Heat Loss Calculations and Principles

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HVAC HEATING LOSS CALCULATIONS & PRINCIPLES

Introduction

There are two different but related calculated values of interest to the heating system designer. The first is to estimate the maximum rate of heat loss to properly size the heating equipment (furnace). The second calculated value that must be determined is the annual heating bill. This is determined by calculating the annual energy requirement based from the design heat loss rate.

In this course, we will learn to determine the rate at which heat is lost through building elements using a process called heat loss calculation. You will learn how to extrapolate your calculation of a maximum hourly rate into an annual energy usage rate. You will also learn some useful tips on saving heating energy.

The section-3 of the course includes one sample example.

Factors Affecting Comfort in winter

1. TEMPERATURE difference between the inside and outside of the building is the primary cause of heat loss in the winter months. The greater this difference, the higher the rate of heat loss. Since most buildings are controlled to a constant inside temperature by the occupants, higher heat loss occurs when it is colder outside. This also means that the annual heating bill can be reduced by lowering the setting on the thermostat …. (but only if the occupants agree to it!)

2. WIND is the second greatest source of heat loss during the winter. High winds can occur on the cold nights and when they do, heat loss can be higher because of air scrubbing the outside of the space covering. Winds can also force their way through cracks in the structure, causing infiltration and drafts. In fact, up to one-third of the annual heating energy goes to heat this moving infiltration air many times each winter day.

3. HUMIDITY levels can also affect the comfort within a structure. Very low humidity levels (less than 20% relative humidity) cause scratchy throats and dry noses in most people.

Very high humidity levels (over 60%) are also uncomfortable, since the body's ability to perspire is restricted.

4. RADIATION sources can also affect comfort in a structure. The sun shining through a window will make a room very comfortable in winter; that same sun could make it unbearable in summer. Walls and windows also release and absorb radiation. A Trombe wall heated by the sun will keep a room feeling warm with an air temperature less than 60°F. A large expanse of cold glass windows can also make a room feel chilly.

Remember that these same four factors are also important in determining cooling requirements, but control of humidity and solar gain are much more important during that season.

HEATING LOSS ESTIMATION

The heat loss is divided into two groups:

1) The conductive heat losses through the building walls, floor, ceiling, glass, or other surfaces, and

2) The convective infiltration losses through cracks and openings, or heat required to warm outdoor air used for ventilation.

Normally, the heating load is estimated for winter design temperature usually occurring at night; therefore, in determining the heating load, credit for heat generation from internal heat sources such as lights, machinery, appliances, and people is usually ignored. Also in determining the heating load, credit for solar heat gain is usually NOT included and is generally ignored. Credit for solar heat gain is a plus factor in winter heating.

HEAT LOSS FROM BUILDING ENVELOPE (Wall, Roof, Glass)

Heat loss occurs from a building structure primarily due to conduction. Because heat moves in all directions, when calculating the heat loss of a building, we much consider all surfaces (external walls, roof, ceiling, floor, and glass) that divide the inside, heated space from the outside. We refer to that dividing line as the ***Building Envelope.*** The heat loss is determined by equation:

$Q = A * U * (Ti – To)$

Where

- Q = Total hourly rate of heat loss through walls, roof, glass, etc in Btu/hr
- U = Overall heat-transfer coefficient of walls, roof, ceiling, floor, or glass in Btu/hr ft^2 °F
- A = Net area of walls, roof, ceiling, floor, or glass in ft^2
- Ti = Inside design temperature in °F
- To = Outside design temperature in °F

Let's examine each one of these terms, starting at the bottom with the outside design temperature.

Outside Design Temperature (To)

Look up for location

Since the inside of the building is controlled to a fixed temperature by the thermostat, the maximum rate of heat loss will occur during the record cold temperature. When designing the heating system for a structure, the first step is to obtain data on the local micro climate of the region. This information is available from a variety of sources, but HVAC designers normally use the ASHRAE Fundamentals Handbook for ready reference. As a basis for design, the most unfavorable but economical combination of temperature and wind speed is chosen. The winter month heating load conditions are based on annual percentiles of 99.6 and 99%, which suggests that the outdoor temperature is equal to or lower than design data 0.4% and 1% of the time respectively. For example, the Pittsburgh, PA, 99% design temperature is 4°F. Only one percent of the hours in a typical heating season (about 35 hour’s total) fall at or below that temperature. Since most of these hours are during the night-time when most people are sleeping, and because these extremes are buffered by the large storage mass of the building, these cooler periods usually go unnoticed.

Inside Design Temperature (Ti)

Always use 65°F

The inside design temperature is traditionally taken as 65°F, because in most buildings there is enough heat internally generated from people, lighting, and appliances. Today people are keeping thermostats set lower, so load predictions based on this method are usually conservative, and will result in furnace size recommendations that are slightly larger than actually needed.

Note that the temperature difference between the inside and outside of the building is the primary cause of heat loss in the winter months. The greater this difference, the higher the rate of heat loss. Since most buildings are controlled to a constant inside temperature by the occupants, higher heat loss occurs when it is colder outside.

Net Area (A)

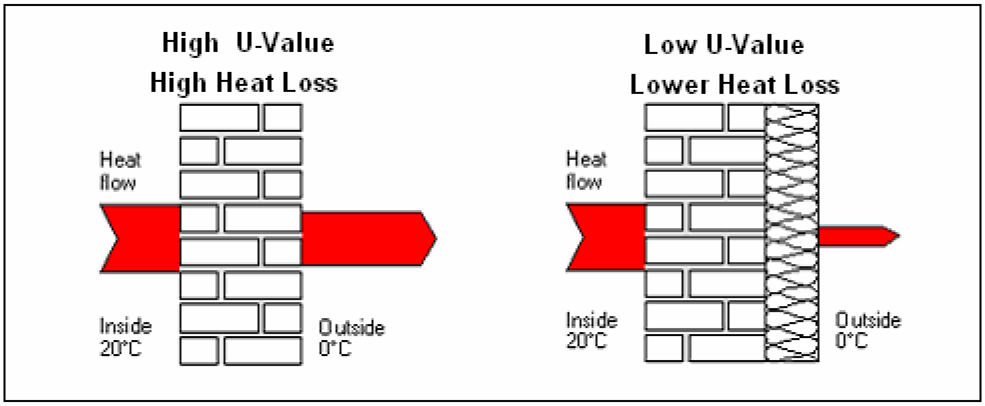
Measured on the drawing/building

The net area of each building section is determined from either the drawings (in new construction) or from field measurements (in retrofit situations). In addition to the areas of the four walls, floor, and ceiling, we must also consider heat loss from doors and windows. We will also need to determine the volume of the building to estimate the rate of infiltration into the building measured in air changes per hour.

Overall Coefficient of Heat Transfer (U)

Look up for materials used

The letter *"U"* represents the overall coefficient of heat transfer. The U-value measures how well a building component, e.g. a wall, roof or a window, keeps heat inside a building. For those living in a warm climate the U-value is also relevant as it is an indicator of how easy it is to keep the inside of the building cold.



The higher the U-value the more heat flows through so a good U-value is a low one as you want to keep heat inside the building or outside depending on the climate you live in. A house built with low U-value building components will use less energy and thus the building owner saves money on the energy bill. Using less energy is good for the environment.

"U" factor is the inverse of "R" factor, ("U" = 1 / "R"); *the larger the R-value or the lower the "U" factor, the lower the heat loss.* Calculating the U-value is often complicated by the fact that the *total* resistance to the flow of heat through a wall made of several layers is the sum of the resistances of the individual layers. This aspect is discussed in detail in subsequent sections.

Heat Loss (Q)

Total hourly rate of heat loss through walls, roof, glass is given by equation Q = U * A * ΔT.

For example: 10 sq-ft. of single glass [U value of 1.13] with an inside temperature of 70°F and an outside temperature of 0°Fwould have 791 BTUH heat loss:

A (10) x U (1.13) x ΔT (70) = 791 Btu/hr

Since the building structure is made of different materials, for example a wall that contains windows and door, just calculate the heat loss through each of the components separately, then add their heat losses together to get the total amount.

Q (wall) =Q (framed area) +Q (windows) +Q (door)

In North America, heat loss is typically expressed in terms of total British Thermal Units per Hour or Btu/hr.

HEAT LOSS FROM FLOORS ON SLAB

Heat loss from floors on slab can be estimated by equation:

$Q = F * P * (T_i - T_o)$

Where:

1) F is the Heat Loss Coefficient for the particular construction in Btu/hr- ft-°F

2) P is the perimeter of slab in ft

3) T_i is the inside temperature in °F

4) T_o is the outside temperature in °F

Heat loss from slab-on- grade foundations is a function of the slab perimeter rather than the floor area. Perimeter is the part of the foundation or slab nearest to the surface of the ground outside. The losses are from the edges of the slab and insulation on these edges will significantly reduce the heat losses.

For basement walls, the paths of the heat flow below the grade line are approximately concentric circular patterns centered at the intersection of the grade line and the basement wall. The thermal resistance of the soil and the wall depends on the path length through the soil and the construction of the basement wall. A simplified calculation of the heat loss through the basement walls and floor is given by equation:

$Q = A * U_{base} * (T_{base} – To)$

Where

- *A* = *A*rea of basement wall or floor below grade in ft^2
- U_{base} = Overall heat-transfer coefficient of wall or floor and soil path, in Btu/hr ft^2 °F
- T_{base} is the basement temperature to be maintained in °F

- T_o is the outside temperature in °F

The values of U_{base} are roughly given as follows:

	0 to 2 ft below grade	Lower than 2 ft
Un insulated wall	0.35	0.15
Insulated wall	0.14	0.09
Basement floor	0.03	0.03

Source: *ASHRAE Handbook 1989*, *Fundamentals*

Calculating heat loss through a basement or slab on grade is more difficult for two main reasons: First because the soil can hold a large quantity of heat, second because the temperature in the ground is not the same as outside temperature (in fact it varies little by season). Because of these reasons, buildings loose more heat through their perimeter and the standard practice is to insulate basement walls and 2-4 feet under the slab near those walls. The ASHRAE method is to calculate heat loss for this situation is to look up a perimeter heat loss factor (called "F") in a table based on the "R" value of perimeter insulation used.

Note that the portion of heat transmission from basement is usually neglected unless the weather in winter is severe and the values are significant in comparison with other forms of heat transmission.

HEAT LOSS DUE TO INFILTRATION & VENTILATION

The second type of heat loss in buildings is infiltration. To calculate this, you need to know the volume of the space (i.e. sq ft of floor times ceiling height) and how much air typically leaks out , which is often stated as how many times per hour the entire air in the building space is lost to outside and referred to as air changes per hour or ACH. Infiltration can be considered to be 0.15 to 0.5 air changes per hour (ach) at winter design conditions. The more the windows on the external walls, the greater will be the infiltration.

The infiltration/ventilation air quantity estimation is usually done by one of the three methods 1) air change method, 2) infiltration through the cracks and 3) based on occupancy i.e. number of people in the space.

Ventilation rate based on Air change method:

V = ACH * A * H / 60

Where

- V = Ventilation air in CFM
- ACH = Air changes per hour usually 0.15 to 0.5 ACH depending on the construction of the building
- A = Area of the space in ft^2
- H = Height of the room in ft

Note A * H is the volume of the space.

Ventilation rate based on Crack method:

Volume of air = I * A

Where

- V = Ventilation air in CFM
- I = Infiltration rate usually 0.15 cfm/ft^2
- A = Area of cracks/openings in ft^2

Ventilation rate based on Occupancy method:

V = N * 20

Where

- V = Ventilation air in CFM
- N = Number of people in space usually 1 person per 100 sq-ft for office application
- 20 = Recommended ventilation rate is 20 CFM/person [based on ASHRAE 62 standard for IAQ]

In heat loss estimation, we choose the method that gives the most amount of load.

As soon as the volume flow rate of infiltrated air, CFM, is determined, the sensible heat loss from infiltration can be calculated as

$$Q = V * \rho_{air} * C_p * (Ti – To) * 60$$

Where:

- o $Q_{sensible}$ is sensible heat load in (Btu/hr)
- o V = volumetric air flow rate in (cfm)
- o ρ_{air} is the density of the air in (lbm/ft³)
- o C_p = specific heat capacity of air at constant pressure in (Btu/lbm -F)
- o Ti = indoor air temperature in (°F)
- o To = outdoor air temperature in (°F)

ANNUAL HEATING VALUE

The annual heating value is the function of the “degree days” of heating.

Heating **degree day** is defined as a measure of the coldness of the weather experienced. The degree-day concept has traditionally been used to determine the coldness of a climate. When the weather is slightly cool, a little bit of heat might be needed for a few hours in the evening or early morning to stay comfortable. On a very cold day, a lot of heat will be needed all day and all night. A day’s average temperature gives some idea of how much heat will be needed on that day. Climatologists use a measurement known as heating degree-days (HDDs) to estimate heating needs more precisely. They assume that people will use at least some heat on any day that has an average outdoor temperature of less than 65ºF. They then calculate the heating needs for each day by subtracting the day’s average temperature from 65. The result is the number of heating degrees for that day or HDDs. The higher the number, the more fuel will be used in heating your home or building.

Example for any given day:

High Temp = 50° F

Low Temp = 20° F

$$\text{Average Temperature} = \frac{50° + 20° \text{ F}}{2} = 35° \text{ F}$$

Degree Day = 65°F - 35° F = 30° F

Therefore, the day was a 30 Degree Day.

From the above data, we can make an educated guess about the annual heat loss. To determine the annual heat loss, divide the energy loss rate by the design temperature difference and then multiply it by 24 hours per day and the number of annual degree days (from the weather files of the location).

For example, a house with a design heating load of 30,000 Btu/hr in Pittsburgh (average temperature of 4°F) will use:

[30,000 Btu/hr * 24 hr/day / (65 - 4) (°F)] x 6000 DD/yr = 71million Btu/yr

The concept of degree days is used primarily to evaluate energy demand for heating and cooling services. In the United States, for example, Pittsburgh, Columbus, Ohio, and Denver, Colorado, have comparable annual degree days (about 6000 DD/year). It can be expected that the same structure in all three locations would have about the same heating bill. Move the building to Great Falls, MT (7800 DD/year), it would have a higher heating bill; but in Albuquerque, NM, (4400 DD/year), it would have a relatively lower heating cost.

Although the degree day reading is useful, keep in mind that other factors such as sun load or excessive infiltration due to high wind also affect the heating requirements of a building and are not taken into account by the degree day calculation.

We will learn more about the Degree days and the Heat loss estimation in a sample example presented in section-3 of the course but before that let’s briefly discuss the concepts of heat transmission.

SECTION # 2 HEAT TRANSMISSION THROUGH BUILDINGS

The Physics of Heat Transmission

Although it is not necessary to understand the physics of heat movement, it is useful to understand it in general terms. Heat transfer is the tendency of heat or energy to move from a warmer space to a cooler space until both spaces are the same temperature. Obviously the greater the difference in temperatures, the greater will be the heat flow. There are three types of heat transfer:

1. Via Conduction - This occurs when two objects are in direct contact, for example the air against a window or the soil against a foundation. In buildings, this is typically the most significant method of heat transfer. Conduction moves in all directions at the same time. The total heat transferred by conduction varies *directly* with time, area, and temperature difference, and *inversely* with the thickness of the material through which it passes.

2. Via Convection - This occurs within a fluid medium (e.g. air or water) and is the result of the warmer part of the fluid rising while the colder part sinks. Convection results in the entire fluid rapidly reaching the same temperature. The old saying that "heat rises" is really a misstatement that should say "warm air rises". Heat has no sense of direction, but warm air being lighter rises due to being displaced by colder air which has a greater pull of gravity. The heated air leaking out through door and window openings is an example of convection.

3. Via Radiation - This occurs between a warm object and a colder object when they are separated only by a medium which is transparent to infrared radiation. This is easiest to understand by just standing in the sun: while the sun is very far away, it is also very big and very hot while space and the atmosphere block very little of that incoming radiation. With smaller and much cooler objects, radiation is a much less significant source of heat transfer, although its affects can still easily be noticed. In a home, windows are transparent to some heat radiation (more about this in solar power), but the rest of the building is relatively opaque.

The primary heat loss is via conduction and convection. Let's discuss these further.

Heat Loss by Conduction

With buildings, we refer to heat flow in a number of different ways: “k” values, “C” values, "R" values and “U” values.

What it all means?

Basically all these letter symbols denote heat transfer factors and describe the same phenomenon; however, some are described as determined by material dimensions and boundaries.

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k = Thermal Conductivity

The letter *"k"* represents thermal conductivity, which is the rate of heat transfer through one inch of a homogeneous material. A material is considered homogeneous when the value of its thermal conductivity does not depend on its dimension. It is the same number regardless of the thickness. Thermal Resistance, or “R” is the reciprocal of thermal conductivity i.e. R = 1/k. Thermal conductivity is expressed in (Btu-in/hr ft^2 °F). Materials with lower k-values are better insulators.

Example:

Calculate the heat loss through a 3” thick insulation board that has an area of $2ft^2$ and has a k-value of 0.25. Assume the average temperature difference across the material is 70°F.

Solution:

Q = 0.25 *(k)* * 2 (ft^2) * 70°F (ΔT) / 3 (in. of thickness)

Q = 35 / 3 = 11.66 Btu/hr

It should be apparent from the example that in order to reduce heat transfer, the thermal conductivity must be as low as possible and the material be as thick as possible. Most good insulating materials have a thermal conductivity (k) factor of approximately 0.25 or less, and rigid foam insulations have been developed with thermal conductivity (k) factors as low as 0.12 to 0.15.

Note: In some technical literature, k-values are based on thickness per foot instead of per inch.

C = Thermal Conductance

The letter "C" represents thermal conductance, which, like thermal conductivity, is a measure of the rate of heat transfer through a material but it differs from conductivity (k -value) in one significant way*. Thermal conductance is a specific factor for a given thickness of material whereas thermal conductivity is a heat transfer factor per inch of thickness.* The lower the C value, the better the insulator or lower the heat loss.

Typically, building components such as walls or ceilings consist of a "series" or layers of different materials as you follow the heat flow path out. The overall C value is not additive because if you were to take two insulating materials with a C-value of .5 each and were to add them together, you get the result of a total C-value of 1.0. This would mean that the heat flow rate has increased with the addition of more insulating material. Obviously then you cannot add C-values to find the "series" value.

Therefore, we now have to bring in the perhaps more familiar "R"-value which is a measure of a material's Resistance to heat flow and is the inverse or reciprocal of the material's C-value (R=1/C).

So if a material has a C-value of .5, it has an R-value of 2 (1/.5). If you have to add two materials in series or layers, say each with a C-value of .5, you take the inverse of both to get an R-value for each of 2. These can be added together to get a total R-value of 4.

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h = Film or Surface Conductance.

Heat transfer through any material is affected by the resistance to heat flow offered by its surface and air in contact with it. The degree of resistance depends on the type of surface, its relative roughness or smoothness, its vertical or horizontal position, its reflective properties, and the rate of airflow over it. It is similar to thermal conductance and is expressed in Btu/ (hr ^{0}F ft^{2}).

R = Thermal Resistance

The thermal resistance (R) is a measure of the ability to retard heat flow in a given thickness of material. By definition, the resistance of a material to the flow of heat is the reciprocal of its heat transfer coefficient. In other words, the *R-value* is the reciprocal of either the k-value or the C-value.

When a building structure is composed of various layers of construction elements, the overall total resistance is the sum of all individual resistances for whole wall, internal air spaces, insulation materials and air films adjacent to solid materials. Individual R-values for common building materials can be checked from the ASHARE fundamentals handbook.

U = Overall Coefficient of Heat Transmission

The U-value is the rate of heat flow passing through a square foot of the material in an hour for every degree Fahrenheit difference in temperature across the material (Btu/ft^{2}hr°F).

For thermal heat loss calculations, we normally use U-values (U for Unrestrained heat flow) which is a material's C-value but also includes the insulating effect of the air films on either side of the material. So it is, therefore, a smaller number (less heat flow).

As with C-values discussed above, you can not add U-values for series calculations. To obtain a U-value for such an assembly, you add the individual R-values of the layers and the air films on either side of the assembly. Then you take the reciprocal of the total R-value to get the total U-value of the assembly ($U = 1/R_{Total}$).

Here are a few of the most common covering materials and their associated “U” factors:

Material	**“U” Value (Btu / hr-ft^2-°F)**
Glass, single	1.13
Glass, double glazing	.70
Single film plastic	1.20
Double film plastic	.70

Material	"U" Value (Btu / hr-ft^2-°F)
Corrugated FRP panels	1.20
Corrugated polycarbonate	1.20
Plastic structured sheet; 16 mm thick 8 mm thick 6 mm thick	 .58 .65 .72
Concrete block, 8 inch	.57

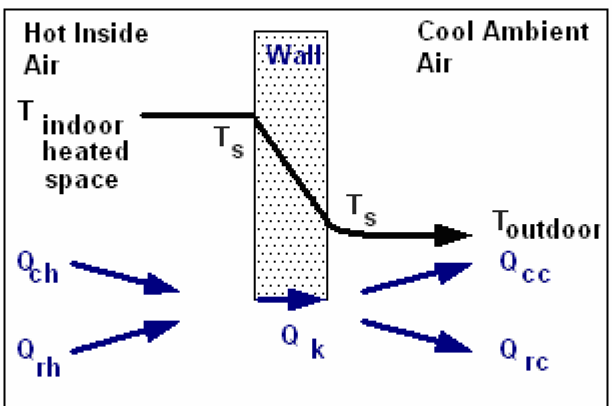
Note that the windows are commonly described by their U-values while descriptions of building walls, floors, or ceilings, often use R-values which is than converted to U-values by inverse relationship.

Combined Modes of Heat Transfer

1) Heat transfer by convection Q_{ch} and radiation Q_{rh} from the hot air and surrounding surfaces to the wall surface,

2) Heat transfer by conduction through the wall Q_k

3) Heat transfer by convection Q_{cc} and radiation Q_{rc} from the wall surface to the cold air and surrounding surfaces.



Heat Exchange Configuration

When one side of the wall is warmer than the other side, heat will conduct from the warm side into the material and gradually move through it to the colder side. A temperature gradient is established across the thickness of the wall. The temperature gradient is linear between the two surfaces for a homogenous wall and the slope of temperature gradient is proportional to the resistances of individual layers for a composite structure.

If both sides are at constant temperatures--say the inside heated surface at 77°F (25°C) and the outside surface at 40°F (4.4°C)--conductivity will carry heat inside the building at an easily predicted rate.

Under steady state conditions, the total rate of heat transfer (Q) between the two fluids is:

$$Q = Q_{ch} + Q_{rh} = Q_{k} = Q_{cc} + Q_{rc}$$

In real-life situations, however, the inside and outside temperatures are not constant. In fact the driving force for conductive heat flow can further increase as night falls to still lower outside air temperatures.

Calculation Methods

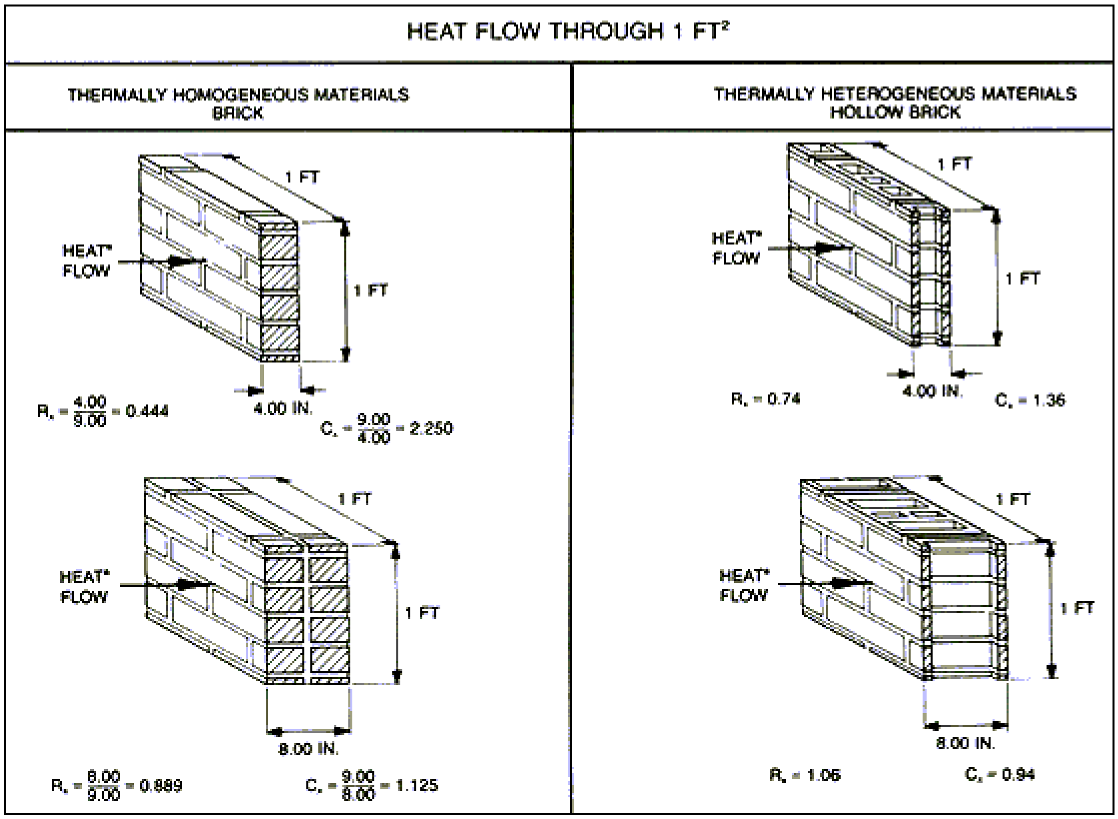
Conductance and resistances of homogeneous material of any thickness can be obtained from the following formula:
C_x=k/ x, and R_x=x /k

Where:

- x=thickness of material in inches
- k = thermal conductivity

Materials in which heat flow is identical in all directions are considered thermally homogeneous.

This calculation for a homogeneous material is shown in figure below. The calculation only considers the brick component of the wall assembly. Whenever an opaque wall is to be analyzed, the wall assembly should include both the outside and inside air surfaces. The inclusion of these air surfaces makes all opaque wall assemblies layered construction.



Thermal Transmittance through Materials

In computing the heat transmission coefficients of layered construction, the paths of heat flow should first be determined. If these are in series, the resistances are additive, but if the paths of heat flow are in parallel, then the thermal transmittances are averaged. The word "series" implies that in cross-section, each layer of building material is one continuous material. However, that is not always the case. For instance, in a longitudinal wall section, one layer could be composed of more than one material, such as wood studs and insulation, hence having parallel paths of heat flow within that layer. In this case, a weighted average of the thermal transmittances should be taken.

Series heat flow

To calculate the "R_{Total}" value of anything that is composed of multiple different materials, just add up the "R" values of each of the components. For example for composite wall (layered construction), the overall thermal resistance is:

$R_{Total} = R_1 + R_2 + ...$

Or

$R_{Total} = 1/h_o + x_1/k_1 + ... + 1/C + x_2/k_2 + 1/h_i$

Where:

- h_o, h_i are the outdoor and indoor air film conductance in Btu/hr.ft^2.F
- k_1, k_2 are the thermal conductivity of materials in Btu/hr.ft^2.F
- x_1,x_2 are the wall thickness (in)
- C is the air space conductance in Btu/hr.ft^2.F

And the overall coefficient of heat transmission is:

$U = 1/R_{Total}$

Or

$$U = \frac{1}{R_i + R_1 + R_2 + \ldots R_o}$$

Where:

- R_i = the resistance of a "boundary layer" of air on the inside surface.
- R_1, R_2 …= the resistance of each component of the walls for the actual thickness of the component used. If the resistance per inch thickness is used, the value should be multiplied by the thickness of that component.
- R_o = the resistance of the "air boundary layer" on the outside surface of the wall.

The formula for calculating the U factor is complicated by the fact that the total resistance to heat flow through a substance of several layers is the sum of the resistance of the various layers. The resistance to heat flow is the reciprocal of the conductivity. Therefore, in order to calculate the overall heat transfer factor, it is necessary to first find the overall resistance to heat flow, and then find the reciprocal of the overall resistance to calculate the U factor.

Note that in computing U-values, the component heat transmissions are not additive, but the overall U-value is actually less (i.e., better) than any of its component layers. The U-value is calculated by determining the resistance of each component and then taking the reciprocal of the total resistance. Thermal resistances (R-values) must first be added and the total resistance (R-Total) divided into 1 to yield the correct U-factor.

Correct:

$$U = \frac{1}{R_1 + R_2 + R_3 + \ldots + R_n} = \frac{1}{R_{Total}}$$

Incorrect:

$$U = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n} = U_1 + U_2 + U_3 + \ldots + U_n$$

The total R-value should be calculated to two decimal places, and the total U-factor to three decimal places.

Example #1

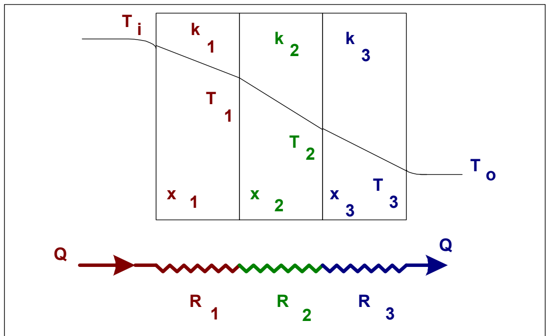
Determine the U-value for a layered wall construction assembly composed of three materials:

1) Plywood, 3/4-inch thick (R_1 = 3/4 X 1.25 = 0.94)

2) Expanded polystyrene, 2-inches thick (R_2 = 2" X 4.00 = 8.00)

3) Hardboard, 1/4-inch thick (R_3 = 0.18)

Assume resistance of inside still air is Ri = 0.68 and resistance of outside air at 15 mph wind velocity is Ro = 0.17



Thermal Resistance of Composite Wall

The U-values is:

$$U = \frac{1}{R_i + R_1 + R_2 + R_3 + Ro_o}$$

$$= \frac{1}{0.68 + 0.18 + 8.00 + 0.94 + 0.17}$$

$$= \frac{1}{9.97} = 0.10 \frac{\text{BTU}}{\text{hr. - sq. ft. - }^\circ\text{F}}$$

To calculate heat loss for say for 100 square feet of wall with a 70° F temperature difference, the Q will be:

$$Q = (.10)\,(100)\,(70) = 700 \text{ BTU/ HR}$$

In the calculations above the ΔT is taken as 70°F, which is temperature difference between indoor and outside air. If the sun shines on a wall or roof of a building and heats the surface much hotter than the air (as typical in the summer), the heat flow through the wall or roof would be greatly influenced by the hot surface temperature; hence, use a surface temperature rather than air to obtain a more realistic heat flow rate. Similarly, when calculating the heat flow through a floor slab resting on the ground, there will not be an air boundary-layer resistance underneath (Ro = 0) and the temperature (t_o) will be the ground temperature (not the outside air temperature).

<u>Example # 2</u>

Calculate the heat loss through 100 ft^2 wall with an inside temperature of 65°F and an outside temperature of 35°F. Assume the exterior wall is composed of 2" of material having a ‘k’ factor of 0.80, and 2" of insulation having a conductance of 0.16.

Solution:

U value is found as follows:

R total = 1/C + x1/k1 or

R total = 1/0.16 + 2/0.80

R total = 8.75

U = 1/R or 1/8.75 = 0.114 Btu/hr ft^2 °F

Once the U factor is known, the heat gain by transmission through a given wall can be calculated by the basic heat transfer equation:

Q = U x A x ΔT

Q = 0.114 x 100 x 30

Q = 342 Btu/hr

Conductance and resistance coefficients of various wall elements are listed in Table below: These coefficients were taken from the 1981 ASHRAE *Handbook of Fundamentals,* Chapter 23.

HEAT TRANSMISSION COEFFICIENTS OF COMMON BUILDING MATERIALS

Material Description	***Density Lb/ft^3***	***Conduction (k) Btu-in/hr ft^2 °F***	***(C) Btu/hr ft^2 °F***	***Resistance (R) Per inch thickness x/k***	***For thickness listed 1/C***
Masonary Units					
Face Brick	130	9.00		0.11	
Common Brick	120	5.00		0.20	
Hollow Brick					
4” (62.9% solid)	81		1.36		0.74
6” (67.3% solid)	86		1.07		0.93
8” (61.2% solid)	78		0.94		1.06

Material Description	***Density Lb/ft^3***	***Conduction (k) Btu-in/hr ft^2 °F***	***(C) Btu/hr ft^2 ^{0}F***	***Resistance (R) Per inch thickness x/k***	***For thickness listed 1/C***
10” 60.9% solid)	78		0.83		1.20
Hollow Brick vermiculite fill					
4” (62.9% solid)	83		0.91		1.10
6” (67.3% solid)	88		0.66		1.52
8” (61.2% solid)	80		0.52		1.92
10” 60.9% solid)	80		0.42		2.38
Lightweight concrete block-100 Lb density concrete					
4”	78		0.71		1.40
6”	66		0.65		1.53
8”	60		0.57		1.75
10”	58		0.51		1.97
12”	55		0.47		2.14
Lightweight concrete block vermiculite fill - 100 Lb density concrete					
4”	79		0.43		2.33
6”	68		0.27		3.72
8”	62		0.21		4.85
10”	61		0.17		5.92
12”	58		0.15		6.80
Building Board					
3/8” -Drywall Gypsum	50		3.10		0.32
1/2” -Drywall Gypsum	50		2.25		0.45
Plywood	34	0.80		1.25	
½” Fiberboard sheathing	18		0.76		1.32
Siding					
7/16” hard board	40			1.49	0.67
½” by 8” Wood bevel	32			1.23	0.81
Aluminum or steel over sheathing				1.61	0.61
Insulating Material					
Boards					
• Expanded Polystrene	1.80	0.25		4.00	
• Expanded Polyurethane	1.50	0.16		6.25	
• Poly isocyanurate	2.0	0.14		7.14	
Loose Fill					
• Vermiculite	4 - 6	0.44		2.27	
• Perlite	5 - 8	0.37		2.70	
Woods					
Hard woods	45.0	1.1		0.91	

Material Description	***Density Lb/ft^3***	***Conduction (k) Btu-in/hr ft^2 °F***	***(C) Btu/hr ft^2 ^{0}F***	***Resistance (R) Per inch thickness x/k***	***For thickness listed 1/C***
Soft woods	32.0	0.80		1.25	
Metals					
Steel	-	312		0.003	
Aluminum	-	1416		0.0007	
Copper	-	2640		0.0004	
Air Space					
¾” to 4”- winter			1.03		0.97
¾” to 4” - summer			1.16		0.86
Air Surfaces					
Inside – Still air			1.47		0.68
Outside – 15 mph wind-winter			5.88		0.17
Outside – 7.5 mph wind - summer			4.00		0.25

Heat Loss by Convection

The other mechanism of heat loss is convection, or heat loss by air movement. In homes, this is principally heat loss by exfiltration and infiltration. Exfiltration is the loss of heated air through building cracks and other openings. Infiltration is the introduction of outside cold air into the building. This air movement also causes discomfort (drafts) to occupants in addition to the heat loss itself.

The driving force for this exchange of air is the difference between indoor and outdoor air pressures. Air pressure differences are principally caused by wind pressures and the "stack" effect of warm inside air that tends to rise. Mechanically induced air pressure differences can also occur due to such things as exhaust fans and furnace venting.

To calculate the heat loss by convection, we go back to the general heat loss calculation and modify it to:

Heat Loss = Heat Capacity of Air * Air Volume Exchanged/hour * Temp. Difference

The volume exchanged can be determined by measuring or judging how many air changes that a building goes through in an hour. You can assume a rate between .25 and .50 air changes per hour (ACH), usually with a lower rate for basements with little outside air exposure, and higher rates for living areas or exposed basements.

The heat capacity of air is product of ρ_{air} * Cp and is equivalent to 0.018 Btu per (°F) (cu.ft.)

Where

- ρ_{air} is the density of the air in (lbm/ft³)
- C_p = specific heat capacity of air at constant pressure in (Btu/lbm -F)

Example

If you have a 1500 square foot house on a crawl space with 8-foot ceilings, the calculation of the volume exchanged can be:

1500 sq. ft. x 8 ft x .25 ACH

= 3000 ft^3/hr

Heat Loss

The heat capacity of air is a physical constant and is .018 Btu per (°F) (cu. ft.). Considering an outside temperature of -20°F and indoor temperature of 70°F, the heat loss due to infiltration will be:

.018 Btu/ (°F) (ft^3) x 3,000 ft^3/hr x 90°

= 4860 Btu/hr

Another method of determining heat loss by convection is the crack method. For this method you obtain the air leakage rates in cubic feet per minute for the doors and windows from their manufacturers and multiply by the lineal feet of sash crack or square feet of door area. (A more exact analysis would multiply the door infiltration rates by 1 or 2 due to open/close cycles and add .07 CFM per linear feet of foundation sill crack). This gives an air change rate per minute. This has to be converted to an hourly rate by multiplying by 60. Then you substitute this figure for the air change rate in the infiltration heat loss equation above.

SECTION # 3 **EXAMPLE**

A heating system is to be designed for the top 3 floors of an office building in Montreal area with following specifications:

Specification:

Location:		Montreal
Type of building:		office
Number of floors:		3
Floor area:		64ft x 80ft =5120 ft
Floor to floor height:		12 ft
Window area:		25% of wall area
Wall construction:	Face brick-	4 in
	Styrofoam insulation -	2 inches
	Concrete block -	8 inches
	Air space -	1.5 in
	Plaster board-	0.5 in
Roof construction:	Tar and gravel (built-up) -	0.375 in
	Rigid insulation -	4 in
	Concrete -	8 in
	Air space -	16 in
	Acoustic tile -	0.5 in
Windows:		double glazed (U value = 0.70)

Ventilation:	mechanical
Recommended ventilation:	minimum ½ air change per hour
	0.05 to 0.25 cfm/ft^2
	20 cfm/person, 8 persons/1000 ft^2 (max)

Calculation Methodology:

To calculate a design heating load, we should prepare the following design about building design and weather data at design conditions.

1. Outdoor design weather conditions: temperature, wind speed.
2. Decide on the Indoor air temperature
3. Divide the building into thermal zones (exterior and interior)
4. Determine heat transfer coefficients (U-values) for outside walls, glass and roof by finding the inverse of the sum of individual R-values for each layer of material
5. Determining the net area of outside walls, glass and roof.
6. Computing heat transmission losses for each kind of wall, glasses and roof.
7. Computing infiltration around outside doors, windows porous building materials and other openings.
8. The sum of the transmission losses or heat transmitted through walls, ceiling and glass plus the energy associated with cold air entering by infiltration or the ventilation air required to replace mechanical exhaust, represents the total heating load.

Design Conditions:

Location: Montreal

Outdoor air: - 20°F

Indoor air: 70°F

Wind velocity: 15 mph

Reference: 1993 ASHRAE Handbook- Fundamentals, pp.24. 17

Zone Division:

Identifying the thermal zones is the first step in the design of any HVAC system. Thermal Zoning is a method of designing and controlling the HVAC system so that occupied areas can be maintained at a different temperature than unoccupied areas using independent setback thermostats.

A zone is defined as a space or group of spaces in a building having similar heating and cooling requirements throughout its occupied area so that comfort conditions may be controlled by a single thermostat. In practice the corner rooms and the perimetric spaces of the building have variations in load as compared to the interior core areas. The buildings may be zoned into individual floors, rooms, or spaces with distinct loads, such as perimeter and interior zones. Smaller buildings are usually divided into two major zones.

a. Exterior Zone: The area inward from the outside wall (usually 12 to 18 feet if rooms do not line the outside wall). The exterior zone is directly affected by outdoor conditions during summer and winter.

b. Interior Zone: The area contained by the external zone. The interior zone is only slightly affected by outdoor conditions. Thus, the interior zone usually has uniform cooling. Heating is generally provided from the exterior zone.

In our example, the whole building envelope is divided into six zones:

1. Corner zone on the 1st and 2nd floors (zone 1)

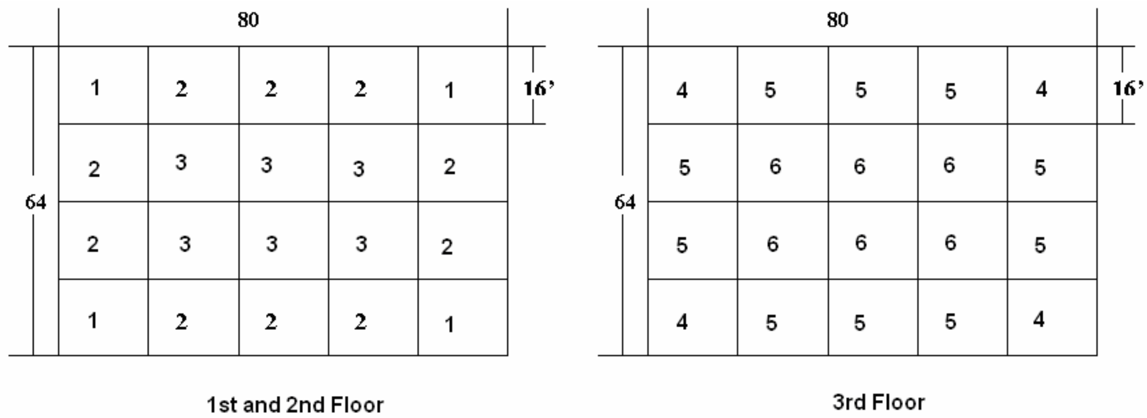
2. A corner zone on the 3rd floor (zone 4)

3. A central zone on the 1st and 2nd floors (zone 3)

4. A central zone on the 3rd floor (zone 6)

5. An interior zone on the 1st and 2nd floors (zone 2)

6. An interior zone on the 3rd floor (zone 5)



HEAT LOSS CALCULATION

Heat losses from the different zones will be calculated in steps and the overall heat loss is obtained from the sum of the heat loss through the individual zones.

There are two types of heat losses from the building envelope that will be considered.

1. $Q_{\text{Conductive}}$

2. $Q_{\text{Infiltration}}$

The total heat loss is the summation of conductive and infiltration loss.

$Q_{\text{Total}} = Q_{\text{Conductive}} + Q_{\text{Infiltration}}$

CONDUCTIVE HEAT LOSS ($Q_{\text{Conductive}}$)

Step – 1:

Calculate the U-Value of Wall Material by finding the inverse of the sum of individual R-values for each layer of material.

Table – 1 Total resistance of Wall Construction

Layer	x (inch)	(k) Btu-in/hr ft^2 °F	(C) Btu/hr ft^2 ^{0}F	(h) Btu/hr ft^2 ^{0}F	R =x/k =1/c = 1/h ft^2 ^{0}F hr / Btu
Outside air	Film	-	-	5.88	0.17
Face brick	4”	9	-	-	0.44
Styrofoam	2”	-	0.151	-	6.62
Concrete	8”	-	0.57	-	1.75
Air space	1.5”	-	1.03	-	0.97
Plaster board	0.5”	-	2.25	-	0.44
Inside air	Film	-	-	1.47	0.68
Total					11.07

Source: 1997 ASHARE Fundamentals Handbook, Tables 22-1, 22-2, 22-4

Heat transfer coefficient for the wall U = 1/R = 1/11.07 = 0.09 Btu/hr ft^2 ^{0}F

Step -2: Calculate the U-Value of Roof Construction

Table – 2 Total resistance of the roof components:

Layer	x (inch)	(k) Btu-in/hr ft^2 °F	(C) Btu/hr ft^2 ^{0}F	(h) Btu/hr ft^2 ^{0}F	R =x/k =1/c = 1/h ft^2 ^{0}F hr / Btu
Outside air	Film	-	-	5.88	0.17
Tar-gravel	0.375”	-	2.99	-	0.33
Insulation	2”	0.14	-	-	14.29
Concrete	8”	-	0.57	-	1.75
Air space	4”	-	1.03	-	0.970

Layer	x (inch)	(k) Btu-in/hr ft^2 °F	(C) Btu/hr ft^2 ^{0}F	(h) Btu/hr ft^2 ^{0}F	R =x/k =1/c = 1/h ft^2 ^{0}F hr / Btu
Acoustic tile	0.5”	-	0.14	-	7.14
Inside air	Film	-	-	1.63	0.61
Total					25.26

Source Reference: 1997 ASHARE Fundamentals Handbook, Tables 22.1, 22.2, 22.4

Heat transfer coefficient for the roof U = 1/R =1/25.26 = 0.04 Btu/hr ft^2 ^{0}F

<u>Step - 3: Calculate the Heat Loss</u>

Heating load of the surfaces:

$Q_{\text{Conduction}}$ = Q wall + Q roof + Q window

The calculation is made for center zone on the 3rd floor – zone 4:

<u>Conductive Loss thru Wall (Q wall)</u>

Q wall = U *A * ΔT

U = 0.09 Btu/hr ft^2 ^{0}F

ΔT = 90°F ---- [Ti = 70°F and To = -20°F]

<u>Net Area of Wall</u>

Area of surface = 16 * 12 = 192 ft^2

Area of glazing = 25% * 192 = 48 ft^2

Area of walls = Area of surface – Area of glazing = 192 – 48 = 144 ft^2

Number of surface walls = 8 no --- [refer to zoning diagram for 3rd floor]

Total Area of walls in zone - 4 = 1152 ft^2

Q wall = 0.09 * 1152 * 90

Q wall = 9331 Btu/hr

Conductive Loss thru Roof (Q roof)

Q roof =U * A * ΔT

U = 0.04 Btu/hr ft^2 ^0F

ΔT = 90°F

Net Area of Roof

Area of surface = 16 * 16 = 256 ft^2

Number of zone-4 roofs = 4 no

Total Area of roof = 256 * 4 = 1024 ft^2

Q roof = 0.04 * 1024 * 90

Q roof = 3686 Btu/hr

Conductive Loss thru Glazing (Q window)

Q window =U * A * ΔT

U = 0.70 Btu/hr ft^2 ^0F

ΔT = 90°F

A = 48 ft^2 [25% of the wall area]

Total Glazing Area = 8 * 48 = 384 ft^2 [… there are 8 surface walls in zone-4]

Q window = 0.70 * 384 * 90

Q window = 24192 Btu/hr

So: $Q_{Conductive}$ = Q wall + Q roof + Q window

Or: Q1 = 9331 + 3686 + 24192

Q1 = 37209 Btu/hr

Total Conduction heat losses:

The conduction heat loss above is done for Zone-4, third floor. If you repeat this for all other zones of the building, you could obtain the total heat loss through the envelope at design temperatures.

Refer to the zoning diagram –

Zone 1 has 8 walls on 1st floor and 8 walls on the second floor – thus total number of surfaces = 16 number.

The other zones are calculated likewise in table below:

Table 3 Conduction heat losses:

Zone	Surface	Area ft²	Number of surfaces; n	U Btu/hr ft^2 ^{0}F	ΔT (° F)	Q=U *A * ΔT Btu/hr	Total, Q Btu/hr
1.	Wall Window Roof	144 48 -	16 16 -	0.09 0.70 -	90 90 -	18662 48384 -	67046
2.	Wall Window Roof	144 48 -	20 20	0.09 0.70 -	90 90 -	23328 60480 -	83808
3.	Wall Window Roof	- - -	- - -	- - -	- - -	- - -	-
4.	Wall Window Roof	144 48 256	8 8 4	0.09 0.70 0.04	90 90 90	9331 24192 3686	37209
5.	Wall Window	144 48	10 10	0.09 0.70	90 90	11664 30240	51120

Zone	Surface	Area ft²	Number of surfaces; n	U Btu/hr ft^2 ^0F	ΔT (° F)	Q=U *A * ΔT Btu/hr	Total, Q Btu/hr
	Roof	256	10	0.04	90	9216	
6.	Wall Window Roof	- - 256	- - 6	- - 0.04	- - 90	- - 5530	5530

Total = 244713 Btu/hr

HEAT LOSS BY VENTILATION ($Q_{Infiltration}$)

Calculation of volume of air:

For finding ventilation rate in "cfm", we choose the method that gives the most amount of load. For this reason we calculate cfm based on three methods (air change, crack and the people).

Ventilation rate based on Air change method:

According to division, the area of each zone is 16 * 16 = 256 ft^2

Volume of each zone = 256 * 12 = 3072 ft^3

Recommended air change/hr = 0.5

Volume of air = ½ ACH * 3072 / 60

Volume of air = 25.6 cfm/zone

Ventilation rate based on Crack method:

According to division, the area of each zone is 16 * 16 = 256 ft^2

Expected infiltration = 0.15 cfm/ft^2

Volume of air = 0.15 * 256

Volume of air = 38.4 cfm/zone

Ventilation rate based on Occupancy method:

According to division, the area of each zone is 16 * 16 = 256 ft^2

Recommended ventilation rate = 20 cfm/person [based on ASHRAE 62 recommendation for IAQ]

Number of people = 8 people/1000 sq-ft

Volume of air = cfm/person * number of people in one zone (256 ft^2 area)

Volume of air = 20 * 8 * 256/1000

Volume of air = 40.96 cfm/zone

Or

Total ventilation for the building (60 zones) = 40.96 * 60 = 2457cfm

Here, cfm according to people is more than the other ones and therefore, we will consider this as method of ventilation for calculating heat loss.

Heat Loss by Ventilation

$Q_{Ventilation} = V * \rho_{air} * C_p * (Ti – To) * 60$

Where:

- $Q_{sensible}$ is sensible heat load in (Btu/hr)
- V = volumetric air flow rate in (cfm)
- ρ_{air} is the density of the air in (lbm/ft^3)
- C_p = specific heat capacity of air at constant pressure in (Btu/lbm -F)
- Ti = indoor air temperature in (°F)
- To = outdoor air temperature in (°F)

Heat loss for ventilation from one zone:

$Q_{ventilation}$ = 0.075 * 40.96 * 0.24 * 90 * 60 = 3981Btu/hr

RESULTS

Table - 4: Total Heat Loss:

Zone Designation	**No. Of Zones**	**Ventilation heat loss per zone Btu/hr**	**$Q_{ventilation}$ Btu/hr**	**$Q_{conductance}$ Btu/hr**	**Total heat loss Q_{Total} Btu/hr**
1.	8	3981	31848	67046	98894
2.	20	3981	79620	83808	163428
3.	12	3981	47772	-	47772
4.	4	3981	15924	37209	53133
5.	10	3981	39810	51120	90930
6.	6	3981	23886	5530	29416
Total	60		238860	244713	**483573**

Q_{Total} with 10% safety factor = 483573 * 1.1 = 531930 Btu/hr

CONCLUSION

In this example, the total heating load for the building is 531930 Btu/hr with 10% safety factor. This value shall be used for sizing the heating furnace.

Total ventilation required for the total building is 2457cfm that with 10% safety factor is equal 2702cfm.

ANNUAL HEAT LOSS

After determining the total heat loss rate, we are going to take our calculation one step further to determine the annual heating loss and its related cost. If you want to figure the total seasonal heat loss, you would perform a degree day calculation.

The table below gives heating and cooling needs for 13 locations in each of the ten provinces and three territories of Canada. Heating needs in Vancouver are about half those in Winnipeg, although differences between other cities in southern Canada are less dramatic. Cooling needs, on the other hand, differ much more widely across the country.

Heating and Cooling Degree-Days for Selected Canadian Cities (Average Annual Totals, 1971–2000)

	HEATING DEGREE-DAYS	COOLING DEGREE-DAYS
St. John's, Newfoundland & Labrador	4,881	32
Charlottetown, Prince Edward Island	4,715	100
Halifax, Nova Scotia	4,367	104
Saint John, New Brunswick	4,754	37
Montreal, Quebec	4,575	235
Toronto, Ontario	4,066	252
Winnipeg, Manitoba	5,777	186
Regina, Saskatchewan	5,661	146
Edmonton, Alberta	5,708	28
Vancouver, British Columbia	2,926	44
Yellowknife, Northwest Territories	8,256	41
Whitehorse, Yukon	6,811	8
Resolute, Nunavut	12,526	0

Source: *Environment Canada*

From our heat loss calculations for Montreal, we know that the expected rate of energy loss per hour is 483573 Btu/hr. For Montreal the heating degree days are 4575 and the average winter temperature is 5°F.

The annual heat loss can be calculated by following equation:

[483573 Btu/hr * 24 hr/day / (65 – 5)] * 4575 DD/yr = 88 million Btu/yr.

Note that the value is rounded to the nearest million Btu. Since the numbers we are using in our calculations are very squishy (the infiltration rate can change by over 200%), the answer we get is really nothing more than an educated guess.

SELECTING FUEL & HEATING SYSTEM

Selecting the fuel and heating system best suited for your needs depends on many factors. These include: the cost and availability of the fuel or energy source; the type of appliance used to convert that fuel to heat and how the heat is distributed in your space; the cost to purchase, install, and maintain the heating appliance; the heating appliance's and heat delivery system's efficiency; and the environmental impacts associated with the heating fuel.

One somewhat simple way to evaluate heating options is to compare the cost of the fuel. To do that, you have to know the energy content of the fuel and the efficiency by which it is converted to useful heat.

Natural Gas: *The heating capacity of gas heating appliances is measured in British thermal units per hour (Btu/h). (One Btu is equal to the amount of energy it takes to raise the temperature of one pound of water by 1 degree Fahrenheit.) Most gas heating appliances have heating capacities of between 40,000 and 150,000 Btu/h.*

Consumption of natural gas is measured in cubic feet (ft^3). This is the amount that the gas meter registers and the amount that the gas utility records when a reading is taken. One cubic foot of natural gas contains about 1,007 Btu of energy.

Propane: *Propane, or liquefied petroleum gas (LPG), can be used in many of the same types of equipment as natural gas. It is stored as a liquid in a tank, so it can be used anywhere, even in areas where natural gas hookups are not available. Consumption of propane is usually measured in gallons; propane has an energy content of about 92,700 Btu per gallon.*

Fuel Oil: *Several grades of fuel oil are produced by the petroleum industry, but only # 2 fuel oil is commonly used for space heating. The heating (bonnet) capacity of oil heating appliances is the steady-state heat output of the furnace, measured in Btu/h. Typical oil-fired central heating appliances have heating capacities of between 56,000 and 150,000 Btu/h. Oil use is generally billed by the gallon. One gallon of #2 fuel oil contains about 140,000 Btu of potential heat energy.*

Electricity: *The watt (W) is the basic unit of measurement of electric power. The heating capacity of electric systems is usually expressed in kilowatts (kW); 1 kW equals 1,000 W. A kilowatt-hour (kWh) is the amount of electrical energy supplied by 1 kW of power over a 1-*

hour period. Electric systems come in a wide range of capacities, generally from 10 kW to 50 kW.

When converted to heat in an electric resistance heating element, one kWh produces 3,413 Btu of heat.

ANNUAL HEATING COST

To convert Btu/yr values into dollars per year for the annual heating cost, we have to guess at how much energy costs. Again these values vary widely, depending on season, geographic location and type of fuel.

Comparing Fuel Costs

Comparing fuel costs is generally based on knowing two parameters viz. the efficiency of the appliance and the unit price of the fuel. Follow the steps below:

1) Convert the Btu content of the fuel per unit to millions of Btu by dividing the fuel's Btu content by 1,000,000. For example: 3,413 Btu/kWh (electricity) divided by 1,000,000 = 0.003413 millions Btu per unit.

2) Use the following equation to estimate energy cost:

   Energy cost ($ per million Btu) = Cost per unit of fuel ÷ [Fuel energy content (in millions Btu per unit) × Heating system efficiency (in decimal)]

The table below provides examples of heat cost tabulation for different fuels and heating equipment.

Heating Equipment	**Fuel**	**Fuel Cost (Note #1)**	**Fuel energy content (in millions Btu per unit)**	**Heating System Efficiency (Note #2)**	**Heat Cost in $ per million Btu (Note #3)**
Resistance	Electric	$0.086 per	0.003412	0.99	= $25.46

Heating Equipment	Fuel	Fuel Cost (Note #1)	Fuel energy content (in millions Btu per unit)	Heating System Efficiency (Note #2)	Heat Cost in $ per million Btu (Note #3)
Baseboard		kWh			
Heat Pump	Electric	$0.086 per kWh	0.003412	2	= $12.60
Medium Efficiency Furnace	Natural Gas	$9.96 per thousand cubic feet	1.03	0.90	= $10.74
Medium Efficiency Furnace	Fuel Oil	$1.25 per gallon	0.14	0.85	= $10.5
Medium Efficiency Furnace	Propane	$1.09 per gallon	0.0913	0.85	= $14.05

Note #1: The fuel costs used are the national annual average residential fuel prices in 2001 according to the Energy Information Administration (EIA), U.S. Department of Energy. Prices will vary by location and season.

Note #2: The system efficiencies used are assumed examples only.

Note #3: Energy cost ($ per million Btu) = Cost per unit of fuel ÷ [Fuel energy content (in millions Btu per unit) × Heating system efficiency (in decimal)]

The average Btu content of fuel values make comparisons of fuel types possible. For example:

- The heat content of one gallon of fuel oil roughly equals that of 41 kWh of electricity, 137 cubic feet of natural gas, 1.5 gallons of propane, 17.5 pounds of air-dried wood, 17 pounds of pellets, a gallon of kerosene, or 10 pounds of coal.

- One million Btu is the heat equivalent of approximately 7 gallons of No. 2 heating oil or kerosene, 293 kWh of electricity, 976 cubic feet of natural gas, 11 gallons of propane, 125 pounds of air-dried wood, 121 pounds of pellets, or 71 pounds of coal.

Since this is an introductory course, we will assume one value for all situations. This assumption is too general to use for making large economic decisions, but it is certainly easier than trying to keep up with these constantly changing values. For the purposes of this course, all energy will cost exactly $10 per million Btu. At today's energy prices, this average value is high for gas heat (by about a factor of 2), about right for fuel oil, and low for electric resistance heat (by about a factor of 2). Even these prices vary substantially across the nation.

So for our example building above using 88 million Btu/yr, we would calculate the heating cost to be 88 * $10 = $880 per year. But in reality the heating cost might range from under $440 for gas heat to over $1400 for electric resistance heat.

WINDOWS

Windows provide light, ventilation and in many cases passive solar heating, but are otherwise a source of great heat loss.

In the heat loss calculation, all windows are created equal, no matter which direction they face. Disallowing for wind factors, similar types of glazing's lose heat at the same rate. On the other hand, when calculating heat gain, windows facing east and west GAIN more heat that those facing north and south. This results in larger quantities of air being distributed to rooms with east and west facing windows. This air is necessary for cooling but not for heating. In the more northern climates, heat loss occurs equally from all windows regardless of which direction they face. This will restore the emphasis on a balanced distribution system rather than one weighted toward solar radiation.

A decently insulated wall easily achieves R21, while most windows do no better than R3: meaning that a window loses seven times more heat per square foot than a wall does! So clearly we have to pay attention to how we use windows.

Windows Ratings

Windows are rated according to a standard set by NFRC (the National Fenestration Rating Council) and consist of four values that tell about the performance of the window:

1. Heat Transmission Coefficient (U-value) - tells how much heat the window will loose. In the past manufacturers measured the "U" value at the center of the glass, because it is often higher than for the whole unit. While this practice has been abandoned, buyers should verify that the "U" value given is for the entire window unit. Typically values are "U" for a double pane, Low-E, argon gas fill window is around .33 (i.e., R3), while a triple pane super window achieves a "U" of about .15 (i.e. R6.6). By comparison, an old style double pane window has a "U" of about .5 (i.e. R2). Because the frame of the window often lets more heat out than the glass, larger window units have better overall "U" values. Likewise, using true divided lights (consisting of multiple glass panes instead of one), reduces the "R" value significantly.

2. Visible Transmission (VT) - represents the percentage of the available visible light that is allowed to pass through the window. Even clear glass isn't perfectly transparent, and multiple glazing and Low-E coatings reduce this value.

3. Solar heat gain coefficient (SHGC) - signifies the percentage of the available solar gain that is allowed to pass through the window. As with visible transmission, this value is lower when multiple glazing and Low-E coatings are present. A double pane window with a Low-E coating that stops solar gain and allow only 30-40% of the solar gain through, while a Low-E designed to allow solar gain lets in only slightly less than plain clear glass, about 75%. By comparison, a super-window which has a U of .15 has a SHGC of only 50%. Note that these numbers are for glass only, and must be reduced to account to the space taken up by the frame and any pane dividers that shrink the overall glass area.

4. Air Leakage (AL) - air leakage, the amount of air leakage through the window. Note that this does not include the air leakage around the window unit where it is attached to the wall, which should be sealed tightly. The air leakage amount for a window that opens is higher than one that doesn't (due to greater difficulty in sealing) and that for double hung or sliding windows is greater than that for awning or casement.

The key recommendations for energy savings include:

- Single-pane windows are impractical in heating-dominated climates. In these regions, multiple-pane, low-E, and gas-filled window configurations are advisable.

- Avoid aluminum frame windows or specify aluminum-frame windows with thermal breaks. Even in milder climates, these windows tend to have low inside surface temperatures during the heating season, giving rise to condensation problems. Wood, vinyl, and fiberglass are the best frame materials for insulating value.

- Buy windows with energy efficient label. The window energy label lists the U-factor, solar heat gain coefficient, visible light transmittance, and air leakage rating.

INSULATING MATERIALS

Insulation is the material added to a building structure when the building materials themselves don't provide the desirable amount of resistance to heat transfer. The amount of insulation that can be added is limited to the available space between the framing materials, and is typically the most significant factor in determining how well a wall insulates. Since the framing material itself is at best a mediocre insulator, framing act as a *thermal bridge* leaking heat, and reducing the overall "R" value of the wall. Advanced framing is a method of making six inch thick walls (instead of the traditional four inch), without increasing the amount of wood used. Alternatively, foam board sheets can be attached to the exterior of a standard 2x4 wall also yielding a better insulating wall. The use of light-gauge steel framing to replace wood creates a problem because it conducts heat so well, and so must always be used with an exterior layer of foam board insulation to stop the thermal bridging of the steel. In all cases light-gauge steel framed walls have a lower overall "R" value to a wood framed wall.

There are many kinds of insulating materials, each of which has its own set of advantages and disadvantages, and none of which are the perfect solution. A material "R" value will differ based on how it is manufactured and how it is installed and possibly other conditions as well. The numbers used here are typical, and should be used for relative comparison purposes only.

1. **Fiberglass**: In its familiar form, glass fibers are spun together and formed into batts with glue and then typically also attached to a vapor barrier backing. This glue is a skin irritant, making this form of insulation unpleasant to handle. Fiberglass in this form is a good insulator (between R3 and R3.5 for every inch installed), but does loose some insulation ability as the outside temperature gets very cold due to having large air spaces which will transfer heat by convection. Fiberglass is also available without the glues in a blown in systems that creates a higher density, and hence somewhat higher "R" value, and presumably less susceptibility to convection heat transfer. There is some concern that fiberglass fibers break down with age and create tiny sharp filaments causing a disease called silicosis.

2. **Mineral Wool:** A fibrous product made out of various mineral by-products and all having similar properties to fiberglass. Mineral wool is no longer popular in modern buildings.

3. **Polystyrene**: Polystyrene is a plastic (known mostly by the brand name "Styrofoam") made from petroleum that is "blown" with some kind of gas (i.e. filled with lots of bubbles) and formed into boards. It's "R" value is somewhat better than Fiberglass, about R4 per inch. Polystyrene is the insulation of choice for around foundations and under concrete slabs. It is also sometimes used on roofs and in other places where its board form is more convenient.

4. **Polyurethane/PolyIsocyanurate:** Like Polystyrene, these are plastics blown with a gas, but promising a higher "R" value: up to R7.5 per inch for PolyIsocyanurate. Polyurethane can be "foamed in place" in an existing wall cavity. “Icycene” brand polyurethane is marketing itself as more environmentally friendly foam, and has been used on a number of "Healthy House" demonstration projects sponsored by the American Lung Association.

5. **Air Crete:** This unique product is cement with a lot of air in it, installed as foam. Its "R" value is similar to fiberglass, but it has all the environmental properties of cement (and therefore does not have problems with silicosis). Its raw materials are abundant, but it takes a lot of energy to make it. It’s recyclable, but there is currently not a strong market for cement products.

VENTILATION & INFILTRATION

Design the HVAC system with the outdoor air rates required by ASHRAE Standard-62 to maintain indoor air quality. “Build Tight & Ventilate Right”.

Build Tight / Ventilate Right

Air leaks out of a building due to two main driving forces: 1) Wind and 2) a temperature difference, each of which creates a pressure difference between inside and outside forcing air through the cracks in the building. What this means is that on cold windy days we loose a lot of heat, and on calm days where the inside temperature is near the outside temperate, even if we open the windows wide, we get very little air movement! Clearly, we'd like to even these extremes out as much as possible to provide for a steady supply of fresh air.

Of course there is a compromise, and most people don't want to live in a hermetically sealed building. There is a point where we've tightened our house up enough so that we're not paying a big energy penalty, but not so much that mechanical ventilation is the only source of fresh air. Since air leakage varies with weather, even a very tight house that has only 1/10 ACH under normal conditions, might see 1 ACH on a cold, windy day. As with many areas of Green Building, there are no fixed answers and each person must find their own compromise. In most buildings it is difficult to get it super tight anyhow, so this question won't come up unless you're taking extra air tightening measures.

Select windows with air leakage ratings of 0.2 cubic feet per minute per square foot of window area (cfm/ft^2) or less. Check the seals between window components for air tightness. To minimize infiltration around installed windows, caulk and weather-strip cracks and joints.

Air Sealing Techniques

In general, the majority of air leaks will be found around doors & windows, followed by any place where two parts of the building meet, such as the walls against the floor or ceiling. Air, like water will find a way through any place that can possibly be gotten through.

The tightness of a house is measured in the number of times per hour all the air in the house is lost, and is often abbreviated by ACH (air changes per hour). To determine how tight a house is, a test called *the blower door test* is done. To do this, all openings in the house are closed except an exterior door and that opening is filled with a device the size of a door that contains a powerful fan, a flow meter and a pressure gage that measures the difference between inside and outside. The fan removes air from the house until there is a pressure difference of 50 Pascals (a metric pressure measurement), at which point the fan speed is adjusted so as to maintain that constant pressure difference. The amount of airflow is now equal to the air leakage of the home (at a pressure of 50 Pascals).

Remember that the amount of air leakage on any given day is determined by the wind velocity and the temperature outside, so the result of the blower door test is not how much air your house will actually leak (which varies greatly), but a relative measure. By using a formula, the air leakage under mild weather conditions can be estimated.

The blower door can also be used to find air leaks by walking around with a device that gives off smoke and looking for places where moving air moves the smoke. This is typically done once the structural work is completed, but before any finish work is done to allow for easy fixes for any leaks found.

The most important and least cost technique is to make sure you have adequate caulking and weather stripping around all windows and doors. During construction, your contractor, or an air tightening specialist should walk around the house sealing all the potential leaks, typically with either caulk or expanding spray foam.

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USEFUL TERMS

1) Ambient Air - The air surrounding a building; outside air

2) Air Change - The term air change is a rate at which outside air replaces indoor air in a space. It can be expressed in one of two ways: the number of changes of outside air per unit of time air changes per hour (ACH); or the rate at which a volume of outside air enters per unit of time - cubic feet per minute (CFM).

3) Building Envelope - The term building envelope indicates the surfaces that separate the inside from the outdoors. This includes the parts of the building: all external building materials, windows, walls, floor and the roof. Essentially the building envelope is a barrier between the conditioned indoor environment and the outdoors.

4) Building Location Data- Building location data refers to specific outdoor design conditions used in calculating heating and cooling loads.

5) British thermal unit (BTU): Theoretically, it is approximate heat required to raise 1 lb. of water 1 deg Fahrenheit, from 59^0F to 60^0F. Its unit of heat and all cooling and heating load calculations are performed in Btu per hour in US.

6) Cooling load: The rate at which heat is removed from a space to maintain the constant temperature and humidity at the design values

7) Cooling Load Temperature Difference (CLTD) – A value used in cooling load calculations for the effective temperature difference (delta T) across a wall or ceiling, which accounts for the effect of radiant heat as well as the temperature difference. CLTD value calculates the instantaneous external cooling load across a wall or roof. CLTD value is used to convert the space sensible heat gain to space sensible cooling load.

8) Cooling Coil Load – The rate at which heat is removed at the cooling coil that serves one or more conditioned spaces and is equal to the sum of all the instantaneous space cooling loads.

9) Cubic feet per minute (CFM) - The amount of air, in cubic feet, that flows through a given space in one minute. 1 CFM equals approximately 2 liters per second (l/s). A typical system produces 400 CFM per ton of air conditioning.

10) Comfort Zone- The range of temperatures, humidity's and air velocities at which the greatest percentages of people feel comfortable.

11) Design Conditions- Cooling loads vary with inside and outside conditions. A set of conditions specific to the local climate is necessary to calculate the expected cooling load for a building. Inside conditions of 75°F and 50% relative humidity are usually recommended as a guideline. Outside conditions are selected for the 2.5% climate occurrence.

12) Exfiltration- Uncontrolled air leakage out of a building through window and door openings

13) Exhaust - The airflow leaving the treated space from toilets, kitchens, laboratories or any hazardous area where negative pressure is desired.

14) Enthalpy - Heat content or total heat, including both sensible and latent heat.

15) Fenestration – is an architectural term that refers to the arrangement, proportion and design of window, skylight and door systems within a building. Fenestration consists of glazing, framing and in some cases shading devices and screens.

16) Heating load: The heating load is a rate at which heat is added to the space to maintain the indoor conditions.

17) Infiltration- Leakage of air inward into a space through walls, crack openings around doors and windows or through the building materials used in the structure.

18) Latent Cooling Load- The net amount of moisture added to the inside air by plants, people, cooking, infiltration, and any other moisture source. The amount of moisture in the air can be calculated from a combination of dry-bulb and wet-bulb temperature measurements. The latent loads will affect absolute (and relative) humidity.

19) Latent Heat Gain – is the energy added to the space when moisture is added to the space by means of vapor emitted by the occupants, generated by a process or through air infiltration from outside or adjacent areas.

20) Radiant Heat Gain – is the rate at which heat absorbed by the surfaces enclosing the space and the objects within the space is transferred by convection when the surface or objects temperature becomes warmer than the space temperature.

21) Sensible Cooling Load- The heat gain of the building due to conduction, solar radiation, infiltration, appliances, people, and pets. Burning a light bulb, for example, adds only sensible load to the house. This sensible load raises the dry-bulb temperature.

22) Space Heat gain: The rate at which heat enters to and/or is generated within a space during a time interval.

23) Space Heat loss: The rate at which energy is lost from the space during a time interval.

24) Sensible Heat Gain or Loss – is the heat directly added to or taken away the conditioned space by conduction, convection and/or radiation. The sensible loads will affect dry bulb air temperature.

25) Space Cooling Load – the rate at which energy must be removed from a space to maintain a constant space air temperature. Note that "space *heat gain* $\neq$ *space-cooling load."*

26) Space Heat Extraction Rate: The rate at which energy is removed from the space by the cooling and dehumidification equipment. Space heat extraction rate is usually the same as the space-cooling load if the space temperature remains constant.

27) Shading- The effectiveness of a fenestration product plus shade assembly in stopping heat gain from solar radiation is expressed as the Solar Heat Gain Coefficient (SHGC). SHGC values range from 0 to almost 1. The more effective at stopping heat gain, the lower the SHGC value.

28) Solar Heat Gain Coefficient (SHGC) - Solar heat gain coefficient (SHGC) is the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space. Solar Heat Gain Coefficient (SHGC) replaces the Shading Coefficient (SC) used in earlier versions of the standards as a measure of the solar heat gain due to windows and shading devices.

29) Temperature, Dry Bulb – is the temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

30) Temperature, Wet Bulb – is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

31) Temperature, Dewpoint – is the temperature at which the condensation of water vapor is a space begins for a given state of humidity and pressure as the temperature of the air is reduced.

32) Thermal conductivity – is the time rate of heat flow through a unit area and unit thickness of a homogenous material under steady conditions when a unit temperature gradient is maintained in the direction perpendicular to the area.

33) Thermal Transmittance or Coefficient of Heat Transfer (U-factor) – is the time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids.

34) Thermal Conduction – is the process of heat transfer through a material medium in which kinetic energy is transmitted by particles of the material from particle to particle without gross displacement of the particles.

35) Thermal Convection – is the transfer of heat by movement of fluid. Forced convection is the transfer of heat from forced circulation of fluid as by a fan, jet or pump. Natural convection is the transfer of heat by circulation of gas or liquid due to differences in density resulting from temperature changes.

36) Thermally Light Buildings- A building whose heating and cooling requirements are proportional to the weather is considered a thermally light building. That is, when the outdoor temperature drops below the desired room temperature, heating is required and when the outdoor temperature goes above the desired room temperature, cooling is needed. In a thermally light building, the thermal performance of the envelope becomes a dominant factor in energy use and can usually be seen as seasonal fluctuations in utility consumption.

37) Thermally Heavy Buildings- When factors other than weather determine the heating and cooling requirements, the building can be considered thermally heavy. The difference between thermally light and thermally heavy buildings is the amount of heat generated by people, lighting, and equipment within the building. Thermally heavy buildings typically have high internal heat gains and, to a certain extent, are considered to be self-heating and more cooling dominated. This need to reject heat makes them less dependent on the thermal performance of the building envelope.

38) Thermal Weight- A simple "rule of thumb" for determining the thermal weight of a building is to look at heating and cooling needs at an outdoor temperature of 60°Ft. If the building requires heat at this temperature, it can be considered thermally light and if cooling is needed, it is thermally heavy.

39) Ton - A unit of measure for cooling capacity; One ton = 12,000 BTUs per hour

40) U-Factor- The U-factor is the "overall coefficient of thermal transmittance of a construction assembly, in Btu/ (hr ft^2 ºF), including air film resistances at both surfaces."

41) Zone- Occupied space or spaces within a building which has its heating or cooling controlled by a single thermostat or zone is a is a space or group of spaces within a building with heating and/or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device.

42) Zoning - A system in which living areas or groups of rooms are divided into separate spaces and each space's heating/air conditioning is controlled independently.