The sensible heat, q_s, to raise the temperature of the snow to 32 F is

$$q_s = 2.6s\,(32 - t_a) \qquad (3)$$

where

s = rate of snowfall, inches of water equivalent per hour.
t_a = air temperature, Fahrenheit.

The heat of fusion, q_m, to melt the snow is

$$q_m = 746s \qquad (4)$$

The heat of evaporation, q_e, (mass transfer) is

$$q_e = h_{fg}(0.0201v + 0.055)(0.185 - p_{av}) \qquad (5)$$

where

h_{fg} = heat of evaporation at the film temperature, Btu per pound.
v = wind speed, miles per hour.
p_{av} = vapor pressure of moist air, inches of mercury.

The heat transfer, q_h, (convection and radiation) is

$$q_h = 11.4(0.0201v + 0.055)(t_f - t_a) \qquad (6)$$

where t_f = water film temperature, Fahrenheit. (Usually taken as 33 F.)

In addition to determining the four heating requirements, it is necessary to make allowance for back and edge losses. These losses vary from 30 to 50 percent, depending upon the slab construction and fluid temperature.

The equation for the required fluid temperature to provide an output q_o has been derived in Reference 2. For construction similar to Fig. 1, the equation is

$$t_m = 0.5q_o + t_f \qquad (7)$$

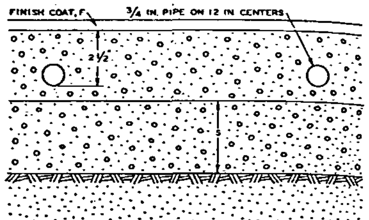
where

t_m = mean fluid temperature (antifreeze solution), Fahrenheit.

Equation 7 will apply to 1 in. as well as ¾ in. IPS pipe—see Fig. 1.

Equations 2 to 7 permit the designer to determine the heating requirement of a snow-melting system. The solutions of these equations, however, require the *simultaneous consideration* of the four climatic factors: (1) wind speed, (2) air temperature, (3) relative humidity, and (4) rate of snowfall. It is not satisfactory to use annual averages or maximums for the climatic factors. If averages or maximums are used there is no assurance that they will *ever* occur simultaneously. It is necessary, therefore, to make a frequency analysis of the solutions to Equation 2 for all the occurrences of snowfall for a period of several years. Such an analysis for 33 cities appears in Table 1 which contains the operating information for a snow-melting system. For freezing temperatures (32 F and below) without snowfall the system may be *idling* which means that some heat is supplied to the slab so that there will be immediate melting when snow starts to fall. Column 4 of Table 1 gives the average temperature during freezing periods. This temperature is used in calculating the *idling load*. The other term needed to calculate *idling load* is the wind speed during the period of freezing temperatures.

The column, Hours of Snowfall, indicates the number of hours that snow is falling at rates equal to or greater than 0.01 in. of water equivalent per hour. There are snowfalls of



F = Depth of Finish Coat—Assumed as ½ in. of concrete. Finish Coat may be asphalt but then cover slab should be reduced from 3 in. Depth of slab should always keep thermal resistance equal to 3 in. of concrete.
S = Depth required by structural design (should be a minimum of 2 in. of concrete).

Fig. 1 .... Detail of Snow Melting Panel

trace quantities about twice as often as there are for measurable quantities of 0.01 in. or more. It is assumed that these light falls can be handled by the *idling load*.

The remaining columns of Table 1 represent the frequency distribution of required heat output. This distribution is based on the solution to the basic equation for two values of the free area ratio, A_r. This distribution represents the basis of the analysis and is also the basis for Tables 2 and 3.

For specific conditions, or for cities other than those given in Table 1, the designer will have to use Equations 2 and 7. Solutions to these equations are given in Table 4 for relative humidities of 80 percent. For other values of relative humidity, Equations 8 and 9 can be used to determine the corrections.

$$\frac{dq_o}{dp_{av}} = -A_r(0.0201v + 0.055)h_{fg} \qquad (8)$$

$$\frac{dt_m}{dp_{av}} = \frac{-A_r}{2}(0.0201v + 0.055)h_{fg} \qquad (9)$$

It will be necessary for the designer to determine values for the appropriate climatic variables before solving Equation 2. Probably the best procedure is to contact the local weather bureau office and examine the *Local Climatological Summary*. An approximation can be made by using Table 5 for values of s, and solutions for Equation 2 taken from Table 4, with the following qualifications:

1. When designing a Class I system use: $A_r = 1.0$, $t_a = 30$ F, and $v = 15$ mph
2. When designing a Class II system use: $A_r = 1.0$, $t_a = 20$ F, and $v = 15$ mph
3. When designing a Class III system use: $A_r = 1.0$, $t_a = 0$ F, and $v = 15$ mph

Snow-melting installations are classified in Table 2 according to types as Class I, II, or III. These classes have been discussed thoroughly in Reference 3, and are defined in the footnotes to Table 2. Briefly, snow-melting systems are classified as to the urgency for melting as follows:

Class I (minimum): Residential walks or driveways and interplant areaways.
Class II (moderate): Commercial (stores and offices) sidewalks and driveways, and steps of hospitals.
Class III (maximum): Toll plazas of highways and bridges, and aprons and loading areas of airports.

These classifications depend upon the allowable rate of snow melting. For example, a residential system does not have to melt snow as rapidly as a commercial system. In fact, a depth of snow of an inch for an hour or so during a heavy storm might not be objectionable with a residential system. On the other hand, a store manager would consider the system inadequate if half an inch of snow accumulated on the sidewalk in front of the store. The difference, then, between a Class I system and a Class II system is in the required ability of each system to melt snow. The one feature that is common to all classes is that the systems must be adequate for some combination of weather factors. The designer may select equipment having capacity to melt snow whenever conditions are milder than some critical values, but be willing to have an inadequate system for a given fraction of the time. In other words, the designer will take a calculated risk providing he knows the odds of that risk. For a residential system, where initial cost must be at a minimum, the designer must accept more frequent snow accumulations.

Table 2 contains the design heat requirements for the 3 classes of snow-melting systems. Under Class I systems, the values in parentheses are *idling rates* and, since they exceed the Class I design rates, should be taken as design output for this classification. Design rates may be altered by the designer if he feels that a particular job should have different design criteria from those given in the footnotes of Table 2. Any change in design conditions used should be based on the frequency distribution given in Table 1.

Use of Tables 1, 2 and 3 is illustrated by *Example 1*.

Example 1: An engineer has been retained to design snow-melting systems for the service areas of a turnpike running from the eastern edge of the Wisconsin-Illinois border northwest to the Wisconsin-Minnesota border just east of St. Paul. He decides that Chicago data will be adequate for the southern terminus and that Minneapolis-St. Paul data will be adequate for the northern terminus. His problem is to determine the heat and hydraulic requirements of the systems for service areas between Chicago and St. Paul.

Solution: Assume, for this example, that the city in question is Madison, Wis. Weather bureau records indicate that the annual average number of days with snow cover of an inch or more would be 100, and that the engineer can assume an average snowfall of 40 inches. In addition, he can estimate about 11 days per year with a snowfall of an inch or more (see Reference 3).

For the walkways to the restaurant from the parking area a Class I design rate could be used. This rate could be taken as 90 Btuh per sq ft. This is in good agreement with data in Tables 2 and 3, which give the rate at 89 (design rate) for Chicago and 95 (idling rate) for Minneapolis.

The lanes leading from the turnpike to the gasoline pumps and parking areas should be rated as Class II areas. A check of Tables 1 and 2 would indicate that 160 Btuh per sq ft would be adequate.

If an emergency area were included, for a wrecking truck, ambulance, or police garage, it would be wise to consider a Class III rate for such areas. An inspection of Table 1 for Chicago shows that a rate of 275 Btuh per sq ft would be adequate for $A_r = 1$ for 99.4 percent of the time. Similarly, 275 would be adequate 99.4 percent of the time in St. Paul. Therefore, 275 Btuh per sq ft seems sufficient for the emergency areas. Table 2 in Class III column lists 350 Btuh per sq ft for Chicago and 254 for St. Paul but for uses similar to the areas in this example, 275 should be adequate.

Hydraulic Requirement

After determining the heating requirements, it is necessary to determine the hydraulic requirements of the system. This

Table 2 .... Design Data for Three Classes of Snow-Melting System*

City	Design Output, Btu per (Hr) (Sq Ft)		
	Class I system[1]	Class II system[2]	Class III system[3]
Albuquerque, N. M.	71	82	167
Amarillo, Tex.	98	143	241
Boston, Mass.	107	231	255
Buffalo-Niagara Falls, N. Y.	80	192	307
Burlington, Vt.	90	142	244
Caribou-Limestone, Me.	89 (93)	138	307
Cheyenne, Wyo.	83	129	425
Chicago, Ill.	89	165	350
Colorado Springs, Colo.	49 (63)	63	293
Columbus, Ohio	52	72	253
Detroit, Mich.	69	140	255
Duluth, Minn.	83 (114)	206	374
Falmouth, Mass.	93	144	165
Great Falls, Mont.	84 (112)	138	372
Hartford, Conn.	115	254	260
Lincoln, Neb.	64 (67)	202	246
Memphis, Tenn.	134	144	212
Minneapolis-St. Paul, Minn.	63 (95)	155	254
Mt. Home, Idaho	50	90	140
New York, N. Y.	121	298	342
Ogden, Utah	98	216	217
Oklahoma City, Okla.	66	81	350
Philadelphia, Pa.	97	229	263
Pittsburgh, Pa.	89	157	275
Portland, Ore.	86	97	111
Rapid City, S. D.	58 (86)	102	447
Reno, Nev.	98	154	155
St. Louis, Mo.	122	152	198
Salina, Kan.	85	120	228
Sault Ste. Marie, Mich.	52 (78)	144	213
Seattle-Tacoma, Wash.	92	128	133
Spokane, Wash.	87	127	189
Washington, D. C.	117	121	144

From *Air Conditioning, Heating and Ventilating*, August 1957, p. 92.

* Where idling rate is greater than Class I design rate, idling rate is given in parentheses and should be used as Class I design output.

[1] For Class I (residential) Systems, the design output is set at that required heat output (see Table 1) when $A_r = 0$ at the 98th percentile of the frequency distribution; that is where 98% of the hours have this output or less.

[2] For Class II (commercial) Systems, the design output is the maximum output when $A_r = 0$ in Table 1 (last column).

[3] For Class III (industrial) Systems the design output is determined by the following four requirements: (1) Output is never exceeded for two consecutive hours; (2) Output for $A_r = 1$, Table 1, is at least 1 Btu per hour per sq ft greater than maximum output for $A_r = 0$; (3) A_r is greater than or equal to 0.5 maximum requirement shown in Table 1 for $A_r = 1$. That is, $q_o = q_s + q_m + 0.5(q_e + q_h)$ for the conditions where $q_t = q_s + q_m + q_h + q_e$ are a maximum; (4) The free area ratio A_r is unity for at least 98% of the hours listed in Table 1.