appropriately. When data on degree days are available these may be used in the calculation of average outdoor temperature for use in Equation 2 or 3. (See definition of degree day, Chapter 4.)

It may be noted that a portion of Equation 3, $(t - t_o)N$ will, when divided by 24, correspond exactly to the degree days for the period, provided that $t = 65$ F, the usual basis for calculating degree days (see discussion of degree days in following sections). Some engineers substitute degree days for the period, multiplied by 24, for the value of $(t - t_o)N$ in Equation 3. Since this amounts to the basis for degree-day calculations, assuming that $t = 65$ F, some allowance is thus made for the fact that F will frequently be overestimated, when H is taken as the maximum, or design, heat load.

Example 1: A residence building is to be heated to 70 F from 6 a.m. to 10 p.m. and 65 F from 10 p.m. to 6 a.m. The calculated hourly heat loss is 120,000 Btu per hour based on 70 F inside at −10 F outdoors. If the building is to be heated by metered steam, how many pounds would be required during an average heating season?

Solution: The heating value of steam may be taken as 1000 Btu per lb, and since it is purchased steam, the efficiency can be assumed as 100 percent. Assume average outdoor temperature as 36.4 F. The average inside temperature is:

$$\frac{(16 \times 70) + (8 \times 65)}{24} = 68.3 \text{ F.}$$

Substituting in Equation 1

$$F = \frac{120{,}000(68.3 - 36.4)5088}{1.00[70 - (-10)]1000} = 243{,}000 \text{ lb.}$$

Example 2: What would be the fuel cost to heat the building in *Example 1* during an average heating season, using stoker-fired bituminous coal at $14.00 per ton having a calorific value of 13,000 Btu per lb, assuming that the seasonal efficiency of the system is 65 percent?

Solution: Substituting in Equation 1

$$F = \frac{120{,}000(68.3 - 36.4)5088}{0.65[70 - (-10)]13{,}000} = 28{,}800 \text{ lb.}$$

The fuel cost is then $(28{,}800 \div 2000)\ (14) = \$201.00$

Example 3: What will be the estimated fuel cost per year of heating a building with gas, assuming that the calculated hourly heat loss is 92,000 Btu based on 0 F, which includes 26,000 Btu for infiltration? The design temperatures are 0 F and 72 F. The normal heating season is 210 days, and the average outdoor temperature during the heating season is 36.4 F. The seasonal efficiency will be 80 percent. The heating plant will be thermostatically controlled, and a temperature of 65 F will be maintained from 11 p.m. to 7 a.m. Assume that the price of gas is 7.5 cents per 100,000 Btu of fuel consumption, and disregard the loss of heat through open windows and doors.

Solution: The average hourly temperature is

$$t_a = \frac{(72 \times 16) + (65 \times 8)}{24} = 69.7 \text{ F.}$$

The maximum hourly heat loss is

$$H = 92{,}000 \text{ Btu.}$$

The seasonal heat loss is

$$M = \frac{92{,}000(69.7 - 36.4) \times 24 \times 210}{100{,}000 \times 0.80 \times (72 - 0)}$$

$$= 2697 \text{ hundred thousand Btu.}$$

The estimated seasonal fuel cost will be

$$2697 \times \$0.075 = \$202.00$$

It should be noted that savings from night setback may not result as calculated. Room temperature may not decrease and combustion efficiency may be poor during morning pickup.[10]

Several time-saving procedures have been devised for quickly estimating the hourly Btu loss of one- and two-story residences in order that fuel estimates can be predicted more quickly from Equation 1. A graphical method of calculating heat losses has been developed[11] which makes possible a quick solution if the gross wall, ceiling, or floor areas and respective transmission coefficients are known.

The Federal Housing Administration has originated a short-cut formula for residential heat loss determinations which makes use of the floor area and three selected transmission coefficients. The formula was developed to apply to detached houses approximately rectangular in shape with total exterior door and window areas equal to about 25 percent of the floor area, and with a floor area not greater than about 1500 sq ft. Equation 4 is for a one-story residence, and Equation 5 is intended for two-story structures.

$$H_1 = A(G + U_w + U_c + U_f)(t_i - t_o) \qquad (4)$$

$$H_2 = A(G + 1.2U_w + 0.5U_c + 0.5U_f)(t_i - t_o) \qquad (5)$$

where

H_1 = heat loss from one-story residence, Btu per hour.
H_2 = heat loss from two-story residence, Btu per hour.
A = floor area, square feet, measured to the inside faces of enclosing walls and is the sum of the following areas: (1) all the area on each principal floor level; (2) the area of all finished habitable attic rooms, including bathrooms, toilet compartments, closets, and halls; (3) all other areas intended to be heated and not located in the basement.
G = glass and infiltration factor for ordinary construction: (0.45 for no weatherstripping or storm windows), (0.40 for weatherstripping), (0.30 for storm windows with or without weatherstripping).
U_w = coefficient of transmission for outside wall.
U_c = coefficient of transmission for ceiling.
U_f = coefficient of transmission for floor.
t_i = indoor design temperature, Fahrenheit degrees.
t_o = outdoor design temperature, Fahrenheit degrees.

Notes for application of Equations 4 and 5.

1. The calculation of heat loss from heated spaces into adjacent spaces such as attics, basementless areas, and heated or unheated garages shall be based on the assumption that the temperature of such adjacent spaces is the same as the outdoor design temperature.

2. For all floors over basements or other warmed spaces assume $U_f = 0$.

3. For structures having concrete slab floors laid on the ground a modified application of the formula may be made. Assume $U_f = 0$ and calculate the heat loss in accordance with the check formula. Then add the slab loss determined in accordance with the procedure developed by the National Bureau of Standards and described in *Building Materials and Standards Report* 103.

4. No basement area is to be included in the formula calculation. If finished habitable rooms in the basement are to be heated, the additional heat loss should be calculated separately and added to the amount obtained by the formula.

Both the graphical method[11] and FHA formulas, when used within the limitations established, have been found to give reasonably accurate results for the average residence, but if precise estimates are required, the heat loss should be calculated as outlined in Chapter 12.

In the case of gravity warm air heating installations, the load was formerly expressed in square inches of leader pipe which can be converted into Btu per hour by multiplying the square inches of leader area by 111, 167, and 200 for first, second, and third floors, respectively.

DEGREE-DAY METHOD

This method is based on consumption data which have been taken from buildings in operation, and the results have been computed on a degree-day basis. While this method may not be as theoretically precise as the Calculated Heat Loss Method, it is considered by many to be of more value for practical use.

The amount of heat required in a building depends upon the outdoor temperature, if other variables are eliminated. Theoretically it is proportional to the difference between the outdoor and indoor temperatures. The American Gas Association[12] determined from records in the heating of residences that the gas consumption varied directly as the degree days, or as the difference between 65 F and the mean outdoor temperature. In other words, on a day when the mean temperature was 20 deg below 65 F, twice as much gas was consumed as on a day when the temperature was 10 deg below 65 F. For any one day, when the mean temperature is less than 65 F, there are as many degree days as there are degrees difference in temperature between the mean temperature for the day and 65 F. Degree days may be calculated on other than the 65 F base for use mainly for warehouse and other industrial spaces in which temperatures to be maintained are considerably below the 68 to 72 F range. They are listed in a later section of this chapter.

Studies made by the National District Heating Association[13] of the metered steam consumption of 163 buildings located in 22 different cities, and served with steam from a district heating company, substantiate the approximate correctness of the 65 F base chosen by the gas industry.

Table 2 lists the average number of degree days that have occurred over a long period of years, by months, and the yearly totals for various cities in the United States and Canada. The number of degree days for United States cities were calculated by taking the difference between 65 F and the daily mean temperature computed as half the total of the daily maximum and the daily minimum temperatures. The monthly averages were obtained by adding daily degree days for each month each year and dividing by the number of days in the month; then totaling the respective calendar monthly averages for the number of years indicated and dividing by the number of years. The total or long term yearly average degree-day value is the summation of the 12 monthly averages. Degree days for Canadian cities were supplied by the Canadian Meteorological Division of the Department of Transport, and were computed from the mean temperature normals on record for the various stations. (See Note c, Table 2.)

Any attempt to apply the degree-day method of estimating fuel consumption for less than one month would be of very little value. It should be noted that this method of calculation is based on a long term average and cannot be expected to coincide with any single year in calculating fuel requirement. Individual yearly degree-day calculations may vary as much as 20 percent above and below the long term average.

If the degree days occurring each day are totaled for a reasonably long period, the fuel consumption during that period as compared with another period may be assumed to be in direct proportion to the number of degree days in the two periods. Consequently, for a given installation, the fuel consumption can be calculated in terms of fuel used per degree day for any sufficiently long period, and compared with similar ratios for other periods to determine the relative operating efficiencies with the outdoor temperature variable eliminated.

Such results should be used with some reservation since it is possible to have wide variations, for example, as between early and late winter periods.[14]

Computation and Application

The general equation for calculating the probable fuel consumption by the degree-day method is:

$$F = U \times N \times D \times C_f \qquad (6)$$

where

F = fuel consumption for the estimate period.
U = unit fuel consumption, or quantity of fuel used per (degree day) (*building load unit*).
N = number of *building load units* (when available, use calculated hourly heat loss instead of actual amount of radiation installed).
D = number of degree days for the estimate period.
C_f = temperature-correction factor from Table 3.

Table 3 . . . . Correction Factors for Outdoor Design Temperatures[a]

Outdoor Design Temp F. . . .	*−20*	*−10*	*0*	*+10*	*+20*
Correction factor.	0.778	0.875	1.000	1.167	1.400

[a] The multipliers in Table 3, which are high for mild climates and low for cold regions, are not in error as might appear. The unit figures in Tables 4, 5, and 6 are per square foot of radiator or thousand Btu heat loss per degree day. For equivalent buildings and heating seasons, those in warm climates have lower design heat losses and smaller radiator quantities than those in cold cities. Consequently, the *unit* figure in quantity of fuel per (square foot of radiator) (degree day), is larger for warm localities than for colder regions. Since the northern cities have more radiator surface per given building and a higher seasonal degree-day total than cities in the south, the total fuel per season will be larger for the northern city.

Values of N depend on the particular building for which the estimate is being prepared and must be found by surveying plans, by observation, or by measurement of the building. Values of U for use in this equation are the unit fuel consumptions per degree day, obtained as a result of the collection of operating information and listed in Tables 4, 5, and 6. Attention is directed to the nature of these units in the next following sections.

Unit Fuel Consumptions per Degree Day

The quantity of fuel used per degree day in a given heating plant can be reduced to a unit basis in terms of quantity of fuel or steam per degree day per thousand Btu hourly heat loss at design conditions. A less frequently used basis is quantity of fuel per (degree day) (square foot of floor area). In fact any convenient unit can be used to relate the consumption to the degree day and to the building.

The choice of these units requires explanation, and some discrimination and judgment. If the volume basis is used, the net heated space is preferable to the gross building cubage, since gross cubage includes outer walls and certain portions of attic and basement space that are usually unheated. In the absence of data on net heated volume, a value of 80 percent of the gross volume may be used to obtain the estimated net heated volume. The volume basis has been rather widely used primarily because it is simple to apply. In industrial buildings it is usually easier to obtain the correct