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Theme III b c d

HEAT TRANSMISSION THROUGH TEST WALLS OF AUTOCLAVED CELLULAR CONCRETE

By

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A study of the heat transmission through walls of autoclaved cellular concrete has been carried out by the Norwegian Building Research Institute in the wall laboratory in Trondheim. The measurements which also include other types of lightweight concrete walls were started 2½ years ago and are still going on. In the following will be given an account of the results from the first two years measurements.

1. Description of the test panels, etc.

The test panels, about 3 m high and 1.5 m wide, have been built up in the wall laboratory. There are 8 test panels of autoclaved cellular concrete, four facing east and four facing west. *Fig. 1* shows a plan of the test rooms II and III with the 8 panels and a vertical section through a test room.

The thickness of the cellular concrete is the same (0.25 m) for all the walls. Two opposite walls except panel no. 3 and no. 18 are always of the same material and are also equal with respect to the joints and to the inner surface treatment. The treatment of the outer surface is, however, different. The joints and the surface treatment are in accordance with directions given by the manufacturers of the various materials. A description of the walls is given in the following.

Test panel number and exposure.		Material denomination	Dimensions in m, width × height. Thickness is 0.25 m	Bulk density of dry material in kgs/cub.m.
East	West			
3 E	18 W	Blocks	0.50 × 0.25	510
4 E	17 W	Reinforced elements	0.50 × 3.00	550
5 E	16 W	Blocks	0.50 × 0.25	520
6 E	15 W	Staves	1.00 × 0.15	470

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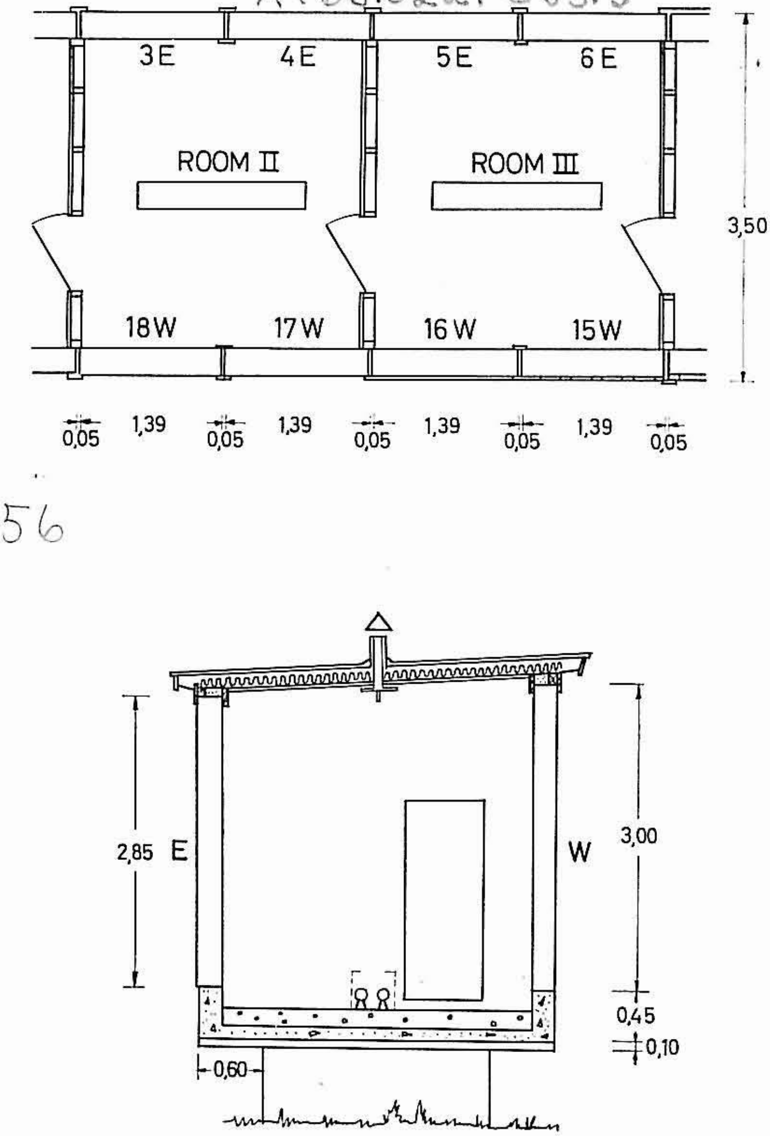


Fig. 1. Plan of the test rooms II and III with the test panels of autoclaved cellular concrete.

Mortar joints.

3 E	18 W	The thickness of both the horizontal and vertical joints is 8 mm. By 18 W the joints are completely filled with an activated lime-cement mortar, C:L:S = 1:1:9 by the volume, whilst 3 E has two separated strings of the same mortar.
4 E	17 W	Vertical joints only. An activated cement mortar C:S = 1:2.5 is poured into a cylindrical space in the interfaces between the elements.
5 E	16 W	The thickness of both the horizontal and vertical joints is 2—3 mm. The joints are filled with a special mortar, delivered by the manufacturer of the wall material. Informations about the composition of the mortar not available.
6 E	15 W	The staves are glued with a special cement glue, delivered by the manufacturer of the wall material. Informations about the composition of the glue not available.

Inside surface treatment.

3 E, 18 W, 6 E, 15 W	Factory made thin plaster on gypsum base. Average thickness about 3 mm. Smaller variations in the thickness.
4 E, 17 W, 5 E, 16 W	Factory made thin plaster on cement base. Average thickness about 3 mm. Smaller variations in the thickness.

Outside surface treatment.

6 of the test panels are rendered on the outside while two of them have a cement-asbestos cladding. There are three main types of renderings called:

1. Normal rendering. Thickness approximately 10 mm.
2. Thin rendering (factory made). Thickness 3—6 mm.
3. Paint type rendering (factory made). Thickness approximately 1 mm.

Panel no. 3.	Thin backing coat of cement mortar C:S = 1:3 (by the volume), activated. Main coat of lime-cement mortar C:L:S = 1:1:9 (by the volume), activated, and one coat of cement paint.
Panel no. 4.	Paint type rendering 2 coats.

Panel no. 5.	As panel no. 3.
Panel no. 6.	Paint type rendering 2 coats.
Panel no. 15.	Building paper (vapour permeability approx. 3.0 g/m²h mm Hg) with overlap joints under vertical 1″×4″ boards, center to center distance 0.30 m. Cement-asbestos cladding.
Panel no. 16.	As panel no. 15 but with 1″×2″ horizontal battens instead of vertical boards.
Panel no. 17.	Paint type rendering 2 coats.
Panel no. 18.	Thin rendering 2 coats.

The building paper used on the outside surface on the panels no. 15 and no. 16 is impregnated but has a very high vapour diffusance 3.0 g/m^2h mm Hg compared with approx. 10.0 g/m^2h mm Hg for an air space of 10 mm thickness. The air ducts between the vertical boards (panel no. 15) are open below and are in direct communication with the outside air. The top openings of the ducts are protected by horizontal boards.

The walls were built up in Aug.—Sept. 1957 and to ensure a workmanship that would correspond to practice, the construction of the walls was left to a mason contractor, but of course under supervision by people from the laboratory. Special care had to be taken to get a smooth and plane inside wall surface to procure a good underlayer for the heat flow meters.

The test rooms are as shown in *fig. 1* about 3×3 m^2 with four test panels in each room. In the middle of the floor are two tubular heaters, one of which is normally switched on a fixed load, while the other one is controlled by thermostat. On both sides of the heaters are placed double screens of aluminium foils to prevent a too strong radiation against the walls. In each room there is also equipment for control of the humidity.

2. Heat flow and temperature measurements

The heat flow through the walls is measured by heat flow meters placed at midheight on the inner wall surface. A proper thermal contact between the heat flow meter and the wall surface is obtained by using a very thin soft cloth under the meter plates and by pressing the heat flow meters firmly against the walls by means of special arrangements of springloaded wooden pins. The thin cloth under the heat flow meters also serves to prevent a downfalling air flow which was otherwise likely to occur even in narrow spaces between the meter plates and the wall surface. The thermal resistance of the heat flow meters, cloth included, is 0.05 m²h° C/kcal.

Each heat flow meter is recorded 16—17 times per day by means of recording potentiometers. This is also done for all temperatures measured either by thermocouples or resistance thermometers. For the daily control, all room temperatures are read from mercury thermometers. A meteorological screen equipped for measuring the humidity of the air, maximum and minimum temperatures, etc., is placed outside the wall laboratory. The reference junction for the outside air temperature is placed in this screen, whilst the reference junction for the room temperature is placed 0.25 m from wall surface at midheight. The vertical precipitation and the amount of driving rain are recorded daily. The wind velocity is recorded continuously (1).

3. Moisture determinations

When the walls were built up, moisture samples were taken from the blocks, staves etc. These samples were also used to determine the dry state bulk density of the various materials. Later on, determinations of the moisture content in the walls were taken at regular intervals by boring out samples of the wall material at three different heights. To find the distribution of the moisture content, the 0.25 m long cores are cut into 5 pieces and dried in an oven. In order not to damage the wall where the heat flow measurements are done, the moisture samples are not taken from the middle part of the walls but about 0.25 m from the vertical edges of the panels.

4. Evaluation of the heat transmittance coefficients and the apparent heat conductivity of the wall material

The heat transmittance coefficient U is computed from the average heat flow and air to air temperature difference for the whole measuring period, i. e. for the period from the middle of November till the end of April. The corresponding expression for the heat transmittance coefficient is

$$U = \frac{1}{\dfrac{\sum\limits_{o}^{n} (t_{ia} - t_{oa})}{\sum\limits_{o}^{n} Q} - R_h} \text{ kcal/m}^2\text{h °C} \qquad (1)$$

The term $t_{ia} - t_{oa}$ is the difference between the inside and outside air temperature (°C). Q is the heat flow (kcal/m²h) and R_h is the thermal resistance (m²h° C/kcal) of the heat flow meters. n gives the number of observations. For the whole measuring period n will be about 2500.

In order to calculate the apparent or equivalent heat conductivity of the wall materials it would in some respect be an advantage to measure the wall surface temperature (2) and compute the conductivity k from the formula

$$k = d \cdot \frac{\sum\limits_{o}^{n} Q}{\sum\limits_{o}^{n} t_{is} - t_{os}} \text{ kcal/mh° C} \qquad (2)$$

where the term $t_{is} - t_{os}$ is the difference between inside and outside surface temperature d is the thickness of the cellular concrete. It was, however, found to be difficult to measure the correct mean surface temperature because of the influence of the joints and the heat conductivity is therefore calculated from the formula

$$\frac{d}{k} = \frac{1}{U} - (R_i + R_o + R_p + R_r + R_c) \qquad (3)$$

R_i, $R_o = \dfrac{1}{\alpha_i}, \dfrac{1}{\alpha_o}$ = the inside resp. outside surface resistance.

R_p, R_r, R_c, thermal resistance of plastering, rendering and cladding.

$$k = \frac{d}{\dfrac{\partial t_{ma}}{Q_m} - \Sigma R} \text{ kcal/m h° C} \qquad (4)$$

where Q_m is the mean heat flow and ∂t_{ma} is the mean air to air temperature found for the whole period.

$$Q_m = \frac{1}{n} \sum_{o}^{n} Q$$

$$\partial t_{ma} = \frac{1}{n} \sum_{o}^{n} t_{ia} - t_{oa}$$

$$\Sigma R = R_i + R_o + R_h + R_p + R_r + R_c$$

Formula 4 yields the general expression for the apparent heat conductivity of the wall material.

For the panels without cladding ($R_c = 0$) the conductivity is

$$k = \frac{0.25}{\dfrac{\partial t_{ma}}{Q_m} - 0.25 - (R_p + R_r)} \text{ kcal/m h° C} \qquad (5)$$

$$R_i + R_o = 0.20 \text{ m}^2 \text{ h° C/kcal}, \; R_h = 0.05 \text{ m}^2 \text{ h° C/kcal}$$

$$d = 0.25 \text{ m.}$$

For most of the walls the thermal resistance of the plastering and rendering is negligible ($R_p + R_r = 0$) and k is given by the formula

$$k = \frac{1}{4 \cdot \dfrac{\partial t_{ma}}{Q_m} - 1} \text{ kcal/m h° C} \qquad (6)$$

For the panels with cladding ($R_p + R_r = 0$)

$$k = \frac{1}{4\left(\dfrac{\partial t_{ma}}{Q_m} - R_c\right) - 1} \text{ kcal/m h° C} \qquad (7)$$

The weekly values of the heat transmittance coefficients have also been computed, using formula 1. These values vary fairly much from one week to another because of the influence from the thermal capacity of the walls.

5. The measurements 1957/58 and 1958/59

The measurements have been carried out without interruption in the two periods Nov. 1957—May 1958 and Nov. 1958—May 1959.

5.1. Climatic conditions in the test periods

During the winter 1957/58, the room temperature (t_{ia}) was approx. 22° C, see *fig. 2.* The next winter the room temperature was about 20° C. In both periods the relative humidity of the room air was mostly in the range 40—50 %. In some short periods with extraordinary low outside temperature the humidity sank to about 30 %.

In *fig. 2* is also shown the weekly mean values of the outside air temperature (t_{oa}). It will be seen from the graph that the temperature was varying quite much the first winter and that most of the weekly mean values are below 0° C.

Fig. 3 shows the amounts of driving rain from east (R_E) and west (R_W) measured at the wall laboratory. The hatched areas indicate that most of the precipitation has been in form of snow or sleet.

With respect to driving rain the west-faced panels are exposed to a much harder climate than the east-faced ones, as the amount of driving rain against west-faced walls is quite considerable and many times as high as the amount of driving rain from east.

In both periods the weather has been mostly calm and cloudy. The wind speed has on an average been 2—3 m/s, with the dominant wind direction between SW and NW. In *table 1* is given the degree of obscurity of the sky observed every morning at 9.00 a. m.

Table 1

Degree of obscurity	0	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8
Percentage of observations in time interval									
15/11 1957—1/5 1958	18	4	3	4	11	11	10	9	30
1/11 1958—1/5 1959	9	7	4	4	6	4	10	7	49

The greater part of the clear days have been in the late winter.

5.2. Moisture content and moisture distribution in the walls

In *fig. 4, 5* and *6* is shown the moisture content and moisture distribution in the walls. The two upper graphs in *fig. 4* show the variations in the average moisture content (in % by dry weight) for

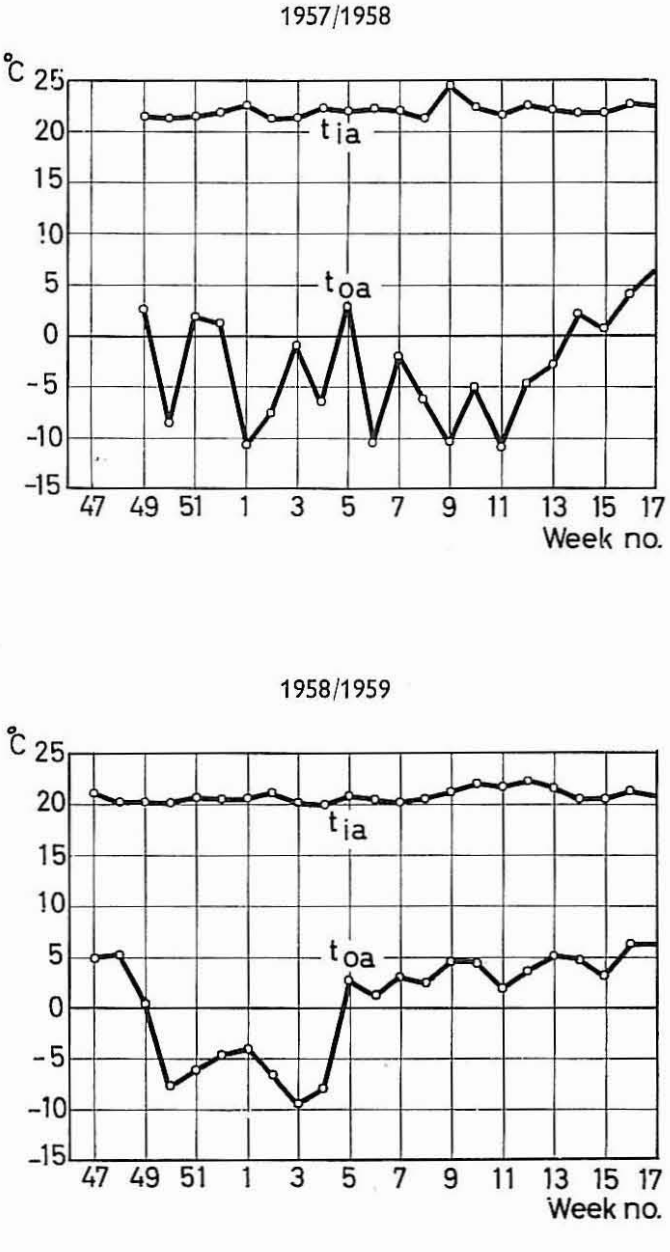
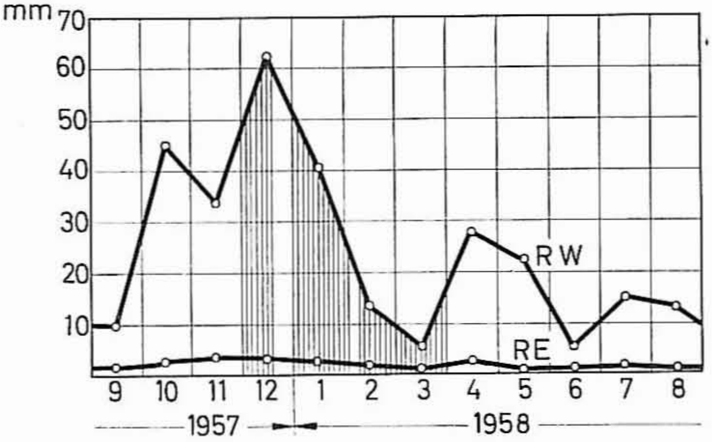


Fig. 2. Weekly mean inside and outside temperature in the measuring periods 1957/58 and 1958/59.



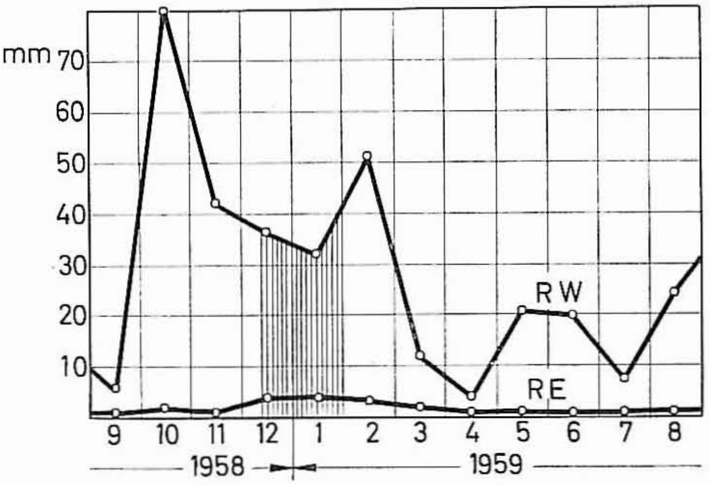


Fig. 3. Driving rain against east- and west-faced test panels, measured at the wall laboratory 1957/1959. Hatched areas indicate periods when the precipitation is mainly snow and sleet.

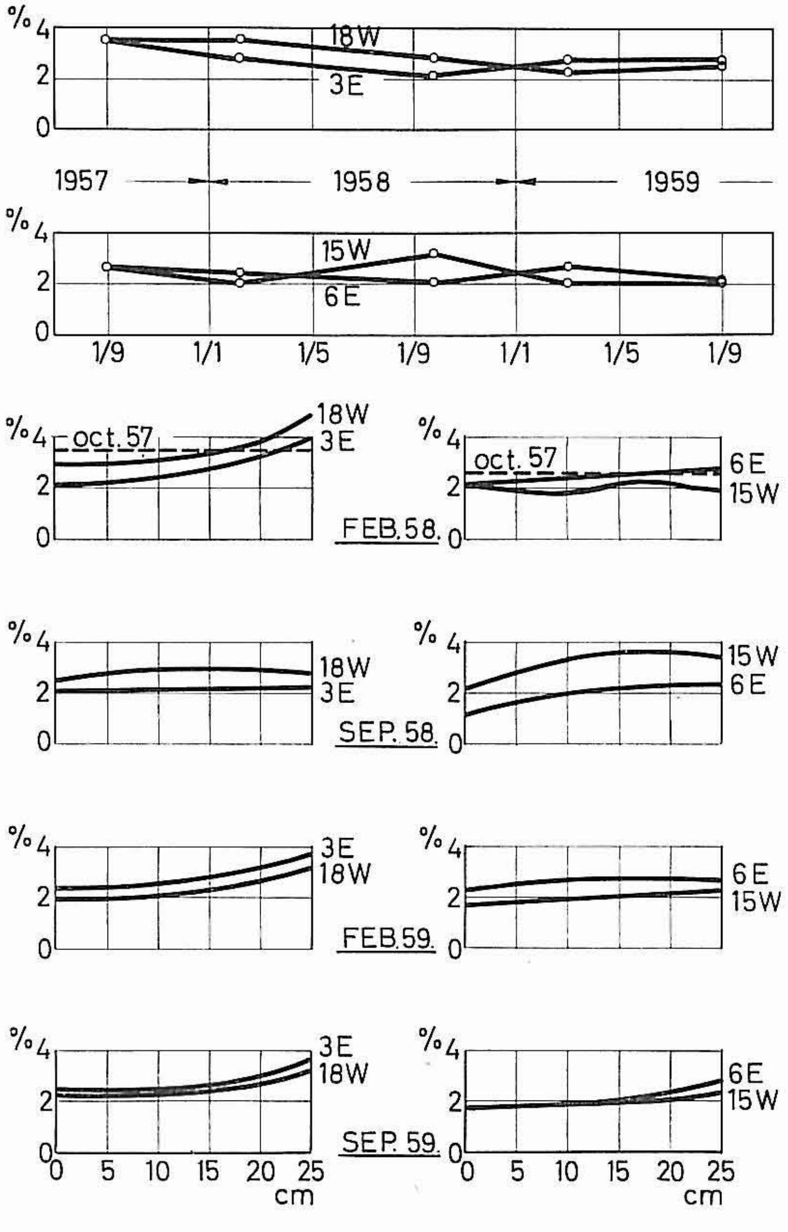


Fig. 4. Average moisture content and moisture distribution in the panels 3 E, 18 W, 5 E and 16 W. Wall thickness reckoned from inside surface.

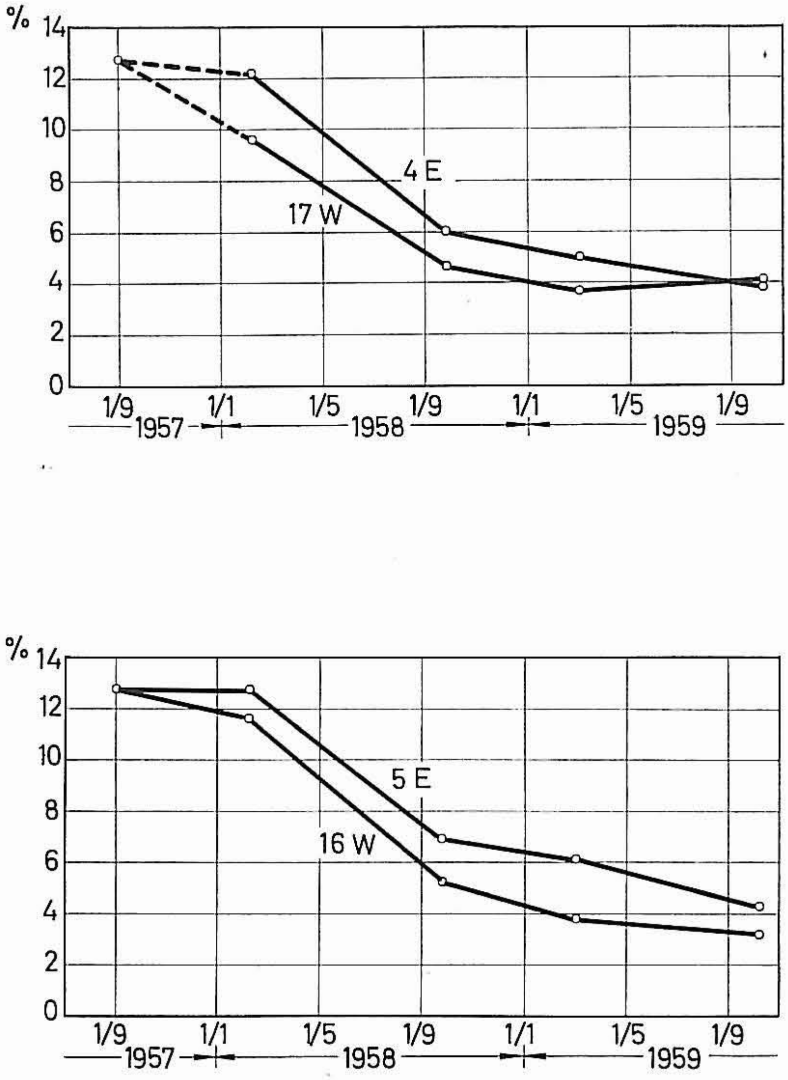


Fig. 5. Average moisture content in the panels 4 E, 17 W, 5 E and 16 W.

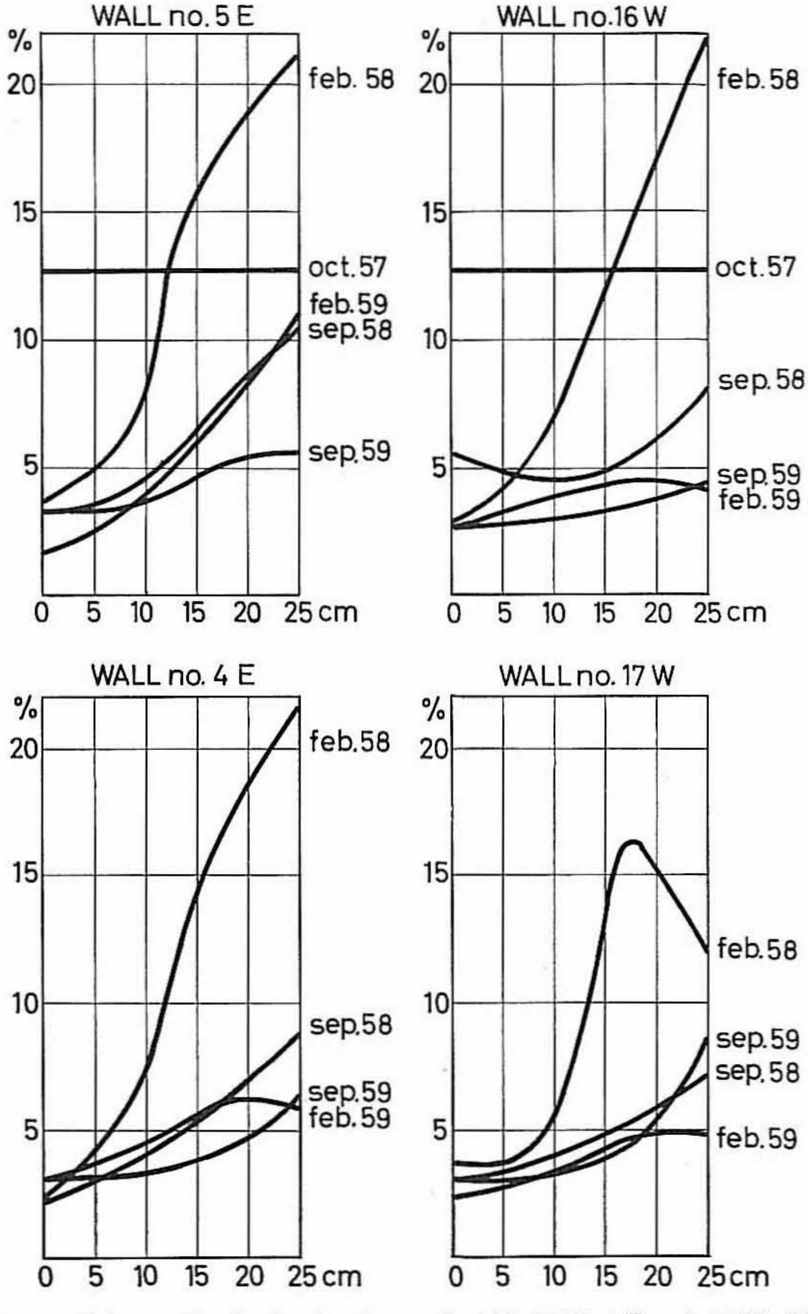


Fig. 6. Moisture distribution in the panels 4 E, 17 W, 5 E and 16 W. Wall thickness reckoned from inside surface.

four test panels which started out with a low moisture content. The graphs below show the moisture distribution through the walls. The wall thickness is reckoned from the inner surface.

It will be noticed that the variations in moisture content are small and that there are no particular signs of moisture accumulation from driving rain or from other sources. The moisture is fairly evenly distributed, but with a small increase towards the outer surface.

Fig. 5 and *6* show the moisture content and its distribution in some walls which started out with a higher moisture content. A redistribution of the moisture takes place the first winter, while the average moisture content is nearly constant. The following summer the walls dry out from an average moisture content of about 12 % in Febr. 1958 to 5 % in September the same year. Later on the walls are still drying out, but now more slowly, and the average moisture content two years after construction is approximately 4 %. All the tests show a distinct increase in moisture content towards the outer wall surface, but no particular signs of accumulation of moisture from rain etc. It may also be noticed that there is hardly any difference in the drying curves for the panel with exterior cladding compared with the panel without cladding.

5.3. Heat transmittance coefficients

In *table 2* are given the heat transmittance coefficients found by the measurements in the two periods.

It will be seen from table 2 that the U-values for the panels 3 E, 18 W, 6 E and 15 W are the same for both periods. These are the panels for which no particular change in moisture content was observed, which is not unexpected as the initial moisture content in these panels can be assumed to be near the hygroscopic state. Panels 4 E, 17 W, 16 W show a reduced heat transmittance in the last period, what may be ascribed to the drier walls. The thermal transmittance value for panel 5 E is however nearly unchanged, although the panel has dried out quite much.

The difference in U-values for panels 18 W and 3 E may be explained by the difference in the mortar joints, as panel 18 W has completely filled joints and panel 3 E has two separated mortar strings. Another difference between those two walls is that panel 18 W is white on the outside and has probably a higher reflectivity to solar radiation than has the greyish outside surface of panel 3 E. This may perhaps count for some of the difference in heat transmittance.

Table 2

Wall no.	1957/58			1958/59				
	U kcal/m²h°C	Moisture content		U kcal/m²h°C	Moisture content		Density of cellular concrete kgs/m³	Remarks
		Oct. 57	Febr. 58		58 Sept.	59 Febr.		
3 E	0.44	3.5	2.8	0.44	2.1	2.7	510	
18 W	0.52	3.5	3.5	0.53	2.8	2.3	510	
4 E	0.50	(12.7)	12.2	0.45	6.0	5.0	550	
17 W	0.48	(12.7)	9.5	0.46	4.6	3.7	550	
5 E	0.51	12.7	12.7	0.50	6.7	6.1	520	
16 W	0.42	12.7	11.6	0.38	5.2	3.8	520	external cladding
6 E	0.40	2.6	2.4	0.40	2.0	2.6	470	
15 W	0.35	2.6	2.0	0.34	3.2	2.0		external cladding

It may of course also be a difference in the wall material or in the moisture content of the wall material just under the heat flow meters. This will be looked after when the panels are torn down.

The U-values for the panels 6 E and 15 W are 0.40 and 0.34 kcal/m²h° C. These panels are of the same construction except to the outside surface, and have the same moisture content. A calculation of the thermal resistance of the external cladding $\left(R_c = \frac{1}{0.34} - \frac{1}{0.40} = 0.44 \text{ m}^2\text{h}^\circ \text{ C/kcal}\right)$ gives a thermal resistance which is higher than expected. Doing the same calculation for the panels 5 E and 16 W gives $R_c = \frac{1}{0.38} - \frac{1}{0.50} = 0.63 \text{ m}^2\text{h}^\circ \text{ C/kcal}$.

This higher value of R_c may be ascribed to the difference in moisture content for the two walls, or there may be other causes.

The weekly mean values of the heat transmittance coefficients are shown in *fig. 7, 8, 9* and *10*. The weekly values are varying quite much due to a capacity effect. Most of the curves in *figs. 7—10* indicate lower heat loss factors in the last part of the period. It is likely to assume this decrease to be related to a change in the outside surface conditions which is caused by a change in the net radiation

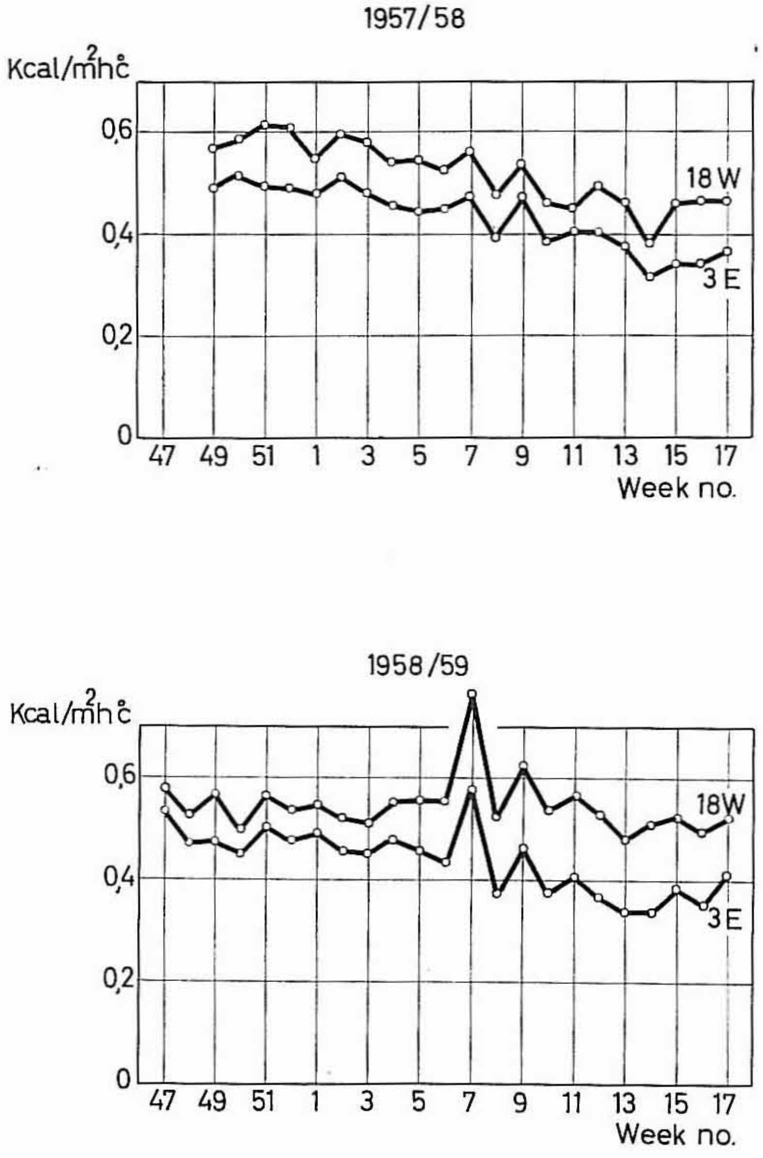


Fig. 7. Weekly mean heat transmittance values for the panels 3 E and 18 W.

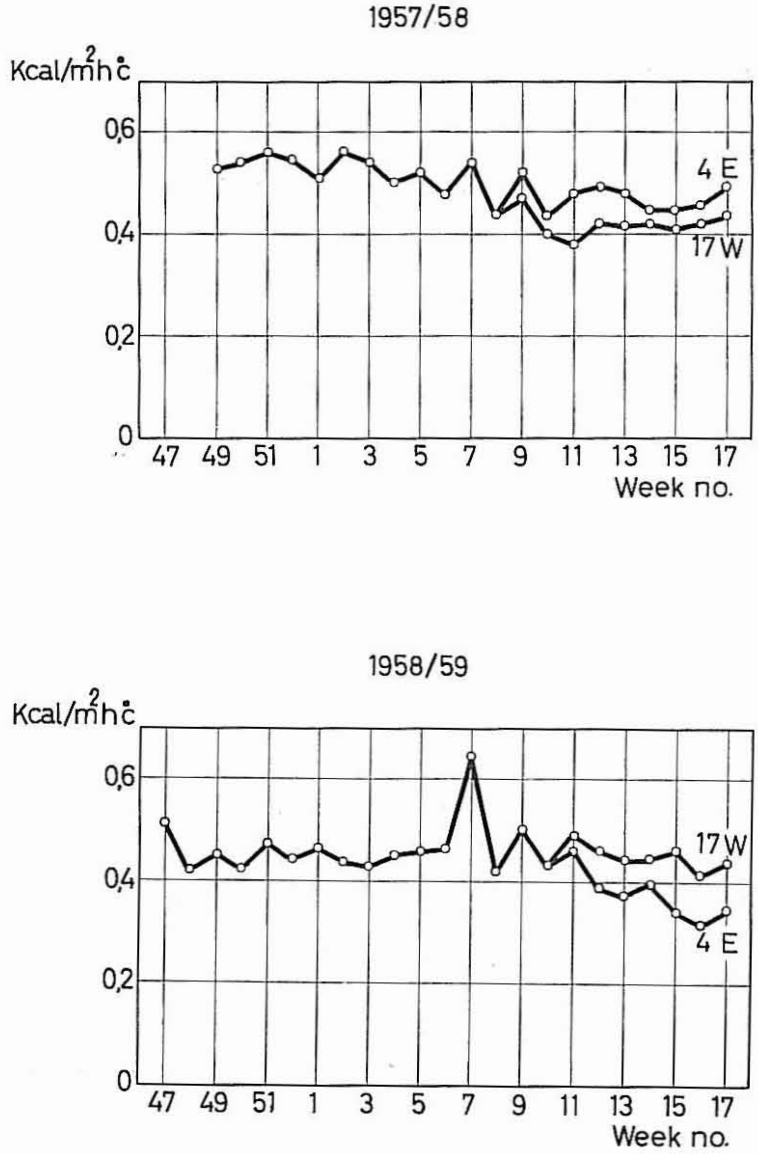


Fig. 8. Weekly mean heat transmittance values for the panels 4 E and 17 W.

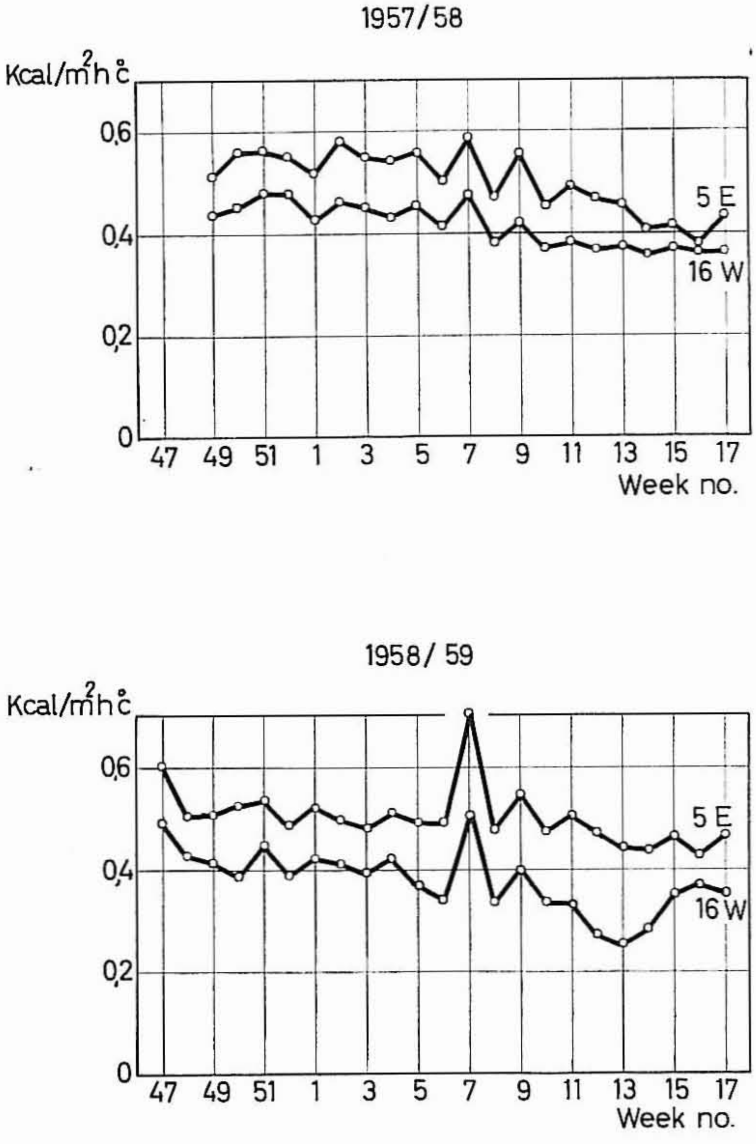
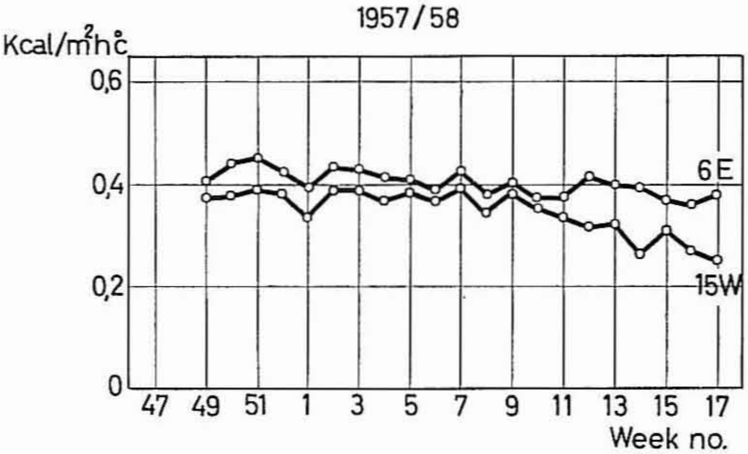


Fig. 9. Weekly mean heat transmittance values for the panels 5 E and 16 W.



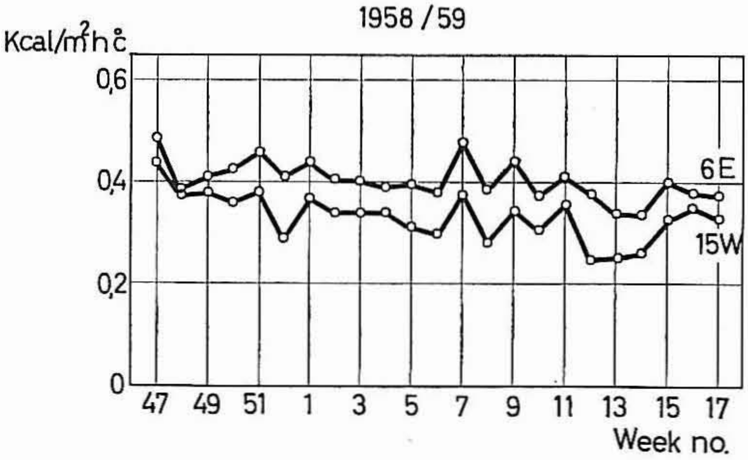


Fig. 10. Weekly mean heat transmittance values for the panels 6 E and 15 W.

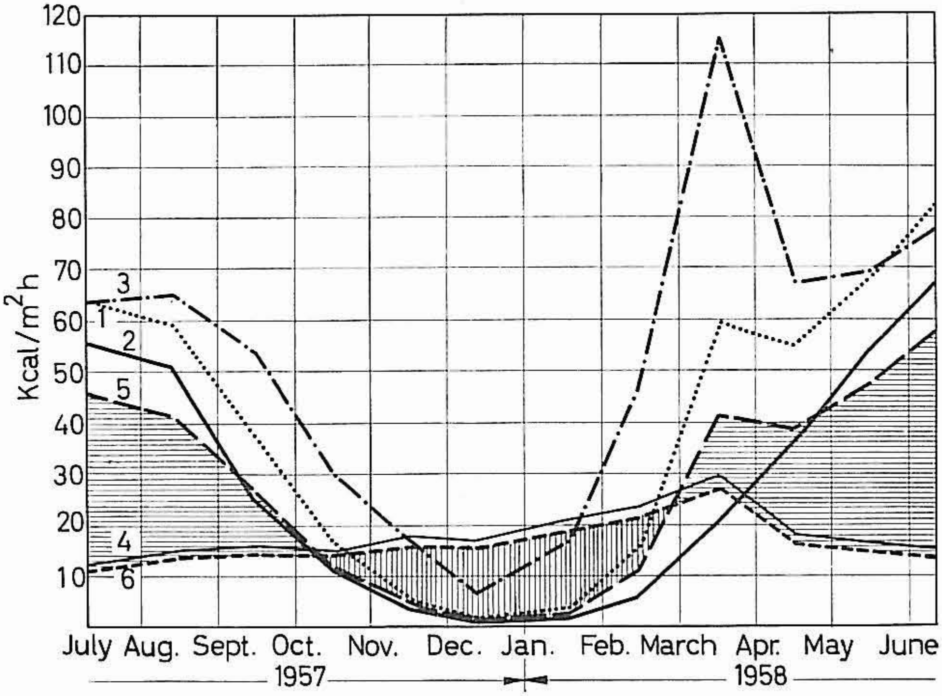


Fig. 11. Heat exchange by radiation, computed values for the conditions at the wall laboratory July 1957—June 1958. The curves 1, 2 and 3 give the computed total solar radiation on vertical walls faced 1 east or west 2 north 3 south. Curve 5: Amount of solar heat which may be absorbed by east or west walls having an absorbtivity $\alpha = 0.7$ for solar radiation. Curve 4: Net long wave radiative heat exchange, assuming the emissivity $\varepsilon = 1.0$ for walls and surroundings. Curve 6: as curve 4, but assuming the long wave emissivity $\varepsilon = 0.9$ for the walls and $\varepsilon = 1.0$ for the ground. Horizontally and vertically hatched areas indicate radiative heat gain resp. heat loss. (The lines are drawn only to connect the points giving the computed monthly mean values).

heat exchange at the outer surface. This is illustrated in *fig. 11.* The curves 1.2 and 3 give the total amount of solar radiation i. e. the direct and diffuse radiation on vertical walls exposed to the respective directions. The values are computed on basis of observations taken at a meteorological station near the wall laboratory. The monthly solar radiation is evaluated from the solar heat radiation by clear sky taking into account the observed cloud factors (3). Curve 5 indicates the amount of solar heat which may be absorbed by vertical walls faced east or west and having an apparent absorb-

Table 3

Wall no.	Apparent conductivity k kcal/m h °C	Dry bulk density	Moisture content in %	
			Sept. −58	Febr. −59
3 E	0.124	510	2.1	2.7
18 W	0.150	510	2.8	2.3
4 E	0.127	550	6.0	5.0
17 W	0.130	550	4.6	3.7
5 E	0.139	520	6.7	6.1
6 E	0.109	470	2.0	2.6

tivity to solar radiation $\alpha = 0.7$. Curve 4 gives the net long wave radiation i. e. the heat radiated from the walls diminished by the radiation received from the water vapour in the atmosphere (4), (5) and radiation from the ground, assuming the walls and the ground have an emissivity $\varepsilon = 1.0$. As the outer wall surface temperature and ground temperature were not recorded, they are in this calculation assumed to be the same as the outside air temperature. Curve 6 gives the net long wave radiation, assuming an emissivity $\varepsilon = 0.9$ for the wall surface. The horizontally and vertically hatched areas indicate the intervals where a radiation heat gain resp. loss is taking place.

5.4. The apparant heat conductivities of the wall materials

The apparent heat conductivities for the wall materials, including the influence from mortar joints are given in *table 3.*

The conductivities are computed using equation 4. All the values of the heat conductivities are in the range 0.1—0.15 kcal/m h° C.

6. Summary

The Norwegian Building Research Institute has during a couple of years studied the heat transmission through test panels of various types of autoclaved cellular concrete with dry state bulk densities in the range 470—550 kgs/cub.m. The heat losses were measured by means of heat flow meters on the middle part of the walls. The heat transmittance coefficients are evaluated from the average heat flow during two periods of about 20 weeks and the corresponding air to air temperature difference. Measurements of the moisture content and moisture distribution in the walls have also been taken at regular intervals. Four of the eight walls being studied had a low initial moisture content i. e. 2.5—3.5 % by the dry weight of the material. The rest of the walls had an initial moisture content of 12—13 %. The moisture content in the first mentioned four walls has not changed appreciably. The moisture content in the most damp walls did not decrease the first winter, but there was a very marked redistribution of the moisture. The moisture content in these walls sank already the first summer to 5 % and is after 2 years about 4 %. The heat transmittance values for the driest walls were the same in both periods. The values for the most damp walls were lower in the second than in the first period corresponding to a lower moisture content. The apparent heat conductivity for the wall materials are found to be in the vicinity of 0.1—0.15 kcal/m h° C, depending upon the density of the material, the type of mortar joints and the moisture content. None of the test panels being investigated have shown any signs of moisture accumulation from driving rain or other sources. A change in radiation conditions seems to give lower heat losses for the last half of the measuring periods, which have been from the middle of November till the end of April.

Résumé

L'Institut Norvégien de Recherche du Bâtiment (Norges Byggforskningsinstitutt) étudie depuis quelques années la transmission de la chaleur au travers de panneaux d'essai en béton cellulaire de différentes sortes passé à l'autoclave et de poids spécifiques en masse à l'état sec compris entre 410 et 550 kg/m^3. Les pertes de chaleur ont été mesurées à l'aide d'indicateurs de flux de chaleur dans la partie médiane des murs. Les coéfficients de transmission thermique sont évalués à partir du flux moyen de chaleur au cours de deux périodes d'environ vingt semaines et de la différence de température air-air correspondante. Des mesures de la teneur en humidité et de la répartition de cette humidité dans les murs ont aussi été faites à intervalles réguliers. Quatre des huit murs étudiés présentaient un taux initial bas d'humidité, à savoir de 2,5 à 3,5 % calculé sur le poids à sec du matériau. Les autres murs avaient un taux initial d'humidité de 12 à 13 %. La teneur en humidité des quatre premiers murs n'a pas varié d'une façon appréciable. Le taux pour les murs les plus humides n'a pas décru au cours du premier hiver, mais on

a observé une nouvelle répartition très nette de l'humidité. Le taux d'humidité pour ces murs diminua de 5 % dès le premier été, et il est d'environ 4 % après deux ans. Les valeurs de la transmission thermique pour les murs les plus secs ont été les mêmes dans les deux périodes. Les valeurs pour les murs les plus humides étaient plus basses dans la seconde période que dans la première, en relation avec un taux d'humidité plus bas. La conductivité thermique apparente des matériaux des murs a été trouvée être de l'ordre de 0,1 à 0,15 kcal/m h° C, selon la densité du matériau, le genre des joints de mortier et la teneur en humidité. Aucun des panneaux d'essai étudiés n'a montré de signes quelconques d'accumulation d'humidité par suite de pluie battante ou d'autre provenance. La modification des conditions de radiation semble provoquer des pertes de chaleur moindres pour la seconde moitié des périodes de mesure qui ont duré de minovembre à fin avril.

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