

Thermal Conductivity of Building Materials*

Experiments Undertaken to Determine the Heat Losses of Various Structures

By C. Schroeder

THE question of conservation of heat in a building presents far more difficulties than some other problems of construction. Usually persons considering this subject content themselves with the somewhat vague declaration that insulating of "warm" walls should be employed. An opinion which rests rather upon the sense of feeling and upon "non-controllable" experience than upon exact experimental investigations, but the question is undoubtedly of peculiar and pressing importance today because of the scarcity and dearth of fuel. Obviously the more pervious to heat a wall is the greater the waste of fuel when the space enclosed by it is to be kept at a hygienic degree of temperature. . . . It is not until comparatively recent years that an effort has been made to determine these questions by scientific methods. Some time before the beginning of the Great War a start was made in this matter by the Laboratory for Technical Physics connected with the Technical High School in Munich. Assistance was lent by the cooperation of the Munich "Institute for the Study of the Economics of Heat," which was founded by industrial circles in October, 1918.

The investigations made by these bodies were based upon the following well-known facts. A source of heat of a constant strength (a stove, radiator, etc.) was used. By means of this

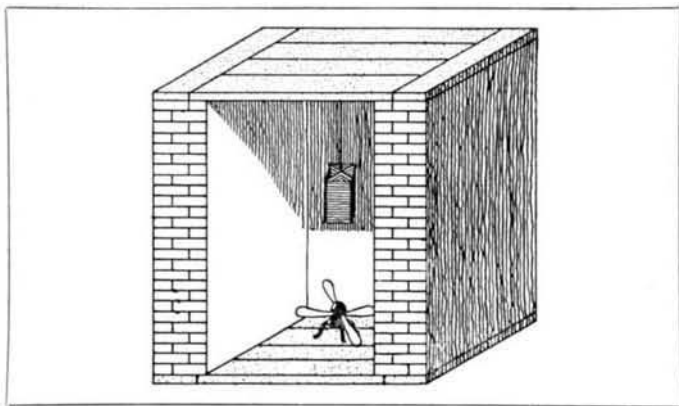


FIG. 1. EXPERIMENTAL COTTAGE FOR TESTING THE CONDUCTIVITY OF HEAT IN BUILDING MATERIALS

The hot air from the electric heater is distributed evenly by the electric fan

source of heat the air in the room is first warm and then the walls which enclose the room become heated and finally a portion of the heat which has penetrated the walls passes out into the surrounding atmosphere. There finally occurs a state of equilibrium in this process, which can be recognized by the fact that when this state is reached the same amount of heat is given off by the wall into the outer air as has been received by the inner side of the wall. . . . This passage of heat through the wall is comparable to the flowing of a fluid. The obstacles met by a stream of water can be overcome only when a certain amount of pressure or a corresponding difference in height is present, and such obstacles may be compared to the resistances (which vary according to the material) encountered by the current of heat and which the latter can overcome only by a change of temperature corresponding to the resistant object in question. Just as the water can flow more rapidly over a smooth surface so the denser the body to be penetrated the less resistance encountered by the current of heat; just as a gutter with uneven and rough walls hinders the flow of water, a loose, light, air filled material checks the flow of the current of heat.

In analogy to the laws of fluid bodies it is found that within like intervals of time the amount of the heat transmitted increases in the same ratio as the area of the surface and as the difference of temperature between the two sides of the wall, while it decreases, on the contrary, in proportion to the thickness of the wall; finally, it is in harmony with a special factor, namely, the degree of conductivity of heat for the given material. This magnitude, known as the thermal conductivity number, gives the units of heat which pass through the surface unit of the wall (1 sq. m.) in the unit of time (1 hour) when there is a difference of 1° C. between the two surfaces of a wall 1 meter thick.

These thermal conductivity figures have been determined by careful experiments with various building and insulating materials, such as common tile or brick, as also the porous and hollow variety, slag, natural stone, mortar, wood, gypsum, sheets of cork, and of peat fiber, etc. These materials were prepared in sheets having a surface extent of about $\frac{1}{4}$ of a square meter and were warmed on one side by exposure to an electric source of heat. Special care was taken to have all the heat produced pass through the material to be tested. The thermal conductivity figure was then determined after the stage of permanency was attained, by a calculation involving the factors of the given amount of heat, the surface, and the thickness of the material. These figures having been obtained it is easy to calculate the quantity of heat transmitted through any given wall composed of one or more of these substances. For example, the following figures were obtained for various walls:

1.44 cal. in a brick wall of a thickness of $1\frac{1}{2}$ bricks (this may be regarded as the normal wall for dwelling houses);

1.66 cal. in a gravel cement wall, 40 cm. thick;

1.87 cal. in a limestone wall, $1\frac{1}{2}$ stones thick;

2.4 cal. in a wall 50 cm. thick built of quarry stones.

On the other hand a wall made of hollow tiles, one brick thick gave the figures 1.3 calories, while still more advantageous was a well plastered wall only 1 brick thick of Rhenish porous stone in which the loss of heat was reduced to 0.77 calories; not quite so good but still excellent was a wall of the same thickness made of furnace slag which allowed the passage of about 1.15 calories.

The higher prices and scarcity of building materials have naturally led to inferior construction with a corresponding increase in the amount of heat transmitted through these poorer and thinner walls. This can be partly compensated, however, by the use of special insulating materials, such as sheets of cork, peat fiber, etc. It has been proven in fact, that this distribution of solidity and insulation among two different materials give especially good results. Thus we find that the loss of heat in a brick wall covered with a layer of insulating material 3 cm. thick reduces the loss of heat as follows:

From 1.44 to 0.78 calories in a wall $1\frac{1}{2}$ bricks thick

From 2.10 to 0.92 calories in a wall 1 brick thick

From 3.85 to 1.17 calories in a wall $\frac{1}{2}$ brick thick

A great many new methods of building have sprung up since the war; these mostly employ gravel cement or slag cement in combination with layers of air or hollow spaces filled with some insulating material; it is impossible to assign fixed values to the heat loss in such cases, since the thermal conductivity of cement varies greatly according to its composition, method of mixture, and density. The heat loss of a structure built with walls consisting of a 6 cm. gravel cement layer, a 12 cm. layer of air, and a 6 cm. layer of slag cement is estimated at approximately 2 calories, but when the air space is filled with slag this value is reduced in

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the case of a brick wall 38 cm. thick. Prepared cement blocks which are frequently divided by air layers show a heat loss of 1.2 calories in the most favorable cases. Houses made of wood, or of wood combined with unburnt brick or slag blocks when they contain well distributed air spaces, vary in their heat law from 1.1 to 1.6 calories.

Testing Heat-loss in Experimental Houses.—For the purpose of testing heat-loss in such forms of construction under conditions approximating those encountered in actual practice, small experimental houses were built with side walls, 2 sq. meters in area (Fig. 1). These were set up in a large laboratory in order to avoid difficulties and complications due to variations in the weather outdoors. Definite forms of structure was chosen for the walls: A brick wall 1½ bricks thick, a concrete wall composed of gravel cement and slag cement, wooden walls and roofs; the floors and ceilings were constructed of an insulating material having a known thermal conductivity. The source of the heat—an electrically heated body, was placed inside each of these little houses near a fan whose purpose was to distribute the heated air evenly. The method of measuring the loss of heat was the same as in the first experiment. In this manner it was possible to make an immediate measurement of the amount of heat transmitted

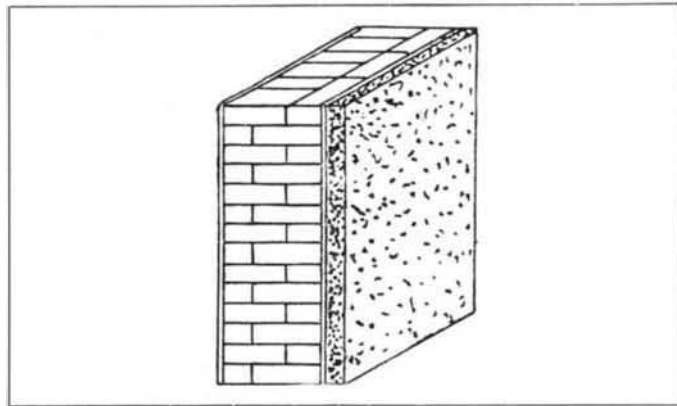


FIG. 2. WALL SHOWING AUXILIARY WALL OF KNOWN THERMAL CONDUCTIVITY IN FRONT OF IT

The heat loss in the wall being tested is found by measuring the temperature on each side of the two walls

through the wall under test. It was also possible to determine the effects produced by outside influences such as the amount and distribution of humidity, etc. The results obtained agreed admirably with the individual values previously secured. Thus, for example, the heat-loss from the brick wall 1½ bricks thick was found to be 1.43 calories. (Figures similar to those obtained by theoretical calculation.) A framework structure which was lined with boards on both sides underlaid by plaster covered boards proved excellent, with a loss of only 0.8 calories; without the underlay of plaster covered boards the heat loss amounted to 1.2 calories. In a structure composed of hollow cement blocks there was a heat loss of 2.1 calories which indicates that this form of building is of doubtful value.

In order to complete the experiments by a study of the influence exerted by location and climate a simple experiment was devised by means of which the conditions of the heat conductivity in the finished building can be tested in any given instance. As shown in Fig. 2, this method consists in placing in front of the wall to be tested an extra wall having a known thermal conductivity. The room is then heated by any desired source of heat and kept at as even a temperature as possible. The warmth thus produced must pass through the auxiliary wall before reaching the wall of the room. In each of the two walls a current resistance makes its appearance and, as explained, in the earlier portion of this article, this resistance can be overcome in the case of a given amount of heat only by a given difference of temperature. Consequently, the resistances exhibited to the flow of the heat

correspond to the differences of temperature. Since the resistance to heat conduction of the auxiliary wall is a known quantity, it is only necessary to find the temperatures upon each side of the auxiliary wall and each side of the wall to be tested, in order to discover the amount of resistance to the conduction of heat exhibited by the latter. A simple calculation enables us to determine the quantity of heat loss from the amount of resistance displayed.

The present conditions obtaining in Germany as to supplies of coal . . . indicate the great economic importance of this question. It is to be hoped consequently that the Department of Buildings and Construction which has hitherto been concerned chiefly with the safety from fire and the solidity of buildings, will require that proper care be taken to secure the proper amount of protection against heat loss in their construction. In their own interest persons erecting buildings should demand of their architects the greatest attention to the securing of economy of fuel, while architects themselves must be advised of the necessity of enlarging their scientific equipment for the practice of their profession by a study of the technology of economy of heat.

RESEARCH IN WOOD FOR THE BUILDING INDUSTRY

For generations the proper size of timbers to use in wood buildings was a matter of custom. Now higher working stresses are permitted by building codes and it is possible to design more economical buildings. This is the result of increasing knowledge of the strength properties of wood. Much of the credit for making available this essential information belongs to the Forest Products Laboratory at Madison, Wisconsin. Considering its relatively meager appropriations from year to year and the financial uncertainties under which it labors, its accomplishments have been great. But the needs of further knowledge in the use of structural timbers are almost unlimited.

How shall built-up beams and columns be designed, and what are these conditions under which their use is desirable? How can structural timbers be preserved from decay and the attacks of borers? What influence have defects on the strength of columns? What stresses should be used in wood girders and trusses of 50 to 70 foot span such as are used in garages? What do we know of the strength of fastenings and joints? Has fireproofing and slow-burning construction been fully developed? What of shrinkage and the better seasoning of wood? And with carefully worked out grading rules and consequent higher working stresses why cannot the cost of wood buildings be materially reduced? The Forest Products Laboratory is seeking to solve some of these problems, but in order to do so, it needs the support of industries which will benefit by its results.

DISINTEGRATION OF ROOFING TILE

According to J. Scott, who writes in *The British Clay Worker*, 29, 138-140 (1920), roofing tile sometimes disintegrates owing to a fungous growth, a type known as *mucor racemose* being especially destructive. Rain and dust settle in the pores of the tile and this becomes a foundation for the spores. A net work running through the pores of the tile is formed as the spores grow and in a few days thread-like spore-bearing stalks are sent up and these soon scatter a new lot of spores. The fungus obtains its food partly from the dust and partly from the tile and the stalks are hollow and filled with a sap traveling upward. The points of these stalks or threads yield ferments which enable them to soften and split off small particles from the tile. During the process volatile mineral matter required for the fungus is drawn from the tile leaving it more susceptible to the destructive action of thawing and freezing. Thus this natural chemical process proceeds, although slowly. Lichen, which very often covers roofing tile, is not destructive to it since it obtains its nourishment from the air.