied by people. The investigation was divided into two parts: people with bare feet and people with footwear. Finally, the paper gives some practical applications of the results.

1. PEOPLE WITH BARE FEET

A knowledge of thermal comfort limits is important for the choice of flooring materials and for the design of floor heating in bathrooms, swimming baths, gymnasiums, dressing rooms, bedrooms, etc. In the experiments at the Laboratory of Heating & Air Conditioning, Technical University of Denmark, 16 young stulents (8 females and 8 males) each participated in two experiments. A detailed description of the experiments is given in ref. (/17/). Two kinds of flooring materials were used: concrete and wood. The subject was dressed in light cotton clothing (0.6 clo) and had bare feet. He stood for 10 min. on the floor, and during this period gave a subjective evaluation of his foot comfort. Each subject tried about 5 or 6 floor temperatures on each floor. While the temperature of the floor was changed the subject was sedentary. During the whole experiment the ambient temperature was altered according to the subject's wishes, so that he was in a state of general thermal neutrality.

The connection between comfort vote and floor temperature was estimated by means of a linear regression analysis. There was no difference between male and female, but the difference between the two floors and between 1 and 10 min. occupancy was significant. There was also a considerable difference between subjects. By means of the linear regression analysis it was possible to estimate the connection between floor temperature and the expected percentage of dissatisfied. This connection for the two floors after 1 min. and 10 min. occupancy is shown in Fig. 1.

It is not possible to find a floor temperature that will satisfy all subjects. The optimal for 1 min. is 2% dissatisfied and for 10 min. 11% dissatisfied. These percentages will occur if the floor has the optimal temperature, which is for concrete 28.3°C and 27.2°C for 1 min. and 10 min., and for wood 26.6°C and 25.5°C for 1 min. and 10 min. At the optimal floor temperature there is only a small difference between the two floors (1.7°C). If the temperature deviates from the optimal the difference will be greater. At a floor temperature of 20°C there will be 84% dissatisfied after 10 min. occupancy on a concrete floor and 25% on a wooden floor.

To estimate recommended floor temperatures for different materials it is important to have a thermal characterization of the floor. In West Germany there is a norm (DIN 52614) according to which the floor is characterized by means of the heat loss from an artificial foot to the floor for 1 min. and 10 min. contact. By means of this characterizing method and the results from the experiments, a connection between the heat loss after 1 min. and 10 min. and the optimal floor temperature was estimated. Furthermore, a floor temperature interval for 1 min. occupancy was estimated where less than 10% were expected to be dissatisfied (Fig. 2), and for 10 min. an interval where less than 15% were expected to be dissatisfied (Fig. 3). The 15% interval for 10 min. occupancy is included in the 10% interval for 1 min. occupancy so if floor temperatures are recommended on the basis of the results for 10 min. occupancy the same limits for 1 min. can be used and the number of dissatisfied persons will be less.

In other series of experiments it was found that after 10 min. and until 30 min. occupancy there was only a small change in the preferred floor temperature. Sedentary persons preferred a floor temperature only about 1°C higher than did standing persons, and if they put on light cotton socks no change was found in the preferred floor temperature. Small variations in the general thermal state of the body had no influence on the preferred floor temperature.

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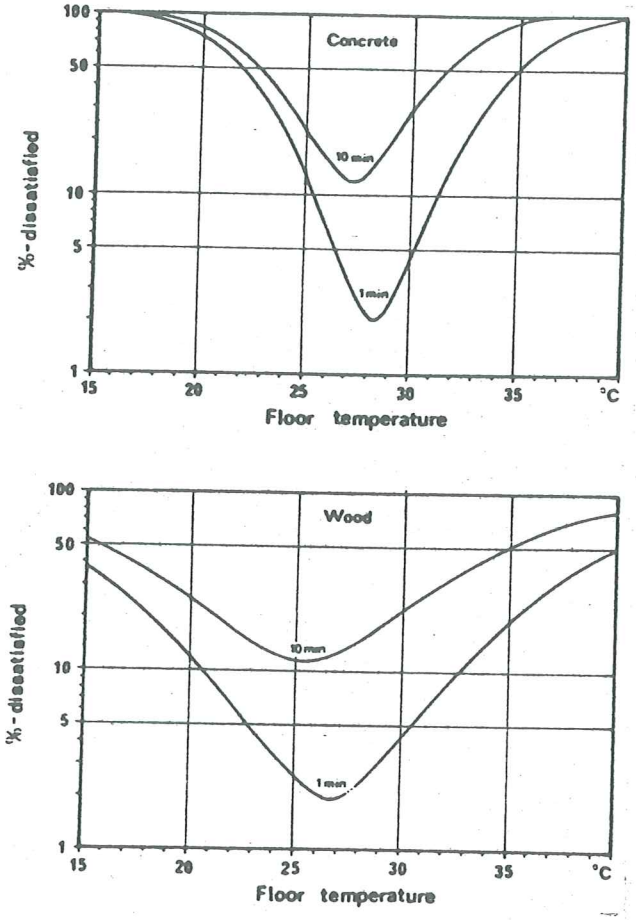

Fig. 1. Connection between floor temperature and the expected percentage of dissatisfied. Standing persons with bare feet after 1 min. and 10 min. occupancy.

It is recommended that a floor be thermally characterised according to DIN 52614, where the heat loss from an artificial foot to the floor is measured for 1 min. and 10 min. For floors occupied by sedentary, standing or walking subjects for less than 30 min. it is recommended that a floor temperature be used which is within the interval where less than 15% are expected to be dissatisfied. This interval is estimated from the experiments with standing subjects after 10 min. occupancy. The recommended floor temperatures are shown in Table 1 for a number of typical floor constructions.

2. PEOPLE WITH SHOES

The recommendation will be based on earlier published experiments from Kansas State University (Nevins et al., /13/ /14/ /15/ /21/) and experiments from the Technical University of Denmark (/16/). Nevins et al. made experiments with about 122 subjects. Only four groups (about 65 subjects) were used in the present analysis of the results. These subjects were in general thermal neutrality, dressed at a clo-value between 0.6 and 1.0 clo. The shoes had soles about 3-6 mm thick; half of the subjects were standing and half sedentary. The subjects occupied the floor for 3

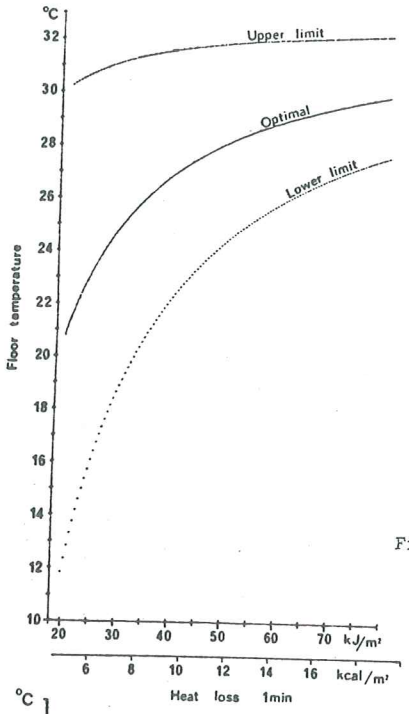

Fig. 2. Connection between measured heat loss from an artificial foot according to DIN 52614 and the optimal floor temperature (2% dissatisfied), together with the limits for the interval within which less than 10% are expected to be dissatisfied. Standing subjects with bare feet, 1 min. occupancy.

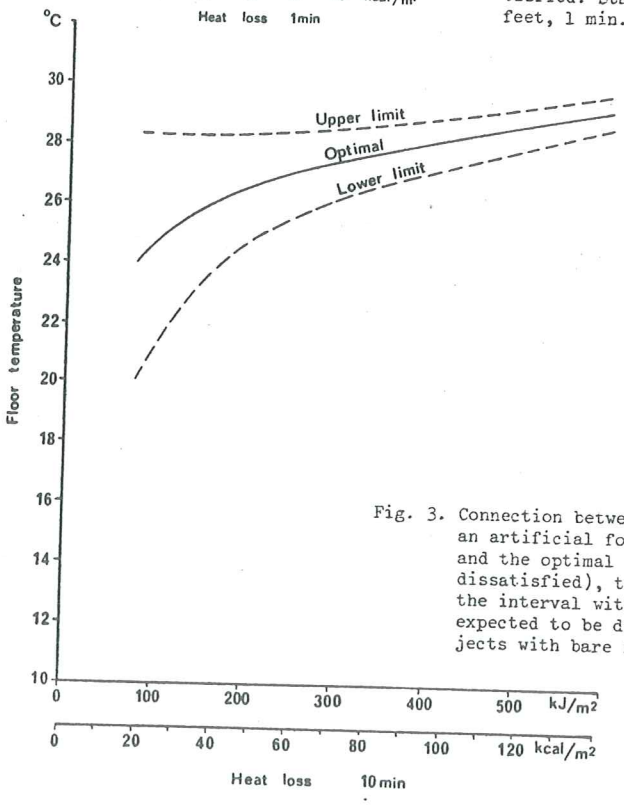

Fig. 3. Connection between measured heat loss from an artificial foot according to DIN 52614 and the optimal floor temperature (11% dissatisfied), together with the limits for the interval within which less than 15% are expected to be dissatisfied. Standing subjects with bare feet, 10 min. occupancy.

TABLE I

Comfortable floor temperatures for typical floor constructions

Floor construction (The underlayer is concrete)		Heat loss estimated according to DIN 52614 1 min	10 min	Optimal floor temperature 1 min	10 min	Recommended floor temp. interval - less than 15% dissatified
		kJ/m²	kJ/m²	°C	°C	°C
Wooden floor used in the experiment		38	134	26.5	25.5	23 - 28
Concrete floor used in the experiment		50	293	28.5	27	26 - 28.5
Textile layer	1)	17	75	19	24	20 - 28
Wilson-carpet	2)	20	91	21	24.5	21 - 28
Sisal-carpet	2)	24	123	23	25	22.5 - 28
Needled felt sheet	2)	21	111	22	25	22 - 28
5 mm cork	3)	26	145	24	26	23 - 28
Pinewood floor	4)	39	124	25	25	22.5 - 28
Oakwood floor	4)	36	182	26	26	24.5 - 28
Vinyl-asbestos tile	2)	80	485	30	28.5	27.5 - 29
PVC-sheet with felt underlay	2)	49	242	28	27	25.5 - 28
PVC-sheet (2 mm)	2)	60	365	29	27.5	26.5 - 28.5
5 mm tesselated floor on gas concrete	3)	60	301	29	27	26 - 28.5
5 mm tesselated floor on 20 mm cork	3)	63	211	29	26.5	25 - 28
2.5 mm hard linoleum on wood	3)	46	176	28	26	24 - 28
2.5 mm hard linoleum on concrete	3)	45	296	28	27	26 - 28.5
Painted concrete floor	2)	77	487	30	28.5	27.5 - 29
Marble	3)	75	511	30	29	28 - 29.5
Concrete slab finished with steel trowel	3)	63	475	29	28.5	27.5 - 29
Concrete slab finished with wooden float	3)	60	419	29	28	27 - 29

1) Schüle and Monroe (/19/), 2) Wäänänen and Veijalainen (/21/)
3) Cammerer (/3/) , 4) Cammerer (/2/)

hours and tried about 6 floor temperatures on different days. During the experiment the subject voted in his foot comfort.

The results were analysed in the same way as for the experiment with bare feet. The estimated connection between floor temperature and percentage of dissatisfied subjects after 3 hours' occupancy is shown in Fig. 4. The optimal floor temperature was 23.8°C and the optimal percentage of dissatisfied subjects was 6%.

In earlier experiments by Muncey and Hutson (/10/ /11/), Frank (/6/ /7/ /8/) and Monroe and Chrenko (/12/) it was found that the flooring material had only a very small influence on the preferred floor temperature for people with shoes.

In experiments at the Technical University of Denmark two types of footwear were compared. One type was winter suède boots with a 12 mm rubber sole and the other an indoor leather shoe with a 6 mm sole. It was found that this variation in footwear had no influence on the preferred floor temperature, and the optimal floor temperature (24°C) was the same as found by Nevins et al. In the same experiments it was shown that the difference between ½ hour and 2½ hour occupancy was less than 1°C. In the same experiments and in experiments by Chrenko (/4/ /5/) it was found that standing or walking subjects preferred the floor temperature to be about 1-3°C lower than did sedentary subjects.

As the curve in Fig. 4 is estimated for both sedentary and standing subjects, it is recommended that for sedentary persons the temperature estimated from Fig. 4 be raised by 1°C and for standing and walking subjects, lowered by 1°C. The optimal floor temperature for sedentary persons is 25°C and for standing or walking persons 23°C.

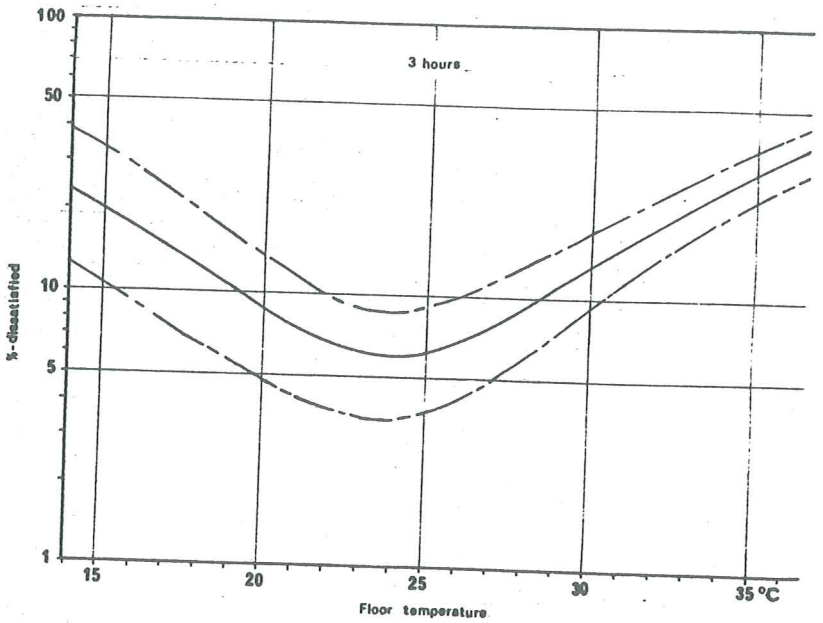

Fig. 4. The connection between floor temperature and the expected percentage of dissatisfied people. The broken lines indicate the 95%-confidence interval. Estimated after 3 hours' experiment including both sedentary and standing subjects with footwear. Sedentary prefer 1°C higher temperature than the shown curve, standing prefer 1°C lower.

The percentage of dissatisfied people which the project engineer will accept depends on how often this percentage will occur. At the floor design temperature i.e., the temperature which occurs at the same time as the design outdoor temperature (in Denmark -12°C), which will occur on only a very few days each year, it is recommended that 12% dissatisfied be accepted (the double of the optimal 6%). At a floor temperature which will occur for the greater part of the year it is recommended that 8% dissatisfied be accepted (1/3 more than the optimal 6%).

Thus the recommendations are as follows: as floor design temperatures, it is recommended that for standing or walking persons, min. 17°C and max. 28°C be used.

In rooms where the floor temperature will remain at the same level for the greater part of the year it is recommended that for standing or walking persons, min. 20°C, max. 26°C be used.

For rooms occupied by sedentary persons it is recommended that the floor temperature be raised by 2°C.

The temperatures are recommended for persons in general thermal neutrality, the soles of their footwear being thicker than approximately 5 mm.

3. PRACTICAL APPLICATIONS

The use of floor heating has increased during recent years, especially for bathrooms and dressing rooms where the floor often is a type of stone floor. The recommended surface temperature will, according to Table I, be around 26-29°C. If there is no floor heating system in rooms occupied by people with bare feet or in those where children play on the floor, it is very important to choose a flooring material with a wide comfort range. According to Table I, pinewood, cork and a kind of textile layer are the most acceptable.

The use of floor heating as the only heating system in a house has often been rejected because of the risk of too high surface temperatures in the coldest months. However, new insulation requirements have now made possible the use of floor heating.

The heat dissipation from a floor heating system depends on the heat exchange coefficient (radiation and convection) and the temperature difference between the floor and the surroundings. In the literature (/1/ /9/ /18/) the total heat exchange coefficient is reported to be around 7 to 10 W/m^2 °C for floor temperatures which are 20 to 10°C above the ambient temperature. For sedentary persons engaged in light office work and wearing normal indoor winter clothing (1.0 clo) the comfort temperature is 22°C. The recommended design floor temperature is 30°C. The heat dissipation from the floor to the room will then be around 80 W/m^2 °C. In Denmark, which has a design outdoor of -12°C, the total design heat loss (transmission and infiltration) will be around 50 W/m^2, if the house is built according to the new insulation standards.

Floor heating, compared to other heating systems, gives a very even distribution of air temperatures, low air velocities and small vertical air temperature gradients. If the room has rather poorly insulated windows there can arise problems with downdraught; the thermal capacity of a floor heating system can also give problems regarding the regulation of the room temperature, especially if there occur quick changes of the heat-input from the sun or from the occupants.

With the use of alternative energy from the sun and the wind and the use of heat pumps, it is advantageous to adopt a low temperature heating system such as floor heating. This method improves the efficiency as the inlet temperature is 30-35°C whereas other heating systems use an inlet temperature of 50-60°C.

In summer it would be possible to use the floor system for cooling also. The recommended lower temperature limits are 19-20°C. The preferred indoor temperature in summer will be 24-25°C and with a total heat exchange coefficient (convection, radiation) of approx. 6 W/m^2 °C the cooling effect will be 30 W/m^2. Moreover, most of the direct solar radiation on the floor will be eliminated, this often being a major part of the heat load in summer.

I feel that there is need for further research with low temperature heating systems as floor heating, and also for investigations concerning the possibilities of cooling. At the Institute of Thermodynamics, Université de Liège, and at the Laboratory of Heating and Air Conditioning, Technical University of Denmark, experiments are at present under way comparing the thermal comfort and the energy requirements in a room heated by different heating systems.

The results of these experiments will be of great value and will provide answers to some of the questions which arise in the discussion of heating systems, thermal comfort, and energy requirements.

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EXIGENCES DE CONFORT THERMIQUE RELATIVES AUX PLANCHERS

RÉSUMÉ : Le présent traité porte sur les limites de confort thermique relatives à la température des planchers de locaux habités. Le traité comprend deux parties suivant que les personnes concernées ont les pieds nus ou portent des chaussures.

Dans l'expérience avec 16 personnes qui avaient les pieds nus, la température optimale du plancher, c'est-à-dire la température qui a causé le plus petit pourcentage d'insatisfaits, a été établie pour deux types de parquetage: le béton et le bois. L'influence de l'activité, de l'état thermique général du corps, et de la durée de séjour sur la température de plancher préférée a été établie. Des calculs ont permis d'appliquer les résultats à d'autres parquetages, et le traité indique les exigences de confort thermique recommandées pour différents parquetages qui sont occupés par des personnes qui ont les pieds nus.

Les recommandations pour les parquetages qui sont occupés par des personnes qui portent des chaussures sont établies sur la base d'expériences qui ont été traitées dans des publications antérieures et sur la base d'expériences qui ont été réalisées à l'Université Technique du Danemark. L'influence des chaussures, de l'état thermique général du corps, la durée de séjour et de l'activité a été établie. L'article comprend une discussion de l'utilisation pratique des résultats et des avantages et des inconvénients du plancher pour les installations de chauffage ou frigorifiques.