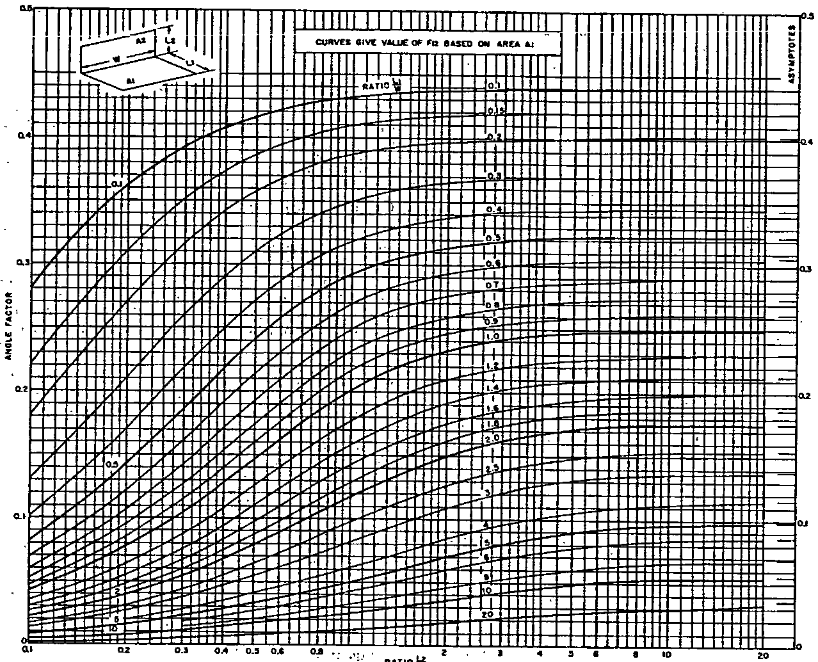

Fig. 1 .... Angle Factors Between Perpendicular Rectangular Areas with a Common Edge.[10]

$A_1, A_2 \cdots A_n$. The fraction of W_1A_1 absorbed at A_j due to direct radiation from A_1 is $F_{1j}\alpha_j$. The fraction of W_1A_1 absorbed at A_j because of reflection and re-reflection off the other surfaces A_i is $B_{ij}F_{1i}\rho_i$. It follows, therefore, that the total fraction of W_1A_1 absorbed at A_j is:

$$B_{1j} = F_{1j}\alpha_j + \sum_{i=1}^{n} F_{1i}\rho_i B_{ij}$$

Radiation emitted from the other surfaces may be treated similarly:

$$B_{2j} = F_{2j}\alpha_j + \sum_{i=1}^{n} F_{2i}\rho_i B_{ij}$$

$$B_{3j} = F_{3j}\alpha_j + \sum_{i=1}^{n} F_{3i}\rho_i B_{ij} \qquad (14)$$

$$\cdots\cdots\cdots\cdots$$

$$B_{nj} = F_{nj}\alpha_j + \sum_{i=1}^{n} F_{ni}\rho_i B_{ij}$$

There are n simultaneous equations for the n values of B_{ij} required in Equation 13 for a given q_j, that is, for a given surface A_j. Equations 14 are simply solved on a modern computer. For calculating the q for other enclosure surfaces, one merely changes the first term on the right hand side of each equation. There is only one set of $F_{ni}\rho_i$ for an enclosure. Several additional useful relations are as follows:

$$\sum_{j=1}^{n} B_{ij} = 1;\ \epsilon_i B_{ij} A_i = \epsilon_j B_{ji} A_j;\ \text{and}\ \sum_{j=1}^{n} q_j = 0 \qquad (15), (16), (17)$$

All of the calculation methods which have been applied to multisurface enclosures assume that each surface uniformly irradiates each other surface. Only a limited number of special arrangements have this characteristic. Subdividing the various surfaces will improve the approximation, but the work required to obtain a solution increases rapidly with each subdivision. A balance must be found which is consistent with the importance of the problem.

Special Surfaces in Enclosures

All types of diffuse-radiation processes are included under the enclosure method discussed above, and surfaces having special characteristics are treated by being assigned consistent

properties. An opening is treated as an equivalent area A_e with a reflectivity of zero. If energy enters the enclosure diffusely through the opening, A_e is assigned an equivalent temperature; otherwise its temperature is taken as zero. If the loss through the opening is desired, q_e is found. A window in the enclosure is assigned its actual properties.

A surface in radiant balance is one for which radiant emission is balanced by radiant absorption. Such a surface, sometimes called a no-flux surface, may be simulated for the calculation of the rate of loss for any other surface by assigning to it a reflectivity of 1.0 and an emissivity of 0. The absorption factors are then found from Equation 14 by using these values. If the temperature of this surface is desired, the actual values of emissivity and reflectivity are used to determine the absorption factors. They are then substituted into Equation 13, with $q_j = 0$, to find W_j and T_j. The calculation of surface temperatures in radiant surroundings has been treated in detail by Gebhart.[18]

This general method may also be applied to enclosures containing gray absorbing and emitting media.

NATURAL CONVECTION

Heat transfer involving motion in a fluid due to a difference in density and the action of gravity is called natural convection. It is called forced convection if the motion is due to external means, such as a blower or pump. Heat transfer coefficients for natural convection are generally much lower than for forced convection and, as a consequence, it is important not to ignore radiation in calculating the total heat loss or gain from a body. Radiant heat transfer may be of the same order of magnitude as natural convection, even at room temperatures, as evidenced by the fact that wall temperatures in a room can affect human comfort. (See Chapter 7.)

Natural or free convection is important in a wide variety of heating and refrigeration equipment. Examples are the so-called gravity coils used in high-humidity cold storage rooms and in roof-mounted refrigerant condensers, the evaporator and condenser of household refrigerators, baseboard radiators and convectors for space heating, and cooling panels for air conditioning. Natural convection is also involved in the

Table 5 .... Natural Convection Heat Transfer Coefficients

I. *General Relationships*	$N_{Nu} = c(N_{Gr} \cdot N_{Pr})^n$	(1)
	or $h = c \cdot \frac{k}{L}\left(\frac{L^3\rho^2\beta g(\Delta t)}{\mu^2}\right)_f^n \left(\frac{\mu c_p}{k}\right)_f^n$	(2)
Characteristic Length, L, for Vertical Plates, or Pipes	L = height	
Horizontal Plates	L = length	
Horizontal Pipes	L = diameter	
Spheres	L = ½ (diameter)	
Rectangular Block, with horizontal length L_h and vertical length L_v	$\frac{1}{L} = \frac{1}{L_h} + \frac{1}{L_v}$	
II. *Planes and Pipes* Horizontal or Vertical Planes, Pipes, Rectangular Blocks, and Spheres (excluding horizontal plates facing downward for heating and facing upward for cooling).		
(a) Laminar Range ($N_{Gr} \cdot N_{Pr}$) between 10^4 and 10^9	$N_{Nu} = 0.56(N_{Gr} \cdot N_{Pr})^{1/4}$	(3)
(b) Turbulent Range ($N_{Gr} \cdot N_{Pr}$) between 10^9 and 10^{12}	$N_{Nu} = 0.13(N_{Gr} \cdot N_{Pr})^{1/3}$	(4)
III. *Wires* For horizontal or vertical wires use L = dia, for ($N_{Gr} \cdot N_{Pr}$) between 10^{-7} and 1.	$N_{Nu} = (N_{Gr} \cdot N_{Pr})^{0.1}$	(5)
IV. *With Air* ($N_{Gr} \cdot N_{Pr}$) = $1.6 \times 10^6 L^3(\Delta t)$, (70 F, L in ft, Δt in F deg)		
(a) Cylinders Small Cylinder, Laminar Range	$h = 0.27\left(\frac{\Delta t}{L}\right)^{1/4}$	(6)
Large Cylinder, Turbulent Range	$h = 0.18(\Delta t)^{1/3}$	(7)
(b) Vertical Plates Small Plates, Laminar Range	$h = 0.29\left(\frac{\Delta t}{L}\right)^{1/4}$	(8)
Large Plates, Turbulent Range	$h = 0.19(\Delta t)^{1/3}$	(9)
(c) Horizontal Plates, facing upward when heated or downward when cooled Small Plates, Laminar Range	$h = 0.27\left(\frac{\Delta t}{L}\right)^{1/4}$	(10)
Large Plates, Turbulent Range	$h = 0.22(\Delta t)^{1/3}$	(11)
(d) Horizontal Plates, facing downward when heated, or upward when cooled Small Plates	$h = 0.12\left(\frac{\Delta t}{L}\right)^{1/4}$	(12)