Floor Topping and its Thermal Significance

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PREFACE

It is common experience that the sensation of foot warmth or coldness is conditioned by the floor materials. Thus, for example, rugs or cork tiles may appear comfortable to the bare foot while other types of floors will seem cold, even though their temperatures are high. In these cases, comfort is conditioned by the rate of heat exchange at the floor. Ordinarily, the minor discomforts occasioned in this way would be negligible but there are many instances in playrooms and at schools and nurseries where children will go about with bare feet for extended periods of time. The design of such floors for comfort is not merely a matter of the type of flooring layer but also of the sub-floor materials.

Another aspect of thermal foot comfort occurs under ordinary circumstances when the floor surface temperature is below about 60°F (the room air temperature being 70°F). In this case, discomfort occurs solely due to the floor temperature and is not related to the materials of the floor.

It has not been usual in floor design in North America to give any appreciable attention to foot comfort as related to the thermal characteristics of the floor. On the other hand, there is a considerable volume of European literature on the subject. Although the present translation is limited ostensibly to the influence of floor toppings immediately under the flooring, it nevertheless presents the entire subject in fairly comprehensive form.

The translation has been prepared by Dr. W.G. Brown, Building Services Section, Division of Building Research, National Research Council.

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THE FLOOR TOPPING AND ITS THERMAL SIGNIFICANCE

(With Respect to Foot Comfort)

The thermal resistance of solid floor partitions used at present does not in general fulfill the requirement of the German Engineers' Standard No. 4108 (Heat protection in high-rise buildings) without additional insulation. For this reason an attempt should be made to ensure that the basic floor construction (covering and underlayer) has the required heat resistance. With thin flooring laid directly over the floor topping, the floor covering and the topping, together with an insulation layer under them, determine the thermal properties of the complete floor-ceiling construction.

In the following, the significance of the floor topping with respect to heat transfer will be investigated. In evaluating a building component (that is, a ceiling with flooring) from the thermal standpoint, the thermal resistance and the foot warmth are determining factors. The heat flow resistance (thermal resistance) of the whole partition* construction with flooring is mainly of economic interest because it determines the heat requirements of the rooms, insofar as the floor-ceiling partitions divide rooms with different temperatures. Nevertheless, the foot warmth, which has a unique health significance, is influenced by the insulation of the whole partition. In this connection the construction of the floor itself - the walk-way, together with the floor topping - plays an important role in foot warmth.

1. Thermal Data of Floor Topping

Floor toppings are, in principle, thin layers laid either directly on the partition or on insulating material over the partition. Serving as floor toppings are: concrete, to some extent with insulating additives; gas and foam concrete of sufficient pressure resistance; gypsum and plaster; asphalt and wood concrete (wood layers bound with magnesite with or without additives). In their thermal performance the topping materials are specified through their thermal conductivity (k), specific heat (c), and specific weight (w), as well as through a combination of these three variables, the thermal penetration number (b)**[(1)].

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* Note: The English word partition is used to designate the German equivalent of floor-ceiling (or deck).

** $b = \sqrt{c.k.w}$ kcal/m²-hr$^{\frac{1}{2}}$-°C

Earlier investigations of a large number of floor toppings laid under practical conditions and additional measurements have given the values in Table I. The thermal conductivities given there also depend on the moisture content of the material according to German Engineers' Standard No. 52612[2] and they represent "calculation values of thermal conductivity" in the sense of this standard. On the basis of these values and with the specific weight and estimated values of the specific heat, the heat penetration numbers were calculated.

The thermal conductivity of the floor toppings generally increases with increasing specific weight. This may be seen in Fig. 1, which shows the thermal conductivity dependent on the specific weight. The scatter of the measured values in the individual groups of floor toppings is to be considered due to the effect of differing additives (type of sand and so on). In general, however, the thermal conductivity increases steadily with increasing specific weight, and this allows estimation of the thermal conductivity on the basis of the specific weight. For this purpose the values of Table II may be assumed.

The thermal penetration numbers (b) of the floor topping that determine their performance in unsteady heat flow (heat addition, heat removal and foot warmth) also increase with increasing specific weight. Nevertheless, the different groups of floor toppings differ from each other more strongly for b values than for thermal conductivity (Fig. 2). This is mainly a result of the differing specific heats of the materials of the individual groups. As the c values for concrete and plaster toppings are apparently certain[3] but estimated for the wood concrete toppings (there being no measured values available), it probably makes the curve for wood concrete somewhat uncertain.

2. Thermal Resistance of Floor Toppings

The thermal resistance, or heat flow resistance, $\frac{1}{\Lambda}$, of layered materials is determined from their thickness and thermal conductivity, giving $\frac{1}{\Lambda} = \frac{d}{k}$. For several layers lying one upon another (thicknesses d_1, d_2, $d_3 \ldots\ldots d_n$, and thermal conductivities k_1, $k_2 \ldots\ldots k_n$) the total resistance as a sum of the individual resistances becomes $\frac{1}{\Lambda tot} = \frac{d_1}{k_1} + \frac{d_2}{k_2} + \ldots\ldots \frac{d_n}{k}$. Floor toppings are laid down either alone or on insulation (for example, as "floating toppings"). Assuming the values of thermal conductivities of toppings from Table I or Fig. 1 (about 0.15 to 0.75 kcal/m-hr-°C), one obtains the range of thermal resistance $\frac{1}{\Lambda}$ shown in Fig. 3, attainable for floor toppings of thicknesses up to 6 cm. For the usual topping thickness of about 3 to 4 cm a thermal resistance of about 0.2 to 0.25 m^2-hr-°C/kcal is obtained for the best situation (thermal conductivity of the topping of 0.15 kcal/m-hr-°C); for a topping of higher thermal conductivity correspondingly lower resistance values are obtained.

Comparing the thermal resistance of toppings with those of insulating materials (thermal conductivity between 0.035 and 0.05 kcal/m-hr-°C) of several centimetres thickness, also shown in Fig. 3, it will be recognized that resistance values can be reached that are several times larger than those possible with toppings alone. If account is finally taken of the fact that the required total thermal resistance of partitions (according to German Engineers' Standard No. 4108) lies between 0.55 (living space partitions) and 0.75 m^2-hr-°C/kcal (cellar partitions), then it may be seen that the majority of toppings can only make an appreciable contribution to the thermal protection of the floors when they are combined with insulating materials (that is, as floating toppings, which must often be used to obtain the necessary soundproofing of ceilings). Consequently, the floor topping alone is of little significance for the total thermal protection of the floor (excepting materials of very low specific weight and resultant relatively low thermal conductivity).

Proceeding from the general relationship between thermal conductivity and specific weight of topping, as given in Fig. 1 (Table II), the relationship between attainable thermal resistance and specific weight for different floor toppings is obtained (Fig. 4). This figure can be used for rough approximation of the thermal resistance of given floor toppings of known specific weight. Figure 5 allows estimation of the required thickness and specific weight of a topping for a given thermal resistance.

3. Foot Warmth and Toppings

An especially important aspect when considering the floor is foot warmth or foot coldness. Warm feet are one of the most important requirements for comfort. On the other hand cold feet are not only uncomfortable but they can lead to illness. Consequently, sufficient foot warmth in rooms, whether in dwellings or work places, is a health requirement which is not negligible.

Note: The units used in this paper can be converted as follows: Degrees F = Degrees C × 9/5 + 32; thermal conductivity 1 kcal/m-hr-°C = 0.672 Btu/ft-hr-°F; thermal resistance 1 m^2-hr-°C/kcal = 1.49 ft^2-hr-°F/Btu; specific weight 1 kg/m^3 = 0.066 lb/ft^3; heat penetration number 1 $kcal/m^2$-$hr^{\frac{1}{2}}$-°C = 0.205 Btu/ft^2-$hr^{\frac{1}{2}}$-°F.

In the following a short summary will be given of the present knowledge of the question of foot warmth and foot coldness in connection with the floor and the temperature conditions in the corresponding rooms. To conclude, the influence of the floor topping on foot warmth will be considered.

3.1 Foot warmth

Foot warmth of foot coldness are human sensations that indicate a condition of comfort or discomfort and may have quite different causes. Apart from the sensitivity and the disposition of a person, foot coldness may be induced through draughts, for example, whenever the legs and particularly the ankles come in contact with a cold air stream. Bare feet may feel cold when in contact with floor surfaces at low temperature. To be sure, it is known from experience that the floor material also plays a role. A concrete floor feels colder than a wood floor or even a cork layer. Apparently foot coldness or warmth is closely connected with the heat withdrawn from the foot or the leg. In this connection the heat removal at the sole of the foot can take place through contact with the floor or, in the case of the leg, through the cold air. Whichever of these two causes creates the sensation depends mainly on the type of foot covering. With bare feet the heat transfer from the sole to the floor is of importance, the heat given up from the leg not being of consequence. With covered feet, with the often considerable increase in thermal resistance between the sole and the floor due to the shoe sole and stocking, draughts and low air temperatures in the neighbourhood of the floor surface are the main causes of cold feet.

3.1.1 Bare feet

During walking and standing, the bare foot comes directly into contact with the floor and thereby conducts heat away, because the floor usually has a lower temperature than the sole of the foot. It has proved resonable, therefore, to designate floor properties by employing a characteristic variable which describes the heat transport in connection with foot warmth. In addition, the thermal properties of the floor that determine heat removal also determine the floor temperature and the hot or cold sensation imparted by the floor. The investigation of temperature and heat-flow relationships during contact between two bodies at different temperatures shows that the heat penetration numbers (see Section 1) are characteristic for the materials in contact.

Knowledge of the heat penetration number is sufficient to indicate the influence of sufficiently thick homogeneous floors on the foot warmth for bare feet. The smaller this quantity, the warmer the effect of the floor on the foot. In addition, the floor temperature plays a role, especially for floors of material with large heat penetration numbers. With small heat penetration numbers such as cork ($b = 2$ to 3 kcal/m^2-hr$^{\frac{1}{2}}$-°C) and wood ($b = 6$ to 8 kcal/m^2-hr$^{\frac{1}{2}}$-°C) the effect of the floor temperature on foot warmth becomes less and less important.

For layered floors, which often consist of only a few millimetres of floor surface directly on a floor topping or something similar, the knowledge of the heat penetration number of the individual layers does not suffice for evaluation of the floor.

Investigations of human sensation as well as foot warmth and temperature conditions on the foot during walking and standing, as carried out by Cammerer and his associates(4,5) and Schüle(6,7) have resulted in measuring methods that allow the investigation and evaluation of layered floors with respect to their heat transfer and consequent foot warmth. In his investigations, Cammerer measured the time-dependent amount of heat given up from the foot to the floor by means of a specially developed thin heat meter. Schüle measures the time dependence of the foot sole surface temperature in standing contact with the floor. Both methods give insight into the relationship and allow evaluation of the floors.

The temperature measurement on the sole of a foot in standing contact with a floor gives an easily interpreted curve. After contact of the foot with the floor, the sole temperature decreases with the time of contact in a distinct manner depending on the material and floor construction, until finally, after considerable time, a stationary condition is reached. This time-temperature dependence at the position of contact between foot and floor (for example, the temperature of the ball of the foot) has shown itself to be a useful indication of the heat dissipation of the floor and for judgement of the floor with respect to foot warmth.

The heat dissipation curves of a few floors obtained in this way, that is, the temperature of the ball of the foot in relation to the time of standing on the floor is given in Fig. 6. The subjective sensation of the subject person is also given here. It will be noted that the sensation corresponds simultaneously to a drop in the curve. The smaller the temperature drop and the flatter the curve, the better the floor is with respect to heat withdrawal and consequently to foot warmth. Earlier experience and the results of newer investigations of heat and cold sensations during standing and moving on floors, together with the temperature of the sole of the foot, have shown that a reduction of about 4°C in the temperature of the ball of the foot for several minutes is connected with the feeling of foot coldness. This occurs for cooling of the foot from the sole, not from draughts. As yet it is not known how under-cooling of the sole temperature for very short times afftects foot warmth.

The practical investigation of floors is carried out by means of an artificial foot, which simulates the thermal performance of the human foot with regard to determination of the heat removal[8]. Heat removal curves for several floors measured with the artificial foot are given in Fig. 7.

The determination of the heat flow (heat flux) from the foot to the floor also gives curves that can be used for evaluating the floor (Fig. 8). For this measurement method it is also realistic to use a physical apparatus in place of the human foot[9]. The method allows the simple representation of results in the form of numbers, which can be used to specify the floor with respect to its heat removal and thereby evaluate the foot warmth and foot coldness. For this purpose the total heat flow into the floor for one minute and ten minutes after setting the apparatus into operation is made use of; the floor indicating a set temperature.

On the basis of the amount of heat determined in this way (heat removal w_1 and w_{10}), the floor can be evaluated according to the scheme given in ref. 9 and Table III.

Comparative measurements with both methods for determining heat removal[10] have shown that the methods in which the contact temperature between the test foot and the floor is measured place extraordinarily high requirements on the exact maintenance of a given exit temperature for the test foot and on the surface temperature of the floor under investigation (for example, 18°C). Even small deviations from these values change the test results considerably.

To be sure, this method allows the investigation of floors even when their surfaces do not have the given temperature of 18°C. The result in this case holds good only for the actual floor temperature and does not allow conversion to another arbitrary temperature. Consequently, without additional considerations this method does not allow a comparison check of floors whose heat removal has been determined in the laboratory and floors constructed under practical conditions.

Such a conversion is of immediate necessity for determining the heat flux, in order to obtain the requirement of exact constancy of a predetermined floor temperature. It is clearly necessary to determine the surface temperature of the floor before placing the test heat apparatus.

For this reason the method of determining the heat removal of floors has been suggested as a standard; that is, the method in which the heat flux from the foot (test heat apparatus) to the floor is measured, i.e. the heat flow in the given time intervals (1 minute and 10 minutes)[9,10] from the test heat apparatus to the floor.

3.1.2 Covered feet

Normally a floor is used with covered feet. Obviously, however, account must be taken of the fact that in living spaces the floor will be walked upon from time to time with bare feet. The newest investigations into the question of foot warmth with covered feet were carried out by Frank(11) in the Institute of Technical Physics, Stuttgart.

The results of these investigations show that while a covered foot is on a floor, the influence of the floor on the foot sensitivity is, for practical purposes, no longer determinable; on the other hand the floor temperature, air temperature in the neighbourhood of the floor and the duration of contact determine substantially the sensation received by the foot. The resulting relationships are given in Fig. 9 and 10. From these the comfort ranges can be obtained, determined by the ratio of the floor temperature to the duration of contact (Fig. 9) or the ratio of floor temperature to air temperature (Fig. 10).

Frank's investigations concerning foot warmth for extended duration in rooms indicated that the floor can show only a certain minimum temperature if foot coldness is to be avoided. Assuming an air temperature of 20°C in the heated room and a duration of 3 to 4 hours, then the surface temperature of the floor must lie between 16 and 19°C in order to meet the comfort requirement.

Earlier investigations(12) in a great number of dwellings have shown that floors with surface temperatures of 16°C or lower have been found cold by the inhabitants in almost every case. Floors with temperatures around 19°C aroused no complaints about cold feet with a few exceptions. In this connection the influence of the floor material on the findings of the inhabitants with respect to the foot warmth could not be recognized. These results agree in their entirety with those of Frank's investigation. One may therefore set up the requirement that with floors exclusively used with covered feet a minimum surface temperature of 17.5°C must be required. With such floors a low heat removal in the sense of Section 3.1.1 is not required. It is nevertheless conceivable that for specially sensitive people, particularly when shoes with very thin soles (ladies shoes) are worn, a certain influence of the floor material (heat dissipation) on the foot sensitivity occurs.

3.2 Floor construction and foot warmth

Previous considerations have shown that with respect to foot warmth it must be decided whether the floor is to be used only with covered feet, as in work places, or also with bare feet (living and bedrooms). In the first case the floor temperature is most important for the foot sensation (together with the air temperature in the neighbourhood of the floor and the duration); in the second case, however, the floor material (floor proper and topping, i.e. under-floor) which is specified through its heat dissipation is the determining factor. The floor temperature also has an influence on the foot warmth for floors with higher heat dissipation.

3.2.1 <u>Floors used only with covered feet</u>

3.2.1.1 <u>Thermal resistance of the partition and foot warmth during long-term heating</u>

With equilibrium of the temperature distribution, the thermal resistance of a partition including the floor, together with the air temperature on both sides of the partition determines the surface temperature of the floor, that is with long-term heating of the rooms. In this connection, it is immaterial how the materials in the ceiling are arranged, i.e. whether the thermal resistance is obtained through an arrangement of an insulation layer on the under side of a concrete partition (Fig. 11b) or the main part of the thermal resistance is obtained through a suitable floor arrangement on the upper side of the partition (Fig. 11a). Both constructions have practically the same thermal resistance ($\frac{1}{\Lambda}$ = 0.55 m^2-hr-°C/kcal). As the surface temperature of the floor is then the same in both cases, both constructions are practically identical with respect to foot warmth, insofar as the floor is used only with bare feet.

The design thermal resistances of partitions including the floor, according to German Engineers' Standard No. 4108 (Heat protection in high-rise buildings) for room air temperatures of 20°C during steady heating, lead to sufficiently high floor surface temperatures to create the requirements of sufficiency with respect to foot warmth for covered feet.

3.2.1.2 <u>The partition and foot warmth during unsteady heating</u>

During unsteady heating conditions, for example, during heating of a room, a relatively large part of the heating energy is taken up by the building components as stored heat and is not given up to the air on the outer surfaces. For this reason, the heat storage capacity and the thermal conductivity of layers near the surface, that is, principally the floor surface and its under layers (but not the thermal resistance of the whole ceiling and floor construction) play the determining role for the surface temperature of the floor. This is shown in Fig. 12, where results of measurements of the surface temperatures of various floors in dwellings, as dependent on the time after beginning of heating, are given. The floors of materials with low heat penetration numbers (wood: $b = 6$ to $8\ kcal/m^2\text{-}hr^{\frac{1}{2}}\text{-}°C$) are warmed considerably faster than materials with large b values (terrazzo: $b = 20$ to $25\ kcal/m^2\text{-}hr^{\frac{1}{2}}\text{-}°C$).

With respect to foot warmth this means that although the floor material is without influence on covered feet during continuous heating, nevertheless the material very probably plays a role in foot comfort warmth during the warming period because the floor temperature is determined by the floor material. Accordingly, floors of the type of Fig. 11 seem warm to the foot even during heating, but this is not the case for the floors in Fig. 11b. This may be seen from Fig. 13, where the ranges of foot comfort (Fig. 9) are also given(13) in addition to the time dependence of the surface temperature of various floors during heating. It is to be recognized that a wood floor, for example, appears warm to the foot even during the heating process, while concrete floors even after two hours are marginal and have a cold effect for a long period until the surface temperature has risen to the final value for steady-state heating (sufficient thermal resistance of the partition being assumed). With short-time heating that is common in dwellings with unit stoves, however, this stationary condition is ofter not reached; in such cases the floor with large heat penetration number (e.g. concrete floors) has a cold effect even with covered feet, while a wood floor or one with a thin surface layer on a topping of low thermal penetration number has a warm effect for the foot.

3.2.2 Floors used with bare feet

In dwellings, account must always be taken of the fact that floors will be used from time to time with bare feet (small children). In this case, the heat removal of the floor plays the deciding role for foot warmth. The heat removal of a floor can only be influenced by the layers that are affected by the heat flux during the short measuring time (up to 10 minutes) during the determination of the heat removal. These are the layers near the floor surface, floor finish and under-flooring. The construction of the partition itself will generally have no influence on heat removal; it is assumed that the floor is very thin and lies directly on the ceiling surface.

3.2.2.1 The floor finish, topping and heat removal

The first moment of contact with the floor surface determines the warmth sensation and is therefore of pronounced significance for the foot warmth for bare feet on a floor. The heat penetration number, b, of the material also determines the resulting temperature, which is by no means the same as that of the surface temperature of the finish. The relationship between the contact temperature, i.e. the temperature that occurs on the human foot when a material is contacted and the surface temperature is given in Fig. 14 for materials with various heat penetration numbers. The lower the b value, the higher the contact temperature and the warmer the floor finish is found to be.

During long contact (several minutes) with thick floor finishes (wood flooring, cork flooring and toppings without additional finishes) the b value is also important for sensation, as has already been shown. This may also be seen from the "heat removal curve" of these floors (Fig. 7). Directly usable floor toppings (without finish), which, due to the requirements of solidity, may not have too low a value of specific weight and consequently have relatively high heat penetration numbers, show much too large a heat removal when the specific weight exceeds about 700 to 800 kg/m^3. Such floors feel cold.

With thin floor finishes of all kinds (e.g. thin plastic materials), the material lying directly under the surface plays a substantial role in the heat removal and consequently in foot warmth for a contact duration of up to several minutes. The temperature in the first moment after contact is probably determined by the floor finish alone; nevertheless, the material under the finish affects the heat removal from the foot to the floor after a short time. This may be seen in Fig. 15, which shows the heat removal curves of thin surface finishes on various under-floors. It may be seen that toppings of all kinds, together with surface finishes, give warm floors (temperature reduction on the foot not more than 4°C) when the specific weight of the toppings does not exceed about 900 to 1000 kg/m^3. In this connection the question of moisture content of the toppings should be considered. Because of their water content, damp toppings show a substantially higher thermal conductivity than dry toppings. If, therefore, a thin floor layer is placed on a not yet thoroughly dried topping, a floor having too great a heat removal is obtained, and if the floor finish hinders the drying of the topping then this unsatisfactory condition remains. For this reason care must always be taken to ensure that toppings are dry before they are covered, i.e. when toppings are used that are not practically free of water. For toppings with a specific weight higher than about 1000 kg/m^3 that are to be covered with thin floor finishes, the thermal conductivity can be so reduced with thin intermediate insulation layers (e.g. felt paper, foam layers, cork plates) that the floor remains sufficiently warm to the foot (Fig. 7). These thin insulation layers can also be affixed directly with the floor finish.

3.2.2.2 Floating toppings

Floating toppings are used extensively for improving the sound performance of partitions. The usual topping of 3 to 4 cm thickness then lies directly on a non-resilient material, which naturally has a low specific weight and consequently a low thermal conductivity. Such means increase the total thermal resistance of the construction (partition including flooring) but do not affect the heat removal of the floor, which will generally contain a floor finish, i.e. for floating toppings the heat removal is determined by the floor finish together with the topping. An appreciable improvement with respect to foot warmth is not to be expected for floating toppings as a result of the insulation materials employed. In this connection the methods given in Section 3.2.2.1 for reducing the thermal conductivity for toppings with specific weights about 1000 kg/m^3 must also be used.

4. Concluding Consideration of Toppings with Respect to Thermal Performance

4.1 Thermal insulation

Toppings generally have specific weights not exceeding 400 to 500 kg/m^3. Consequently the thermal conductivity of such materials will seldom lie below 0.15 kcal/m-hr-°C. With the usual thickness of toppings of 3 to 4 cm the realizeable thermal resistances $\frac{1}{\Lambda}$ will seldom exceed 0.25 m^2-hr-°C/kcal. Correspondingly, heavy toppings with higher thermal conductivity have lower thermal resistances.

For commonly used reinforced concrete panel partitions, the thermal resistance, as required by German Engineers' Standard No. 4108, cannot be obtained from the partition with topping. By addition of an insulating material, which is usually laid under the topping for the purpose of sound protection (floating topping), the thermal requirements can be fulfilled.

4.2 Foot warmth

Sufficient foot warmth, especially for floors used with bare feet, requires, when the finish itself is thin, a material of sufficiently small heat penetration number under the finish. In this case, toppings with specific weights below about 1000 kg/m^3 have a sufficiently small heat dissipation to obtain sufficient foot warmth. Such constructions have the additional advantage that the floors warm up sufficiently fast to ensure that the required floor surface temperature for foot warmth is obtained.

In the interests of foot warmth toppings used directly without additional finish should not have a specific weight greater than about 700 to 800 kg/m^3.

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TABLE I - THERMAL DATA OF TOPPINGS

Type of Toppings	Specific Weight dry w	Thermal Conductivity k	Specific heat C	Heat penetration number b
	kg/m^3	k cal/m-hr-°C	k cal/kg-°C	k cal/m^2-$hr^{\frac{1}{2}}$ -°C
Cement Toppings	2000	0.57	0.22	18.2
Light concrete topping gas & foam concrete topping	1190	0.22	0.22	7.6
	1230	0.33_5	0.22	9.5
	1265	0.32_5	0.22	9.5
	1320	0.38	0.22	10.5
	1385	0.33	0.22	10.0
	1420	0.42	0.22	11.5
	1445	0.50_5	0.22	12.7
	1570	0.57	0.22	14.0
Gypsum topping	1700	0.52_5	0.2	13.3
	1700	0.54	0.2	13.6
	1840	0.67_5	0.2	15.8
	2000	0.65	0.2	16.2
Anhydrate topping	2150	0.75	0.2	18.0
Wood-concrete topping	425	0.14_5	0.4	5.0
	645	0.23	0.4	7.7
	1140	0.32	0.4	12.0
Asphalt topping	2190	0.83_5	0.22	20

TABLE II - AVERAGE THERMAL CONDUCTIVITY OF TOPPINGS DEPENDENT ON DENSITY

Density w	Thermal Conductivity k
kg/m^3	k cal/m-hr-°C
400	0.15
500	0.18
1000	0.3
1500	0.5
2000	0.7

TABLE III - CONSIDERATION SCHEME FOR THE HEAT REMOVAL OF FLOORS

Evaluation of the floor	Heat given up from the test apparatus to the floor W_1 0 to 1 Minute	W_{10} 0 to 10 minutes
	$k\ cal/m^2$	$k\ cal/m^2$
especially warm to the foot	up to 9	up to 45
sufficiently warm to the foot	from 9 to 12	from 45 to 70
no longer sufficiently warm	from 12 to 15	from 70 to 95
cold to the foot	over 15	over 95

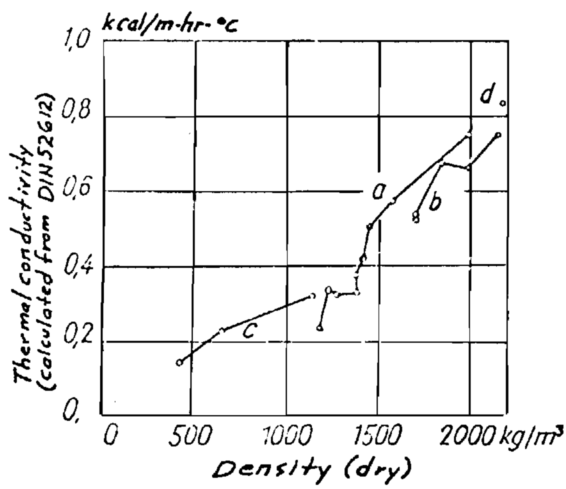

Fig. 1

Calculation values of the thermal conductivity (from DIN 52612) of various toppings as dependent on density (based on hot-plate measurements)

a - gas, foam and pumice concrete toppings, cement toppings
b - gypsum and anhydrate toppings
c - wood concrete toppings
d - asphalt toppings

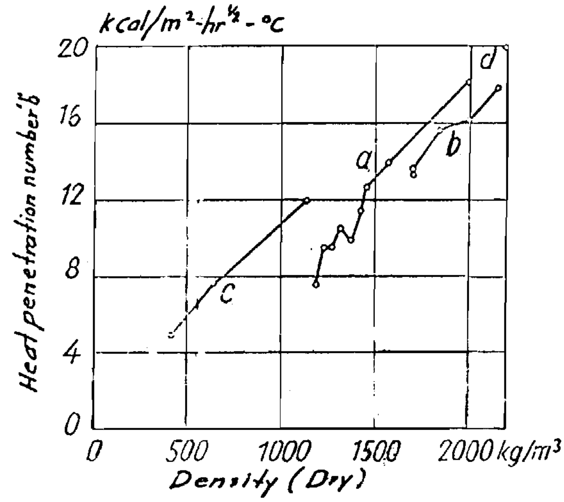

Fig. 2

Heat penetration numbers of various materials as dependent on density

a - gas, foam and pumice concrete toppings, cement toppings
b - gypsum and anhydrate toppings
c - wood concrete toppings
d - asphalt toppings

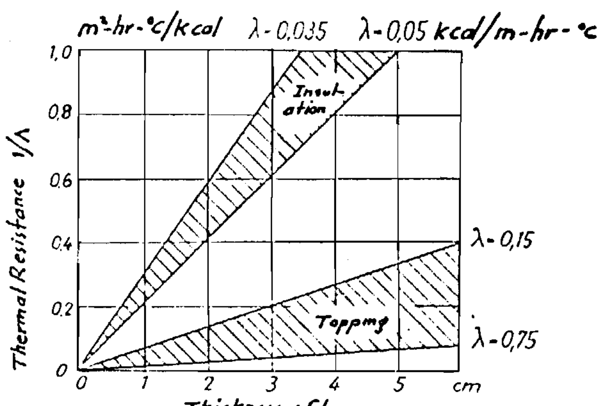

Fig. 3

Thermal resistance $\frac{1}{\Lambda}$ of toppings and insulation layers as dependent on thickness

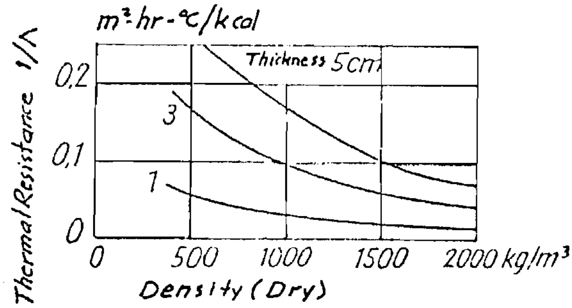

Fig. 4

Thermal resistance $\frac{1}{\Lambda}$ of toppings of varying thickness as dependent on density (for thermal conductivity of the toppings see Fig. 1)

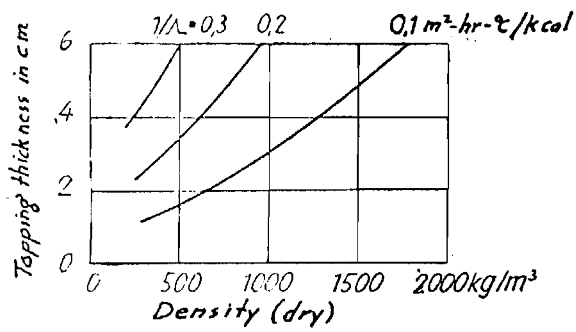

Fig. 5

The topping thickness necessary to obtain a given thermal resistance as dependent on the density

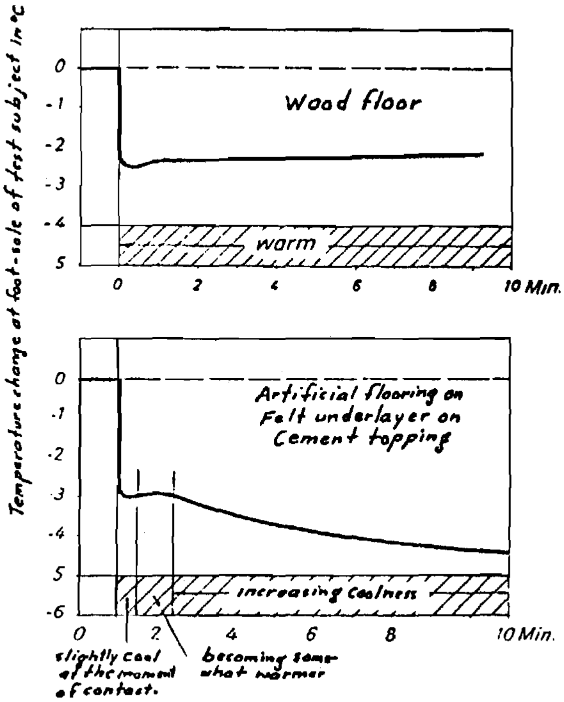

Fig. 6

Heat dissipation curves of various floors (skin temperature on the ball of the foot standing on the floor from the moment of contact) and subjective sensation

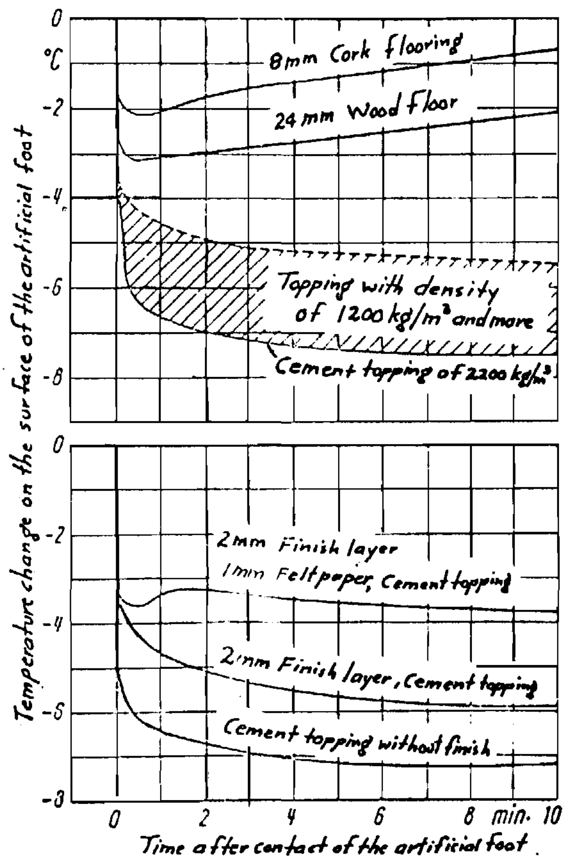

Fig. 7

Heat dissipation curves for floors as determined with the artificial foot according to Schüle

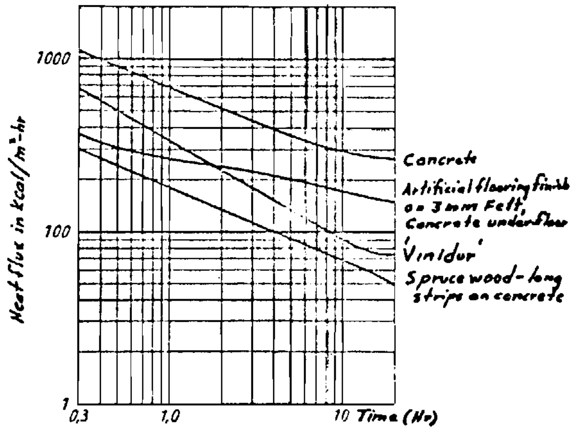

Fig. 8

Heat dissipation of various floors (heat flux between foot and floor as dependent on contact duration) according to Cammerer

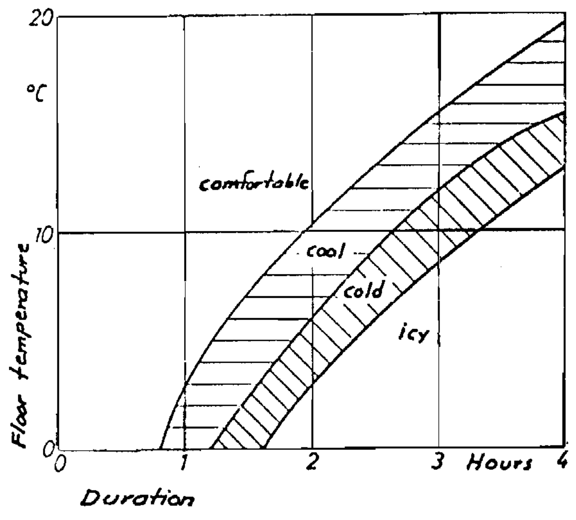

Fig. 9

Comfort sensations with a clothed foot in a room at 20°C air temperature as dependent on floor temperature and duration according to Frank

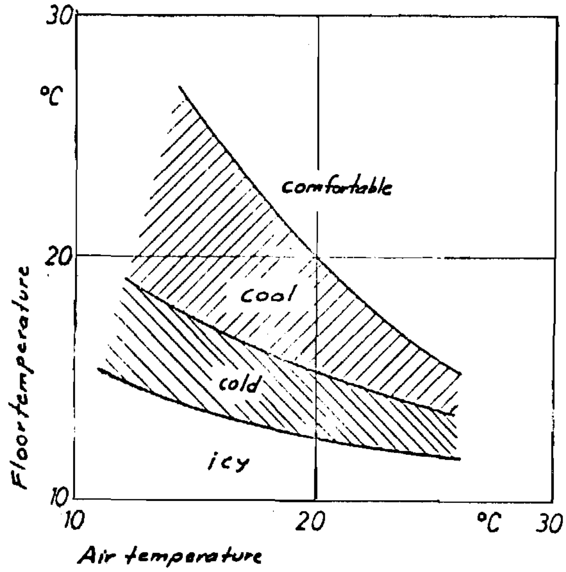

Fig. 10

Relationship between floor temperature and air temperature for various comfort sensations for a duration of four hours, according to Frank

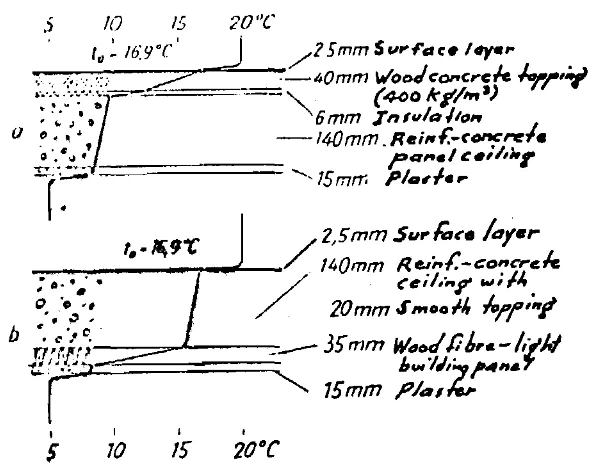

Fig. 11

Partition construction of various arrangements with the same thermal resistance

a - insulation layers arranged on the upper side
b - insulation layers arranged on the lower side

The lines on the diagram give the temperature distributions in the partition in the steady state. Air temperature above the partition of 20°C and under the partition of 5°C. t_o: floor surface temperature

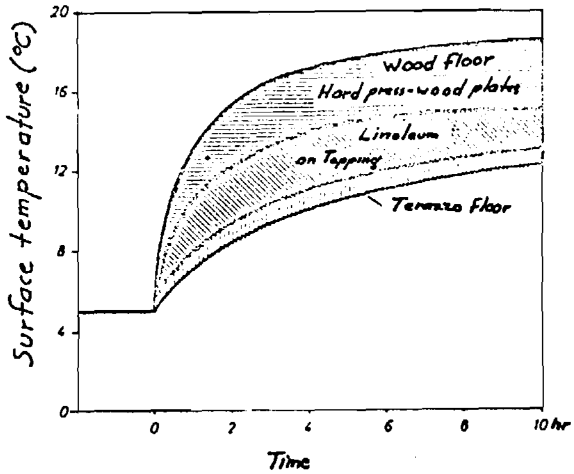

Fig. 12

Range of surface temperature of various floors as dependent on the time from the beginning of heating (heating method: iron stove)

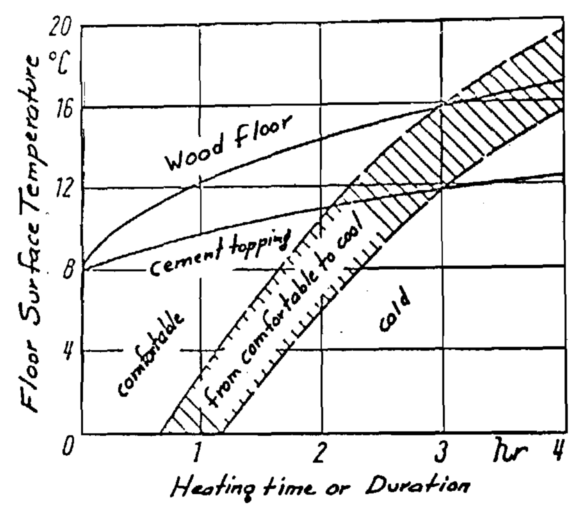

Fig. 13

Surface temperature of a wood floor and a cement topping as dependent on the time after the beginning of heating and on the foot comfort sensations

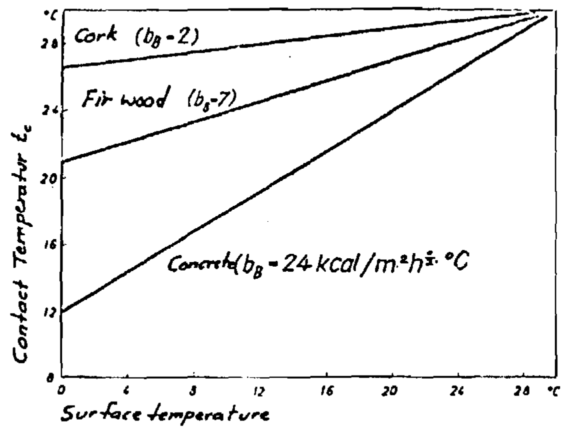

Fig. 14

The contact temperature t_c which occurs during contact of the human foot (foot temperature T_F = 30°C, heat penetration number of the foot b_F = 16 kcal/m^2-$hr^{\frac{1}{2}}$-°C) with various materials (b_M) as dependent on the surface temperature T_M of the material

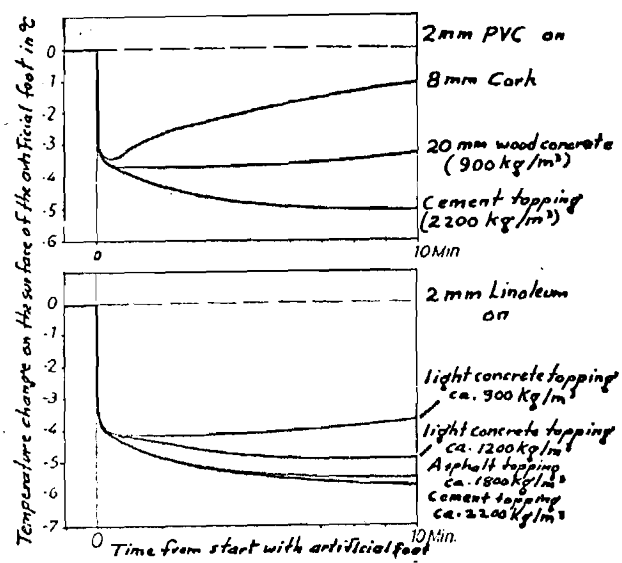

Fig. 15

Heat dissipation curves of thin surface floorings on various under-floorings