Ventilation Rate

The introduction of outdoor air is necessary for the ventilation of conditioned spaces. *Chapter 7 suggests minimum outdoor* air requirements for representative applications, but it should be emphasized that minimum requirements are not necessarily *adequate* requirements for all psychological attitudes and physiological responses. Where maximum economy in space and load is essential, as in submarines or other restricted spaces, as little as 1 cfm of outdoor air per person has been found to be sufficient, provided that satisfactory ventilation is simultaneously obtained by an adequate decontamination of recirculated air.[21]

Local codes and ordinances frequently specify ventilation requirements for public places and for industrial installations. For operating rooms, minimum requirements for safe practice are given in a National Board of Fire Underwriters' pamphlet.[22] This pamphlet does not require 100 percent outdoor air in operating rooms, although 100 percent outdoor air is normally used and recommended.

Recommended and minimum ventilation rates for the most common applications are summarized in Table 2. For further general applications, a basis of estimating the cfm per person may be taken as:

1. People not smoking.......7½ *Recommended* 5 *Minimum*
2. People smoking..........40 *Recommended* 25 *Minimum*

The cooling load due to the introduction of outdoor air for ventilation is determined once the indoor and outdoor design conditions are fixed. Calculations will be discussed later.

INSTANTANEOUS HEAT LOAD

The total cooling load is frequently divided for convenience into two components, *sensible heat* and *latent heat*. While this subdivision is not imperative, past practice has found it convenient.

A gain of *sensible heat* is considered to occur when there is a direct addition of heat to the enclosure by any one or all of the mechanisms of conduction, convection, and radiation. A gain of *latent heat* is considered to occur when there is an addition of water vapor to the air of the enclosure. For example when the *humidity in an enclosure is increased* by water vapor emitted by human occupants, or by water vapor resulting from a process such as cooking, the heat required to vaporize the water does *not* come from the air. Maintenance of a constant humidity ratio in a sealed enclosure requires the condensation of water vapor in the cooling apparatus at a rate equal to its rate of addition within the enclosure. The rate of heat removal from this condensing vapor would be substantially equal to the product of the rate of condensation and the latent heat of condensation; this product, expressed in Btu per hour, would be called a *latent heat* load.

As a further example, the infiltration of outdoor air with a high dry-bulb temperature and a high humidity ratio, and the corresponding escape of room air at a lower dry-bulb temperature and a lower humidity ratio, would increase both the *sensible heat* load and the *latent heat* load.

SOLAR RADIATION

Magnitude of Solar Radiation

If a plane surface were set perpendicular to the sun's rays (i.e., for *normal incidence*) outside the earth's atmosphere, it would receive solar radiation of about 445 Btu per (hr) (sq ft). A similarly oriented surface, at the surface of the earth, would receive considerably less solar energy because a large part of the radiation is scattered in passing through the air, moisture, smoke, and dust which comprise the earth's atmosphere. Some of the atmospheric constituents, notably water vapor, ozone, and carbon dioxide, absorb solar radiation and further reduce the solar energy reaching the earth's surface. The intensity of solar radiation varies with wavelength, reaching a peak at about 0.5 microns (a micron equals 1/1000 of a millimeter) and, for practical purposes, is confined to the radiation spectrum between 0.3 and 2.5 microns. The effects of scattering and absorption vary with the wavelength, but making an exact analysis of these phenomena is impracticable in air-conditioning estimates. The important principle to remember is that the total radiation I_t, received by a surface at the earth, is the sum of I_D and I_d, *where*

$I_D = KI_{DN}$ = the *direct* or *beamed* solar radiation, Btu per (hour) (square *foot of receiving surface*).
I_{DN} = the direct solar radiation on a plane normal to the sun's rays, Btu per (hour) (square foot of receiving surface).
I_d = the *diffuse* solar radiation, Btu per (hour) (square foot of receiving surface). This comes principally from the atmosphere itself as a consequence of scattering. *Vertical surfaces* also receive solar radiation by reflection of direct and diffuse radiation from the ground and other objects. Such radiation is usually diffuse. The diffuse radiation strikes at *all* angles.
I_t = total incident solar radiation, Btu per (hour) (square foot of receiving surface).
K = cosine of the angle of incidence, θ. For a vertical surface, θ is defined in Fig. 1.

Standardized, practical-purpose values of the *direct* solar radiation I_{DN} incident upon a plane *perpendicular* to the sun's rays at the earth's surface have been proposed by Moon.[23] Table 3 gives these values. They are representative of a *clear* summer day at sea level elevation, and are nearly identical with values derived from suggested design sol-air temperatures for Lincoln, Nebraska.[24] Values typical of a humid industrial area derived from sol-air data for New York City[25] are also given in Table 3. Day-to-day changes in the amount of dust and water vapor in the atmosphere cause large differences in solar intensity values observed on cloudless days at a given locality. For example, it has been observed in Cleveland that values of the order of those given for industrial atmospheres are usually associated with dry-bulb and wet-bulb temperatures near the design values of 95 F and 75 F (67 F dew point). On the other hand, values approaching or exceeding those for a clear atmosphere are often encountered during Cleveland summers, but with dew-point and maximum dry-bulb temperatures 10 to 15 deg lower. Considerable judgment, therefore, is required in selecting solar intensity values for design purposes.

Data regarding the irradiation of vertical and horizontal surfaces by diffuse radiation are few. Suggested design values for a 40-deg latitude on August 1 (18-deg declination, north) are given in Table 3 for the two types of atmospheres.

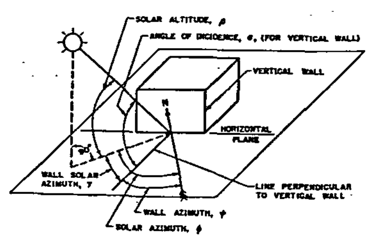

Fig. 1 .... Definition of Solar Angles

Table 3 .... Values of I_{DN}, Direct Solar Radiation Received at Normal Incidence at the Earth's Surface, and Values of I_d, Diffuse or Sky Solar Radiation, Received by Variously Oriented Surfaces

	Btu per (hour) (square foot)											
	For Clear Atmospheres						For Industrial Atmospheres					
Solar Altitude β, Degrees	Direct[a] normal radiation	Diffuse or sky radiation[b, c]					Direct[d] normal radiation	Diffuse or sky radiation[b, c]				
AM → ↓		N	E	S	W	Horiz.		N	E	S	W	Horiz.
5	67	6	11	4	4	7	34	4	11	5	3	9
10	123	11	20	8	7	14	58	8	22	9	7	18
15	166	14	27	11	10	19	80	11	28	13	9	24
20	197	15	32	13	12	23	103	13	36	17	12	31
25	218	16	35	15	13	26	121	16	43	21	16	33
30	235	17	36	17	15	28	136	18	47	24	18	44
35	248	17	36	19	16	30	148	19	50	27	21	48
40	258	18	36	21	17	31	158	20	50	30	23	52
45	266	19	35	23	18	32	165	21	49	31	25	55
50	273	19	33	25	19	33	172	22	47	34	27	58
60	283	21	28	27	21	34	181	22	41	37	30	63
70	289	22	23	29	23	35	188	22	34	41	34	69
80	292	—	—	—	—	—	195	—	—	—	—	—
90	294	—	—	—	—	—	200	—	—	—	—	—
↑ PM →		N	W	S	E	Horiz.		N	W	S	E	Horiz.

[a] Moon's[23] proposed standard for sea level, 20 mm precipitable water vapor, 300 dust particles per cu cm, 2.8 mm Hg partial pressure of ozone.
[b] For 40 deg north latitude on about August 1.
[c] Based on observations by ASHRAE Laboratory at Cleveland on cloudless days during which the observed normal incidence values closely approximated the normal incidence values tabulated.
[d] Derived from recommended design sol-air temperatures[25] for New York City for a horizontal surface with absorptivity of 1.0.

These are based upon observations made on cloudless days in Cleveland over a period of several summers. Since less extensive data were available for industrial atmospheres, there is more uncertainty regarding these values. In both instances, the values include an unknown amount of ground reflection, which may be expected to vary with location. It should be noted that clouds which do not obscure the sun tend to *increase* diffuse radiation values. Nearby buildings may *reduce* diffuse irradiation by partial shading.

Calculation Tables

The irradiation of a surface by the sun is the product of I_{DN}, the direct normal radiation (see Table 3), and K, the cosine of the incident angle θ. For horizontal surfaces, the cosine K equals the sine of the solar altitude. For vertical walls, K is a function of the solar altitude β and the wall solar azimuth γ:

$$K = \cos\theta = \cos\beta\cos\gamma \qquad (1)$$

These three angles are defined in Fig. 1. Values of K are given in Table 4 and values of β and γ are given in Table 5 for 18-deg north declination (August 1).

To compute K values for orientations other than those given in Table 5, third angle ϕ, the solar azimuth, is required. In this discussion, ϕ will be measured east from south in the morning, and west from south in the afternoon. Hence, ϕ values are equal to 90 deg minus the γ values for an east or west facing wall, except when Table 5 shows the south walls to be in the shade. In this case ϕ equals $90 + \gamma$, that is, ϕ is greater than 90 deg.

The wall azimuth ψ is the angle, measured east from south to the perpendicular to the wall for walls which have an easterly component, and west from south for those having a westerly component. For example, ψ for a wall facing northeast is 135 deg.

The wall solar azimuth γ may be found according to the following schedule:

For walls facing east of south:	For walls facing west of south:
$\gamma = \phi - \psi$ a.m.	$\gamma = \phi + \psi$ a.m.
$\gamma = \phi + \psi$ p.m.	$\gamma = \phi - \psi$ p.m.

Treat negative values of γ as if they were positive. If γ is greater than 90 deg, the wall is in the shade.

Values of K for other seasons and latitudes may be found in the literature,[26] or may be computed from data given in *Hydrographic Office Bulletin* No. 214, *Tables of Computed Altitude and Azimuth*[27] and the Ephemeris of the Sun.[28] Table 6 shows the variation of solar declination during the months ordinarily requiring cooling.

Example 1: Find the solar azimuth ϕ at 6:30 p.m. at 40-deg north latitude on August 1.

Solution: From Table 5 in the column of γ for a wall facing west ϕ for 6:00 p.m. is 90 + 14 = 104 deg, and at 7:00 p.m. is 90 + 24 = 114 deg. By interpolation, ϕ for 6:30 p.m. is 109 deg west of south (at 5:30 a.m. ϕ would be 109 deg east of south).

Example 2: Find K for a wall facing *18 deg east of south* at 10:00 a.m. on August 1 at 50-deg north latitude.

Solution: The wall azimuth is 18 deg. The solar azimuth is 48 deg east (Table 5). The wall solar azimuth is 48 − 18 or 30 deg. From Table 5, β is 50 deg. Then:

$$K = \cos\beta\cos\gamma = \cos 50 \times \cos 30 = 0.643 \times 0.866 = 0.557.$$

Example 3: Find K for the wall in *Example 2* at 3:00 p.m.

Solution: The solar azimuth is 65 deg west. The wall solar azimuth is therefore 65 + 18 = 83 deg. The angle β is 42 deg.

$$K = \cos 42 \times \cos 83 = 0.743 \times 0.122 = 0.091.$$

Example 4: Find the total solar irradiation for the wall for the conditions of *Example 2*.

Solution: Use clear atmosphere solar intensities. At 50-deg altitude, the direct normal radiation is 273 Btu per (hr) (sq ft). Then: