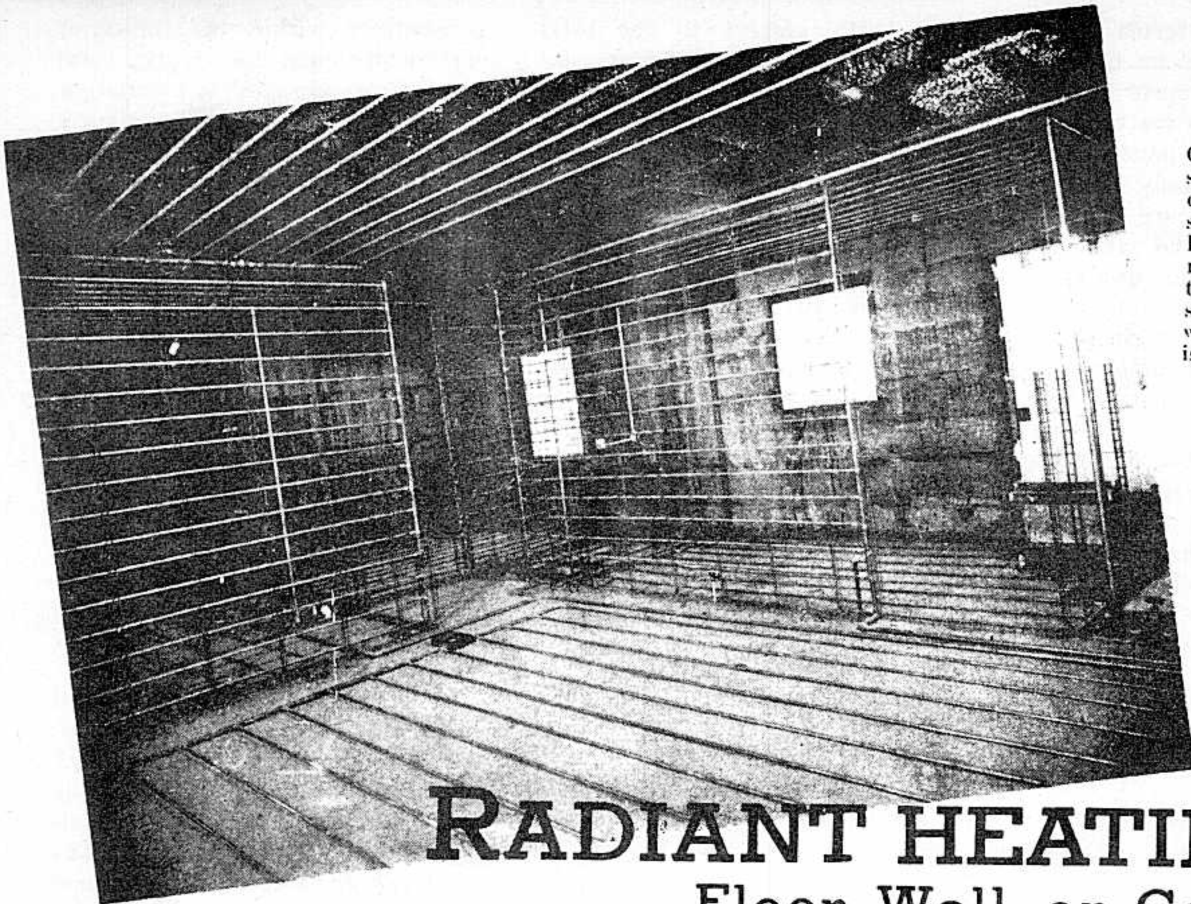

Construction view showing floor, wall, and ceiling panel test installation at Purdue. How to choose the correct location and how to calculate the area of supplementary panels when they are required is explained in the text.

RADIANT HEATING?
Floor, Wall, or Ceiling

F. W. Hutchinson Tells How to Choose Proper Location for Panel Heating; Table Gives Equivalent Panel Areas

THE first decision required for an engineer designing a radiant panel heating system is where to locate the panels. Should they be in the ceiling, floor, interior walls, or exterior walls? In many cases the conditions of the particular problem are such that one or more of the alternatives are automatically ruled out, but in other instances load conditions are such that the engineer has complete freedom of choice and must select a position in terms of his own judgment of the relative merits of the four possible locations.

The location most likely to prove impossible is the floor; for an average installation, a floor panel must be more than twice as large as either a wall or ceiling panel of equal capacity and hence it is hardly surprising that many structures, particularly in cold climates, do not have sufficient floor space to permit installation of the requisite amount of surface. In such cases the alternatives are to use some panel location other than the floor, or to install a floor panel and supplement it with additional wall or ceiling heating surface. If the latter is the choice, the designer will require some simple means of converting the calculated area of excess floor panel to an equivalent area of supplementary wall or ceiling surface.

HOW TO DECIDE between floor, ceiling, or wall location for radiant heating panels is explained by the author, who is professor of mechanical engineering at Purdue University and is widely known for his extensive work on this subject. He gives a table from which coefficients can be obtained to permit approximate transformation of a known area of one type of panel to an equivalent area of some other type. Based on conventional design assumptions, a wall panel installation will require less area than any other type—while a ceiling installation will more closely approximate (in performance) the desired attributes of a radiant panel system. The author says that for rooms of average size, floor-type installations possess neither thermal nor radiant advantages; but for unusually large rooms with high ceilings floor panels are preferable, while for average rooms with high ceilings wall panels are preferred

Existing Information Summarized

The intent here is to summarize existing information on the thermal and comfort characteristics of different panel locations and to provide a simple tabular method of converting areas calculated for one location to equivalent areas for use in some other location. At the same time, the relative merits of the various locations will be discussed with respect to their effectiveness —or lack of it—in providing those particular characteristics which are said to be associated with *radiant* heating.

The designer will still be lacking, however, some of the data required for a final decision, since the importance of the thermal or comfort characteristics of any location can

A technical paper prepared in cooperation with the housing division of the Purdue Research Foundation: G. Stanley Meikle, research director of the foundation; Carl F. Boester, housing executive.

only be evaluated in terms of the cost of achieving such an installation. No attempt is made here to estimate the comparative costs of floor, ceiling, and wall panels. Such a comparison necessarily depends on the type of structure and the specific conditions of the particular installation. Based on his own experience and that of his immediate associates, the local engineer or contractor is in a far better position to estimate comparative costs than is anyone else.

The most outstanding difference in the operating characteristics of floor, wall, and ceiling panels arises from the marked increase in the convective film coefficient of heat transfer which occurs as the heating surface is rotated through 180 deg from the ceiling position. A ceiling panel, particularly if it is large with respect to the total ceiling area, has a minimum convective energy loss for the obvious reason that air heated by the panel tends to rise, presses—in effect—against the heating surface, and hence does not tend to circulate. The velocity of air across the heating surface is therefore low and the film coefficient of heat transfer by convection has been shown experimentally to have an average value of approximately 0.4 Btu per hr per sq ft of panel per 1 F temperature difference between the panel surface temperature and the air temperature. Actually, the film coefficient varies as the one-fourth power of the temperature difference and varies also with the character of the panel surface, but for practical design purposes the assumption of a constant value of 0.4 is accurate within the limits of error which exist in such structural constants as are used in calculating the heat load.

When the heating surface is moved from the ceiling to the wall the air that comes in contact with the panel is heated, tends to rise, and thereby establishes a velocity across the face of the panel with a consequent increase in the convective coefficient of heat transfer to a value of approximately 0.8 Btu per hr per sq ft per F. For a floor panel, an even greater circulation is set up as the heated air tends to move directly away from the surface rather than, as for the wall, parallel to it; the convective film coefficient for a floor surface can be taken as approximately 1.1 Btu per hr per sq ft per F.

Comparison of the convective film coefficients for floor, wall, and ceiling (1.1, 0.8, and 0.4, respectively) shows at once that a floor panel is primarily a convector since it dissipates by convection 275 per cent as much energy as does a ceiling panel operating at the same surface temperature. A wall panel also has marked convector characteristics, since it dissipates 200 per cent as much energy by convection as does a ceiling unit at the same surface temperature. As a very rough approximation, it follows that the rates of energy dissipation by convection from ceiling, wall, and floor panels (at the same surface temperature) can be taken, respectively, as in the ratio of 1 to 2 to 3.

A Frequently Misinterpreted Fact

Energy dissipation by radiation is a surface and surround phenomenon which has no relationship with the aspect (position) of the heated surface. Thus for a given range of surface temperatures an equivalent film coefficient of radiant transfer can be established which will be valid for a heating surface irrespective of its location. For the temperatures usually maintained in comfort heating installations the equivalent radiation coefficient can, with adequate accuracy, be taken as 1.0, thereby giving total energy dissipation coefficients for ceiling, wall, and floor panels of 1.4, 1.8, and 2.1 Btu per hr per sq ft per F, respectively. Thus — for surfaces at the same temperature—a wall panel dissipates 30 per cent more energy than a ceiling panel, whereas a floor panel dissipates 50 per cent more energy than a ceiling panel.

This fact has frequently been misinterpreted as indicating that a floor panel has a greater dissipating capacity and hence will require less surface; if the design surface temperatures were the same for all three locations such an interpretation would be correct, but actually — as will be shown — the much lower design temperature of the floor surface reduces the capacity of a floor panel to about one-half that of a ceiling unit of equal area.

How to Approximate Panel Ratings

The exact rating of 1 sq ft of panel heating surface can be evaluated only in terms of the particular installation. In a room with 65 F air and 75 F mean radiant temperature, the effective comfort temperature will be the arithmetical average, 70 F, but this value cannot be used in calculating energy dissipation from the panel for two reasons: (1) the average temperature of the surfaces which are "seen" by the panel is less than the mean radiant temperature, and (2) the convective and radiant fractions of the equivalent overall film coefficient are not equal, hence an arithmetical average of air temperature and surround temperature is not valid.

For approximate comparison, however, the two factors mentioned above can be neglected and the relative capacities of floor, wall, and ceiling panels evaluated in terms of design surface temperature, equivalent comfort temperature (taken as 70 F), and overall equivalent film coefficient. Arbitrarily taking 1 sq ft of ceiling panel at a surface temperature of 120 F as a standard it is then readily possible to calculate the amount of floor or wall surface, at any selected surface temperature, which would dissipate an equal quantity of energy.

As an example consider a floor panel operating at 85 F surface temperature; the area of such a panel which would produce a heating effect equivalent to that of 1 sq ft of 120 F ceiling panel is $[(120-70)\times 1.4] \div [(85-70)\times 2.1] = 2.22$ sq ft. Table 1 summarizes the equivalent areas similarly determined for most of the panel design conditions which are ordinarily used in practical installations.

Examples Illustrate Use of Table 1

Example 1: Design calculations for a 120 F ceiling panel installation show that 120 per cent of the ceiling area would have to be heated. Since "difficulty" would arise in heating the 20 per cent of the ceiling that does not exist, some means must be found for providing supplementary wall or floor panels equal in capacity to 20 per cent of the ceiling area. Assume that the designer chooses to use supplementary wall panels at a design surface temperature of 100 F. Entering part *A* of Table 1, read 1.30 as the correction coefficient, thereby indicating that 1.30×20 per cent$=26$ per cent of the ceiling area as the necessary size of the supplementary wall panel.

Example 2: A floor panel design shows the need for 250 sq ft of 85 F heated floor surface in a room where bookcases and other interferences reduce the available surface to 200 sq ft. The designer chooses to supplement the floor unit with a ceiling panel at a surface temperature (for maximum load) of 100 F. Entering part *F* of Table 1, read 0.76 as the correction coefficient giving, therefore, $0.76\times 50 = 38$ sq ft of ceiling required for the supplementary panel.

Example 3: A 100 F ceiling design indicates the need for a panel area equal to 120 per cent of the ceiling area. If the design temperature were raised to 120 F, would the requisite area be reduced sufficiently to permit installation in the ceiling? Going to part *B* of Table 1, read 0.60 as the correction coefficient, giving $0.60\times 120=72$ per cent of the ceiling as an adequate panel size.

These three examples illustrate three different uses for the approximate relationships of Table 1. Whenever using this table, however, it should be remembered that it is based on assumptions which are not exact; when the fraction of surface to be converted from one plane to another is small the error resulting from use of the tabular coefficients will likewise be small, but in cases where the area to be converted is a large part of the total panel area the use of the coefficients may lead to serious error.

In no case should the tabular values be used in basic design; their purpose is to simplify minor modifications that may be required in a design which has been carried out by the usual methods, and when so used the results will be accurate well within the limits of accuracy of the basic design coefficients.

Aside from the *quantity* of energy dissipated by various types of panels, consideration should also be given to the *quality* of such energy.

Table 1—Summary of equivalent areas for floor, wall, and ceiling panels for most design conditions used in practice

Surface Temperature	Ceiling Panel	Wall Panel	Floor Panel
A. To convert a known area of **120 F ceiling panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	2.22
100	1.67	1.30	1.11
120	1.00	0.78	***
B. To convert a known area of **100 F ceiling panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	1.33
100	1.00	0.78	0.67
120	0.60	0.47	***
C. To convert a known area of **120 F wall panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	2.84
100	2.14	1.67	1.42
120	1.28	1.00	***
D. To convert a known area of **100 F wall panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	1.71
100	1.29	1.00	0.86
120	0.77	0.60	***
E. To convert a known area of **100 F floor panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	2.00
100	1.52	1.08	1.00
120	0.90	0.70	***
F. To convert a known area of **85 F floor panel** to equivalent area of some other type of panel, multiply the known area by the coefficient selected from this table:			
85°	***	***	1.00
100	0.76	0.59	0.50
120	0.45	0.35	***

As already pointed out, the radiant dissipation rate of a surface is independent of its position, but the convection dissipation rate increases progressively as the surface is moved from the ceiling to the wall to the floor. Thus the fraction of energy transfer by radiation is greatest for a ceiling panel (72 per cent), less for a wall panel (56 per cent) and least for a floor panel (48 per cent). In consequence, a ceiling panel comes closest to realizing the energy characteristics of a true radiant system, whereas a floor system—whatever other advantages it may possess—does not differ appreciably in its operating characteristics from a conventional type of convection heating system.

Probably the most significant criterion for use in estimating the effectiveness of *radiant* heating is the equilibrium value of the air temperature depression below the mean radiant temperature of the room. Fig. 1, taken from an ASHVE research report*, shows the depression for a given room under given conditions as a function of the convective fraction of the total equivalent film coefficient of heat transfer. Specific points on the curve identify the three types of panels under consideration and it is immediately evident that only a negligible depression is associated

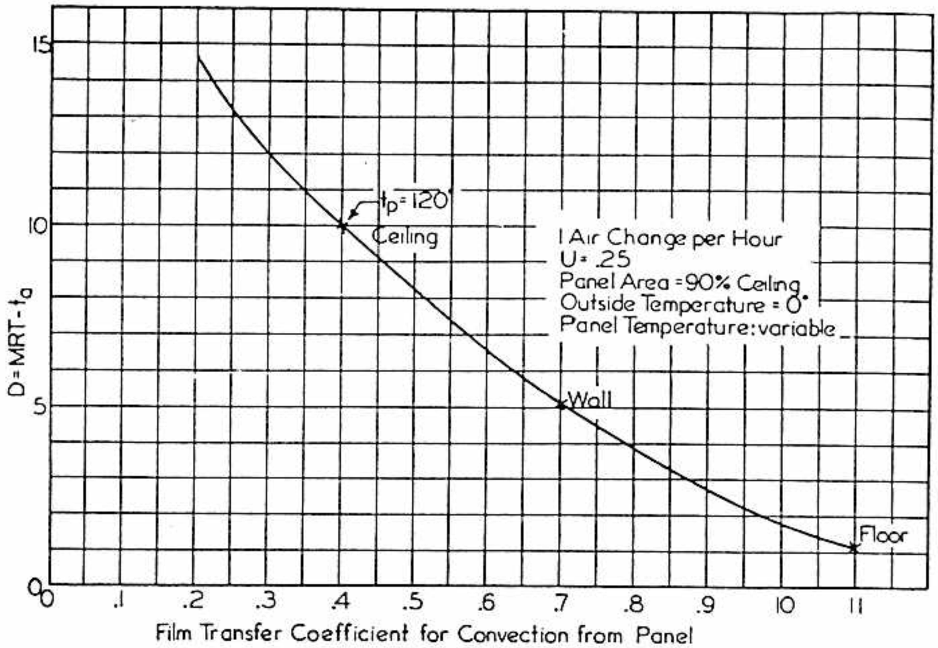

Fig. 1—Panel effectiveness vs. panel location

with a floor panel system. As stated in the paper from which Fig. 1 is taken, "A well designed floor panel installation may equal in performance a convection heating system and may possess other advantages which justify its use, but it does not in any marked degree possess the characteristics which are said to be desirable in radiant panel heating."

The only type of structure in which floor panels have a genuine *radiant advantage* over ceiling units is one in which the ceiling is unusually high. When this is the case, the shape factor of a given ceiling area with respect to the occupant is so much less than that of an equivalent floor area that a floor installation will be much more effective in raising the mean radiant temperature—measured with respect to the occupant or with respect to a unit sphere at the breathing level—than will a ceiling installation. Irrespective of ceiling height, however, a wall installation with panel surface located in the lower 16 ft of wall will be more effective than a floor installation except in unusually large (exceeding 40 ft in length or width) rooms.

*Trend Curves for Estimating Performance of Panel Heating Systems, by B. F. Raber and F. W. Hutchinson, ASHVE Transactions, Vol. 48, 1942, pages 425-436.