THERMOPHYSICAL PROPERTIES OF THE OUTSIDE WALLS OF BUILDINGS

V. L. Shevel'kov

Inzhenerno-Fizicheskii Zhurnal, Vol. 8, No. 2, pp. 251-254, 1965

As a result of an analysis of field observations it is shown that the overall heat engineering characteristic of the walls of buildings can be obtained on the basis of the general theory of heat and mass transfer.

Today many exterior walls are at least partly made of concrete with poor heat and moisture insulating characteristics (Tables 1 and 2). To a greater or lesser extent, they are all capable of absorbing moisture from the outside. Wet soil, moist air, and slanting rain may result in serious wetting of exterior walls, leading to a sharp reduction in heat-insulating properties and life.

TABLE 1
Thermophysical characteristics of some building materials

Material	Wt. by vol., n/m³		Moisture content by vol., %	Temperature of ambient medium °C	Specific heat capacity j/kg. degree	Thermal diffusivity 10^4 m²/hr	Thermal conductivity 10^3 watt/m. degree
	natural	dry					
Keramzit (porous clay filler) sand	10500	8900	4.00/20,5	23.5/23.8	0.84/1.67	9.7/10.0	0.18/0.35
Quartz sand	14500	12240	0.70/4.18	24,5/21.0	0,84/1 46	16.0/19.2	0.423/0.87
Reinforced concrete	22000			60/20	0.84/0.84	30.2/27.5	1.33/1.1

In Russia many precast keramzit-concrete structures are being erected. Investigation of the walls of these buildings in regions with complex climatic conditions [4] has shown that the mean annual moisture content of the walls fluctuates between 3.5 and 14.5%. The moisture content by layers of outside walls varies between the equilibrium value (1.2%) and values characterized by large amounts of free moisture (21%). Especially large fluctuations are observable in parts of the interior of the wall close to the outside surface. Maximum wetting of these parts of the wall follows the autumn rains (Fig. 1). The moisture content is at a minimum in summer. Layer values obtained experimentally con-

TABLE 2
Moisture content by layers and mean moisture content of outside precast keramzit-concrete

Thickness of wall, mm	Date of test	Exposure	Thickness in mm and moisture content in % of layers:							Mean Moisture Content %
			1st	2nd	3rd	4th	5th	6th	7th	
350	7 Feb. 1963	north	55 / 5.9	120 / 3.7	90 / 3.3	85 / 2.0	— / —	— / —	— / —	3.7
300	7 Feb. 1963	north	58 / 5.2	100 / 4.6	62 / 1.7	80 / 1.2	— / —	— / —	— / —	3.2
300	28 Feb. 1962	east	50 / 16.3	100 / 20.8	75 / 17.0	75 / 3.5	— / —	— / —	— / —	14.4
350	10 Feb. 1962	east	75 / 1.3	75 / 10.2	75 / 8.5	75 / 6.5	50 / 1.9	— / —	— / —	5.7
350	31 Jan. 1963	north	50 / 11.0	50 / 13.7	50 / 13.1	50 / 14.4	50 / 8.4	50 / 5.4	50 / 1.2	9.6
350	31 Jan. 1963	south	50 / 12.4	50 / 13.6	50 / 14.4	50 / 16.5	50 / 12.7	50 / 8.6	50 / 2.7	11.5

firm the nonuniform distribution of moisture within the thickness of the wall. A 15-mm cement-sand stucco coating slows down the process of moisture transfer in the wall proper.

Figure 2 shows the temperature curve over the thickness of the wall, together with the thermal conductivities [4] for the individual layers, which fluctuate within wide limits. These data were obtained by dividing the transformed heat flux in the transverse direction of the wall by the temperature period for a given layer. Of course, under the conditions of heat and mass transfer in the wall and in the presence of daily fluctations in the temperature of the outside air, the thermal conductivity can not be determined in this way. However, the data will serve as proof that inside the wall we get not only heat conduction but moisture transfer, which invalidates the classical case of internal heat transfer and temperature field distribution over the cross section of the wall. The daily fluctuations in the temperature of the outside air also mean that at certain periods the temperature of the outside face of the wall is the same as the temperature of the layer 50 mm from its surface.

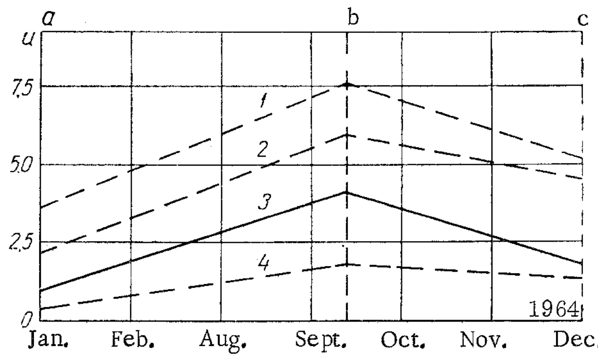

Fig. 1. Distribution of moisture (u, %) in an outside wall 30 cm thick: 1) at a depth of 250 mm, 2) 170, 3) 35, 4) inside face; a, b, c – moisture content sampling points

The considerable daily fluctuations in the temperature of the outside air and moisture transfer in the wall mean that in winter the temperature of the outside air is sometimes slightly higher than or equal to the temperature of the outside face of the wall.

Table 3 shows that the depth of frost penetration of outside walls with a northern exposure reaches 175 mm, whereas the corresponding figure for walls with a southern exposure is only 80 mm.

As field observations show, during the winter in walls facing north (Fig. 2) the daily fluctuations in the temperature of the outside air are damped in the zone of frost penetration, which forms a unique heat storage system.

Owing to the considerable solar radiation, in a wall facing south during the winter at certain times of the day the temperature of the outside air is 9-11°C above zero and its daily fluctuations already reach somewhat beyond the frost penetration zone.

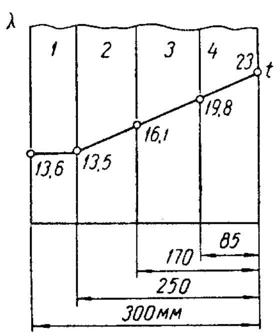

Fig. 2. Thermal conductivity λ (watt/m. degree) for the individual layers of a wall and temperature distribution over thickness of wall. Observations from 7 May to 18 May 1962: 1) λ = 5.4; 2) 0.3; 3) 0.2; 4) 0.25

In autumn (in the absence of frost penetration) the daily fluctuations in the temperature of the outside air affect the entire thickness of the wall.

In order to clarify the changes in the temperature fields in the outside walls of apartment buildings due to the daily fluctuations in the temperature of the outside air, it is worth examining the experimental material of [5] on the thermophysical properties of dry and wet concretes at negative and positive temperatures. The sharp increase in thermal conductivity obtained in [5] for temperatures of wet concrete between –5 and 0° C is not typical of the classical case of heat transfer by conduction. In this case the sharp increase in thermal conductivity is affected by the heat of phase transformations of the water in the wet concrete, internal mass transfer, and changes in the nature of the moisture bond in the material.

The heat capacity by volume of wet concrete increases sharply on heating from –5 to 0°C. In this case, the heat capacity includes the heat of phase transformations of the water. Since over these temperature intervals the thermal conductivity of wet concrete increases to a lesser extent, as compared with the rate of increase in the heat capacity by volume, the thermal diffusivity obviously decreases and, hence, the temperature waves in the frost penetration zone, due to the daily fluctuations in the temperature of the outside air, must be considerably damped, which is confirmed by field investigations of the thermophysical properties of exterior keramzit-concrete walls [4].

The sharp daily fluctuations in the temperature of the outside air and the associated changes in the temperature field show that the heat flow in an outside wall takes different directions: during half the day the flow is into the wall, and during the other half out of the wall, in the direction of its outside face.

Thermal calculations relating to the outside walls of buildings should be carried out for the nonsteady state.

In outside walls with a capillary-porous structure heat and mass transfer is always taking place in some degree or other. Hence the overall thermophysical characteristic of the walls of buildings can be obtained on the basis of the general theory of heat and mass transfer.

TABLE 3
Temperature of outside air, mean moisture content, and depth of frost penetration of wall for different exposures and thicknesses (17 January 1963)

Thickness of wall, mm	Exposure	Mean Moisture content %	Temp. of outside air °C		Depth of frost penetration, mm
			Minimum	Maximum	
350	north	3.7	—19.1	—9.5	175
300	north	4.9	—19.1	—9.5	138
350	north	10.0	—21.5	—8.9	170
350	south	10.5	— 2.3	—2.5	80

For a stationary temperature field and a considerable temperature period heat transfer by transport of matter is observed in the material. In this case we observe the equivalent thermal conductivity, or the ratio of the heat flux density to the temperature gradient for a given section of the wall.

The equivalent conductivity has a maximum for a certain moisture content of the material. The thermal diffusivity depends on the moisture content, at a certain value of which it also has a maximum.

The ratio of the mass and thermal diffusivities gives the criterion $\mathrm{Lu} = a'/a$, which is linearly dependent on the moisture content of the wall material.

REFERENCES

1. V. L. Shevel'kov, Thermophysical Characteristics of Insulating Materials [in Russian], Gosenergoizdat, 1958.
2. V. L. Shevel'kov, Izv. ASiA SSSR, 1962.
3. A. V. Lykov, Theoretical Principles of Building Heat Physics [in Russian], Minsk, 1961.
4. I. B. Zasedatelev et al., Scientific-Engineering Report, Insulating Properties of Outside Walls Under Complex Climatic Conditions [in Russian], NIImontazhspetsstroi, Moscow, 1963.
5. A. M. Butov, Pulse Methods and their Application to the Investigation of Thermophysical Coefficients [in Russian], Candidate's Dissertation, 1964.

1 August 1964

All-Union Structural Engineering Correspondence Institute, Moscow