OPTIMIZING HVAC SYSTEMS

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Contents

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Heating, Ventilating, Air Conditioning, and Building System Optimization

This chapter will review the basics of Heating, Ventilation and Air Conditioning (HVAC) and buildings as related to energy engineering.

DEGREE DAYS

Degree days are the summation of the product of the difference in temperature (ΔT) between the *average outdoor* and hypothetical *average indoor* temperatures (65°F), and the number of days (t) the outdoor temperature is below 65°F. Therefore:

$$DD's = \Delta T \times t, \text{ therefore } \Delta t = DD/t \qquad \textit{Formula (1-1)}$$

Degree Days divided by the total number of days on which Degree Days were accumulated will yield an average ΔT for the season, based on an assumed indoor temperature of 65°F. To find the average outdoor temperature of the season, this figure must be subtracted from 65°F.

Example Problem 1-1

If there are 6750 degree days recorded over a heating season of 270 days, what is the mean outdoor temperature for that season?

Answer

$$\Delta T = DD/t \quad \Delta T = \frac{6740DD}{270 \text{ days}} \quad \Delta T = 25^\circ\text{F}$$

The average outdoor temperature can now be found, since

$\Delta T = T$ (avg. indoor) $- T$ (avg. outdoor)
T (avg. outdoor) $= T$ (avg. indoor) $- \Delta T$
T (avg. outdoor) $= 65^\circ\text{F} - 25^\circ\text{F}$
T (avg. outdoor) $= 40^\circ\text{F}$

RESISTANCE *(R)* TO HEAT FLOW AND CONDUCTANCE *(U)* AND CONDUCTIVITY *(K)*

The rate at which heat flows through a material depends on its characteristics. Some materials transmit heat more readily than others. This characteristic of materials which affects the flow of heat through them, can be viewed either as their *resistance* to the flow of heat or as their *conductance* allowing the flow of heat.

For a section of a building, such as a wall, the conductance is expressed as the *U*-value for that wall; that is, the number of Btu's that will pass through a one-square-foot section of a building in one hour with a one-degree temperature difference between the two surfaces.

U = Btu's per square foot per hour per degree Fahrenheit.

or

$$U = \text{Btu/ft}^2\,\text{h}\,^\circ\text{F}$$

R-Value = Thermal Resistance = The unit time for a unit area of a particular body or assembly having defined surfaces with a unit average temperature difference established between the two surfaces per unit of Thermal Transmission.

$$\frac{\text{hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}}{\text{Btu}}$$

$$R = 1/U \qquad \textit{Formula (1-2)}$$

The conductivity of a material as related to conductance and resistance is illustrated by Formula 7-3.

$$U = \frac{K}{d} = \frac{1}{R} \qquad \textit{Formula (1-3)}$$

where d is the thickness of the material.

VOLUME *(V)* OF AIR

The volume of air within a structure is constant even though the air itself changes—new air enters and old air leaves. The total volume is equal to the volume of space within the conditioned portion of the home. (Only the volume of conditioned space is considered since air entering and leaving the unconditioned part of the home does not demand energy to condition it.)

To determine the volume (V) of air, multiply the height (H) of the space times the width (W) of the space times the length (L) of the space.* While this can be done for the home as a whole, it is more accurate to calculate it for each room and then add these volumes.

AIR CHANGES PER HOUR *(AC)*

The rate at which the volume of air in a structure changes per hour differs greatly from building to building. The number of air changes per hour (AC/h) has wide variation due to a number of factors such as

- *The number and size of openings* in the envelope—around doors and windows and in the siding itself;
- *The average speed* of the wind blowing against the structure and the protection the structure has from this wind;
- *The number and size* of chimneys, vents, and exhaust fans and the frequency of their use;
- *The number of times* that doors and windows are opened; and
- *How the structure is used.*

*This is only appropriate for structures with flat ceilings.

HEATING CAPACITY OF AIR *(HC)*

Air can be heated and cooled. A certain amount of heat is necessary to change the temperature of each cubic foot (ft^3) of air one degree Fahrenheit (F). This amount of heat depends on the density of air which varies with temperature and pressure. This figure will generally be within the range of 0.018–0.022 Btu's/ft^3 °F.

BUILDING DYNAMICS

The building experiences heat gains and heat losses depending on whether the cooling or heating system is present, as illustrated in Figures 1-1 and 1-2. Only when the total season is considered in conjunction with lighting and heating ventilation and air-conditioning (HVAC) can the energy utilization choice be decided. One way of reducing energy consumption of HVAC equipment is to reduce the overall heat gain or heat loss of a building.

CONDUCTION HEAT LOSS

The formula used to determine the amount of heat conducted through the envelope is as follows: Degree days *(DD)* is the product of the difference in temperature, ΔT, and the time *(t)* in days, providing that the days in degree days *(DD)* are converted to hours. This is accomplished by multiplying *(DD)* times 24 hours a day. This will yield the quantity of heat *(Q)* conducted through a particular section of the envelope for the entire heating season.

The formula can be written:

$$Q_{\text{(heating season)}} = U \times A \times DD \times 24 \text{ hours/day} \qquad \textit{Formula (1-4)}$$

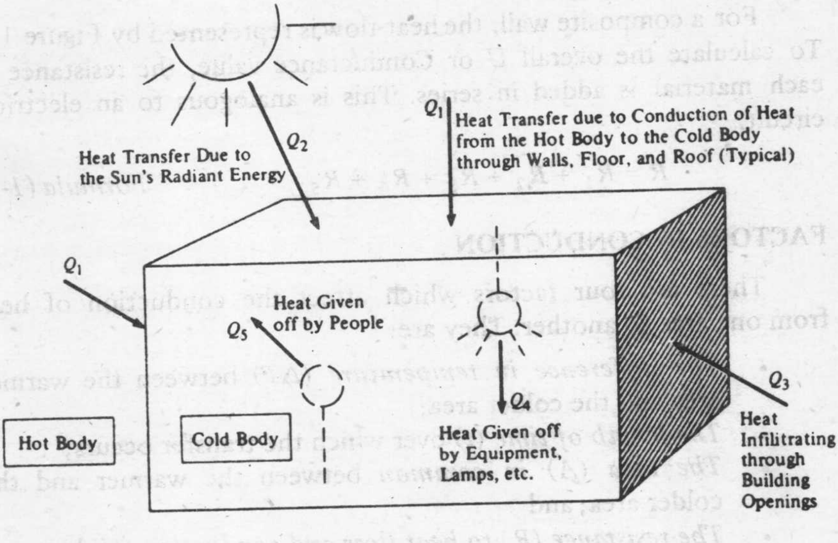
or

$$Q_{\text{(heating season)}} = \frac{A \times DD \times 24 \text{ hrs/day}}{R} \qquad \textit{Formula (1-5)}$$

In general heat flow through a flat surface is defined as

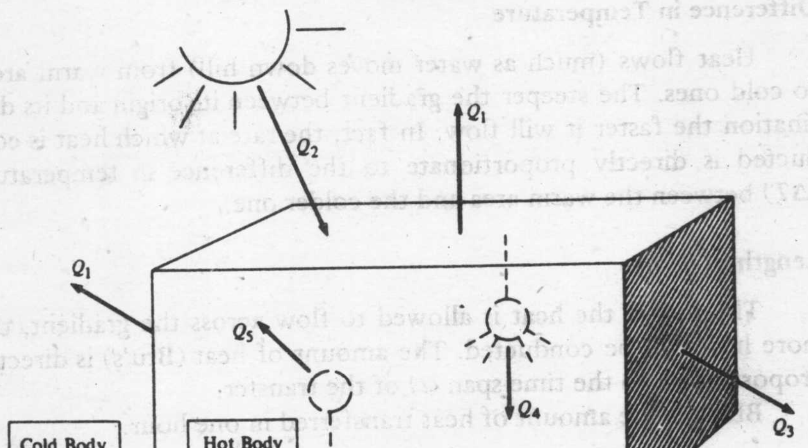
$$Q = U A \, \Delta T \qquad \textit{Formula (1-6)}$$

where ΔT is the temperature difference causing the heat flow.



Heat Gain = $Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

Figure 1-1. Heat Gain of a Building



Heat Loss = $Q_1 + Q_3 - Q_2 - Q_4 - Q_5$

Figure 1-2. Heat Loss of a Building

For a composite wall, the heat flow is represented by Figure 1-3. To calculate the overall *U* or Conductance value, the resistance of each material is added in series. This is analogous to an electrical circuit.

$$R = R_1 + R_2 + R_3 + R_4 + R_5 \qquad \textit{Formula (1-7)}$$

FACTORS IN CONDUCTION

There are four factors which affect the conduction of heat from one area to another. They are:

- *The difference in temperature (ΔT)* between the warmer area and the colder area;
- *The length of time (t)* over which the transfer occurs;
- *The area (A) in common* between the warmer and the colder area; and
- *The resistance (R) to heat flow and conduction (U)* between the warmer and the colder area.

Difference in Temperature

Heat flows (much as water moves down hill) from warm areas to cold ones. The steeper the gradient between its origin and its destination the faster it will flow. In fact, the rate at which heat is conducted is directly proportionate to the difference in temperature (ΔT) between the warm area and the colder one.

Length of Time

The longer the heat is allowed to flow across the gradient, the more heat will be conducted. The amount of heat (Btu's) is directly proportionate to the time span *(t)* of the transfer.

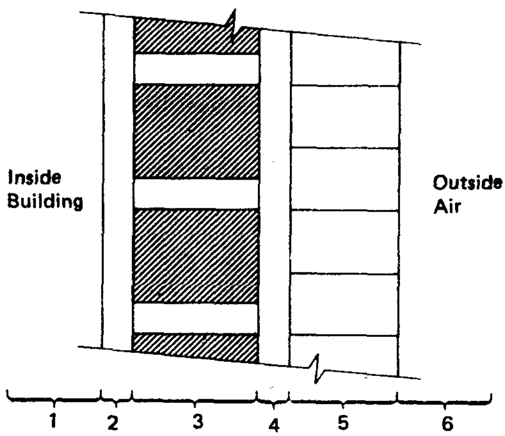
Btu/h is the amount of heat transferred in one hour.

The Area *(A)* in Common

The larger the area common to the warmer and colder surfaces, through which the heat flows, the greater is the rate of conducted heat. For the same material, for the same length of time, at the same ΔT, the amount of heat (Btu's) transferred is directly proportionate to the area (A) in common.

Example Problem 1-2

Calculate the heat loss through 20,000 ft^2 of building wall, as indicated by Figure 1-3. Assume a temperature differential of 17°F.



1 Inside Air Film R = .68
2 ½" Plaster Board Interior Finish R = .44
3 8" Concrete Block, Sand & Gravel Aggregate R = 1.1
4 ½" Cement Mortar R = .1
5 4" Brick Exterior R = .44
6 Outside Air Film @ 15 mph Wind R = .17

Figure 1-3. Typical Wall Construction

Answer

Description		*Resistance*
Outside air film at 15 mph		0.17
4" brick		0.44
Mortar		0.10
Block		1.11
Plaster Board		0.44
Inside film		0.68
	Total resistance	2.94

$U = 1/R = 0.34$
$Q = U A \Delta T$
$= 0.34 \times 20{,}000 \times 17 = 115{,}600$ Btu/h.

In Figure 1-4 a surface film conductance is introduced.

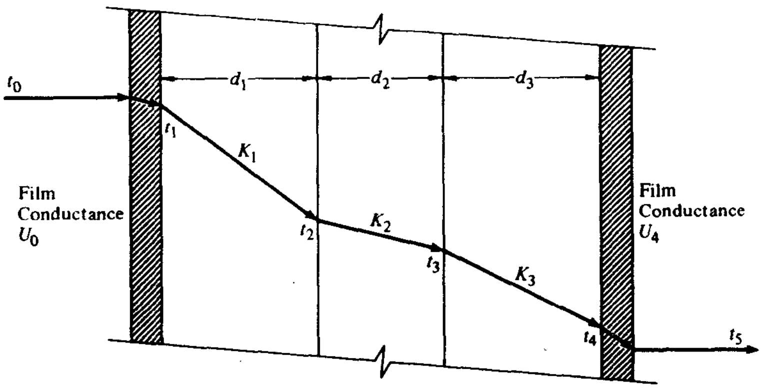


Figure 1-4. Temperature Distribution for the Composite Wall

The surface or film conductance is the amount of heat transferred in Btu per hour from a surface to air or from air to a surface per square foot for one degree difference in temperature. The flow of heat for the composite material can also be specified in terms of the conductivity of the material and the conductance of the air film:

$$Q = \frac{A\ (t_0 - t_5)}{1/U_0 + d_1/K_1 + d_2/K_2 + d_3/K_3 + 1/U_4}. \qquad \text{Formula (1-8)}$$

LATENT HEAT AND SENSIBLE HEAT

The latent heat gain of a space means that moisture is being added to the air in the space. Moisture in the air is really in the form of superheated steam. Removing sensible heat from a space through air-conditioning equipment lowers the dry-bulb temperature of the air. On the other hand, removing latent heat from a space changes the substance state from a vapor to a liquid. The latent heat gain of a space is expressed in terms of moisture, heat units (Btu) or grains of moisture per hour (7,000 grains equals one pound). The average value for the latent heat or vaporization for superheated steam in air is 1050.

Example Problem 1-3

2000 grains of moisture are released in a conditioned room each hour. Calculate the heat that must be removed in order to condense this moisture at the cooling coils.

Answer

$$\frac{2000}{7000} \times 1050 = 299.9 \text{ Btuh}$$

Example Problem 1-4

Calculate the quantity of heat *(Q)* required by infiltration in an 8,000 cubic foot (ft^3) home that has 1.7 air changes per hour (AC/h) when the outside temperature is 48°F and the inside temperature is 68°F (ΔT = 20°F) for one day (24 hours).

Answer

$Q = V \times AC/\text{h} \times 0.020^{*}\ \text{Btu/ft}^3\ {}^\circ\text{F} \times \Delta T \times t$
$Q = 8{,}000\ \text{ft}^3 \times 1.7\ AC/\text{h} \times 0.020^{*}\ \text{Btu/ft}^3\ {}^\circ\text{F} \times 20^\circ\text{F} \times 24\ \text{hrs}$
$Q = 8{,}000 \times 1.7 \times 0.020^{*} \times 20 \times 24$
$Q = 130{,}560\ \text{Btu's}^{**}$

INFILTRATION

Leakage or infiltration of air into a building is similar to the effect of additional ventilation. Unlike ventilation, it cannot be controlled or turned off at night. It is the result of cracks, openings around windows and doors, and access openings. Infiltration is also induced into the building to replace exhaust air unless the HVAC balances the exhaust. Wind velocity increases infiltration and stack effects are potential problems. Air that is pushed out the window and door cracks is referred to as exfiltration.

To estimate infiltration, the Air Change Method or Crack Method is used.

Air Change Method

The five factors which determine the amount of energy lost through infiltration can be put together in a formula that states that:

The quantity of heat *(Q)* equals the volume of air *(V)* times the number of air changes per hour *(AC/*h) times the amount of heat required to raise the temperature of air one degree Fahrenheit (0.018–0.022 Btu's) times the temperature difference (ΔT) times the length of time *(t)*. This is expressed as follows:

$$Q = V \times AC/\text{h} \times 0.020\ \text{Btu's} \cdot /\text{ft}^3\ {}^\circ\text{F} \times \Delta T \times t \qquad \textit{Formula (1-9)}$$

The Air Change Method is considered to be a quick estimation method and is not usually accurate enough for air-conditioning design. A second method used to determine infiltration is the Crack Method.

*This is a regional variable.
** Once again, all of the units in the formula cancel except Btu's, leaving the units for *Q* as Btu's.

Crack Method

When infiltration enters a space it adds sensible and latent heat to the room load. To calculate this gain the following equations (1-10) and (1-11) are used.

Sensible Heat Gain

$$Q_S = 1.08 \text{ CFM } \Delta T \qquad \textit{Formula (1-10)}$$

Latent Heat Gain

$$Q_L = .7 \text{ CFM } (HR_o - HR_i) \qquad \textit{Formula (1-11)}$$

where

Q_S = Sensible heat gain Btuh
Q_L = Latent heat gain Btuh
CFM = Air Flow Rate
ΔT = Temperature differential between outside and inside air, F
HR_o = Humidity ratio of outside air, grains per lb
HR_i = Humidity ratio of room air, grains per lb

BODY HEAT

The human body releases sensible and latent heat depending on the degree of activity. Heat gains for typical applications are summarized in Table 1-1.

EQUIPMENT, LIGHTING AND MOTOR HEAT GAINS

It is important to include heat gains from equipment, lighting systems and motor heat gain in the overall calculations.

For a manufacturing facility, the major source of heat gains will be from the process equipment. Consideration must be given to all equipment including motors driving supply and exhaust fans.

To convert motor horsepower to heat gain in Btuh, equation 1-12 is used.

Table 1-1. Heat Gain from Occupants

Activity	*Sensible Heat Btuh*	*Latent Heat Btuh*	*Total Heat Gain Btuh*
Very Light Work – Seated (Offices, Hotels, Apartments)	215	185	400
Moderately Active Work (Offices, Hotels, Apartments)	220	230	450
Moderately Heavy Work (Manufacturing)	330	670	1000
Heavy Work (Manufacturing)	510	940	1450

Source: ASHRAE–Guide & Data Book

$$Q = \frac{\text{hp} \times .746}{\eta} \times 3412 \qquad \textit{Formula (1-12)}$$

where

hp is the running motor horsepower
η is the efficiency of the motor
Q is the heat gain from the motor Btuh

Similarly, the kilowatts of the lighting system can be converted to heat gain.

$$Q = (\text{KW}_F + \text{KW}_B) \times 3412 \qquad \textit{Formula (1-13)}$$

where

KW_F is the kilowatts of the lighting fixtures
KW_B is the kilowatts of the ballast
Q is the heat gain from the lighting system Btuh

RADIANT HEAT GAIN

Heat from the sun's rays greatly increases heat gain of a building. If the building energy requirements were mainly due to cooling, then this gain should be minimized. Solar energy affects a building in the following ways:

1. *Raises the surface temperature:* Thus a greater temperature differential will exist at roofs than at walls.

2. A large percentage of direct solar radiation and diffuse sky radiation *passes through* transparent materials, such as glass.

SURFACE TEMPERATURES

The temperature of a wall or roof depends upon:

(a) the angle of the sun's rays
(b) the color and roughness of the surface
(c) the reflectivity of the surface
(d) the type of construction.

When an engineer is specifying building materials, he should consider the above factors. A simple example is color. The darker the surface, the more solar radiation will be absorbed. Obviously, white surfaces have a lower temperature than black surfaces after the same period of solar heating. Another factor is that smooth surfaces reflect more radiant heat than do rough ones.

In order to properly take solar energy into account, the angle of the sun's rays must be known. If the latitude of the plant is known, the angle can be determined.

SUNLIGHT AND GLASS CONSIDERATIONS

A danger in the energy conservation movement is to take steps backward. A simple example would be to exclude glass from building designs because of the poor conductance and solar heat gain factors of clear glass. The engineer needs to evaluate various alternate glass constructions and coatings in order to maintain and improve the aesthetic qualities of good design while minimizing energy inefficiencies. It should be noted that the method to reduce heat gain of glass due to conductance is to provide an insulating air space.

To reduce the solar radiation that passes through glass, several techniques are available. Heat absorbing glass (tinted glass) is very popular. Reflective glass is gaining popularity, as it greatly reduces solar heat gains.