



PDHonline Course E304 (4 PDH)

Energy Conservation

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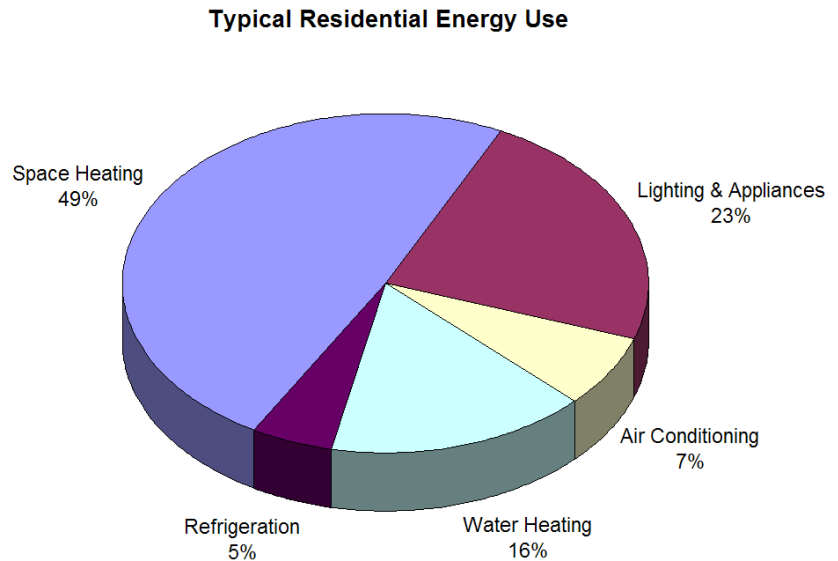
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Introduction

Rising energy costs have created a renewed interest by facilities managers in the energy efficiency of their facilities. Whether it is a commercial building, an industrial plant, or even an individual residence, there are strategies that can improve the efficiency of the facility without reducing its comfort or operational effectiveness.

The adjacent chart shows the typical energy use for a residential building. As you can see space heating is the largest consumer of energy at 49% of the total usage in a home, followed by lighting and appliances, which is 23% of the total. Water heating is the third largest consumer of energy at 16% of the total. These values vary based on the area of the country with air conditioning making up a larger percentage in the South and Southwest parts of the United States. Small commercial buildings will have similar usage patterns except that the water heating will be less and the air conditioning and lighting will be a larger percentage.



Strategies to improve the energy efficiency of facilities include, improving the building envelope, installing energy efficient heating, ventilation, and air-conditioning systems, using appropriate lighting, and managing the various appliances commonly found in commercial and residential buildings. The following information is divided into four sections: Building Envelope, Heating, Ventilation, & Air-Conditioning, Lighting, Equipment. The first section looks at factors affecting the building envelope such as infiltration and fenestration.

I. Building Envelope

The building envelope includes anything that encloses a building such as walls, ceilings, windows, foundations. Basically, the envelope is anything that separates the inside of a building from the outside environment. The foundation of a good energy conservation program begins with having a building envelope that efficiently minimizes heat loss.

From thermodynamics we know that there are three forms of heat transfer. Heat transfer occurs by conduction, convection, and radiation. We will look at how each of these forms of heat transfer work.

Conduction causes heat to flow by way of collisions between atoms and molecules, which causes a transfer in kinetic energy. Hot atoms move faster than cold atoms and when they come in contact the collisions slow down the “fast” atoms and speed up the “slow” atoms, which cause the transfer of some kinetic energy. Different materials transfer heat at different rates and the transfer capability of a material is known as its thermal conductivity. Some materials, such as steel and iron have high thermal conductivity and hence, transfer heat readily. Other materials, such as wood, and fiberglass are poor thermal conductors. Air is a poor thermal conductor so materials that have dead air space, such as fiberglass insulation and double pane windows are good insulators.

The second form of heat transfer is *convection*. Convection is the flow of heat through the movement of a large mass of matter. Convection is most often associated with the movement of air masses. As an air mass heats up the molecules in the air spread out causing the air mass to be less dense than the surrounding air. Since the air is less dense than the surrounding air it will rise in relation to the surrounding air and force the more dense air downward. This is why cooler air is found closer to the floor in buildings and warmer air is found near the ceiling. This same effect is seen in the atmosphere as rising warm air creates low pressure and colder denser air descending creates high pressure. This process creates a “breeze” that attempts to equalize the pressures.

The third form of heat transfer is *radiation*. Radiation is the transfer of energy that does not require the movement of a material from one place to another. In fact, radiation can occur in a vacuum. For instance the heat from sunlight travels through space to reach the earth, which is an example of radiation heating. Of course, sunlight is visible, but not all forms of radiation heating are visible. A microwave oven is another form of radiation heating.

Infiltration

Heat loss through gaps in the building envelope is called *infiltration* and is a form of convection. The most common energy conservation methods to reduce infiltration are caulking, using expanding foam around window and door frames, sealing electrical outlets, and using whole-house infiltration wraps. Some insulation types, such as cellulose, claim to offer significant reductions in infiltration, and it may be slightly better than fiberglass, but insulation alone is not sufficient to achieve acceptable levels of air infiltration.

Air barriers are intended to block random air movement through building cavities. Air barriers can be made of almost anything. A continuous air barrier is an important feature in energy-efficient design not only for the energy it can save but also because the water vapor carried by the air is the primary way moisture related damage gets started in structural cavities. As the water vapor cools it condenses and so promotes structural damage, rotting wood, other mold growth. Air barriers reduce this problem by stopping much of the air movement but still allowing what water vapor that does get in to diffuse back out again.

Some common materials used for this purpose are: "house wrap," plywood, drywall (gypsum) board and foam board. Many of these materials are also used for insulation, structural purposes, and finished surfaces. What to choose and how to use it depends mainly on where you are building and the climate.

The most common air barrier material in use today is "house wrap" such as Tyvek®. Some wraps have better weathering or water repelling abilities than others. All come in a variety of sizes for different purposes and are made of fibrous spun polyolefin plastic, matted into sheets and rolled up for shipping. Sometimes, they also have other materials woven or bonded to them for tear resistance.

House wraps are usually wrapped around the exterior of a house during construction. Sealing all of the joints with tape is a good practice that improves the wrap's performance by about 20%. All house wrap manufacturers have a special tape for this purpose.

An air/vapor retarder attempts to combine water vapor and the air movement control with one material. This method is most appropriate for wet Southern climates where keeping humid outdoor air from entering the building cavities is critical during the cooling season.

An air/vapor retarder is generally placed around the perimeter of the building just under the exterior finish, or it may actually be the exterior finish. In many cases it's constructed of one of the following: polyethylene plastic sheets, builder's foil, foam board insulation, and other exterior sheathings. The key to making this method work effectively is to permanently and carefully seal all of the seams and penetrations, including around windows, doors, electrical outlets, plumbing stacks, and vent fans.

Missed gaps of any size not only increase energy use, but also increase the risk of moisture damage to the house especially during the cooling season. An air/vapor retarder should also be carefully inspected after installation before other work covers it. Small holes can be repaired with caulk or polyethylene or foil tape. Areas with larger holes or tears should be removed and replaced. Patches should always be large enough to cover the damage and overlap any adjacent wood framing.

Insulation

Heat loss through the building structure is caused by conduction where heat moves through gypsum board, wood framing, exterior finish, window glass, and doors. Since heat flows naturally from a warmer to a cooler space, the purpose of insulation is to help slow the outflow

of heat from the building structure during the winter. In the summer, insulation helps slow the inflow of heat into the building. Insulation is the most significant factor impacting the heat loss through a building envelope.

1. Insulation Basics

The purpose of insulation is to slow the flow of heat through a buildings walls, ceilings, and floors. Two important terms in energy conservation are “BTU’s” and “R-Values”.

A BTU is an abbreviation for British Thermal Units.

A *BTU* is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

The effectiveness of thermal insulation is determined using “R-Values”. A thermal insulator is any material that resists the conduction of heat energy. The official definition of R-Value is complex as you can see here,

R-Value is the reciprocal of the BTU’s of energy conducted times inches of thickness per hour of time per square foot of area per degree Fahrenheit of temperature difference between the two sides of the material. The units of R-Value are $\text{hr} \cdot \text{ft}^2 \cdot \text{F} / \text{BTU}$.

What is important to remember about R-Value is that it is a measure of the resistance of a material to heat flow and the higher the number the greater the insulating value. It is also important to remember that R-Values only involve one of the three methods of heat transfer – conduction.

Because insulation is such an important component in an efficient building envelope it is often the first item that is considered in an energy efficiency improvement plan. Adding insulation can be expensive, but it often yields the quickest payback of any energy conservation method. It is easy to determine the potential cost savings that can be achieved with the addition of insulation by using a payback calculation.

The payback calculation takes into consideration the installed cost of the new insulation, the efficiency of the heating source, the marginal cost of energy used to heat the structure, and the outside temperature where the building is located. Actually the temperature data is based on Heating Degree Day data for the building location. The payback calculation is,

$$\text{Payback} = (\text{Cost}_{\text{Ins}} * R_{\text{Existing}} * R_{\text{New}} * \text{Eff}) / (\text{Energy Cost} * (R_{\text{New}} - R_{\text{Existing}}) * \text{HDD} * 24)$$

Where,

Payback = Expected payback, years.

Cost_{Ins} = Installed cost of the insulation, \$/ft².

R_{Existing} = Areas existing R-Value.

R_{New} = New R-Value of area.

Eff = Efficiency of the heating system.

Energy Cost = Energy cost, \$/BTU.

HDD = Heating Degree Days.

Note: The efficiency factor for natural gas, propane, and fuel oil systems is based on the Annual Fuel Utilization Efficiency (AFUE) factor. Typical values are 0.88 for propane systems and 0.92 for natural gas systems. For heat pumps, the Coefficient of Performance (COP) is used and typical values are 2.4 for air source systems and 3.5 for geothermal systems.

The term Heating Degree Day (HDD) refers to a calculation that measures the likely need for heating during a given period. Heating degree days are calculated by recording the mean temperature during a given day and subtracting from 65 degrees Fahrenheit. For instance, if the mean temperature on January 2nd was 38F, then the Heating Degree Days for January 2nd would be $65 - 38 = 27$. This calculation is repeated for each day in the year and the values are summed to find the total number of Heating Degree Days for a location. If the mean temperature for any day is above 65F, then the value is used to determine the Cooling Degree Days (CDD). Both Heating Degree Days and Cooling Degree Days are useful in analyzing energy consumption.

The following chart has recent Heating Degree Day information for several locations in the United States.

Chart 1 Heating Degree Day Data (Base = 65F)	
Location	HDD
Alabama	2,840
Connecticut	6,068
Florida	694
Minnesota	8,754
Alaska	11,525

From this chart you can see that Connecticut has slightly more than twice the heating requirement than Alabama.

Since the payback calculation requires the energy cost in \$/BTU some conversion may be necessary since electricity is typically sold in \$/kWh, natural gas is sold in \$/CCF or \$/Therm, and fuel oil and propane are sold in \$/Gallon. Since the BTU content of each fuel type is readily known we can convert the cost into \$/BTU easily. See the following chart,

Chart 2 Energy Conversion to \$/BTU			
Energy Source	BTU Content	Cost per Unit	\$/BTU
Electricity	3,412 Btu/Kwh	\$0.085 / kWh	\$0.0000249
Natural Gas	103,000 Btu/CCF	\$1.81 / CCF	\$0.0000176
Natural Gas	100,000 Btu/Therm	\$1.76 / Therm	\$0.0000176
Fuel Oil	138,500 Btu/Gal	\$2.40 / Gal	\$0.0000173
Propane	91,000 Btu/Gal	\$2.10 / Gal	\$0.0000231

With this information, consider an example where the existing insulation in the walls of a building located in Connecticut are R-3.5 and the owner desires to improve the insulation to R-11. The installed cost of the insulation will be \$0.29 per square foot. The heating system is an electric heat pump with a COP of 2.5 and the energy cost is 9.5 cents per kWh. What is the estimated payback of the insulation?

For Connecticut we see from Chart 1 that the HDD is 6,068. From Chart 2 we see that the energy cost in \$/BTU for electricity is \$0.0000249 /Btu. The payback is,

$$\text{Payback} = (0.29 * 3.5 * 11 * 2.5) / (0.0000249 * (11 - 3.5) * 6,068 * 24)$$

Payback = 1.02 years.

In this example the payback for increasing the insulation from an R-Value of 3.5 to an R-Value of 11 is only slightly over one year. What would the payback be for the same energy costs, but in Alabama?

From Chart 1 we see that the heating degree days in Alabama are 2,840. The payback calculation is then,

$$\text{Payback} = (0.29 * 3.5 * 11 * 2.5) / (0.0000249 * (11 - 3.5) * 2,840 * 24)$$

Payback = 2.19 years.

Because Alabama does not have as much need for heating as Connecticut, the payback for adding insulation is approximately twice as long in this example. This analysis assumes a uniform space with uniform insulation and calculates the impact of insulation on heating costs. Cooling costs are not considered.

2. Insulation Materials

Some of the common materials used for building insulation include fiberglass, rock or slag wool, cellulose, cotton, plastic foam, and reflective insulation. Each of these materials has special characteristics that make them suited as an insulating medium.

Fiberglass insulation is an effective resistor to heat flow and is made from molten glass and sand that is spun into fibers. The fiberglass has tiny air pockets that resist the flow of heat and cold making it an extremely effective form of insulation.

Slag wool insulation is made from iron ore blast furnace slag that is spun into a fibrous form much like fiberglass. It is often called rock wool or mineral wool and has similar performance characteristics to fiberglass.

Cellulose insulation is made from ground-up newspapers. Cellulose is gaining favor as an excellent building envelope insulator and may actually provide a slight advantage over traditional fiberglass insulation for air infiltration. It also seems to have superior sound absorbing

characteristics. Cellulose will settle over time, which may leave areas un-insulated. The manufacturers of blown-in cellulose note the “settled” R-Value of their material on the bag labels. Untreated cellulose will burn so it must be treated with a special fire retardant chemical before installation. The fire retardant chemical may be corrosive to some plumbing and wiring so special care is required during installation.

Cotton insulation is similar to cellulose, but is made from recycled denim and is an effective insulator, but it must be treated with special chemicals to make it fire retardant. The fire retardant chemicals may be corrosive to pipes and wiring.

Plastic foam insulation includes a wide variety of chemical foam insulators. Plastic foam includes extruded polystyrene, expanded polystyrene, polyurethane, and polyisocyanurate. Polystyrene foam is commonly used for “blue board” and “pink board” that covers the outer shell of a typical residential structure. Polyurethane is chemical foam that must be sprayed into place and offers R-values of between R-4 and R-6 per inch. It is more expensive than other forms of insulation and is considered specialty insulation for hard to reach crevices in buildings such as around window and door frames.

An unusual insulation is *reflective insulation*, which is a reflective material such as aluminum foil or a plastic film that reflects the heat waves away from the structure (for cooling) or reflects the heat back into the structure (for heating). Unlike the other forms of insulation mentioned, reflective insulation does not work to restrict conductive heat flow, but instead reflects radiant heat flow that is emitted from a warm source. Generally the material is installed to either reflect heat away or to reflect heat back into the structure, but not both. One use of reflective insulation is to add a layer of aluminum foil finish onto polystyrene board to cover building shells. Another specialized use of reflective insulation is on satellites and spacecraft where the material is used to reflect heat away from the craft. Some manufacturers claim R-values of up to R-8 for reflective insulation, but in most residential and commercial building applications, reflective insulation only provides a marginal contribution to the structure’s total R-value.

3. Insulation Types

Insulation in residential and commercial buildings is usually installed in batts and rolls, blown-in (loose-fill), or spray applied.

Fiberglass insulation and slag wool insulation are commonly applied in rolls. The rolls are available in several common building industry specific widths and can easily be applied in the wall cavities and between floor and ceiling joist. It is easy to trim to fit using an ordinary utility knife. Roll insulation, including fiberglass and cellulose, have R-values of around R-3.2 per inch of insulation. Rolls of insulation may have a vapor retarding backing attached to the material. In areas where the insulation will be left exposed a special fire retardant facing may be used.

Loose-fill material must be blown-into the space to be insulated using special blowing machines. Loose-fill is very effective at filling small nooks and crannies in an area and is most often used as attic insulation. Fiberglass, slag wool, cotton, and cellulose may be blown-in, but some settling will occur. Loose-fill material is installed dry. The final R-value per inch for loose-fill insulation ranges from R-2.2 for fiberglass to R-3.2 for cellulose.

Spray applied insulation must be applied wet to adhere to a wall cavity. Both fiberglass and cellulose may be applied wet. Spray applied insulation will provide slightly higher R-Values than roll insulation. For instance typical fiberglass roll insulation in a 2x4 wall cavity might be R-11, but if fiberglass is sprayed-in, the insulating value can be up to R-15. The amount of water used in a spray-in installation is critical. Too much water can lower the R-value and may create moisture problems. Manufacturers provide drying times for their insulation for a range of humidity and temperatures.

Windows

Another important component in the energy efficiency of a building envelope is fenestration. *Fenestration* is any opening in a building's envelope such as windows, doors, and skylights.

The big fenestration contributors to heat loss in buildings include windows and skylights. The National Fenestration Rating Council® (NFRC) has developed an energy performance label that manufacturers can use to rate the efficiency of their products. The website for the National Fenestration Rating Council® is www.NFRC.org.

A representative sample of a NFRC label is shown on the right. We will look at each of the label factors individually.

The first factor is the U-Factor. The *U-Factor* is a measure of the effectiveness of the window to prevent heat from escaping. The inverse of the U-Factor is R-value, so a window with a U-Factor of 0.4 has an R-value of 2.5. Windows tend to have U-Factor values between about 0.2 and 1.2. Remember that the lower the U-Factor, the higher the R-value.

The next factor is the Solar Heat Gain Coefficient (SHGC), which is a measure of how well the window blocks heat caused by sunlight. The SHGC measures the fraction of incident solar radiation admitted through a window, whether it is directly transmitted or absorbed and the released into the building structure. The range of values for SHGC is between 0 and 1 with the lower numbers representing less solar heat transmittal.

The third factor is *Visible Transmittance* (VT), which is a measure of how effective the window is at letting light through. The range of values for VT is between 0 and 1 with the higher number representing more light let-through capability.

The fourth factor is *Air Leakage* (AL), which is a measure of how much infiltration occurs through the window assembly. The AL value is the amount of air in cubic feet per minute per

NFRC National Fenestration Rating Council®	All American Windows Model W23 Vinyl Clad Double Glaze – Argon Filled – Low E
Energy Performance Ratings	
U-Factor 0.40	Solar Heat Gain Coefficient 0.35
Additional Performance Ratings	
Visible Transmittance 0.50	Air Leakage 0.30
Condensation Resistance 60	-

square foot of window area that is passing through the window. Low AL values means less infiltration and subsequently less heat loss.

The final factor in the NFRC label is *Condensation Resistance* (CR), which is a measure of the ability of the window to resist the formation of condensation on the interior surface of the window. The CR value is between 0 and 100, with the higher numbers representing better resistance to the formation of condensation.

Using the NFRC label allows consumers and building designers to compare window products and to choose the window product that will offer the best value in terms of cost, energy efficiency and effectiveness at transmitting light.

Vapor Diffusion Retarders

Effective vapor barriers are important for a well insulated home. The normal activities of cooking, cleaning, and breathing all produce moisture in a heated house. Good vapor barriers will assure that most of the moisture from the heated house doesn't pass through the walls, ceiling, or floor of the building.

Moisture can saturate insulation, drastically reducing its ability to resist heat loss. It can also cause mold, mildew, and other decay in building materials and insulation. Wet insulation is much heavier than dry insulation and can overload ceilings, causing sagging or even more serious damage.

The proper term for vapor barriers is Vapor Diffusion Retarders, or VDR's. A Vapor Diffusion Retarder is a material that reduces the rate at which water vapor can move through a material. The term "vapor barrier" is still used to describe Vapor Diffusion Retarders, but this is not technically correct because the material does not stop the transfer of all moisture. Since everything allows some water vapor to diffuse through it to some degree, the term "vapor diffusion retarder" is more accurate.

1. Vapor Basics

Water vapor moves in and out of a building basically in three ways: with air currents, by diffusion through materials, and by heat transfer. Of these three, air movement is the dominant force because, like most fluids, air naturally moves from a high pressure area to a lower one by the easiest path possible. This is generally through any available hole in the building envelope. Moisture transfer by air currents is very fast and accounts for the vast majority of all water vapor movement in building cavities. Thus it is very important that potential paths that moisture may follow be carefully and permanently sealed. The other two driving forces are much slower processes and most common building materials slow moisture diffusion to a large degree, although never stop it completely.

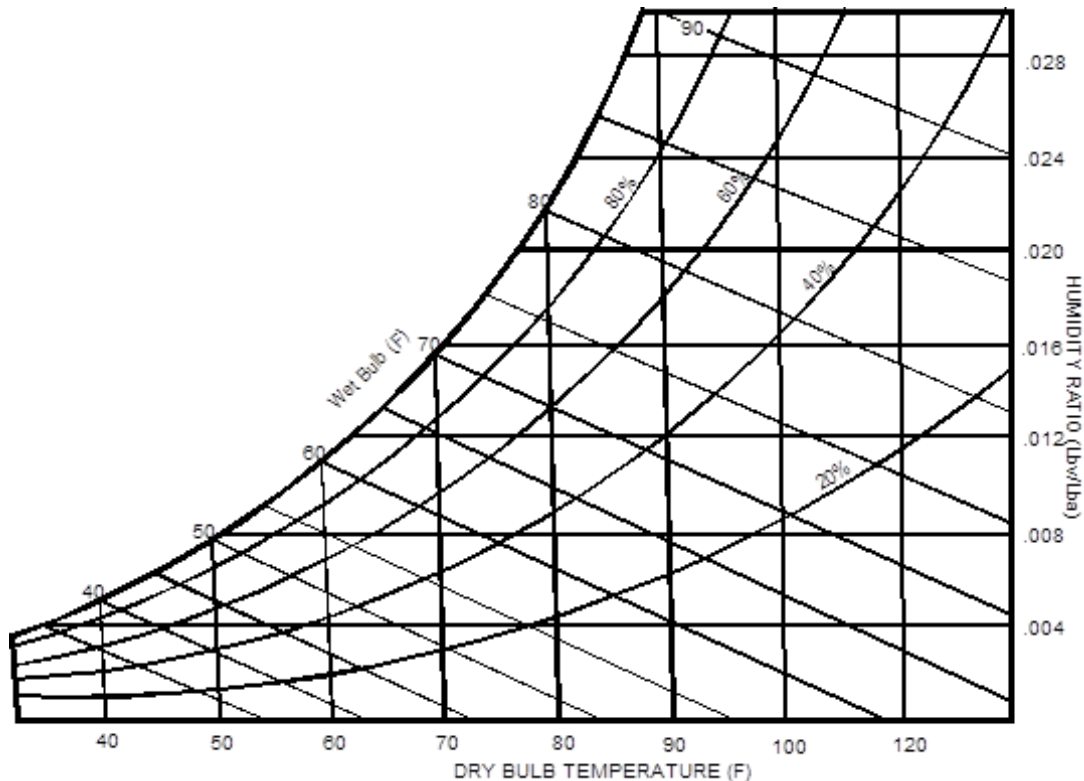
Older buildings did not need to restrict the flow of airborne moisture, since when the building cavities got wet they also dried quickly due to the "leaky" construction methods that allowed air to move freely through the building envelope. The water vapor movement really did not matter much until the introduction of thermal insulation. When insulation is added, the temperature of

the water vapor can drop very quickly since it is being isolated from the heat of the building (in the winter) or from the outdoors in the summer if the building is being air-conditioned.

Some of the less obvious locations where airborne water vapor can move in and out of the thermal envelope include holes around plumbing pipes, ductwork, wiring, and electrical outlets. During the winter in Northern climates, any warm air entering the walls from the house cools and condenses it is water vapor inside building cavities. In the South, humid air does much the same, except it comes from the outdoors and condenses inside the wall cavities during the cooling season.

The laws of physics govern how moist air reacts within various temperature conditions. A psychrometric chart is used to determine at what temperature and moisture concentration water vapor begins to condense. This is called the "dew point." By understanding how to find the dew point, you will better understand how to avoid moisture problems in buildings.

The following is a sample of a psychrometric chart.



The psychrometric chart has the air temperature on the “x-axis”, which is also called the “Dry Bulb Temperature”. The y-axis is the humidity ratio, which is the ratio of the pounds of moisture (Lbv) to the pounds of air (Lba). The curved lines of the chart are lines of constant relative humidity. Relative humidity (RH) refers to the amount of moisture contained in a quantity of air compared to the maximum amount of moisture the air could hold at the same temperature. As air warms, its ability to hold water vapor increases. As air cools this capacity decreases.

Consider the following example where the temperature is 80F at a relative humidity of 100%. Moving up the 80F line to the 100% Relative Humidity line and then moving horizontally we find the humidity ratio is 0.022 lbs water/lbs air. Now, if the temperature decreases to 70F at 100% relative humidity, we find that the humidity ratio is 0.016 Lbv/Lba. At 70F the air can only hold 72% of the moisture of the air at 80F. The moisture that the air can no longer hold condenses on the first cold surface it encounters (the dew point.) If this surface is within an exterior wall cavity wet insulation and framing will be the result.

As you can see in this example, we can control two things; temperature and moisture content. The R-value of the wall cavity insulation moderates the effect of temperature across the building envelope cavity. An airtight, vapor diffusion retarder, properly installed towards the warm side of this cavity, reduces the amount of moisture entering it. Except in deliberately ventilated spaces, such as attics, these two factors work together to reduce the opportunity for condensation in a house's ceilings, walls, and floors.

2. Perm Ratings

The ability of a material to retard the diffusion of water vapor is measured by units known as "perms" or permeability. A perm is defined as,

A measure of the number of grains of water vapor passing through a square foot of material per hour at a differential vapor pressure equal to one inch of mercury (1" W.C.) at 73.4 F (23C).

Any material with a Perm rating of less than 1.0 is considered a vapor retarder and VDR ratings of 0.1 or less are common. To prevent trapping moisture in a cavity the cold-side material's Perm rating should be at least five times greater than the value of the warm-side.

3. Types of Vapor Diffusion Retarders

Vapor diffusion retarders (VDRs) are typically available as membranes or coatings. Membranes are thin, flexible materials, but also include thicker sheet materials sometimes termed "structural" vapor diffusion retarders. Materials such as rigid insulation, reinforced plastics, aluminum, and stainless steel are relatively resistant to water vapor diffusion. These types of vapor diffusion retarders are usually mechanically fastened and the sealed at the joints.

Thinner membrane types of VDRs come in rolls or as integral parts of building materials such as aluminum- or paper-faced fiberglass roll insulation. Foil-backed wallboard is another type commonly used. A plastic sheet material, such as polyethylene, can be used as a VDR for above grade walls and ceilings (only) in very cold climates (in locations with 8,000 Heating Degree Days or higher).

Most paints will retard vapor diffusion. While it was once believed that only special coatings with low perm ratings constituted an effective VDR, it is now believed that any paint or coating is effective at restricting most water vapor diffusion in milder climates.

4. Vapor Diffusion Retarders Installation Practices

It is important for VDRs to minimize condensation or moisture problems in the following areas of a building: walls, ceilings, and floors; under concrete slabs; and in crawl spaces. A continuous VDR with reliable air sealing is very important if the building is constructed on a concrete slab. A VDR with a perm value of less than 0.50 should be used if the water table is high.

In moderate heating climates (less than 4,000 Heating Degree Days), materials like painted gypsum wallboard and plaster wall coatings impede moisture diffusion to acceptable levels and no further VDR is needed. In more extreme climates, a VDR is advisable for new construction. VDRs perform best when installed closest to the warm side of a structural assembly. In cold climates this is towards the interior of the building. In hot/wet climates, this is towards the exterior of the building. Reasonable rules-of-thumb to follow when placing vapor retarders are:

For climates having 2,200 or more heating degree days (HDD) the VDR should be located on the warm side of the exterior structural assembly. If possible, locate it on the inside of the assembly using the "one third, two thirds rule": the VDR has one third of the cavity insulation to its warm side, two thirds to the cold side. This protects the retarder from physical damage through errant construction or remodeling activities.

For climates with fewer than 2,200 HDD (cooling-dominated climates) where the building is near, but not quite in, the 2,200 HDD zone place the VDR in the same location as climates farther north. Farther south (about 1,900 HDD) the location is irrelevant. For climates even farther south than this, and one generally hotter and more humid VDR's are often not used. This is due to the winter heating loads and summer cooling loads being roughly equal. Any choice of location ends up having the VDR on the wrong side of the structure half of the year. Some research suggests that a VDR should be applied directly under the exterior finish.

When installing a VDR it should be continuous and as close to perfect as possible. This is especially important in very cold climates and in hot and humid climates. Be sure to completely seal any tears, openings, or punctures that may occur during construction. Cover all appropriate surfaces. Otherwise moist air condensing within the cavity may cause damp insulation. The thermal resistance of wet insulation is dramatically decreased, and prolonged wet conditions will induce mold and wood rot.

Except for extensive remodeling projects, it's difficult to add materials like sheet plastic as a VDR to an existing home. However, many existing homes do not really need a more effective VDR than the more than likely numerous layers of paint on their walls and ceilings. These multiple layers are quite effective as a VDR in all but the most extreme northern climates.

"Vapor barrier" paints are also an effective option for colder climates. If the Perm rating of the paint is not indicated on the label the paint label may still give a hint as to the perm rating. The label usually indicates the percent of pigment and to be a good VDR it should have a relatively high percent of solids and thick in application. Glossy paints are more effective VDRs than flat paints and acrylic paints are generally better than latex paints. When in doubt apply more coats of paint. However, it's best to use paint labeled as a VDR and follow the directions for applying it.

In any case, the key to controlling unwanted water vapor movement is the careful air-sealing of gaps in the structure and not the VDR alone.

Adequate ventilation, particularly in attics and crawl spaces, will prevent moisture from condensing on the insulation or the building structure. Vent openings in attics and crawl spaces must be placed so that air can flow in one opening, across the insulated area, and out the other. This is usually made possible through cross-ventilation.

Crawl spaces under the house should be covered. This is to slow ground moisture from evaporating into the crawlspace and condensing there. Cross-ventilation can be achieved in crawl spaces by placing vents at direct opposite sides of the space. The venting area should be one square-foot for each 150 square feet of crawl space/floor area.

Attics are best ventilated by taking advantage of convection, the natural tendency of warm air to rise. In an attic, this is called the "chimney effect." Half of the vents are placed at the eaves (the lower part of the attic) and half at the gables or ridges above. The heat of the sun and the force of wind naturally provide attic cross-ventilation with this system.

Cross-ventilated attics must provide one square foot of net free area (NFA) for each 300 square feet of ceiling area (with or without a vapor barrier).

Table 3	
Net Free Area (NFA) of Attic Vents	
Type of Attic Ventilation	Divide Attic Space by
Cross-Ventilated (with or without vapor barrier)	300
Not Cross-Ventilated without vapor barrier	150
Not Cross-Ventilated with vapor barrier	300

If the attic is not cross-ventilated increased ventilation may be recommended. If no vapor barrier is installed, one square foot NFA should be provided for each 150 square feet of ceiling area. If the attic does not provide this much ventilation, it may be easier to install a vapor barrier. Attics insulated with a vapor barrier must provide one square foot of NFA for each 300 square feet of ceiling area when not cross-ventilated.

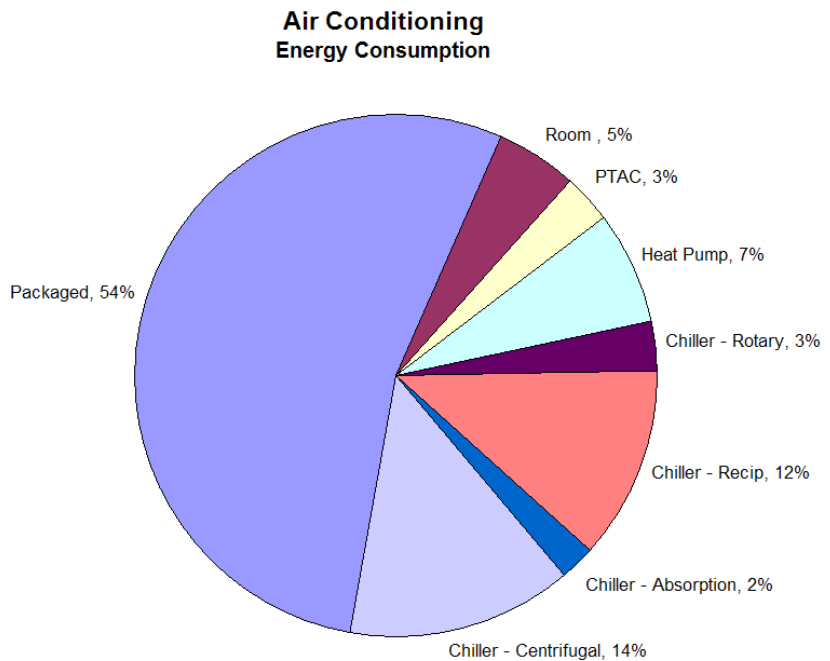
Mesh screens and/or rain louvers can reduce the net free area of vents by as much as one-third. Unless the term "free air" is stamped on the louver, their size must be increased to account for the loss of net free area. Table 4 has area reduction factors for various screens.

Table 4	
Net Free Area Reduction Factors	
Type of Covering	Reduction Factor
¼" Hardware Cloth	1.00
¼" Hardware Cloth with Rain Louvers	2.00
#8 Mesh Screen	1.25
#8 Mesh Screen with Rain Louvers	2.25
#16 Mesh Screen	2.25
#16 Mesh Screen with Rain Louvers	3.00
No Screen with Rain Louvers	2.00

For example, a 1,500 square-foot cross-ventilated attic with a vapor barrier will require one square foot of net free area for each 300 square-feet of attic space or 5.0 square feet. If the ventilation is just covered with ¼" hardware cloth then no reduction in area is required. However, if the ventilators have both hardware cloth and rain louvers then the effective net free area is reduced by a factor of 2.0 (See Table 4) so the NFA is then 2.5. Therefore, the number of ventilators would have to be doubled to yield the same effective NFA.

II. Heating, Ventilation, and Air-Conditioning

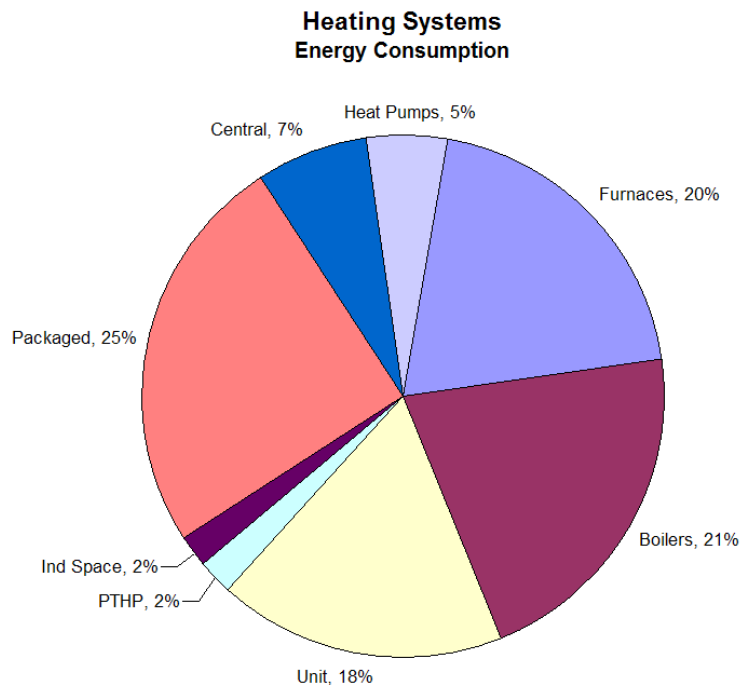
As previously mentioned well over half the energy consumption in residential and small commercial buildings is for the heating, ventilation, and air-conditioning system. The following two pie charts show the types of heating and cooling systems in use today. For cooling needs, packaged systems make up 54% of the systems in use. Chillers are the next largest segment with a total of 31% of the market spread among the different types of chillers. The remaining systems are divided between individual units such as window units and through-the-wall systems. Of the chiller systems, centrifugal units are the predominate system and only 2% of the systems are absorption systems. Unfortunately, packaged systems, which represent the largest share of the market generally have efficiencies that are much lower than chiller type systems.



For heating systems the types of systems are more evenly divided among the different types of systems.

Like the cooling systems, packaged heating systems have the largest percentage share of the market, but the share is only 25% of the total. Next are boiler systems at 21% followed closely by furnaces and unit systems.

In the commercial markets, retail space is the major heating consumer with public buildings and office space being the next largest users. This type of floor space tends to have packaged and boiler systems.



HVAC Terminology

Terms that are important when discussing HVAC systems include “EER”, “SEER”, “COP”, and “Ton”. We will briefly discuss each of these before discussing HVAC systems in more detail.

Heating and cooling systems are measured in BTU’s of capacity. To simplify the numbers, the term “Ton” is used to describe BTU’s of capacity in 12,000 BTU increments. Therefore, a 3-ton air-conditioner doesn’t weigh three tons – instead it has 36,000 BTU’s of capacity and a 5-ton system has 60,000 BTU’s of capacity.

The basic measure of energy efficiency of heating and cooling systems is the electrical demand required per ton of heating or cooling, which is expressed in kilowatts per ton (kW/Ton.) The lower the kW/Ton, the more efficient the system.

The Energy Efficiency Ratio, or EER, is a measure of how efficiently a cooling system operates at a specific outdoor temperature. A 95F outdoor temperature is usually selected for the EER rating. A higher EER rating means the system is more efficient than a system with a lower EER rating. The EER rating relates energy consumed to generate a given level of BTU cooling capacity. The energy consumption of different units can be compared by dividing the BTU cooling capacity of the systems by their EER ratings. The formula is,

$$P_{in} = \text{BTU's} / \text{EER}$$

Where,

P_{in} = Power input, watts.

BTU’s = Cooling Capacity, BTU’s.

EER = Energy Efficiency Ratio.

For example, assume we are comparing two different cooling systems, both of which provide 36,000 BTU’s of cooling capacity. One unit has an EER of 10 and the other has an EER of 12. What is the power consumption of each unit and their relative efficiency?

For the first unit,

$$P_{in} = 36,000 / 10$$

$$P_{in} = 3,600 \text{ watts.}$$

For the second unit,

$$P_{in} = 36,000 / 12$$

$$P_{in} = 3,000 \text{ watts.}$$

The first unit consumes 3,600 watts per hour of operation and the second unit consumes 3,000 watts of power per hour of operation. The second unit uses 600 watts less power than the first unit, which means that it is 20% more efficient ($600 / 3,600 * 100 = 20\%$.) Of course, you can also determine the relative efficiencies by dividing one EER by another EER ($12/10 = 1.20$ or 20% more efficient.)

The EER can be converted to kW/ton by dividing the EER into 12.

A deficiency in the Energy Efficiency Rating is that it only measures the efficiency at one temperature point. To overcome this deficiency, a seasonal EER was developed. The Seasonal Energy Efficiency Ratio, or SEER, is the total amount of cooling the unit will provide for an entire cooling season divided by the total energy used during the cooling season. The SEER allows a consumer to compare the cost of operating different systems over the entire cooling season. Instead of just measuring power consumed like the EER, the SEER measures energy consumed in kilowatt-hours. The formula is,

$$E_{in} = \text{Seasonal BTU's} / \text{SEER} / 1,000$$

Where,

E_{in} = Energy consumed for the cooling season, kWh's.

Seasonal BTU's = The BTU's of cooling capacity provided for the entire season.

SEER = Seasonal Energy Efficiency Ratio.

As an example consider two units that have a seasonal BTU rating of 200,000,000, but one of the units has a SEER of 14 and the other has a SEER of 16. What is the expected energy consumption of the two units?

For the first unit,

$$E_{in} = 200,000,000 / 14 / 1,000$$

$$E_{in} = 14,286 \text{ kWh's.}$$

And for the second unit,

$$E_{in} = 200,000,000 / 16 / 1,000$$

$$E_{in} = 12,500 \text{ kWh's.}$$

As you can see from this example, the SEER allows us to directly evaluate the expected energy consumption of various cooling systems. In this case, the difference is 1,786 kWh's per year.

The term Coefficient of Performance, or COP, is used with heat pump systems and chiller cooling systems. The Coefficient of Performance (COP) is a measure of how efficiently the system will operate at a single outdoor temperature. For heating, the COP measurement point is 47F. It is a measure of how much heat, in BTU's, is provided at 47F compared to the amount of

power, in BTU's of energy required to generate the heating BTU's. Since there are 3.413 BTU's per hour per watt of electrical energy, the formula for COP is,

$$\text{COP} = \text{Heating BTU's} / (P_{\text{in}} * 3.413)$$

Where,

COP = Coefficient of Performance.

Heating BTU's = Heating BTU's at 47F.

P_{in} = Electrical Power consumed, watts.

If a unit has 40,000 of heating BTU's and the input power to the unit is 3,348. What is the heating COP of the heat pump?

$$\text{COP} = 40,000 / (3,348 * 3.413)$$

$$\text{COP} = 3.5.$$

For chiller systems the COP is found by dividing the kW/ton rating of the chiller by 3.516.

HVAC Types

When discussing HVAC systems, the manufacturers categorize systems into three broad categories. The first category is chiller systems and includes rotary-screw systems, centrifugal systems, reciprocating systems, and absorption systems. These systems are sometimes called central systems. The second category is packaged systems, which include the compressor, condenser, and cooling coil in one unit such as roof top systems in commercial buildings and split-type residential systems. The final category is a called individual systems. This category is rather broad and includes window units and through-the-wall type systems that are commonly found in motels.

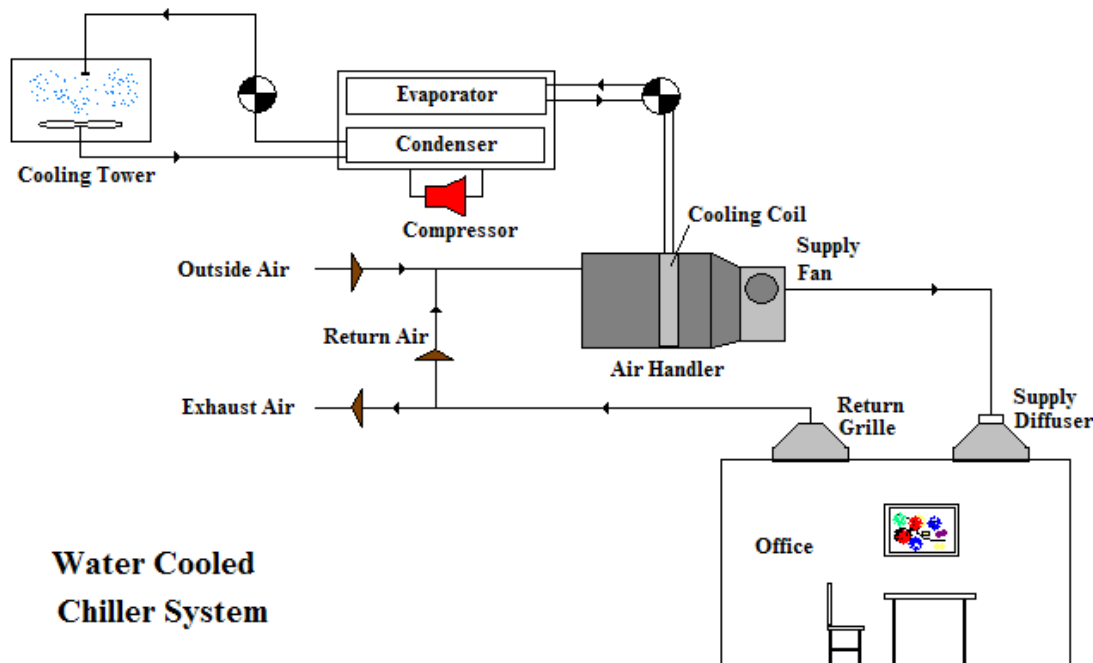
This discussion focuses on the cooling portion of HVAC systems. Heating systems are rather simple consisting of boilers, furnaces, and heat pumps. The heating systems are usually integrated into the cooling systems supply system. Energy for the heating system may come from oil, natural gas, propane, and electricity.

1. Chiller Systems

Chiller systems use chilled water as the cooling medium and use either cooling towers or air cooling systems for heat rejection. These systems are usually packaged with a boiler and hot water system for delivering heat.

The following figure shows a typical chiller system. The boiler heating portion of this system is omitted for clarity. Starting in the center of the drawing is the air handler unit (shown in gray). Using the cooling coil in the unit, the air handler conditions the air and delivers it to the space through a supply diffuser. At the supply diffuser there may be a control unit for variable air units (VAV) that modulates the air flow in the space. A VAV system is able to control the amount of cool air entering the space and thereby regulate the temperature in the space. A reheat coil may

be provided for times when the room temperature cannot be regulated solely by closing the diffuser. Some older systems are constant air volume (CAV) systems, which depend on reheat coils to balance the temperature in the room. Air leaves the room space through a return grille and is sent back to the air handler. The air handler will have a series of dampers to control the mix of outside air and return air introduced into the air handler. When the outside air is cooler than the return air, the return air is exhausted into the atmosphere and fresh outside air is sent to the air handler. When the return air is cooler than the outside air, a large portion of the return air is sent back through the air handler (some outside air is still brought into the mix to provide fresh air). The cooling coil in the air handler is supplied with chilled water from the evaporator. The evaporator, condenser, and compressor make up the vapor compression cooling portion of the chiller system. In this example the system uses a water-cooled chiller with a cooling tower. With this system, the evaporator, which is a heat exchanger, rejects heat to the condenser and the condenser takes the heat from the refrigerant causing it to condense from a gas to a liquid. The water in the condenser, which has absorbed the heat from the refrigerant is then circulated, by way of a water pump, out to the cooling tower and back to the condenser. The purpose of the cooling tower is to reject the building heat into the outside environment.



**Water Cooled
Chiller System**

One of the most common chiller type systems is the *reciprocating chiller*. A reciprocating chiller uses pistons and cylinders for compression and is also called a positive displacement system. The system consists of a reciprocating compressor, condenser (either water-cooled or air-cooled), expansion device, and auxiliary equipment. Multiple units can be combined to increase the capacity of the system. Reciprocating chillers are very cost effective for small to medium size commercial building loads.

Similar in operation to the reciprocating chiller is the *rotary-screw chiller*. A rotary-screw chiller compresses the gas using a rotary motion as opposed to the liner motion of a reciprocating chiller. Two interlocking, rotating screws compress the refrigerant into a smaller volume and

sent it to the outlet of the compressor. Rotary-screw chillers are quieter than other chiller types and are lighter. The advantage of a rotary-screw chiller is flexibility. They can vary capacity infinitely, operate at partial loads, and are stable down to about 10% of capacity. Rotary-screw chillers typically serve small to midsize loads.

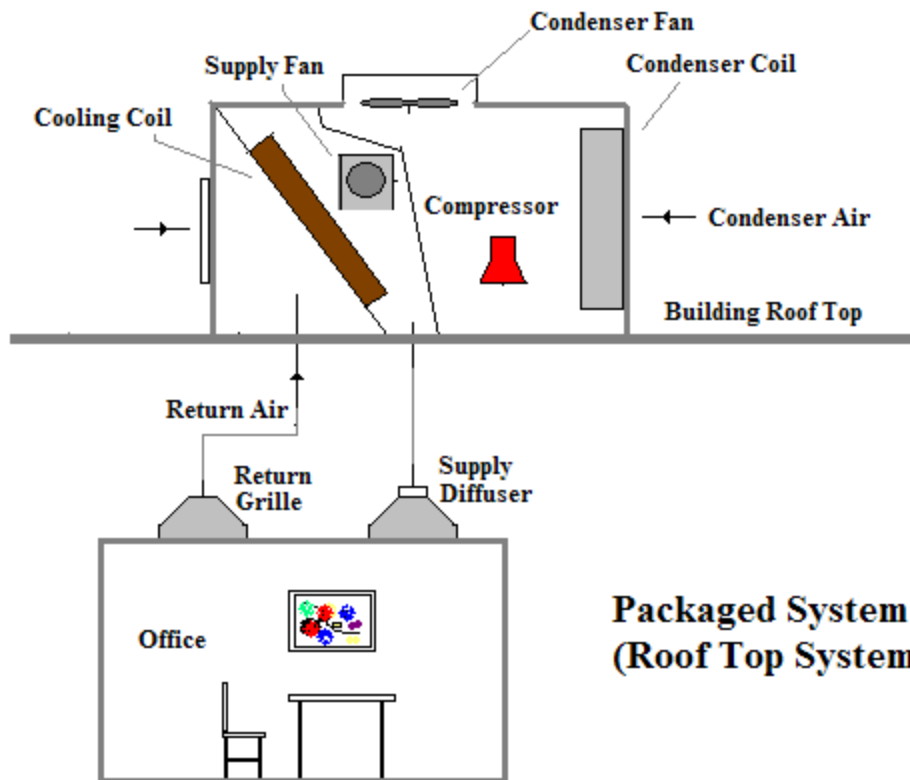
The most efficient chiller system to operate when fully loaded is the *centrifugal chiller*. They are widely used to cool large commercial buildings. A centrifugal chiller is a non-displacement compressor that raises the pressure and temperature of the refrigerant by converting kinetic energy into pressure.

Absorption chillers differ from the previously mentioned compressor chillers in that the cooling effect occurs as a result of heat energy as opposed to mechanical energy. The refrigerant is absorbed by an absorbent and then heated by gas or steam to drive the refrigerant back out of the absorbent. Absorption chillers typically use water as the refrigerant and either ammonia or lithium bromide as the absorbent. Absorption chillers are frequently employed where electricity prices are high and natural gas prices are low. If the peak demand charge of the electric utility is high then an absorption chiller may make sense. Absorption chillers are sometimes combined with conventional compression chillers to manage peak electric loads.

2. Packaged Systems

Packaged systems include both unitary systems, such as rooftop units, and split systems, such as residential air-conditioners and heat pumps. Packaged systems use a vapor compression cooling system just like most chiller systems, but the cooling is delivered directly to the supply air through a refrigerant evaporator coil. Heat from the refrigerant is rejected directly into the environment. Rooftop systems, like the one shown below, have the ability to mix return air with outside air when conditions dictate to provide the most economical supply of fresh air with ambient cool air.

In the drawing of the rooftop system shown below, cooling air is introduced from either the outside or the return air, or both, and passed over the cooling coil. The air is then sent to the room space through a supply diffuser. The refrigerant in the cooling coil is piped to the condenser where ambient air is used to convert the refrigerant from a gas to a liquid. The heat that is rejected into the condenser is then exhausted into the atmosphere using a condenser fan.



Split systems, such as residential systems, has the compressor, condensing coil, and condensing fan, located externally and the refrigerant is piped to the air handler, which is located inside the building structure. The air handler will have the evaporator coil and the supply fan for supplying cooled air into the building ductwork. The photo below is an example of a split system heat pump.

**Split System
Heat Pump**



3. Individual Systems

Individual systems include packaged terminal air-conditioners (PTAC), packaged terminal heat pumps (PTHP), water-loop heat pumps (WLHP), and window air-conditioners. The packaged

terminal units are found in motels and some offices and work similar to a rooftop packaged unit, except they are small, one room systems and do not require any ductwork or other auxiliary equipment.

Water loop heat pumps are a special case of individual systems that are very energy efficient. WLHP systems use water as the heat exchange medium. Water is pumped from underground coils to the WLHP located in the building. WLHP's allow flexibility in placing the units since they can be located anywhere in the building where the water pipes can be installed.

Thermostats

In retail commercial space and residential buildings, programmable thermostats can offer energy savings. The advantage comes from automatically setting the thermostat up during cooling periods when the building is not occupied and setting the thermostat down during heating periods when the building is unoccupied.

There is a misconception that it takes more energy to re-heat or re-cool a facility than to maintain the existing temperature. Studies have shown that the re-heating cost for a building space is equal to the cool down savings for the space. Energy savings result from the unnecessary heating during the vacant time. Generally it makes sense to adjust the thermostat for periods when the building will be unoccupied for eight hours or more. For periods of less than eight hours they may not be any savings or only minimal savings, but there is not a negative impact to adjusting the thermostat.

The Department of Energy recommends that in the cooling mode the thermostat be set at 78F and in the heating mode the thermostat be set to 68F. In the cooling mode, for each one degree the thermostat is raised above 78F, energy savings of be about 1% is possible. The same factor holds true in the heating mode, for each one degree the thermostat is lowered below 68F, the energy savings may be about 1%.

An effective method to adjust building temperatures is with programmable thermostats. Programmable thermostats are prevalent and relatively cheap at less than \$100.00 for most systems. For air-conditioning and gas furnaces programmable thermostats are cheap and offer a quick pay-back. Heat pumps are more complicated than gas furnaces and require more sophisticated programmable thermostats. For heat pumps, the thermostat must have special algorithms to prevent expensive auxiliary heating sources from operating unnecessarily.

Programmable thermostats usually have provisions to set different schedules for weekdays and weekends. Some offer schedules for each day of the week. Most have several set back periods for each day. A "5+2" programmable thermostat has two schedules, a weekday and a weekend schedule. A "5+1+1" programmable thermostat has a weekday schedule and separate schedules for Saturday and Sunday. The photo shown below is an example of a "5+1+1" programmable thermostat.



Commercial building systems use sophisticated energy management systems to control energy usage. These systems can regulate heating and cooling needs in different areas of the building as well as stage the various components of the system for optimal efficiency including managing peak electrical demand.

Energy Recovery Ventilators

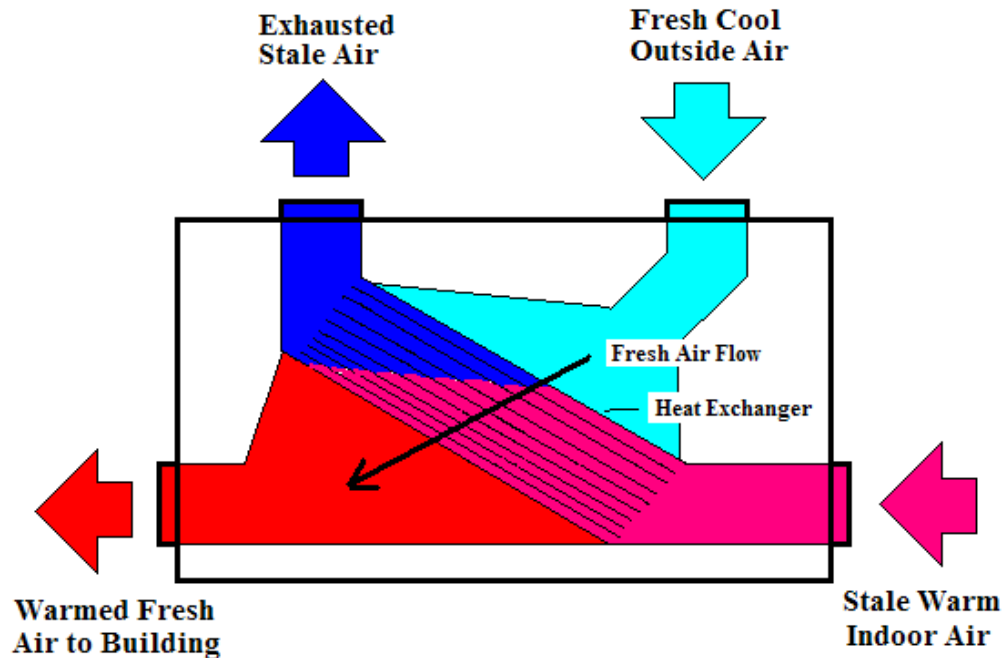
With the advent of tightly insulated houses there is a concern about the quality of air within the building envelope. The air in a building space should be exchanged 0.35 times per hour. In the past, buildings were so “leaky” that hourly fresh air exchanges were virtually guaranteed. However, with today’s well insulated spaces there is concern that the air within the space may not be exchanged often enough. The solution is to continually introduce a certain amount of fresh air into the space. Of course, this lowers the heating efficiency since this fresh air must be heated from the ambient temperature to the desired room temperature.

An Energy Recovery Ventilator, also known as a Heat Recovery Ventilator (HRV), is used with packaged systems to bring fresh air into the building space while benefiting from the previously conditioned air in the building. An HRV is a heat exchanger system.

In the heating mode, fresh air is brought in from the outside environment. This air is pre-heated by running the warm return air from the building space across the fresh air duct before exhausting the stale air. The following drawing shows the mechanics of an HRV.

As the warm return air enters the return duct work it is channeled into the HRV. The HRV brings in fresh air from the outside and this fresh air blows over the warm stale air through a series of thin aluminum passages. The cool fresh air and the warm stale air pass through alternate passages allowing the heat from the stale exhaust air to be passed to the incoming cooler air.

Heat Recovery Ventilator



These systems are effective at recovering approximately 85% of the energy from the outgoing air and passing it along to the incoming air. They are most effective in the heating mode, but some benefits are possible in the cooling mode. HRV's do not increase the efficiency of an HVAC system since it is exhausting previously conditioned air and bringing in conditioned air, but it does make the building space more livable while recovering some of the lost heat.

HVAC Efficiency Improvements

A 2002 study funded by the Department of Energy found several promising improvements to HVAC systems that can yield potential energy savings and increased comfort levels in buildings. A few of the most promising and currently available technologies are,

1. Dedicated Outdoor Air Systems
2. Displaced Ventilation
3. Electronically-Commutated Permanent Magnet Motors
4. Energy Recovery Heat Exchangers
5. Improved Duct Sealing
6. Task-Ambient Conditioning
7. Thermal Energy Storage
8. Radiant Ceiling Cooling
9. Variable Refrigerant Volume

We will briefly discuss the merits of each of these concepts starting with Dedicated Outdoor Air Systems.

The first item is a *Dedicated Outdoor Air System* (DOAS). As previously mentioned, modern central air-conditioning systems combine outside air with return air from the building for ventilation. The outside air mixes with the return air and is then conditioned and distributed to the building space. In the cooling mode, the outside air is likely to be considerably hotter than the return air requiring extra energy to bring it to the desired temperature. In spite of the extra energy required for outside air, the ventilation it provides is effective at diluting and removing indoor air pollutants for the conditioned space. A DOAS conditions the outdoor ventilation make-up air separately from the return air. By conditioning the make-up separately, the ventilation system can be sized appropriately for code required air exchanges, the humidity in the building can be more efficiently controlled, and the building air-conditioning system can be sized for the just the building load, independent of the make-up cooling requirements. The costs of DOAS systems may be slightly higher than conventional systems, but not by much. DOAS allows the building cooling system to be downsized slightly, which should offset most of the costs of installing DOAS.

Displaced Ventilation is a concept that is widely used in other countries, but that has not achieved widespread use in the United States. Displaced Ventilation systems introduce a low-velocity flow of fresh cold air near the floor in a conditioned space. The fresh air slowly displaces the existing stale air, causing the stale air to rise to the ceiling where it enters return ducts. The air movement in a Displaced Ventilation system also assists with cooling since the cooler air passes across the occupants as the air rises. Displaced Ventilation reduces energy consumption because the supply air does not have to be as cool as with traditional systems and a higher average room temperature can be maintained since the cool air is closer to the occupants. These systems do have drawbacks including “cold feet” syndrome and humidity can be harder to control. Displaced Ventilation systems cost about 15% more than traditional systems, and have a payback of around 7-10 years.

In some applications *Electronically Commutated Permanent Magnet* (ECPM) motors can offer considerable energy savings. ECPM motors are effective in the sub-fractional horsepower range such as blower motors in PTAC systems and other small fan motors. ECPM motors are variable-speed motors and, therefore reduce energy consumption by matching the speed required by the application. They are also inherently more efficient than conventional fractional horsepower motors. ECPM motors have payback periods of less than three years.

Energy Recovery Heat Exchangers, which are also called Heat Recovery Ventilators (HRVs) where discussed in detail in the previous section. HRVs reduce the energy needed to condition ventilation make-up air and are most effective in buildings with a tight thermal envelope, where the make-up requirement is significant, and where the temperature and humidity of the return air is close to that of the conditioned space. HRVs reduce conditioning costs by saving energy due to reducing the cooling requirement for the make-up air and by allowing the air-conditioning equipment to be downsized slightly. They are relatively simple to install and typically have paybacks of less than three years.

Improved Duct Sealing is another method to reducing air-conditioning costs. Energy losses due to duct leakage are considerable in most air-conditioning systems and it is especially significant in commercial building duct systems. Some studies have indicated that duct systems in commercial buildings leak between 10 to 20% of the total air flow. By using special duct sealing products, such as Aeroseal®, duct losses can be reduced to less than 5%, which will reduce air-conditioning energy consumption by up to 10%. Poorly supported duct work will pull apart at the joints; therefore these products are only effective if the duct work has structural integrity. Retrofit sealing of duct work can be expensive, but even in retrofit applications the payback is less than 10 years.

Task-Ambient Conditioning is a process of providing cooling to specific locations within a workspace. It is in essence, a personalized cooling system. In a large commercial space it is almost impossible to provide uniform cooling to every workstation and studies indicate that approximately 40% of the workers in any given workspace are unhappy with the temperature at their workstation. Task-Ambient Conditioning provides a microclimate conditioning zone for each workstation. These systems allow the average building temperature to be higher, allow the higher cooling requirements at the workstations to be used only when occupied, and provide higher overall supply air temperatures. The greatest benefit of Task-Ambient Conditioning is providing a more comfortable work environment, but the systems can offer overall energy savings of up to 5% annually.

Thermal Energy Storage (TES) systems essentially store thermal energy off-peak for use during high cooling demand periods. The storage system is often a large vessel filled with a water-based solution and some type of encapsulated material that changes phases (e.g. freezes). If a TES system is used with a chiller system, the chiller water is passed through the TES during peak cooling periods cooling the chiller water, which lowers the cooling demand on the chiller. TES systems save energy by reducing the chiller demand requirements during peak periods, by cooling the TES system at night, which requires less demand on the chiller due to lower ambient temperatures and by taking advantage of off-peak energy pricing. In most cases, TES systems are only practical where off-peak energy pricing is available. TES systems can provide energy savings of about 10% compared to conventional chiller systems.

Radiant Cooling Systems use cold water flowing through pipes in the ceiling of the building to cool the building space. The pipes are installed close to the building ceiling and cool the room by natural convection and radiant heat transfer. These systems need a DOAS and a tight building envelope to maintain acceptable humidity levels. Radiant ceiling cooling systems offer energy savings by delivering cooling directly to the building space without using air moving equipment. The chiller water supplying Radiant Cooling Systems must operate at a higher evaporator temperature to avoid condensation, so the compressor lift is less than conventional systems, which further improves the efficiency of the system. Relative to conventional VAV systems, Radiant Cooling Systems can reduce cooling energy consumption by over 25%.

A *Variable Refrigerant Volume (VRV)* system uses a single condensing unit to supply numerous indoor evaporate units. By using multiple compressors and variable speed drives VRV systems deliver exceptional performance with variable loads and can provide excellent zoned temperature control. In contrast to chiller systems that use water to provide heat transfer, VRV systems

circulate refrigerant directly to multiple evaporate units. VRV systems achieve energy savings by operating efficiently at partial loads, providing effective building zone control, by the ability to operate some of the connected evaporators in cooling mode while simultaneously operating others in heating mode as the building conditioning needs dictate. Energy savings with VRV systems can approach 15% compared to conventional chiller systems.

The nine processes just mentioned, Dedicated Outdoor Air Systems, Displaced Ventilation, Electronically-Commutated Permanent Magnet Motors, Energy Recovery Heat Exchangers, Improved Duct Sealing, Task-Ambient Conditioning, Thermal Energy Storage, Radiant Ceiling Cooling, Variable Refrigerant Volume systems all offer energy savings potential in commercial buildings. Most of these systems are best suited for new installations, but a few can be retrofitted into existing building structures.

III. Lighting

Almost one-fourth of the energy consumption in a typical residential home or small business is caused by lighting and appliances. The good news is that there are several simple lighting improvements that can reduce energy consumption.

Lighting Terminology

The distribution of light on a horizontal surface is called *illumination*. The purpose of lighting is to produce illumination that is sufficient for the activity in a space. The basic unit of measurement of illumination is a *lumen*. The intensity of illumination is known as a footcandle. A *footcandle* is the illumination produced by one lumen distributed over a one square-foot area.

Efficacy is the ratio of light produced to the energy consumed by the lamp and is measured in lumens per watt. A typical 100-watt incandescent lamp produces 1,750 lumens or 17 lumens/watt while a fluorescent lamp produces 60 lumens/watt or more.

The *Color Rendition Index* (CRI) is a relative scale (usually 0-100, but negative values are possible) that measures the ability of a lamp to render colors similar to sunlight. An incandescent lamp has a CRI of 100, and a high pressure sodium lamp may have a CRI of only 25 or so. Related to color rendition is *Color Temperature*. Color Temperature measures the quality of a light source as a temperature and red colors are considered warm and blue colors are considered cool. Color temperature is measured in degrees Kelvin (K). Lower temperatures are considered warm and higher temperatures are considered cool. Warm colors are preferred for residential applications and cooler colors are a good choice where visual acuity is needed.

A hindrance to quality lighting is *glare*. Glare causes the eye to be drawn to the light source, which prevents viewing the intended object. Anytime the lamp in a fixture is directly visible glare is likely. Glare also occurs when light reflects off of a bright surface. The placement of a light source relative to an object being viewed is critical to preventing glare.

Lighting Types

The most common types of lighting systems include incandescent, fluorescent, low-pressure sodium, high-pressure sodium, halogen, and metal halide.

Incandescent lamps generate light by heating a filament. They have excellent color rendition (CRI of 100) and a warm color temperature (2,800K), but have a low efficacy at around 15 lumens/watt. The universal incandescent lamp is an A-17 lamp. The physical dimensions of lamps are measured in eighths of an inch so an A-17 lamp has a diameter of 17/8 inches or 2 1/8 inches in diameter. The “A” designates the shape of the bulb.



In contrast to incandescent lamps, fluorescent lamps use a gas filled tube and a fluorescent phosphorous material to generate light. Fluorescent lamps have efficacies of 60-90 lumens per watt, but the Color Rendition Index is usually low. The most common fluorescent lamps are long slim tubes, the most common being a T-12 (Like incandescent lamps, fluorescent lamps are defined in eighths of an inch, so a T-12 lamp is 12/8 or 1.5 inches in diameter.) A newer, more efficient, lamp is the T-8, which has a one inch diameter. A T-8 lamp is approximately 20% more efficient than a T-12 lamp. A new type of fluorescent lamp is a compact fluorescent lamp or CFL. A CFL is a direct replacement for an A-17 incandescent lamp. CFL's are not as efficient as traditional fluorescent tube lamps, but they are approximately three times more efficient than a conventional incandescent lamp. A CFL is shown on the right.



Some CFL's have a Color Rendition Index of 80 or more, which is often suitable for residential applications. CFL's with CRI's below 80 should not be used in residential applications due to their poor color rendition. CFL's with low CRI's are suitable though for commercial building hallways and storage areas.

The other major classification of light sources is high intensity discharge (HID) lamps. HID lamps include mercury vapor, high pressure sodium, low pressure sodium, and metal halide. The following table shows the efficacy, color rendition, color temperature, and typical life of several common lamp types.

Table 5 Comparison of Light Types				
Lamp Type	Efficacy	CRI	Color Temperature (K)	Life (Hrs)
Incandescent	17	100	2,800	1,000
Fluorescent T-12	75	60	6,500	10,000
Fluorescent T-8	90	70	3,800	10,000
Compact Fluorescent	60	80	2,700	10,000
Mercury Vapor	50	50	3,200	24,000
Metal Halide	90	70	3,700	20,000
High Pressure Sodium	140	25	2,100	24,000
Low Pressure Sodium	200	-40	-	18,000
Note: All values are typical and there may be a wide variation based on wattage and other factors.				

Looking at Table 5 we see that a Low Pressure Sodium (LPS) lamp has the highest efficacy (200), but the lamp has almost no color rendition. LPS is an extremely poor light source and is sufficient only for outdoor security applications. In fact, none of the HID type lamps are very suitable for residential applications, which should have CRI's of 80 or greater. However, HID fixtures are useful in commercial applications where a lower CRI is tolerable. Metal Halide, which has an efficacy of 90 lumens/watt, is a good choice for high dexterity applications. A

benefit of HID lamps is their long life; most have lives in excess of 20,000 hours of operation, which means less re-lamping expenses.

Another specialized lamp is an LED lamp. In commercial buildings these lamps are finding use in small continuously lighted applications such as exit signs. Exit signs with incandescent lamps will use about 40 watts per sign. Exit signs with small T-5 fluorescent tube lamps use about 26 watts. However, LED lighted exit signs use only 5 watts.

Lighting Methods

One key to saving energy with lighting is to use lighting effectively. In most cases one type of lighting will not provide effective and efficient lighting for a space. Instead a “layered” approach will yield the most pleasing and effective lighting plan.

Layered lighting is an approach that includes a combination of ambient lighting, accent lighting, and task lighting as appropriate in a space.

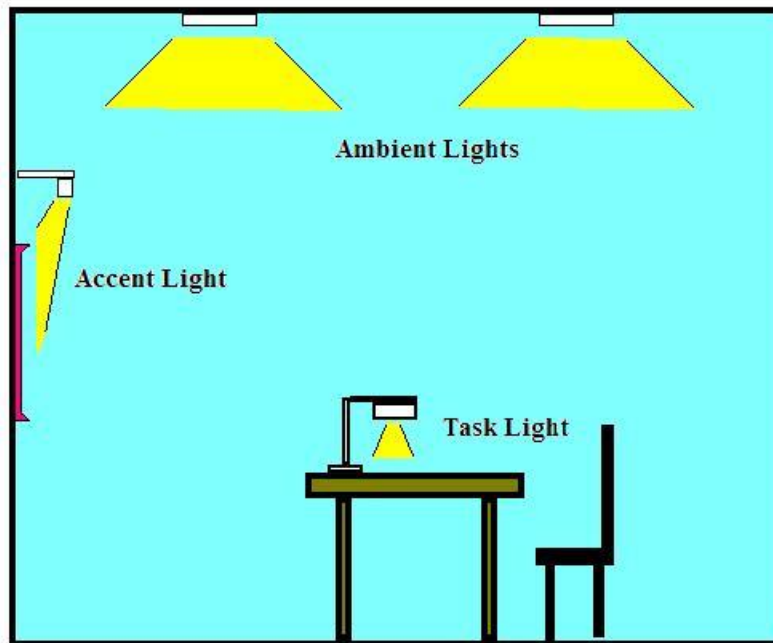
Ambient lighting is used to provide a general level of lighting for an area for safety and security. In an office space, the ambient lighting needs to provide adequate illumination for walking and general office activities.

Task lighting is used to provide additional illumination for activities requiring more lighting than the ambient lighting provides. Task lighting is used for reading, assembly, and other fine work.

The third method of lighting is *accent lighting*. Accent lighting uses specialized lighting to illuminate special features such as illuminating a painting.

In a typical office environment the ambient lighting should be around 30 footcandles depending on the office activity. Specialized activities such as reading and computer work needs a total illumination of between 50 and 80 footcandles. The additional lighting needs for reading can be accomplished with task lighting that will only be illuminated when needed. See the drawing below for a visual explanation of layered lighting.

Layered Lighting Method



Task lighting can save energy in two ways. First task lighting is only used when needed. Second, since illumination varies inversely with the square of the distance from the source, providing 50-footcandles on a work surface from a ceiling mounted lighting system requires considerably more lumens than providing 50-footcandles from a task light that is 30 inches from the work surface.

Layered lighting is obviously a simple concept and when used correctly it can yield dramatic energy savings.

Light Controls

Another way to control lighting energy costs is to only use lighting when needed. The simple way to do this is to manually switch the lights on and off as needed. Of course, this is not always practical or reliable. Occupancy sensors provide an automatic method to control lighting.

Occupancy sensors turn on lights only when a space is occupied and then turn off the lights after some period of inactivity. Most of these sensors use either Passive Infrared (PIR) sensors or Ultrasonic sensors.

Passive Infrared (PIR) sensors respond to changes in background heat energy. They operate in the wavelengths emitted by humans. PIR sensors must have a direct line of sight to the heat source and the sensitivity decreases with distance. They are most effective with objects moving across the sensors field of view.

Ultrasonic sensors use a quartz crystal to generate high frequency sound waves that are reflected back to the sensor by objects in the space. If an object, such as a person walking into the room, disrupts the reflected signal the sensor “sees” the change in the reflected signal using Doppler technology. Ultrasonic sensors can see around objects to some degree. Ultrasonic sensors also have greater range than PIR sensors. They are most effective with objects moving directly toward the sensor.

Some occupancy sensors combine PIR and ultrasonic technology into one sensor providing the benefits of both sensors and minimizing false sensing. Studies have shown that occupancy sensors can reduce lighting energy consumption by 30% (for the lights that are controlled.)

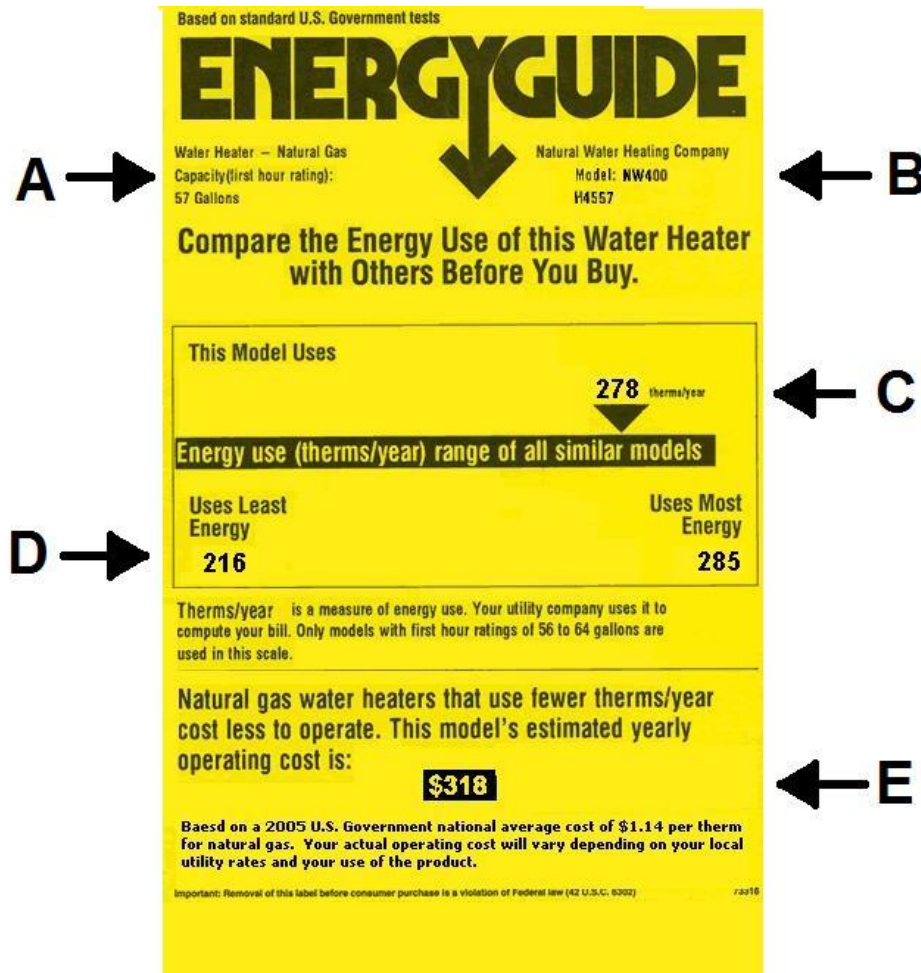
IV. Building Equipment

Approximately 25% of the energy consumption in residential and small commercial buildings is the result of miscellaneous equipment such as water heaters, air compressors, computers, electronics, etc.

The Federal government offers consumers two aides to using energy wisely with residential and small commercial building equipment. They include the Energy Guide label and the ENERGY STAR label.

The Energy Guide label is required for clothes washers, dishwashers, refrigerators, freezers, water heaters, and HVAC equipment (some equipment, such as clothes dryers and microwaves are exempt from the Energy Guide label requirement.)

The image below is a sample of the Energy Guide label. Five of the key components of the Energy Guide label are shown in the image below.



Item “A” is a description of the features, capacity, and size of the appliance. In this example, the label is describing a natural gas water heater. Item “B” lists the manufacturer’s name and model.

Item “C” is a measure of the energy efficiency of the appliance. For water heaters, the measure is energy use in therms per year. Item “D” shows a range of energy efficiencies for similar units from the lowest efficiency to the highest. Item “C” is placed on the energy efficiency continuum. In this example the water heater uses 278 therms/year, which is on the high-end of the efficiency range. Item “E” is the expected energy costs to operate the appliance for a year under typical operating conditions.

Another useful guide is the ENERGY STAR label, which is available for many appliances and electronic equipment. The ENERGY STAR program was started by the Environmental Protection Agency in the early 1990’s to promote energy efficiency and is a voluntary program. Some products, like refrigerators, that are required to have an Energy Guide label may also have an ENERGY STAR label.

Water Heating

There are four primary types of domestic water heaters: Conventional systems, Heat pump water heaters, tankless water heaters, and solar water heaters.

1. Conventional

Conventional water heaters directly heat water in a storage tank and keep the water at the desired temperature until it is demanded. Once the water in the tank is depleted, no hot water is available until the storage tank has refilled and reheated. The recovery time varies depending on the energy source. The energy source for conventional water heaters may be natural gas, propane, or electricity. Natural gas waters are usually the most economical to operate with propane and electric water heaters a distant second. Depending on the cost of propane, electric and propane water heaters have about the same operating costs. Natural gas and propane systems have the fastest recovery time, usually in less than 20 minutes versus up to 45 minutes for an electric water heater.

Conventional electric water heaters use two 4,500-watt heater elements to heat the water. The elements have separate thermostats and both units will be on for the initial tank filling and the top unit will come on periodically to maintain the tank temperature. The water in the tank supposedly mixes by natural convection maintaining a constant temperature in the tank, but in reality the water in the bottom of the tank is likely slightly cooler than the desired temperature if the tank has not been emptied in a few hours. Electric water heaters are easy to place in a structure since gas piping and vents are not required. In some locales the heat elements will cause particles in the water to settle in the bottom of the tank requiring frequent tank cleaning. If the tank is not cleaned the bottom element will become covered with matter damaging the element.

Timers are sometimes used with electric water heaters to reduce energy consumption. For short time periods, such as less than eight hours, timers do not significantly reduce the energy requirements of an electric water heater because the tanks can keep water warm for several hours. It does make economic sense to switch electric waters off if there will not be a demand for hot water for more than eight hours.

2. Heat Pump

The most efficient electric water heater is a heat pump system. These systems resemble a conventional water heater except they have a small heat pump installed on top of the water heater. The heat pump extracts heat from the surrounding air and pumps it into the water heater tank. Heat pump water heaters are expensive and have slower recovery times.

3. Tankless

Although common in other parts of the world, tankless water heaters have just recently begun to find favor in the United States. Tankless water heaters use either gas or electricity as their energy source. A tankless water heater has an extremely high capacity heating element that will heat the stream of water passing through the tank for instantaneous use. Since the water stream is heated as used a virtual endless supply of hot water should be available. Instantaneous or tankless water heaters are ideal for low volume occasional use needs such as sinks in commercial building restrooms.

4. Solar

Solar water heaters use water pipes exposed to solar radiation to heat the water. The water may have an antifreeze solution to protect the water and aid its heat transfer. The solar heated water is run through a heat exchanger where the heat is rejected from the solar heated water into unheated potable water.

Solar water heaters have the potential to supply all of the hot water needs for a typical residential application on most days. However, they are complex and expensive and therefore remain a minor supplier of hot water in the United States and this technology is relegated to special applications.

Compressors

Compressors used in HVAC systems and air systems are a significant user of electrical energy. The purpose of a compressor is to compress a gas to either force the gas to change states, such as what occurs when air conditioning refrigerant is compressed and changed from a gas to a liquid, or to force the gas into a small volume, such as an air compressor. Four commonly used compressors types are centrifugal, reciprocating, screw, and scroll.

Because of their relatively low cost *reciprocating compressors* are prevalent. These units tolerate partial load operation better than other types of compressors. The efficiency of a reciprocating compressor may be in the range of 30 HP for 100 CFM for air compression and 0.8 kW/ton for refrigerant gas.

Centrifugal compressors use an impeller that compresses the gas by centrifugal force. Centrifugal compressors are usually large and are best suited for applications where they can operate at or near their full load rating. In an air compressor application, centrifugal compressors require about 20 HP per 100 CFM and when compressing refrigerant gas their efficiency is about 0.5 kW/ton.

Screw compressors use meshing helical rotors to squeeze the gas and are somewhat smaller than centrifugal compressors. Their efficiency is similar to centrifugal compressors falling in the range of 23 HP for 100 CFM for air and 0.5 kW/ton for refrigerant.

Scroll compressors squeeze the gas along a spiral path in the compressor that allows for a smooth gas flow, which promotes high efficiencies. They are well suited for small applications and are a good candidate to replace reciprocating compressors. In some applications scroll compressors can achieve efficiencies of up to 50% better than reciprocating compressors.

It is often desirable to know the operating cost of an air compressor per CFM delivered. The annual cost per CFM is,

$$\text{Cost}_{\text{CFM}} = \text{HP}_{\text{CFM}} * 0.746 * \text{Hours} * \text{Energy} / \text{Efficiency}$$

Where,

Cost_{CFM} = Annual operating cost of the compressor per CFM, dollars.

HP = HP required per CFM.

Hours = Annual hours of operation.

Energy = Average energy cost, \$/kWh.

Efficiency = Efficiency of the compressor motor, decimal value.

For instance a reciprocating air compressor may have an efficiency of 30 HP for 100 CFM, which is 0.30 HP_{CFM} . If the compressor operates 2,000 hours per year, energy cost is \$0.12 per kWh, and the motor efficiency is 85%, what is the annual operating cost per CFM?

$$\text{Cost}_{\text{CFM}} = 0.30 * 0.746 * 2,000 * 0.12 / 0.85$$

$$\text{Cost}_{\text{CFM}} = \$63.19.$$

In this example, it costs \$63.19 per CFM operate the compressor for 2,000 hours per year.

Electronic Equipment

Office equipment such as computers, monitors, and copiers has benefited from the ENERGY STAR standards.

ENERGY STAR personal computers must have a low-power mode where they use less than 15 watts during periods of inactivity. Monitors that meet the ENERGY STAR standard use up to 85% less than conventional models. To qualify, monitors must not consume more than 2-watts of power in a sleep mode and must consume one watt or less when off.

Copiers that qualify for the ENERGY STAR label must have a sleep mode when not in use and use 40% less energy than conventional models.

Appliances

Refrigerators built in 2005 that have the ENERGY STAR label are likely to use about one-half of the energy of a typical 1995 refrigerator and about 15% less than the required Federal standards. Freezers will use at least 10% less energy than the Federal standards. They achieve these savings by using high efficiency compressors, better insulation, and better temperature and defrost control schemes.

Summary

With rising energy costs it is important for energy managers to consider many different approaches to reducing energy consumption. The preceding material has been an overview of topics related to energy consumption in residential and small commercial buildings. Some of the most significant energy efficiency improvements are most easily made during the construction phase of a facility such as building envelope improvements and HVAC choices. Other decisions, such as lighting changes, equipment purchases, and operating procedures can be implemented relatively easily at anytime. The United States is entering a prolonged period of increasing fuel costs and all viable energy conservation measures should be considered.

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