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A NEW METHOD OF CALCULATING THE THERMAL CONDITION AND REFRIGERATION LOAD OF A ROOM BY PERIODIC STEADY STATE CONDITIONS

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A NEW METHOD OF CALCULATING THE THERMAL CONDITION AND REFRIGERATION LOAD OF A ROOM BY PERIODIC STEADY STATE CONDITIONS

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Nouvelle méthode de calcul des conditions d'ambiance dans un local et de son bilan thermique en régime périodique stable

RÉSUMÉ : *La principale difficulté du maintien de la température à l'intérieur d'une chambre et du calcul de son bilan thermique, est de déterminer convenablement les rentrées de chaleur par les parois.*

À cette fin, les AA. exposent une méthode substituant aux murs de la chambre des murs « équivalents », constitués par un seul matériau homogène.

Le béton a été choisi pour l'étude du mur « équivalent ».

Deux parois sont thermiquement équivalentes quand la température de leurs faces internes a la même valeur, atteinte sensiblement avec le même décalage de temps pour les mêmes fluctuations de l'ambiance appliquées sur leur face externe. L'amplitude et la période de la sinusoïde sont seules prises en compte.

L'épaisseur de paroi équivalente en béton a été calculée par méthode analogique pour un certain nombre de parois usuelles (murs, plafonds et planchers).

Le bilan thermique d'une chambre est obtenu en additionnant les différentes charges thermiques; les apports dus au rayonnement solaire, à l'éclairage et au personnel sont calculés séparément pour être finalement ajoutés heure par heure pendant les 24 heures *d'une journée.*

INTRODUCTION

The calculation of the non-steady state, thermal behaviour of a room is difficult and demands highly developed methods of calculation which are not immediately available to everyone. Various well-known approximative methods exist for the calculation of cooling load and surface temperatures, but these are either too difficult to use or so simplified that the results deviate too much from the truth. One of the most accurate methods for determining the non-steady state thermal behaviour of a room is the use of a RC-network analog computer, and this has been employed in developing the method of calculation described here. The purpose of this method is that it should be readily available and easy to use and at the same time take into account the heat storage of the room in such a way that the results calculated approximate very closely those obtained by means of a RC-network analog computer [1].

Many factors, such as the building materials, the dimensions, the ventilation rate and the type of heat input, its magnitude, duration hour, etc., which are involved in the calculations, make numerous combinations possible. A reduction in the number of combinations is obtained partly by using the superposition principle, and partly by converting the given room to a thermally equivalent standard room, which has the same thermal properties and for which the effect of the various driving functions is known.

APPLICATION OF THE SUPERPOSITION THEOREM

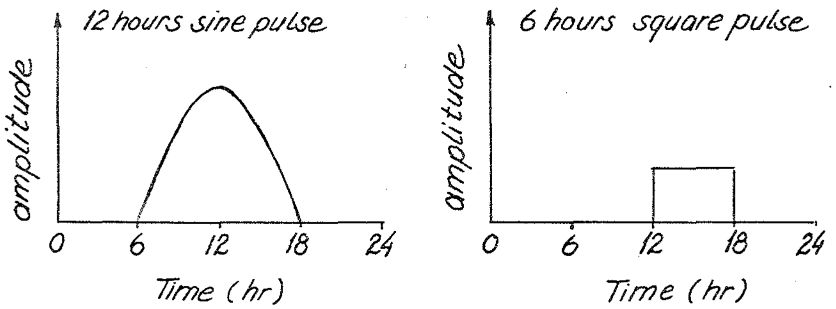
If we assume that the driving functions are steady periodic (24 hr period) the heat storage of the room enclosure can be neglected and the mean temperature of the room air can be calculated from the expression:

$$\vartheta_{a,m} = \frac{A \cdot \vartheta_{o,m} + B \cdot \vartheta_c + C \cdot \vartheta_{v,m} + Q/24}{A+B+C} \qquad (1)$$

where

$\vartheta_{o,m}$ is the 24-hour mean temperature of the outdoor air;
$\vartheta_{v,m}$ is the 24-hour mean temperature of the ventilation air;
ϑ_c is the 24-hour mean temperature in the corridor;
A is the sum of U-value × area of outer walls;
B is the sum of U-value × area of the corridor;
C is the quantity of ventilation air × specific heat;
Q is the 24-hour total heat load from solar radiation, lighting, people, machines, etc.

Two different forms of driving functions are used, i.e., a sine pulse and a square pulse of varying duration and repeated every 24 hours (figs. 1 and 2). The sine pulse is used as driving function for solar radiation and is usually made up of two pulses, one for diffuse radiation and one for direct radiation. The square pulse is used as driving function for the heat load from lighting, people, machines, etc.



Figs. 1 and 2 — Examples of the two types of heat gain driving functions.

Ventilation

The ventilation rate is one of the important parameters in the calculation. If we assume that the ventilation air is perfectly and momentarily mixed with the room air, the significant quantity is the ratio, V/A, of the volume of the ventilation air over the area of the room enclosure. The calculations are carried out for a selected number of values of this ratio.

The equivalent room

The effect of the various driving functions depends largely on the construction and the heat storage of the room envelope elements (wall, floor, ceiling, etc.). In order to reduce the number of all these combinations, the equivalent walls for various known wall constructions have to be found by means of a RC-network analog computer. A standard room is considered where all six "walls" are equal, and all surrounded by rooms with the same temperature variations as in the standard room. The "walls" are homogeneous and consist of a material with $\gamma = 2\,300$ kg/m³,

$\lambda = 1.7$ W/m°C, $c = 0.92$ kJ/kg°C (concrete). For a given driving function, e.g. a sine pulse of 12-hours duration with a maximum intensity of 20 W/m² and a ventilation ratio V/A = 1.5, the amplitude and the phase lag for the room air, and the

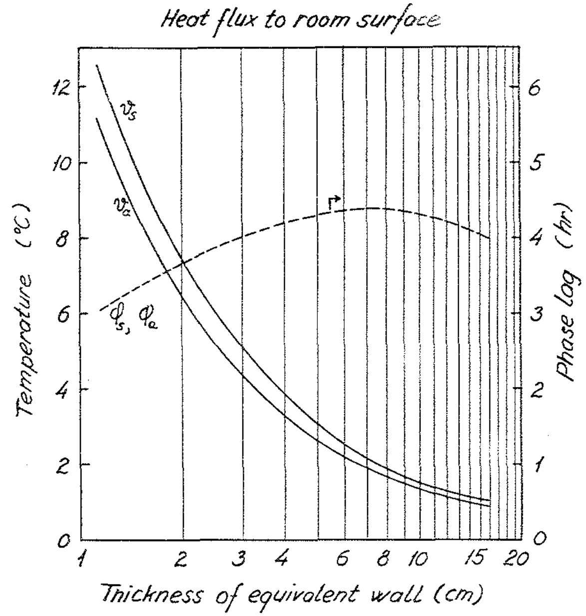


Fig. 3

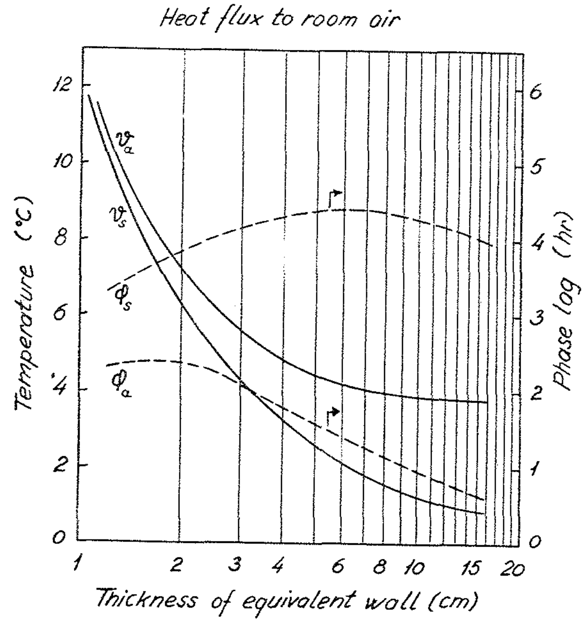


Fig. 4

Figs. 3 and 4 — Amplitude of room air temperature (ϑ_a) and surface temperature (ϑ_s) of a standard room (V/A = 1.5) for a sine pulse heat flux as driving function, period 12 hr and 20 W/m² amplitude.

surface temperature for rooms with different wall thicknesses, are found (fig. 3). The heat flux can be supplied to the room in two different ways, either directly to the room air or to the wall surface. The results are shown in figures 3 and 4, and the difference is clearly seen. Figure 5 shows the 24-hour oscillation for a room with respectively 1.2 cm and 16 cm thick walls. The amplitude of the oscillation in the light room is significantly greater than in the heavy room. In figure 6, the two curves are drawn with the same amplitude, and it will be seen that the relative oscillation, apart from the phase lag, is almost independent of the wall thickness. (For short pulses of, for example, 4 hours, the deviation is somewhat greater.)

If all the concrete walls in the standard room are replaced by a given wall construction (homogeneous or unhomogeneous) and the same driving function is applied,

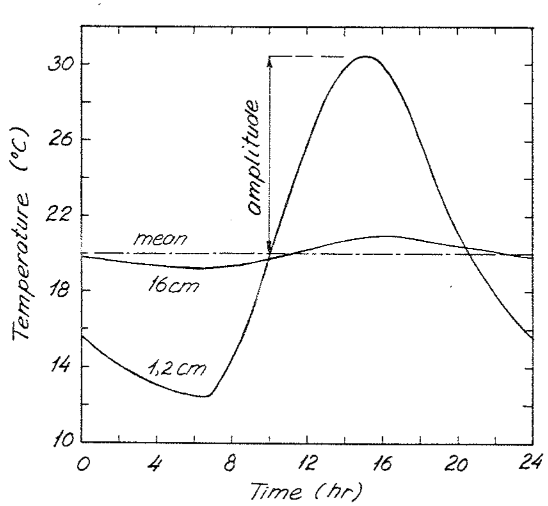


Fig. 5 — The 24-hour oscillation of the room air temperatures for a room with respectively 1.2 cm and 16 cm thick concrete walls.

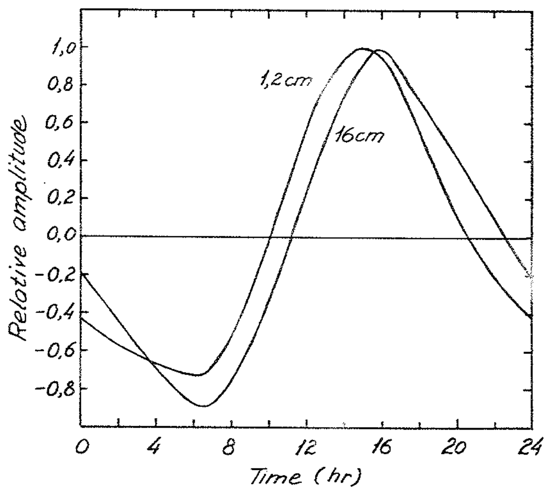


Fig. 6 — The relative amplitude corresponding to the room air temperatures on figure 5.

it is possible, by comparing the amplitude of the given wall with those of the concrete walls, to find from figures 3 and 4 the concrete wall thickness which gives the same amplitude. In this case the two walls are said to be amplitude-equivalent [2]. When an

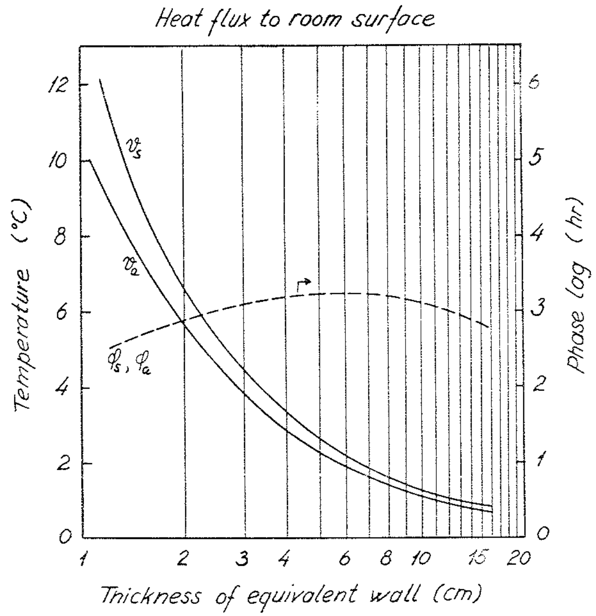


Fig. 7

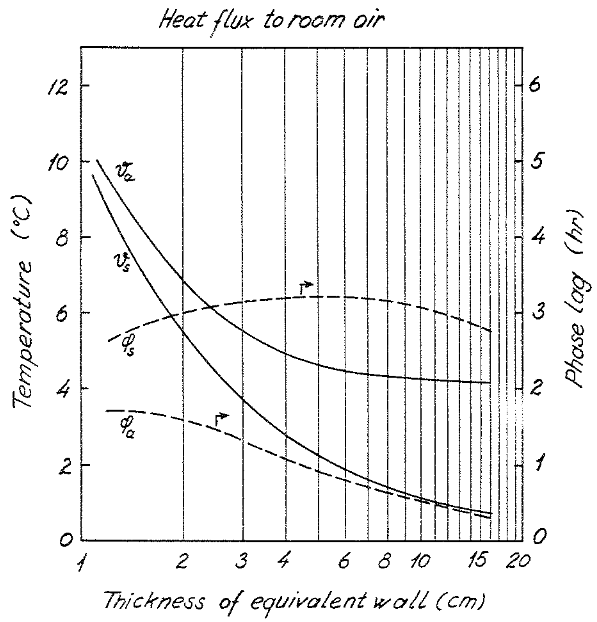


Fig. 8

Figs. 7 and 8 — Amplitude of room air temperature (ϑ_a) and surface temperature (ϑ_s) of a standard room (V/A = 1.5) for a sine pulse heat flux as driving functioh, period 8 hr and 20 W/m² amplitude.

investigation is then made as to how great the difference in phase lag is between the given wall and the concrete wall, it will be seen to be between 0 and 0.7 hours, depending somewhat on the type of wall. This difference is so small that it can be neglected.

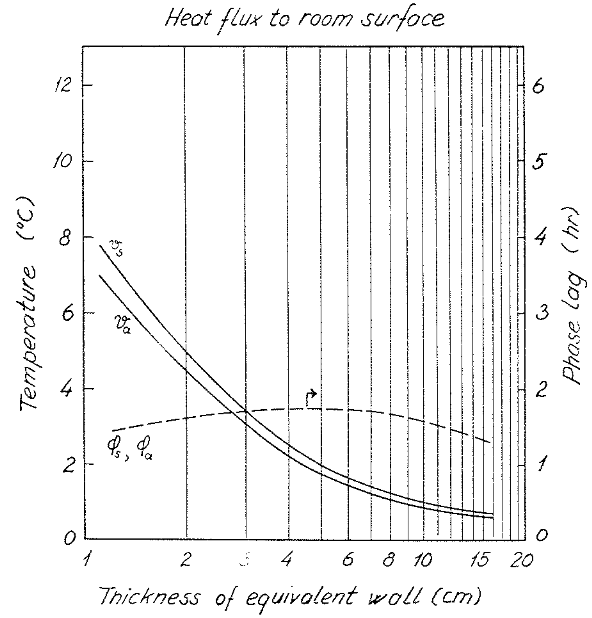


Fig. 9

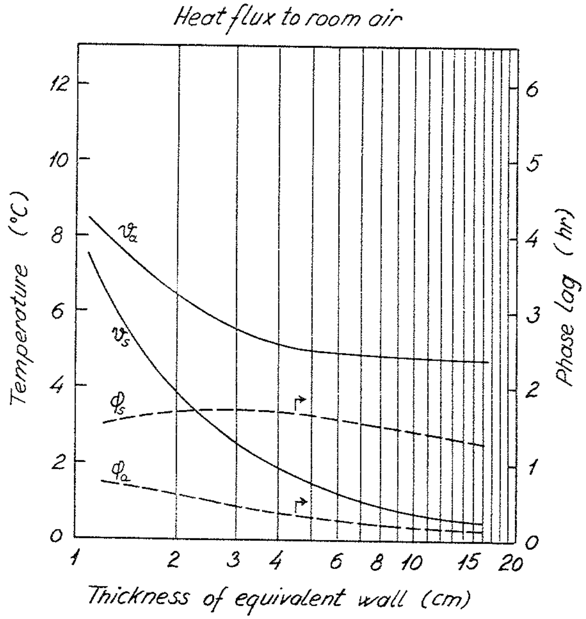


Fig. 10

Figs. 9 and 10 — Amplitude of room air temperature (ϑ_a) and surface temperature (ϑ_s) of a standard room (V/A = 1.5) for a sine pulse heat flux as driving function, period 4 hr and 20 W/m² amplitude.

Table

EXAMPLES OF THE EQUIVALENT WALLS CORRESPONDING TO DIFFERENT PARTITION WALLS

2×9 mm gypsum board 6 cm insulation 2×9 mm gypsum board	→ 1.5 cm equiv. wall
18 mm laminated wood framed partition wall with 6 cm insulation 18 mm laminated wood	→ 2.5 cm equiv. wall
11 cm lightweight concrete	→ 3.2 cm equiv. wall
11 cm brick wall	→ 6.4 cm equiv. wall

The curves giving the amplitude and phase lag are dependent on the form and duration of the heat flow. This can be seen by comparing figures 7, 8, 9 and 10, which show the effect of an 8-hour and a 4-hour sine pulse, with figures 3 and 4, where the input was a 12-hour sine pulse.

DISTRIBUTION OF THE HEAT STORAGE

Another important factor in the thermal behaviour of the room is the distribution of the heat storage on the different walls. A room where half of the walls consists of 12 cm concrete and the other half of 2.4 cm, will have an amplitude of the 24-hour oscillation which is 10% greater than if the heat storage had been evenly distributed corresponding to 7.2 cm concrete for all six walls. On figure 11 are shown some examples.

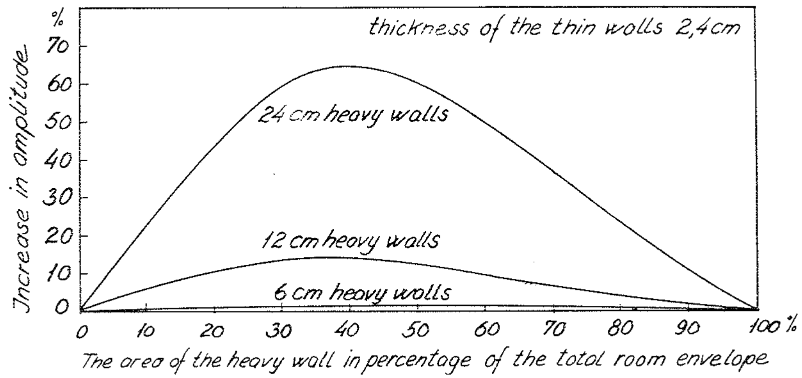


Fig. 11 — Example of the correction when heat storage is not evenly distributed over the surfaces.

COOLING LOAD

When the final 24-hour oscillation has been determined from the individual contributions, one can calculate the cooling load required to bring the temperature down to a desired level. The same curves are used as in the determination of the effect of the heat flux, but with opposite signs. On the basis of the 24-hour mean temperature desired, the 24-hour cooling load can be calculated. The maximum cooling load can be found indirectly by estimating, from a knowledge of the total heat gain, the form which the cooling load should have, e.g. 4, 6, 8, or 12-hours sine pulse or square pulse.

In the same manner as with contributions from the sun, light, persons, etc., the effect of the estimated cooling on the 24-hour oscillation is now calculated. If this deviates from that desired, the procedure must be repeated. As the calculation is very simple, the correct cooling load can quickly be found.

Summary of procedure

In order to make the calculations, it is necessary to have:

A. A table giving the thickness of equivalent walls for various wall, ceiling and floor constructions.

B. For various pulses with varying form and duration, curves for the amplitude and the phase lag as a function of the equivalent thickness, when the heat flux is supplied partly to the room air and partly to the wall surfaces.

C. A table for the relative 24-hour oscillation for each pulse.

D. Curves for the correction to be made when the heat storage is not evenly distributed over the room envelope.

Calculation of the room air temperature.

1. The 24-hour mean temperature is calculated from equation (1).
2. The thickness of the equivalent concrete walls for the actual walls, ceiling and floor are determined by means of a table from which the mean wall thickness for the whole room is calculated.
3. The ratio of the volume of the ventilation air over the area of the room enclosure is calculated.
4. The contribution of the various heat gains to the 24-hour oscillation is calculated, the relative 24-hour oscillation being determined from a table and the values multiplied by the maximum amplitude, after it has been corrected for an uneven distribution of the heat storage.
5. The final room air temperature is obtained by summation of the 24-hour mean temperature and the individual contributions.

Calculation of the cooling load.

1. The 24-hour mean temperature for the room air with the desired maximum value is calculated, and the 24-hour cooling load is calculated from equation (1).
2. The form of the cooling load is estimated and the corresponding maximum amplitude is calculated.
3. The effect of the cooling load is calculated according to point 4 above.
4. The final room air temperature is obtained by summation of the new 24-hour mean temperature and the individual contributions and is compared with that desired.

REFERENCES

[1] V. Korsgaard and Hans Lund, A large passive-electrical computer specially designed to compute the non-steady heating and cooling loads of rooms or buildings. Paper 63 IVB, World Power Conference, Lausanne, 1964.

[2] V. Korsgaard, Thermal equivalent outer walls. *Ingeniøren*, nr. 11, 1961 (in Danish).

[3] V. Korsgaard, Thermal and electrical models for solving problems of non-stationary heat transfer through walls. Commissions II & VI, International Institute of Refrigeration, Liège, 1969.

COMMENTAIRE

The equivalent concrete wall thickness to a given multilayer wall is practically independent of the frequency for oscillating times of 1 to 24 hours. It shall be pointed out that the equivalent thickness is dependent on whether the driving function is applied to the inside or outside face.