
HVAC Tips for Green Buildings

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HVAC TIPS FOR GREEN BUILDINGS

Green buildings! Green technology!

We hear these catch-phrases quite frequently these days. What exactly does this mean?

Incorporating excellent practices that result in environment protection, water conservation, energy efficiency, usage of recycled products and renewable energy, is termed “green”. A “Green Building” is one that is environmentally responsible, profitable and a healthy place to live and work. Green Buildings ensure that waste is minimized at every stage during the construction and operation of the building, resulting in low costs.

Green Building applies to both existing and new constructions, from a simple commercial space to large development projects. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is used as a benchmark for evaluating the design, construction and operation of high-performance green buildings. LEED is often used as a qualifying criterion for a growing array of state and local government initiatives. What many facility managers may not realize is that it is an easy list of steps worth adopting even if LEED certification is not being pursued.

Green HVAC Design

Concerns about healthy indoor environment, maximum energy-efficiency, and thoughtful use of natural resources / water – also happen to be the current concerns of the HVAC industry.

To improve a building’s overall efficiency, it is helpful to understand what sources of heat gain/loss create the greatest cooling/heating load on the HVAC system. By reducing those loads, HVAC energy costs can be lowered and comfort often can be improved. When designing a comfort system, it is not adequate to merely produce a heat loss/gain estimate and select high efficiency equipment; much more is involved in the proper design and installation of a comfort system. Air handling and distribution system (ductwork, dampers, etc), hydronic distribution system (pumps, piping, fittings etc), delivery equipments (fan coil units, induction units, baseboard heaters, grilles, registers etc) and the control system make an important contribution to the performance and efficiency of the system as a whole.

The total performance of a building depends on a balance of envelope, mechanical systems, occupants and external environment. All these parts of the building affect the flow of heat, air, and moisture into and out of the building. Every subsystem should be designed with these concepts in mind to minimize the flows of heat, air, and moisture through the building envelope. Heat flow out of building wastes precious fuel, air leaking out carries both heat and moisture, and moisture that escapes from the interior of a building can condense or freeze in the insulation, reducing the effectiveness of the insulation and causing damage by mold and rot. We will, in this course, look at some key elements related to HVAC and building design.

The green HVAC tips noted in this course are by no means exhaustive; keep in mind that the conservation strategies for greening may vary region to region. Specific strategies should reflect the region's climate, material availability, and building practices. Keeping abreast of developments in real time requires continuing education.

The content in this course is as follows:

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GREEN TIP # 1

BUILDING SITING & ARCHITECTURAL FEATURES

An integrated approach to building design involves addressing several aspects of building design that influence the loads imposed on the HVAC system.

1. Building Siting

Following are some general guidelines for siting of building in different climatic conditions:

- a. Cold: Exposure to morning sun is preferable, but shade should be provided to west and northwest in summer. Buildings should preferably be placed on south-facing slopes; north slopes should be avoided.
- b. Temperate: Buildings should be accessible to winter sun and summer breezes, but sheltered from winter storm winds. Summer shading is important to the east, west, and over the roof.
- c. Hot arid: Summer shading is very important, especially to the west and over the roof. Some access to winter sun and sheltering from winds are desirable.
- d. Hot humid: Buildings should be opened up for natural ventilation. Shading and access to breezes are important. Some access to winter sun is desirable.

2. Solar control

Solar radiation contributes to heat, light, and glare to a site. Trees planted on the east, west and south sides of a building can dramatically reduce cooling loads. To take advantage of the sun in the winter, the location selected must be free of obstructions to winter sunshine.

- a. **Vegetation**: Apart from many aesthetic advantages, related benefits of vegetation include decreased air pollution, noise, and glare. In order to permit summer breezes, vegetation should not be very near to a building.

- External shading with natural deciduous trees is very effective at providing shade and cooling by evaporating water through their leaves: during winter they are bare, allowing sunlight to pass through, but during summer they shade the building. Studies have shown that when shaded by a single large tree in direct sunlight, a wall may experience a drop in temperature by 20° to 25°F. Even when there is no direct sunlight on the walls, shading by a large tree can reduce the wall temperature by 5° to 10°F.
- Excess glare from nearby un-shaded ground, water bodies, etc. can be minimized by the use of ground cover such as grass or ivy, which absorbs a fair amount of light. Maximum local cooling occurs when grasses or ground covers are allowed to reach their maximum height.
- Vines have the potential to cover a large portion of building in a very short period. They, however, require a supporting trellis away from the wall to ensure adequate air circulation and minimize potential for root damage to the wall. Vines can provide temperature reductions up to about 15°F.

3. **Wind control**

Wind speed and direction can cause large pressure differences across the building envelope. A positive pressure on the windward side of the building drives air in through cracks and holes. At the same time a negative pressure is created on the leeward side of the building, drawing air out through cracks and holes.

In contrast to the sun, wind should be utilized during summer to aid natural conditioning and blocked during winter. In designing for wind protection and wind use, directions and velocities of the wind should be known in relation to cool and warm periods of the day and year. Of all the climatic variables, wind is the most affected by individual site conditions.

- a. **Sheltering:** It can be done by providing windbreaks: a wall, earth berm, or just another building. Velocity of wind striking a solid break can be reduced to about half at distances equivalent to 10 to 15 times the height of the break.

- b. **Channeling:** Site development can be utilized to channel cool breezes in order to carry unwanted heat and moisture from a building. Hedge rows and shrubbery can block cold winter winds or help channel cool summer breezes into the building.

BUILDING ARCHITECTURAL FEATURES

Adopting appropriate passive solar design strategies e.g. orientation, shape, shading, area classification, fenestration sizing and shading, landscaping and day-lighting are few techniques in minimizing HVAC loads.

1. Building Shape, Form and Orientation

The orientation of a building often is determined by siting considerations. However, for those sites where there is a choice, analyzing the effect of orientation on energy and equipment costs can lead to a more energy-efficient building.

Long, narrow buildings with their long axis running east/west will permit orienting more windows to the north and south. These have LOWER cooling loads and may be able to utilize smaller cooling equipment. Conversely, buildings facing east or west with their long axis running north/south will have higher peak cooling loads and electricity demand costs, and may require larger cooling equipment.

For more northerly locations, only the south glass receives much sunlight during the cold winter months. If possible, maximize south-facing windows by elongating the floor plan in the east-west direction and relocate windows to the south face.

2. Shading

External overhangs or some type of internal shading device are desirable because they provide comfort for the occupants (overhangs provide shade without interfering with the view).

- Tropical regions need both vertical and horizontal shading throughout the year. In higher latitudes, horizontal and vertical shading is only needed during the summer on the south-facing sides of buildings.

- Any breeze in the lower latitude (tropical and arid climates) is beneficial for most of the year whereas in higher latitudes most wind is detrimental and has to be screened.
- In the arid zone, the low level of humidity can be beneficial for evaporative cooling. In the tropical zone the high level of humidity can be very uncomfortable.

3. Atrium

- In the tropical zone the atrium should be located in a way to provide ventilation within the built form.
- In the arid zone the atrium should be located at the center of the building for cooling and shading purposes.
- In cool and temperate zones the atrium should be at the center of the building for heat and light.

4. Exterior spaces

In tropical and arid climates there is a high potential to make use of all external spaces, whereas moving towards the northern latitudes (cool and temperate locations) the external spaces should be covered.

5. Vertical cores

- In tropical zone, the cores should be located on the east and west sides of the building form, so as to help shade the building from the low angles of the sun during the major part of the day.
- In arid zone, the cores should be located on the east and west sides, but with major shading only needed during the summer. Therefore, the cores are located on the east and west sides, but primarily on the south side.
- In temperate zone, the cores should be on the north face, so as to leave the south face available for solar heat gain during the winter.

- In cool zone, the maximum perimeter of the building should be open to the sun for heat penetration. Therefore the primary mass should be placed in the center of the building so as not to block out the sun's rays and to retain heat within the building.

6. Zoning for transitional spaces

Contemporary architecture tends to produce buildings that require a zoned system and/or variable capacity equipment. Transitional areas are one that does not require total climate control and natural ventilation may be sufficient. These include lobbies, stairs, utility spaces, circulation, balconies and any other areas where movement take place.

- For the tropical and arid zones, the transitional spaces should be located on the north and south sides of the building where the sun's penetration is not as great. An atrium can also be used a transitional space.
- In temperate and cool zones the transitional spaces should be located on the south side of the building to maximize solar gain.

7. Solar Heat Gain

Solar heat gain is most effectively controlled on the outside of the building. Significantly greater energy savings are realized when sun penetration is blocked before entering the windows.

- Horizontal overhangs located at the top of the windows are most effective for south-facing façades and must continue beyond the width of the windows to adequately shade them.
- The vertical extension of the overhang depends on the latitude and the climate. Vertical fins oriented slightly north are most effective for east- and west-facing façades.

Consider louvered or perforated sun control devices, especially in primarily overcast and colder climates, to prevent a totally dark appearance in those environments.

8. Effective Aperture (Daylight)

The window-wall ratio (WWR) times the visual light transmission (VLT) in an individual space results in the “effective aperture,” predicting the daylighting potential of the glazing. Depending on the latitude and predominant sky conditions (clear or overcast), effective apertures for daylighting are generally between 0.15 and 0.30. The smallest effective aperture that will meet daylighting needs should be pursued. It is unlikely that sufficient daylighting savings or user acceptance will be realized with effective apertures much less than 0.15.

9. Window-Wall Ratio (WWR)

The window-wall ratio is the percentage resulting from dividing the total glazed area of the building by the total wall area. A reduction in the overall WWR ratio will save energy, especially if glazing is significantly reduced on the east and west façades. High, continuous windows are more effective than individual or vertical windows to distribute light deeper into the space and provide greater comfort for the occupants. Try to locate the top of windows close to the ceiling line (for daylighting) but locate the bottom of windows no higher than 48 in. (for view). Consider separating windows into two horizontal strips, one at eye level for view and one above to maximize daylight penetration.

10. Light to Solar Ratio

The use of high-performance and selective low-e glazing reduces the visual light transmission (VLT) proportionately less than do reflective coatings or tints.

Dividing the VLT by the solar heat gain coefficient (SHGC) is a good rating of the performance of the glass. If the result is less than 1.0, then the glass is a poor choice for visual quality and daylighting. If the result is higher than 1.55, it is a high-performance option.

Increases in either the WWR or the VLT will have a corresponding impact on the thermal characteristics of the glazing system. Balance the visual requirements of the daylighting design with the thermal comfort and performance of the building envelope and HVAC system.

11. Operable versus Fixed Windows

Operable windows provide natural ventilation and offer the advantage of personal comfort control. If this option is exercised, the mechanical system should employ interlocks on operable windows to ensure that the HVAC system responds by shutting down in the affected zone if the window is opened. It is important to design the window interlock zones to correspond as closely as possible to the HVAC zone affected by the open window. Operable window option is however not recommended for dusty locations.

12. High Ceilings

More daylight savings can be realized if ceiling heights are 10 ft or higher. Greater daylight savings can be achieved by increasing ceiling heights to 11 ft or higher and specifying higher VLTs (0.60-0.70) for the daylight window than for the view windows. North-facing clerestories are more effective than skylights to bring daylight into the building interior.

13. Light Shelves

Consider using interior or exterior light shelves between the daylight window and the view window. These are effective for achieving greater uniformity of daylighting and for extending ambient levels of light onto the ceiling and deeper into the space. Other options include light conveyors and light louvers. Consult supplier for detailed energy and cost analysis.

GREEN TIP # 2

BUILDING ENVELOPE

In an air-conditioned space, the accumulation of heat during the day is stored in the building envelope. The quantity (mass), characteristics (specific heat, Btu/lb-°F) and configuration of the building materials are important factors that affect the heat storage capacity of buildings. In air-conditioning spaces, if the building envelope contains a large quantity of mass, it will store a large quantity of heat and cause a delay in heat transmission. This delay is called thermal lag. The more the mass, the longer will be the delay.

The desirability of high or low thermal storage mass depends on the climate, site, interior design condition, and operating patterns. High thermal storage mass is *advantageous* when outdoor temperature swings widely above and below recommended indoor temperature.

Recommended Building Construction

Heat loss or heat gain through the building material is governed by equation:

$$Q = U * A * \Delta T$$

Where

- Q = Total hourly rate of heat gain or loss through walls, roof, glass, etc in Btu/hr
- U = Overall heat-transfer coefficient of walls, roof, ceiling, floor, or glass in Btu/hr ft² °F
- A = Net area of walls, roof, ceiling, floor, or glass in ft²
- ΔT = Temperature difference between inside and outside in °F

"U" represents the overall coefficient of heat transfer. A lower conductivity (U value) of building material is more insulated, while a higher U value will conduct heat. The optimal U-values for opaque wall are recommended below:

Climate Zone	Wall "U" Btu/h/sq-ft/°F	
	24-Hour use buildings (Hospitals, Hotels, Call-centers etc)	Daytime use buildings
Composite	0.10	0.13
Hot and Dry	0.10	0.13
Warm and Humid	0.10	0.13
Moderate	0.13	0.15
Cold	0.06	0.07

Roofs

The optimal U-values for roof are recommended below:

Climate Zone	Roof "U" Btu/h/sq-ft/°F	
	24-Hour use buildings (Hospitals, Hotels, Call-centers etc)	Daytime use buildings
Composite	0.05	0.08
Hot and Dry	0.05	0.08
Warm and Humid	0.05	0.08
Moderate	0.08	0.08
Cold	0.03	0.05

Cool Roofs

Energy efficient buildings require “Cool Roofs”. Cool roofs have two characteristics:

1. The roof has a high reflectance. The high reflectance keeps much of the sun's energy from being absorbed.
2. The roof has a high thermal emittance. The high emittance radiates away any solar energy that is absorbed, allowing the roof to cool more rapidly.

Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single-ply and liquid applied.

Examples of single-ply products include:

- White PVC (polyvinyl chloride)
- White CPE (chlorinated polyethylene)
- White CPSE (chlorosulfonated polyethylene, e.g., Hypalon)
- White TPO (thermoplastic polyolefin)

Liquid-applied products may be used to coat a variety of substrates. Products include:

- White elastomeric, polyurethane, or acrylic coatings
- White paint (on metal or concrete)

Flooring

The optimal U-values for floor are recommended below:

Climate Zone	Floor "U" Btu/h/sq-ft/°F	
	24-Hour use buildings (Hospitals, Hotels, Call-centers etc)	Daytime use buildings
Composite	0.13	0.13
Hot and Dry	0.13	0.13
Warm and Humid	0.13	0.13

Climate Zone	Floor "U" Btu/h/sq-ft/°F	
	24-Hour use buildings (Hospitals, Hotels, Call-centers etc)	Daytime use buildings
Moderate	0.13	0.15
Cold	0.06	0.07

Rather than use expensive hardwoods that endanger the land and deplete forests, evaluate use of alternatives in bamboo (which is technically not a wood but a grass, and yet one of the hardest and most easily replenished flooring materials).

Glazing and Skylights

For custom buildings that feature a large amount of architectural glass and provides a panoramic view or architectural theme, the performance of the glass (U-value and solar heat gain coefficient - SHGC) has a significant effect on comfort, equipment size and energy use. Glazing should be carefully selected – the typical specifications are as follows:

Frame Type	Glazing Type	Clear Glass			Tinted Glass		
		U-Factor	SHGC	VLT	U-Factor	SHGC	VLT
Wood, Vinyl, or Fiberglass Frame	Double Glazing	0.60	0.59	0.64	0.60	0.42	0.39
	Triple Glazing	0.45	0.52	0.57	0.45	0.34	0.21
Metal and other Frame Types	Double Glazing	0.90	0.68	0.66	0.90	0.50	0.40
	Triple Glazing	0.70	0.60	0.59	0.70	0.42	0.22

Notes

- a) The glazing U value measures the glazing's ability to conduct heat. To be useful and consistent, the U-factors for windows should be measured over the entire window assembly, not just the center of glass. Look for a label that denotes the window rating is certified by the National Fenestration Rating Council (NFRC).
- b) The glazing solar heat gain coefficient (SHGC) measures glazing's ability to absorb or reflect solar heat. The SHGC is a number between 0 and 1. A low SHGC will block heat, while a higher SHGC will absorb heat.
- c) The glazing visible light transmission (VLT) measures glazing's ability to provide daylight. A higher value indicates higher natural lighting.

Recommendations for High Performance Glazing

1. Choose:

SHGC

- SHGC < 0.25 [for composite, hot & dry, warm & humid climates]
- SHGC < 0.4 [for moderate climates]
- SHGC < 0.50 [for cold climates]

U - Factors

- < 0.40 [for composite, hot & dry, warm & humid climates]
- < 0.90 [for moderate climates]
- < 0.60 [for cold climates]

VLT

VLT > 0.65 [especially for day lighting applications]

2. Window SHGC should be selected according to orientation. East- and west-facing windows in warm climates should be selected for an SHGC of no more than 0.25.

[Note - All values are for the entire fenestration assembly, in compliance with NFRC procedures, and are not simply center-of-glass values.]

3. For buildings in warm climates that do not utilize daylight-responsive lighting controls, the south window glazing should be selected with a solar heat gain coefficient (SHGC) of no more than 0.35.
4. SHGC for north-facing windows is not critical for most latitudes in the continental United States. There isn't much point in spending more dollars to obtain lower solar heat gain coefficients for north-facing windows.
5. For cold climates, where passive solar heating energy is desired, south-facing windows with high SHGC values coupled with low U-factors should be specified. In these regions, multiple-pane and gas-filled window configurations are advisable. Single-pane windows are impractical in heating-dominated climates.
6. For warm climates, a low SHGC is much more important than the window assembly U-factor. Certain window coatings, called "solar low-e" windows transmit the visible portions of the solar spectrum selectively, rejecting the non-visible infrared sections. These glass and coating selections provide superior view and daylighting, while minimizing solar heat gain. The "solar low-e" windows are recommended for warm climates.
7. Specify aluminum-frame windows with thermal breaks. Conventional aluminum frame windows without thermal breaks 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.
8. Skylights and east- and west-oriented windows may warrant lower solar heat gain coefficients since they transmit the most solar heat during cooling periods.
9. Buy windows with energy efficient label.

Air Leakage

Air leakage for glazed swinging entrance doors and revolving doors shall not exceed 0.4 cubic feet per minute per square foot (cfm/ft²). Air leakage for other fenestration shall not

exceed 0.2 cubic feet per minute per square foot of window area (cfm/ft²). Check the seals between window components for air tightness. To minimize infiltration around installed windows, caulk and weather-strip cracks and joints. (Refer Tip #3 for more details).

Insulation

Like glazing, insulation - should be considered in coordination with the rest of the building envelope. Insulation is any material that restricts heat flow. It is installed continuously throughout the building envelope to reduce the conduction of heat through walls, ceilings and floors, keeping heat in during winter and out in summer. It comes in a wide variety of materials and in many forms, such as batts, blankets, loose fill, rigid and foam. Proper insulation installation is among the most important tools in controlling home comfort and fuel costs. When choosing insulation, there are several points to consider:

1. Thermal performance: installed R-value
2. Lifetime performance: will it lose R-value over time?
3. Fire safety: If it is flammable, how should you protect it and the building?
4. Moisture: What happens if it gets wet?
5. Air infiltration: what happens if air gets into it?
6. Does the insulation also work as an air barrier?
7. Environmental issues: what does it do to the environment to manufacture it? Is it made of recycled material?
8. Health issues: safety concerns of the installer and safety for the occupants

R-value measures how well a material insulates; the higher the R-value, the more effective the insulation. R-8 insulation blocks heat movement twice as well as R-4 and half as well as R-16.

- To compare the effectiveness of different kinds of insulation, look at the R-value per inch of insulation. R-value is proportional to the insulation's thickness, but it

also depends on the type of material and its density. The more air pockets an insulating product has, the higher the R-value.

- The R-value assumes no air is leaking through the insulation. Air leakage lowers the R-value of insulation. It is important to seal air leaks. Standard density materials such as fiberglass batts and loose-fill materials do not seal effectively against air leaks. Some insulation materials, such as rigid foam and spray-☐in-☐place products, reduce or eliminate air leakage.
- Proper installation is as important as how much insulation is installed. Gaps and compressed areas can lower the R-value over 30%.

The table below shows what levels of insulation are cost-effective for different climates and locations.

Cost-effective Insulation R-Values

If you live in a climate that is...	And your heating system is...	Insulate to these levels in the...			
		ceiling	wood-frame wall	floor	basement/crawl space walls
Warm with cooling and minimal heating requirements (i.e., FL & HI; coastal CA; southeast TX; southern LA, AR, MS, AL & GA).	gas/oil or heat pump	R-22 to R-38	R-11 to R-13	R-11 to R-13	R-11 to R-19
	electric resistance	R-38 to R-49	R-13 to R-25	R-13 to R-19	R-11 to R-19
Mixed with moderate heating and cooling	gas/oil or heat pump	R-38	R-11 to R-22	R-13 to R-25	R-11 to R-19

requirements (i.e., VA, WV, KY, MO, NE, OK, OR, WA & ID; southern IN, KS, NM & AZ; northern LA, AR, MS, AL & GA; inland CA & western NV).	electric resistance	R-49	R-11 to R-26	R-25	R-11 to R-19
Cold (i.e., PA, NY, New England, northern Midwest, Great Lakes area, mountainous area (e.g., CO, WV, UT, etc.)).	gas/oil heat pump or	R-38 to R-49	R-11 to R-22	R-25	R-11 to R-19
	electric resistance	R-49	R-11 to R-28	R-25	R-13 to R-19

Source: U.S. Department of Energy 1997 Insulation Fact Sheet.

Insulation Application

Insulation for concrete roofs - Use of over deck roof insulation using expanded polystyrene slabs/spray applied polyurethane foam topped by reflective flooring. The insulation entirely above deck should be continuous insulation rigid boards.

Insulation for metal building roofs - Metal buildings pose particular challenges in choice and application of insulation. The metal skin and purlin/girt connection results in thermal bridging, which limits the effectiveness of the insulation. [A purlin is a horizontal structural member that supports the roof covering]. Use of foam blocks of 1 inch by 3 inches, should be installed parallel to the purlins to reduce the impact of thermal bridging. Use closed cell spray polyurethane foam (SPF) insulation.

Insulation for roofs attics - Ventilated attic spaces need to have the insulation installed at the ceiling line. Unventilated attic spaces may have the insulation installed at the roof line. When suspended ceilings with removable ceiling tiles are used, the insulation performance is best when installed at the roof line.

Insulation for masonry walls - Insulation may be placed either on the inside or the outside of the masonry wall. When insulation is placed on the exterior of the wall, (a) rigid continuous insulation is recommended. When insulation is placed on the interior of

the wall, a furring or framing system should be used. The greatest advantages of mass can be obtained when insulation is placed on the exterior of the mass. In this case, the mass absorbs internal heat gains that are later released in the evenings when the buildings are not occupied.

Insulation for metal building walls – A single or double layer of fiberglass batt insulation is recommended. The insulation is installed continuously perpendicular to the exterior of the girts and is compressed as the metal skin is attached to the girts.

Insulation for steel framed walls - Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as continuous insulation is the preferred method to upgrade the wall thermal performance because it will increase the overall wall thermal performance and tends to minimize the impact of the thermal bridging. Cavity insulation should be used within the steel-framed wall, while rigid continuous insulation should be placed on the exterior side of the steel framing.

Insulation for floors - Insulation should be continuous and either integral to or above the slab. This can be achieved by placing high-density extruded polystyrene as continuous insulation above the slab with either plywood or a thin layer of concrete on top. Placing insulation below the deck is not recommended, due to losses through any concrete support columns or through the slab perimeter.

GREEN TIP # 3

MATERIALS THAT CONTROL AIR & VAPOR INFILTRATION

Infiltration is the unintended entry of unconditioned air into the building through doors, windows, and other openings in the building envelope. Infiltration can be caused by wind blowing against the building, by the building stack effect, or by negative pressurization of the HVAC system. Exfiltration on the other hand is the unintended escape of conditioned air out of the building.

Air infiltration and exfiltration account for a significant amount of energy loss in commercial buildings. According to a 2005 National Institute of Science and Technology (NIST) study, an energy savings of up to 62 percent can be realized by undertaking specific air-tightness measures. In addition to energy loss, infiltration reduces occupant comfort, interferes with efficient operation of mechanical systems, reduces indoor air quality and contributes to condensation and moisture damage in the building envelope system.

Many infiltration control strategies are inexpensive and relatively simple to implement. Air leakage is reduced by installing a continuous air retarder. Air retarder materials are highly impermeable to air. They should be applied to the exterior of the envelope. The most important concept is that to be effective, an air retarder must be continuous and all seams or penetrations must be sealed with an appropriate caulk, sealant, or tape over solid backing.

GREEN BUILDING MATERIALS

Materials selected during the design and construction phases need to be appropriate to the building location, climatic conditions, and building usage and must be compatible with each other.

Materials that control air flow

The air barrier is not one material but a combination of materials used to block air movement through building cavities. Acting as a continuous system, they protect the building structure and the insulation from heat loss and moisture damage. The most common components of an air-barrier system are:

1. Sheet or rigid materials for large surfaces
2. Caulking and gaskets for joints between materials that do not move
3. Weather stripping for joints that do move

Sheet materials

Sheet materials can bridge large gaps in the air barrier.

- Polyethylene sheeting - Polyethylene sheeting ("Visqueen") is not vapor permeable and should only be used on the warm side of an insulated surface.
- House wraps - House wraps are permeable to water vapor but stop air movement if taped at joints and the perimeter. They are used on the cold side of an insulated wall to provide a wind barrier.

Rigid materials

Rigid building components (plywood, drywall, OSB, glass, and poured concrete but not concrete blocks) will act as air barriers.

Caulks and foams

1. Spray foam - Expands to fill large cracks and small holes. Not recommended near sources of heat such as flue vents etc. because it is flammable.
2. Siliconized acrylic latex caulk - Adheres well to clean, dry surfaces; and is paintable, inexpensive, easy to use, has a long life in interior applications, cleans up with water; has a low tolerance for joint movement.
3. Polyurethane (one-part) caulk - Many uses, paintable, more tolerant of dirt and moisture, long life in both interior and exterior use, very elastic and flexible, high tolerance for joint movement, no shrinkage; however, it is harder to use requires solvent cleanup.
4. High-temperature silicone caulk - Used to seal flue or chimney penetrations; long life, high tolerance for joint movement, no shrinkage.

5. Nonexpanding urethane foam - Adheres well to clean and dry surface, long life, no shrinkage; does not tolerate joint movement.

Gaskets and Adhesives

1. Polyethylene sill sealer- Closed-cell gasket used to seal the foundation-to-mud-sill joint. Gasket materials (EPDM, saturated urethane, many others are used to seal between drywall and framing and between framing members.
2. Polyethylene backer rod - Used to seal window and door frames to rough openings, and seal plastic plumbing stack penetrations.
3. Mastic - Designed specifically for duct sealing.
4. Inner tube rubber - This is flexible and works well for sealing plastic plumbing stacks to surrounding framing.
5. Sheet metal - Light-gauge material can be cut and stapled to seal large gaps around flues and other hot surfaces.

Insulation

Some insulation materials save time and money by insulating and providing an air sealing benefit in one step.

1. Cellulose insulation - Loose-fill cellulose slows air movement somewhat. When blown into a closed cavity at high density, it significantly reduces air leakage.
2. Closed cell foam insulation (such as urethane) - Impermeable to air movement, whether applied in a thin layer or used to fill a cavity.

Weather-stripping

Weather-stripping is used to block air leakage around doors and the operable parts of windows. Weather-stripping comes in a variety of shapes; it can be a flat strip, tube, or V shape and can be designed to work under compression or by sliding along the joint. To be effective, the product must close the gap and not allow air to pass. When choosing weather stripping, consider the size of the gap to be sealed and the durability, ease of

installation, and appearance of the product. Look for products that are flexible and that spring back to their original shape quickly and easily. Avoid products that make it difficult to operate the window or door.

Materials That Control Moisture Flow

Moisture control is a balance of wetting and drying. The goal is to avoid wetting as much as possible by use of vapor barriers/retarders.

The vapor barrier does not need to be perfectly continuous like an air barrier, but it should cover as much of the building envelope as possible. Although it needs to be located on the warm side of the insulation, the vapor barrier can be installed partway into the wall, provided that no more than one third of the insulating value of the wall is on the warm side of the vapor barrier. Like an air barrier, the vapor barrier can be made up of different materials; even some existing building components such as plywood, paint, or vinyl wallpaper may form part of the vapor barrier.

Vapor retarder effectiveness is measured in “perms,” which stands for the *permeance* of the materials; one perm equals one grain of water per square foot per hour per unit vapor pressure difference. The lower the perm rating of a material, the better the material is at slowing moisture transfer.

Knowing the perm rating of a material is critical when choosing materials for walls. To allow any moisture that does pass through the vapor retarder to escape, the outer skin of the wall should be at least five times more permeable than the vapor retarder. This 1:5 ratio should be applied when choosing a vapor retarder and also when choosing sheathing materials for the outer skin of the building.

All building materials can be separated into three general classes based on their permeability:

1. Vapor impermeable: referred to as vapor barriers: 0.1 perm
2. Vapor semi-impermeable: 1 perm or less, but greater than 0.1 perm
3. Vapor semi-permeable: More than 1 perm and 10 perms or less
4. Vapor permeable: referred to as breathable: more than 10 perms

Materials that are generally classed as impermeable to water vapor are: Rubber membranes, polyethylene film, glass, aluminum foil, sheet metal, oil-based paints, vinyl wall coverings, foil-faced insulating sheathings

Materials that are semi-permeable are: Plywood, OSB, unfaced expanded polystyrene (EPS), fiberfaced isocyanurate, heavy asphalt-impregnated building papers, the paper and bitumen facing on most fiberglass batt insulation and most latex based paints.

Materials that are permeable are: Unpainted gypsum board and plaster, unfaced fiberglass insulation, cellulose insulation, unpainted stucco, lightweight asphalt-impregnated building papers, asphalt-impregnated fiberboard, exterior gypsum sheathings, cement sheathings, house wraps

GREEN TIP # 4

LIGHTING AND APPLIANCES

Lighting accounts for approximately 10 to 20% of a building's energy that is only next to HVAC systems. The lighting also contributes to significant heat to the air-conditioning system indirectly. [Note - Every 4 kW of lighting adds about a ton of air-conditioning load (1kW = 3414 Btu/hr and 1 ton of refrigeration = 12000 Btu/hr)].

Strategies for Energy Efficient Lighting

The challenge in lighting design is to provide sufficient light where it is required at the times when it is required, without providing excess light. If this is done using the most appropriate light sources and fittings, and combined with an effective control system, then substantial energy savings can be achieved. The key strategies are as follows:

Define light requirements (Recommended Lighting Density)

An accounting approach is probably best, establishing a clear 'budget' that specifies the lighting levels required at different locations at different times or more easily the lighting power density. Lighting power density is the maximum allowable measurement of watts per square foot for a given type of space. Avoid specifying lighting levels that are higher than recommended by ASHRAE 90.1-2004 below:

Office	Conference Room	Toilet Room	Corridors	Stairways
1.1 w/sq-ft	1.3 w/sq-ft	0.9 w/sq-ft	0.5 w/sq-ft	0.6 w/sq-ft

In new buildings with sufficient daylight controls, one should strive to restrict the average power density not exceeding 0.9 w/ft² for the entire building. Individual spaces may have higher power densities if they are offset by lower power densities in other areas.

Select efficient light sources and fittings

Only 10% of the energy used in an incandescent bulb is used to create light. The other 90% is emitted as waste heat. Compact Fluorescent Lights (CFLs) are approximately 75% more efficient than incandescent and last 10 to 15 times longer. While CFLs cost about 10 times more than incandescent, their longer lifetime and higher efficiency give

them an average payback of three years or less. For localized task lighting and most residential applications, CFL lamps are most appropriate. They should not be undersized, and it is recommended to use a ratio of 3:1, when replacing incandescent bulbs, rather than the more optimistic 4:1 ratio often claimed (i.e. a 75W incandescent bulb can be replaced with a 25W CFL).

For most commercial applications, the most effective lighting is fluorescent tubes. Linear fluorescent lamps are categorized by their diameter in 8th of an inch. T12 lamps are 12/8th of an inch in diameter (1.5 inches), and T8 lamps are 8/8th of an inch in diameter (1 inch). T8s decrease energy costs by over 70% compared to T12s, flicker less, have better color, produce twice the amount of lumens and require fewer lamps.

High Intensity Discharge lamps, such as Metal Halide lamps should be used in situations where high intensity point sources of light are required, typically in high ceiling industrial or commercial applications and for outdoor lighting.

Efficacy Comparisons

Lamp efficacy is calculated by dividing lamp lumens by lamp watts and is expressed in lumens per watt (lm/W). For example, 100-W A19 incandescent lamp produces 1740 lm therefore the efficacy will be $1740 \text{ lm} \div 100 \text{ W} = 17.4 \text{ lm/watt}$

Characteristic	T5	T5 HO	T8	Metal Halide
Initial Output (lumens)	2900	5000	2950	36000
Mean Output (lumens)	2740	4750	2800	25000
Lamp Power (watts)	28	54	32	458
Mean Efficacy (lumens/watt)	98	87	88	63
Lighting Quality (Color rendering index)*	85	85	78	70

Notes

*Color rendering index (CRI) - This is an index from 0-100 measuring a light source's ability to render color accurately. Any lamp rated above 80 CRI tend to be good color rendering. [Sodium lamps can have a CRI as low as 22, while tungsten halogen lamps can have a CRI as high as 100].

Efficacy is not same as efficiency. Efficiency is defined as the ratio of luminous flux (lumens) emitted by a luminary to that emitted by the lamp or lamps used therein. A porcelain socket, utilizing a 100-W lamp, has an efficiency of 100%, since no lamp lumens are trapped in the luminary. A deeply recessed down light with black multi-groove baffle, utilizing the same 100-W lamp, may have an efficiency of 70%. Depending upon the application, the less efficient luminary may be the more appropriate choice of the two, because of reduced glare potential.

Effective design of lighting layouts

The type, number and location of light fittings is important to ensure that the required light levels are achieved with a minimum of fittings. Recessed direct fixtures may meet the watts per square foot allowance and the illuminance recommendations for offices, but they do not provide the same quality of light as pendant direct-indirect lighting fixtures. Extensive use of totally indirect luminaries or recessed direct-indirect (coffer-type) fixtures may not achieve the desired light levels while meeting the optimum 0.9 w/ft² power density.

The use of formulae and diagrams has largely been replaced with software packages that are available, many for free, that allow modeling of different lighting arrangements. Seek supplier's recommendations.

Task Lighting

Consider hardwiring the lower output level of two-stepped T8 electronic ballast (ballast factor 0.40 to 0.50) for under cabinet lighting, since full output is too bright and wastes energy. Use "articulated" task lights (i.e., adjustable in three planes by the worker) with compact fluorescent sources for desktops. Provide local switches on task lighting, or connect them to specialized plug strips controlled by local occupancy sensors.

Exit Signs

Use LED exit signs or other sources that consume no more than 5 watts per face. The selected exit sign and source should provide the proper luminance to meet all building and fire code requirements.

Effective control systems

Lighting schemes are normally designed for providing desired lumen levels for night-time conditions, i.e. without considering presence of daylight. Lights should be turned ON only when actually required, and OFF at all other times.

This requires appropriate zoning, whereby the lights that are required at different times are on separate switching circuits. Typically this may result in two or three zones in a room, based on distance from windows. Areas furthest from windows may require lights to be on at all times of occupation. Areas closer to the windows can use daylight for much of the daytime. Zoning should also relate to occupancy patterns, so that if only one two people are working they have the opportunity to turn on only those lights that are needed.

People tend to switch lights ON when there is insufficient light for the task they are doing, but not switch them off when they are no longer required. It is therefore often best to design the system such that the occupants turn lights on manually, and the lights turn off automatically using time switches, occupancy sensors and/or light level sensors. Light level sensors in combination with dimmers are recommended to maximize the use of daylight.

Maximize Daylight

Day lighting with skylights and other types of architectural glazing features can provide natural lighting. Day lighting strategies may be particularly effective using skylights in large open areas such as atriums and in office spaces where the electrical lighting system output can be efficiently varied over a wide range of light levels.

To increase interior day lighting, remove evergreen trees and replaced with deciduous trees especially on the buildings' south side.

Other effective way to maximize day lighting is the use of light shelves, light louvers and light conveyor. Check with the suppliers of lighting products for details.

Surface Reflectances

The use of light-colored materials and matte finishes in all daylighted spaces increases efficiency through inter-reflections and greatly increases visual comfort. A 90% ceiling reflectance is preferred for indirect luminaires and daylighting. Reflectance values are available from paint and fabric manufacturers. Avoid shiny surfaces (mirrors, polished metals, or stone) in work areas.

Appliances

Engineers often base HVAC sizing decisions on the full nameplate or “connected” load of computers, copiers, printers, and so on; and assume simultaneous operation of such equipment. In fact, most of this equipment operates at a fraction of the nameplate value, and rarely operates simultaneously. The calculated values with this method sometimes exceed 5 w/sq-ft. According to an ASHRAE study, 1 w/sq-ft is a reasonable upper bound when equipment diversity and reasonable estimates of the true running load are included. Note the following:

1. Always buy equipment with ‘Energy Star’ label. The energy use can be reduced by 50% or more. A typical non-Energy Star-compliant computer and color monitor draw a continuous electrical load of 150 watts or more (ASHRAE Journal, Sept. 1991). With sleep settings activated, ENERGY STAR-qualified monitors, for example, can operate on as much as 33% less energy than a conventional monitor (U.S. EPA, 2008e).
2. Energy Star-labeled monitors automatically enter two successive low-power modes of 15 watts and 8 watts. In addition to reducing wasted energy, Energy Star-compliant monitors emit fewer electromagnetic fields in sleeping mode because most of their electronic components are turned off.
3. Typically, printers and fax machines are left on 24 hours a day, although they are active for only a small percentage of that time. To conserve energy, consider a combination printer/fax machine, which consumes half as much energy when idle as two stand-alone products.
4. Plug-in timers automatically turn equipment off at the power sources at certain times of day. They are especially useful for copiers and printers.

5. Laser printers consume more energy than inkjet printers.
6. Color printers use more energy than black and white.
7. Liquid crystal displays use less energy than conventional monitors.
8. Laptops draw about one-tenth the power of a conventional desktop computer. You can connect a laptop computer to a conventional monitor and still save almost half the energy of a standard computer.
9. To improve water efficiency, look for low flow shower heads and low flush or composting toilets.

GREEN TIP # 5

PACKAGED & DUCTLESS HVAC SYSTEMS (DX)

Packaged Units

Packaged HVAC systems are a common choice for low-rise buildings, especially when first cost is a factor. These are most effective for smaller buildings less than 20000 sq-ft.

Packaged units operate on direct expansion (DX) principle of air cooling in contact with refrigerant in evaporator tubes. There are two options for package units.....1) rooftop system and 2) modular split systems.

A rooftop unit is fully self-contained equipment consisting of a supply fan, direct expansion (DX) cooling coil, filters, compressors, condenser coils and condenser fans. Units are typically mounted on roof curbs but can be also mounted on structural supports or on grade. It is more suitable for single storied structure such as big warehouses although up to 3 storied buildings can be easily be air-conditioned with provision of shafts for supply and return air. Rooftop units are generally air-cooled.

Split systems typically consist of an air handler (located indoors) and a remote condensing unit with compressor located outdoors. Because the air handler and condensing unit/s are typically separate units, these are referred to as “split systems”. The indoor air handler and outdoor condensing unit are connected through refrigerant piping. The indoor units are available in horizontal and vertical configurations that can be either floor mounted or ceiling suspended.

Both rooftop and modular split packaged units are factory assembled, self contained units, typically available in capacities from two tons to more than 50 tons. Where more capacity is needed, multiple units can be installed, each controlling its own thermal zone. Condensing units with multiple compressors are highly recommended for large capacities to provide energy efficient part load operation.

The rooftop and modular split package units use ductwork to distribute conditioned air to the large spaces. A ductless split system is similar to modular split units in operation but is much smaller usually limited to 1.5 to 5 tons. These units however do not use ducts.

Ductless Split System

A ductless split system with a single outdoor unit and a single indoor unit also is known as a mini-split. The indoor unit fan coil unit is located within the conditioned spaces unlike modular split indoor unit which is usually located in small plant room adjacent to the conditioned spaces.

These are also available in variable refrigerant flow (VRF) arrangement comprising of multiple fan coil units with individual thermostats for different zones connected to a single condensing unit. Ductless split-systems that provide heating as well are called “heat pumps” and this use a reversing valve to change the flow of the refrigerant to create warm air.

The indoor unit is available in several forms: high wall mount, ceiling mount, and above-ceiling mount. The high wall mount is least costly but is usually limited to about 2 tons. Capacities up to 5 tons are available with suspended ceiling units.

Efficiency Recommendations

The cooling efficiencies of package units under 250,000 Btu/hr* are certified according to standards published by the Air Conditioning and Refrigeration Institute (ARI). ARI standards also apply to units of 250,000 Btu/hr and over, but ARI has no certification program and does not publish efficiency data for this size range.

[* Note that the capacity of air conditioner units is generally stated in tons of refrigeration and each ton of refrigeration (1 TR) is equivalent to heat extraction rate of 12000 Btu/hr.]

The three common cooling-efficiency measurements defined in the ARI standards are EER, the energy efficiency ratio; SEER, the seasonal energy efficiency ratio; and IPLV, the integrated part-load value.

- EER is a ratio of the rate of cooling (Btu per hour) to the power input (W) at full-load conditions. The power input includes all inputs to compressors, fan motors, and controls.
- SEER and IPLV are estimated or calculated ratios of annual cooling (Btu) to the annual energy consumption (watt-hours). SEER is a seasonally adjusted rating based on representative residential loads that apply only to units with a cooling capacity of less than 65,000 Btu per hour.
- IPLV, a seasonal efficiency rating method based on representative commercial loads, applies to units with cooling capacities at or greater than 65,000 Btu per hour.

EER is the rating of choice when determining which unit will operate most efficiently during full-load conditions. SEER and IPLV are better than EER for determining which unit will use less energy over the course of an entire cooling season.

Recommended Efficiency Values for Packaged Units

Equipment Type	Size Category	Sub-Category or Rating Condition	Required Efficiency
Air Conditioners, Air Cooled	< 65,000 Btu/h	Split System Single Package	13.0 SEER
	\geq 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	11.0 EER 11.4 IPLV
	\geq 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	10.8 EER 11.2 IPLV
	\geq 240,000 Btu/h	Split System and Single Package	10.0 EER 10.4 IPLV
Air Conditioners, Water and Evaporative Cooled	All Sizes	Split System and Single Package	14.0 EER

Source: Consortium for Energy Efficiency, 2002.

The rated EER/SEER for packaged units is normally based on the sensible cooling load under design conditions. A higher EER/SEER unit may yield a lower latent cooling capacity. When sizing packaged systems, make sure there is adequate latent cooling capacity. Air flow for packaged systems usually maintains over 400 CFM/ton to prevent coil freezing, which may require a significant amount of reheat for dehumidification applications running in low load conditions.

Efficiency Ratings of HVAC Equipment

Federal law mandates a minimum efficiency of 13 SEER for unitary equipment of less than 65,000 Btuh capacity. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) recommend 10 EER for equipment between 65,000 and 135,000 Btuh. ASHRAE standard 90.1 recommends other efficiencies for larger equipment. It is often cost effective to pay for more efficient equipment. For example, upgrading from a 13 SEER to a 14 will reduce cooling costs by about 7 percent. Upgrading from a 13 to a 15 reduces cooling costs by about 13 percent.

The following links provide an overall analysis of the number of ARI-listed models and the percentage of all models on the market that meet CEE Tier I and Tier II specifications.

http://www.cee1.org/com/hecac/ac_tiers/eff_toc.htm

http://www.cee1.org/com/hecac/ac_tiers/mod_toc.htm

WHEN/WHERE IT'S APPLICABLE

Packaged equipment is most suitable for single zone comprising of 20000 sq-ft area or less. Single zone means an area with similar heating and cooling requirements so that the temperature and humidity conditions can be controlled by a single thermostat. Air cooled packaged units are also recommended for applications where water is scarce and where quick installation is needed.

A ductless split system can serve spaces up to about 1,000 ft², or perhaps 2,000 ft² if multiple units are installed. These are good for spot cooling applications and are most useful for buildings where space for ducts is limited, for example, small offices, shops, motels and hotels, residences, schools and university classrooms, equipment rooms,

computer rooms, banks and currency exchanges, and labs to name a few. Ductless systems are also useful as auxiliary back-up air-conditioning to central system.

PROS AND CONS

Pros (Package Units)	Cons (Package Units)	Pros (Ductless Split Units)	Cons (Ductless Units)
Available as factory standard units and have low capital costs.	Not an energy efficient option for larger buildings above 20000 sq-ft area.	Offer room-by-room zone control, which minimizes over-cooling typical of central air conditioning systems.	Do not provide good outside air ventilation.
Small, compact and require less space. Roof top units save valuable floor space.	Higher operating costs compared to central plants. Package unit consumes 1 to 1.15 kW/ton whereas large centrifugal/ screw chillers consume as low as 0.5 kW/ton of refrigeration.	Provides high flexibility in interior design options: there are floor-standing, ceiling-suspending, wall-hanging models...	Relatively poor indoor air distribution and poor throw.
Easy to install and replace.	Shorter life span than central chiller systems.	Easy installation; do not require large holes in the walls: a three-inch hole is often sufficient to bring refrigerant supply/return tubes.	Systems have limited capacity.
Can be individually metered at the unit.	Can not provide effective comfort control for multi-zone applications, which may require different thermostat settings.	These units install very easily and if you rent and move, all you have to do is disconnect the unit and pack up the parts.	Not suitable for large spans. Maximum air throw is limited to 12 - 15 ft.
Tend to be	Not suitable for	When used as an	Exceeding the

Pros (Package Units)	Cons (Package Units)	Pros (Ductless Split Units)	Cons (Ductless Units)
distributed in large buildings which provide more reliability and localized shutting when the zone is not in use.	applications requiring high air delivery rates. A standard package unit generally provides 400 CFM of air delivery per ton of refrigeration.	auxiliary device to central systems, these save considerable energy during off hour's operation.	refrigerant pipe length beyond 50 feet degrades the unit capacity and has impact on energy efficiency.
Recommended for single zone applications.	Compressors generate noise, and that must be considered when deciding on their location.		

GREEN TIP # 6

CENTRAL COOLING PLANT (CHILLERS)

In large commercial and institutional buildings, devices used to produce air-conditioning via the use of chilled water are called chillers. The type of chiller used in any given application is often determined by the cooling capacity (tons), product or manufacturer preference, and the viability of a chilled-water system for the application. Other considerations include footprint, weight, and availability.

From an energy viewpoint there are two critical selection criteria:

1. The type of condenser (air- or water-cooled) and
2. The type of compressor.

Condensers

Condensers are heat exchangers that transfer heat to the outdoors, causing gaseous refrigerant to condense back into a liquid for use in the next cycle. Condensers can be either air-cooled or water-cooled.

1. Air cooled condensers - As the name suggests, these use ambient air to remove heat from the refrigerant. A fan forces air across small tubes containing the hot refrigerant and discharges that heat into the ambient air. Compared to water, air is a poor conductor of heat and therefore air-cooled chillers are larger and less efficient.
2. Water cooled condensers - Water condensed units are more efficient than air condensed, often operating in the range of 15 EER or better. Water cooled chillers require a source of cooling water, such as cooling tower water, to extract heat from the refrigerant at the condenser and reject it to the ambient environment. The typical condensing temperature in a water-condensed chiller is 105°F as opposed to 120°F in a comparable air cooled condenser.
3. Evaporative Condensers - Another alternative to the air or water-cooled condensers is the evaporative condenser. Evaporative condensers are like cooling towers with built in heat exchangers. Refrigerant passes through a copper tube bundle in the evaporative cell. Water cascades over its outer surface and airflow counter to the

flow of water causes some of the water to evaporate. This results in the efficient cooling of the refrigerant. There is a sump in the bottom of the condenser to store water and a pump draws the water to spray over the coils. In winters, the pump is de-energized and only the air flows across the coils just like air-cooled condenser.

Circumstances Favoring Air-Cooled or Water Cooled Condensers

40 to 200 Tons:	Air-cooled chilled water system (explore the pros and cons of using multiple DX systems if possible)
200 Tons and above:	Water-cooled chilled water system

Chiller Types

Four types of electrical chillers dominate the market:

1. Reciprocating compressors

Reciprocating compressors are driven by a motor and use pistons, cylinders and valves to compress the refrigerant. These compressors are suitable for capacities less than 100 tons and are available in hermetic, semi-hermetic or externally driven versions.

- In a hermetic unit, the motor and compressor are enclosed in a common housing, which is sealed. These are used in household refrigerators and freezers and in medium-capacity air-conditioning units.
- In semi-hermetic compressors, both the compressor itself and the drive motor are housed inside the casing, which is designed so as to be opened for inspection and maintenance. In this case, the drive shaft and the crankshaft are one single piece. Semi-hermetic compressors are made so as to prevent air or dust from entering the mechanisms.
- In a direct drive unit the motor and compressor are separated by a flexible coupling. These types of units utilize older technology and are not commonly used today.

2. Scroll compressors

Scroll compressors features two involute scrolls, one stationary and one orbiting around the first. This movement draws gas into the outer pocket and the gas is forced toward the center of the scroll, creating increasingly higher gas pressures. The upper limit of the refrigeration capacity of currently manufactured scroll compressors is 60 tons. A scroll compressor also has only about half as many parts as a reciprocating compressor at the same refrigeration capacity. Few components result in higher reliability and efficiency. Power input to the scroll compressor is about 5 to 10% less than to the reciprocating compressor. A scroll compressor also operates more smoothly and is quieter.

3. Screw compressors

Screw compressors are based on a mechanism made up of two threaded rotors (screws) that are coupled together. The gas is compressed due to the progressive overlapping of the lobes, causing a reduction in the volume occupied by the gas. Continuous and step-less capacity control is provided by moving a sliding valve toward the discharge port, which opens a shortcut recirculating passage to the suction port.

The refrigeration capacity of twin-screw compressors is 50 to 1500 tons but is normally used in the 200 tons to 800 tons range. Twin-screw compressors are more efficient than reciprocating compressors and are equipment of choice especially at large ratings and air-cooled options.

4. Centrifugal compressors

Centrifugal compressors are made up of a rotor located inside a special chamber. The rotor is rotated at high speed, imparting high kinetic energy to the gas, which is forced through the narrow outlet opening, thus increasing its pressure. The characteristics of a centrifugal compressor make it ideal for air conditioning applications because it is suitable for variable loads, has few moving parts, and is economical to operate. The power requirement of the centrifugal compressor is about 0.75 kW/ton when 45°F chilled water is produced and modern machines of larger capacities go down to as low as 0.48 kW/ton. The available refrigeration

capacity for centrifugal compressors ranges from 100 to 2,000 tons. Centrifugal compressors have higher volume flow per unit refrigeration capacity output than positive displacement compressors. They are the most widely used refrigeration compressors in large air-conditioning systems but are used ONLY in water cooled configurations due to lower compression ratios.

Selection Guidelines

The most effective chiller is primarily a function of chiller size and in general the following guidelines apply:

<=100 tons	1 st Choice – Reciprocating 2 nd Choice – Scroll 3 rd Choice - Screw
100 -300 tons	1 st Choice – Screw 2 nd Choice – Scroll 3 rd Choice - Centrifugal
> 300 tons	1 st Choice – Centrifugal 2 nd Choice – Screw

Energy Performance Terms

Efficiency rating procedures for liquid chillers are defined in ARI 550, ARI 560, and ARI 590 as applicable. The following terms are used by ARI to define efficient ratings of liquid chillers.

1. **Tons:** One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day: 12,000 Btu/h or 3.516 thermal kilowatts (kW).

2. **kW/ton rating:** Commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced. Lower kW/ton indicates higher efficiency.
3. **Coefficient of performance (COP): is the measure of chiller efficiency** measured in Btu output (cooling) divided by Btu input (electric power). Typical values are 2 – 4.
 - Cooling capacity is specified in tons of refrigeration; 1 ton is equivalent to 12000 Btu per hour.
 - 1 kWh of electric power is equivalent to 3412 Btu per hour; multiplying the COP by 3.412 yields energy efficiency ratio.
4. **Energy-efficiency ratio (EER):** is calculated by dividing a chiller's cooling capacity (in Btu/hour) by its power input (in watts) at full-load conditions. EER is always greater than one; typical values are 8 – 10. The higher the EER, the more efficient the unit. Dividing 12 by the EER value yields kW/ton.
5. **ARI conditions:** Standard reference conditions at which chiller performance is measured, as defined by the Air-Conditioning and Refrigeration Institute (ARI): 44°F water leaving the chiller and, for water entering the condenser, 85°F at 100 percent load and 60°F at 0 percent load.
6. **Integrated part-load value (IPLV):** This metric attempt to capture "average" chiller efficiency over a representative operating range. It is the efficiency of the chiller, measured in kW/ton, averaged over four operating points according to a standard formula. Other metrics for *average* efficiency include APLV (application part load value) and NPLV (non-standard part load value).

Chiller Capacity (Tonnage Output)

The following equation calculates the refrigeration output in “Tons” of a chiller:

$$\text{Tons} = \text{GPM} * (\text{T1} - \text{T2}) / 24$$

Where

- T1 = Chilled water return temperature in degrees F

- T2 = Chilled water supply temperature in degrees F
- GPM = Volume of water passing through the chiller

Chiller Coefficient of Performance (COP)

The following equation calculates the coefficient of performance of a chiller:

$$\text{COP} = (T1 - T2) * \text{GPM} * 500 / (3412 * \text{kW})$$

Where

- T1 = Chilled water return temperature in degrees F
- T2 = Chilled water supply temperature in degrees F
- GPM = Volume of water passing through the chiller
- kW = Kilowatts

Chiller performance ratings

ASHRAE Standard 90.1 establishes minimum energy efficiency levels for chillers. The New Buildings Institute has developed more stringent recommendations that provide increased energy and operating cost savings. These are contained in the table below.

Recommended Chiller Performance Levels

Equipment Type	Size Category	Required Efficiency- chillers without ASDs		Required Efficiency- Chillers with ASDs		ASHRAE 90.1-2001 (kW/ton)	
		Full Load (kW/ton)	IPLV (kW/ton)	Full Load (kW/ton)	IPLV (kW/ton)	Full Load	IPLV
Air cooled w/ condenser	All	1.2	1	N/A	N/A	1.26	1.15
Air cooled w/o condenser	All	1.08	1.08	N/A	N/A	1.13	1.02
Water cooled, reciprocating	All	0.84	0.63	N/A	N/A	0.84	0.70
Water cooled, rotary screw, and scroll	< 100 tons	0.78	0.6	N/A	N/A	0.72	0.63
	*100 tons and < 150 tons	0.73	0.55	N/A	N/A	0.72	0.63
	*150 tons and ≤ 300 tons	0.61	0.51	N/A	N/A		
	> 300 tons	0.6	0.49	N/A	N/A	0.64	0.57
Water cooled, centrifugal	< 150 tons	0.61	0.62	0.63	0.4	0.70	0.67
	*150 tons and ≤ 300 tons	0.59	0.56	0.6	0.4	0.63	0.60
	> 300 tons and ≤ 600 tons	0.57	0.51	0.58	0.4	0.58	0.55
	> 600 tons	0.55	0.51	0.55	0.4		

Various chiller designs have different partial load and full load efficiencies. Usually, a centrifugal chiller is most efficient at full while rotary screw chillers usually have the best efficiency at partial load.

Compare chillers under the conditions they are most likely to experience

Even though chiller performance can vary dramatically depending on loading and other conditions, designers frequently select chillers based on full-load efficiency. But typically the full load occurs only 1% to 2.5% of the time. Or in other words, the chillers are intentionally oversized at least 99% to 97.5% of the time. In fact, most systems operate at 50% or less of their capacity. To select the chiller that will have the lowest operating costs, you need to evaluate the efficiency of various chillers under the actual operating conditions the equipment is like to be subjected to. Simply selecting high-efficiency chillers at full load do not guarantee high performance. Instead, compliance with both the full load efficiency numbers and IPLV numbers is required.

Chiller Sizing

The effective capacity of chiller should match the load as closely as possible. Important strategies for selecting and improving chiller plant load efficiency include:

- **Peak load** demand determines the overall capacity of the system. The total chiller capacity in tons of refrigeration shall match the peak building load.
- **Part load** requirements determine the number and size of chillers required. Cooling load profile will help to determine the type of chiller to use and if single or multiple chillers should be installed. Multiple chiller installations allow facilities professionals to stage their operation to match building loads while keeping the chillers operating at energy efficient loading.
- **Standby strategy** - Adopt standby or (N+ 1) strategy. The provision of 1 additional back up unit is known as N+1 strategy. The applications where cooling is required for critical service delivery, one back up unit would be required.

Condenser Water Temperature Adjustment

Chiller energy consumption is a function of the condenser pressure and temperature. Lowering the condenser water temperature reduces the refrigerant condensing temperature and condensing pressure. Energy savings, at full-load, will be 1 to 2% per degree of reduction in entering condenser water temperature.

Caution

Check with different manufacturers about their ability to provide chillers that can operate at reduced condensing water temperatures. In some chillers, lowering condenser water temperatures may cause operational problems, such as tripping a low oil pressure alarm.

Chilled Water Supply Temperature Adjustment

Raising the chilled water temperature lowers the compressor head, resulting in decreased energy consumption. For centrifugal chillers at constant speed, this strategy saves 0.5% to 0.75% per degree of reset at full load operation. [Note that the efficiency will drop at operating loads of 40% and less].

Chiller Water Flow Isolation

Effective management of water flow to the chiller is a source of potential energy savings. Water pumped through idle chillers consumes unnecessary energy by adding temperature to the water. This can be as much as 2-2.5°F. Keep provision to isolate inactive chillers from the chilled water and condenser water loops when they are not in operation. The use of automatic shut-off valves is recommended.

Variable Speed Drive (VSD) Chillers

The use variable speed drives greatly enhances energy efficiency. This enables the chiller to match the speed of the compressor to the load at the maximum efficiency. It also allows the chiller to function, without damage, at much lower condenser water temperatures. The availability of variable speed centrifugal chillers has improved in recent years, thus reducing initial purchase costs. Most VSD chillers offer good part load efficiency even better than at full load.

Variable Flow thru Chillers

The variable flow chillers vary the volume of chilled water flow per demand. The system design makes use of two loops of primary and secondary distribution, each equipped with variable speed pumps to deliver chilled water per demand. Carefully designed variable flow chillers offer 5 to 10% energy savings but cautions needed to ensure minimum flow circulation through the bypass line.

Select the number and size of chillers based on anticipated operating conditions

Select both the quantity and the capacity of individual chillers based on the anticipated operating conditions. If only portion of building is functional during lean periods, it makes sense to install a smaller-capacity, “pony” chiller to serve that relatively small but constant cooling load. In addition to improved energy efficiency, this strategy will reduce short cycling of the larger chiller compressor, which can extend its useful life.

Select unequally sized machines for multiple chiller installations

For a plant composed of single speed chillers, varying chiller sizes can help meet intermediate loads more efficiently. For example, splitting the chiller sizes 1/3 – 2/3 lets the chiller sized for 2/3 of plant capacity be used on days where the load is not expected to exceed 2/3 of design. In this way the capacity of the plant can be staged in increments

of 33 percent so there will seldom be occasions when any chiller operates at extremely light loads.

The benefit is that only one chiller operates near its most efficient point. The disadvantage is that some flexibility is lost with respect to taking a chiller offline for preventative maintenance. If the larger chiller requires service, only one-third of the design capacity will be available to meet building cooling loads.

Chiller Sequencing

Chiller sequence can have a major impact on the overall energy efficiency of the chiller plant. When operating multiple chillers, always load the one that has the best efficiency for the current cooling demand before loading the other chillers, which use more energy.

- For plants composed of mixed line of centrifugal, screw and/or reciprocating chillers, choose the best combination for the best energy efficiency. *Consider operating the centrifugal chillers at full load and swing with the screw chiller at part load.*
- Plants composed of single speed chillers (centrifugal, screw or reciprocating) should operate no more chillers than required to meet the load.
- Plants composed of variable-speed centrifugal chillers should attempt to keep as many chillers running as possible, provided they are all operating at above approximately 20% to 35% load. For example, it is more efficient to run three chillers at 30% load than to run one chiller at 90% load. The exact minimum load point will depend on the relative power required by ancillary devices (particularly condenser water pumps), cooling tower control strategies, the number of chillers, and exact chiller performance characteristics.

Always consider efficiency vs. load when starting and stopping chillers.

Automatic Tube Cleaning Systems

Fouling of condenser increases the condensing temperature, the head pressure and the chiller compressor energy use. Where quality of cooling water has high tendency of fouling heat exchanger surfaces, specify chillers with in-built automatic tube cleaning

captured brushes in each tube and a flow reversing valve. The system typically cleans the tubes four times per day. Common applications are river water condensers, process evaporators, and condensers on towers or systems where fouling is critical. Energy savings commonly range from 15-20% on condensers. Additional savings from reduced maintenance and less downtime are possible.

Chiller Plant Automation, Reporting, and Control

The use of a well-designed automation package can greatly reduce the energy consumption of a chiller plant and provide an improved level of monitoring and reliability. Specify chillers with DDC controls compatible to building energy management systems.

An automation system can provide 24-hour electronic monitoring and control of chiller plant operation, and can report information to a control center or cell phone. This type of system can report operational problems and even dispatch a service call. It can detect and report problems earlier and prevent equipment damage. Control functions include employment (on-off), demand limiting, chill water reset, pump employment, and water flow control. Additional duties can be monitoring of maintenance items, filters, oil changes and out of range conditions.

Automated systems can also pickup many of the logging duties for operators. A control system does not replace a good operator and/or the normal inspections required for sound operating practices.

High Delta T chillers

Long standing conventional practice of designing the chiller systems on 'ARI' conditions [54/44°F chilled water (or 10°F, ΔT), 85/95 °F condenser water] has been standard norm over years and was primarily to establish a high order safety factor against flow balance problems. But this approach is wasteful because the system is over pumped when compared with other design of higher ΔT possibilities. To evaluate this, let's look at the following equation governing chiller's capacity:

$$\text{Load (tons)} = \text{Flow (GPM)} \times \text{Temperature range (°F)} / 24$$

Or

Flow (GPM) = Load (tons) x 24/ Temperature Range (°F)

Note that the chilled water supply temperature is not part of the equation.

As the chilled water temperature range is increased, the flow rate is decreased for the same capacity. Smaller flow means smaller pipes, smaller pumps and lesser insulation. This equates to capital savings.

Smaller pumps also mean savings on pumps energy. To evaluate the operating cost, consider the pumping horsepower equation:

Pump power (hp) = [Flow (GPM) x Head (ft)] / [3960 x Pump efficiency]

As the chilled water flow is decreased, the pump work is also decreased.

Thus, increasing the chilled water temperature range is a good way to reduce the capital and pump operating cost, particularly if the pump head is large or the piping runs long.

Caution

The discussion above is a very strong argument for increasing the chilled water temperature range. But what about chiller power consumption.

Raising the ΔT across the chiller means lowering the chilled water supply temperature. We have learnt before that raising the chilled water supply temperature is beneficial or in other words, lowering the chilled water supply temperature will increase the chiller power consumption.

It is therefore necessary to strike a balance between capital cost and operating cost. Studies indicated that there is little capital saving to go beyond the 14°F temperature range. Designers must perform an annual energy analysis* and evaluate the impact of changing the chilled water temperature range on the overall system.

[Where it is absolutely necessary to reduce chilled water temperatures, consider oversizing the cooling tower to reduce the condenser water temperature and minimize the affect on the chiller].

*The author recommends DOE-2 energy simulation software developed by the Simulation Research Group at Lawrence Berkeley National Laboratory. Other simulation programs are available from manufacturers that can carry out the numerous and complex equations needed to evaluate how buildings use energy under different conditions. The most sophisticated programs are capable of calculating building energy consumption hour by hour for an entire year; they can also account for interactions between building components. This allows you to experiment with different combinations of efficiency strategies to determine which ones will be most cost-effective.

Demand Limiters and Staggered Start

Chillers draw maximum current (or power) during start-up. Most electric utilities base their demand charges on the amount of energy used during any 15- or 30-minute interval. This may be monthly or, in some instances, the demand rate may be set annually. When starting multiple chillers, stagger the starts at least by one demand period. Start the second chiller after the first has loaded. The use of demand limiting can save significantly energy cost on utility bills in the category of demand charges.

Chiller Plant Automation, Reporting, and Control

Direct digital controls compatible with building management systems improve level of monitoring and reliability. A well-designed automation package can greatly reduce the energy consumption.

WHEN/WHERE IT'S APPLICABLE

Chiller system is most suitable for larger buildings of 20000 sq-ft area or more and where the buildings are distributed such as school campus, airports, hospitals and office blocks. They are mostly used in mid to high rise buildings, which are structures with 5-7+ floors.

The economics of a chiller system is highly dependent on the rate of energy costs, and the hours of operations. If you are paying \$.03 per kWh, you would indeed need a large tonnage requirement before chiller would make sense economically. At \$.15 it makes sense in much smaller tonnages.

PROS AND CONS

Pros

1. Lower operating costs especially if you use a cooling tower or an evaporative condenser. The COP of water cooled chiller is high compared to other options and the operating costs can be as low as 0.5 kW per ton.
2. Centrifugal chillers are highly efficient both at full load and part load operation. Screw chillers are next best option.
3. Chilled water systems are the engineering systems that are tailor made to suit the design requirements of high sensible and high latent loads. The air delivery systems (AHUs) can be custom designed to provide higher or lower CFM per ton suiting the specific requirements. [Note that the standard package units provide 400 CFM per ton of refrigeration].
4. Chilled water systems can be easily balanced and are suitable for multi-zone applications.
5. Closer control is available in chilled water system due to modulating the chilled water flow thru cooling coil.
6. Chillers are best for applications where loads are distributed. The air handling units (AHUs) can be located at distributed locations away from occupied spaces and thus minimize inconvenience due to occupied spaces during servicing.
7. Chilled water is a closed loop and does not have such limitations of chilled water pipe lengths as the pump can handle the flow and dynamic head.
8. Chiller capital costs decreases with economy of scale and usually have lower life cycle costs over 300 tons installation. Larger capacity refrigeration equipment is more efficient than the small capacity equipment.
9. Chillers driven through variable speed drives (VSDs) improve the chiller efficiency both at part load and full load. Speed control option available with centrifugal chillers improves part load efficiency and minimizes the inefficiencies associated with oversized equipment.

10. Chiller systems are amenable to centralized energy management systems that if properly managed can reduce building energy consumption besides providing effective indoor temperature and humidity control.

Cons

1. The major reservations about chilled-water systems are higher first cost and cooling tower issues. Chiller systems are more expensive to install especially for smaller systems below 150 tons.
2. Maintenance is complex and demands operators' skill. These and are usually more sophisticated to operate and maintain.
3. Failure of any key component may affect the entire building. Standby equipment needs to be perceived during design.
4. Although coefficient of performance (COP) of large scale chiller plant is high, the applications requiring part load operations may consume high energy. System configuration in terms of multiple chiller units needs to be perceived for overall economy during conceptual stages.
5. A centrifugal chiller is not suitable for air cooled applications and is NOT a choice where water is scarce.
6. These systems cannot readily be individually metered; therefore, the energy costs are difficult to ascertain in multi tenant buildings.

GREEN TIP # 7

ABSORPTION CHILLERS

This type of chillers uses thermal energy instead of electrical energy. Compressor is replaced here by a) an absorber with salt solution that absorbs water vapor from the evaporator, b) a pump that circulates a diluted salt solution, and c) a generator that boils water to reconstitute the salt solution. Because of this reason, the absorption equipment may be very large.

In the absorption chiller, refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped to the generator. There the refrigerant re-vaporizes using a waste steam heat source. The refrigerant-depleted solution then returns to the absorber via a throttling device. The two most common refrigerant/ absorbent mixtures used in absorption chillers are water/lithium bromide and ammonia/water.

Compared with mechanical chillers, absorption chillers have a low coefficient of performance ($COP = \text{chiller load/heat input}$). However, absorption chillers can substantially reduce operating costs because they are powered by low-grade waste heat.

Absorption chillers can be direct-fired, using natural gas or fuel oil, or indirect-fired using steam from a boiler or steam generated from waste heat recovery from the exhaust of furnace, boilers or power-generation equipment (e.g. turbines, micro-turbines, and engines).

Absorption chillers come in two commercially available designs: single-effect and double-effect. Single-effect machines provide a thermal COP of 0.7 and require about 18 pounds steam per ton-hour of cooling at low pressure of 15 psig. Double-effect machines are about 40% more efficient, but require a higher grade of thermal input, using about 10 pounds of high pressure (100 - to 150-psig) steam per ton-hour.

Most absorption machines are limited to chilled-water temperatures of 40°F or above, and are available in capacities ranging from 100 to 1,500 tons.

WHEN/WHERE IT'S APPLICABLE

Absorption cooling may be worth considering if at least one of the following applies:

1. When natural gas prices (used to produce steam) are significantly lower than electric prices or other alternate low-cost source of fuels is available
2. When there is steam available from an on-site process; an example is steam from a turbine or where waste heat can be easily tapped
3. When a steam plant is available but lightly loaded during the cooling season. Many hospitals have large steam plants that run at extremely low loads and low efficiency during the cooling season. By installing an absorption chiller, the steam plant efficiency can be increased significantly during the cooling season.
4. When the design team and building owner wish to have fuel flexibility to hedge against changes in future utility prices.
5. When the site has electric load limitation that is expensive to upgrade

PROS AND CONS

Pros

1. Reduce electric charges.
2. Allows fuel flexibility, since natural gas, No. 2 fuel oil, propane, or waste steam may be used to supply thermal energy for the absorption chiller.
3. Uses water as the refrigerant, making it environmentally friendly.
4. Allows system expansion even at sites with limited electric power.
5. When the system is designed and controlled properly, it allows versatile use of various power sources.
6. Ideal where waste heat can be easily and economically tapped.

Cons

1. Cost of an absorption chiller will nearly be double that of an electric chiller of the same capacity.
2. Size of an absorption chiller is larger than an electric chiller of the same capacity.
3. The interior of the chiller experiences corrosive conditions.
4. Larger cooling towers, condenser pipes, and cooling tower pumps are required compared with electric-drive machines since the amount of heat rejected is significantly higher than that of an electric chiller of similar capacity.
5. Higher cooling water is required. Remember that conservation of water is another element of the 'green' approach. Both air-cooled and water-cooled machines are available in the vapor compression machine category, whereas absorption machines are just water-cooled machines. Since, the heat rejection of absorption machines is 50% higher than that of vapor compression machines; this means that water consumption is higher for absorption machines compared to vapor compression machines.
6. Improper operation may lead to crystallization of Li-Br absorbent.
7. Few plant operators are familiar with absorption technology. Maintaining vacuum conditions, proper cooling water treatment is vital for efficient running of vapor absorption chillers.

GREEN TIP # 8

REFRIGERANTS

The refrigerants are synonym with major environmental concerns. The chlorofluorocarbons (CFC's) and hydro-chlorofluorocarbons (HCFC's) used traditionally as the refrigerants in all types of vapor compression air-conditioning equipment have been or will be phased out according to the Montreal Protocol. CFC's such as CFC-11, which was traditionally used in many centrifugal chillers, is no longer produced as of 12/31/95.

The EPA has established a phase-out schedule for specific refrigerants to meet the overall Ozone Depletion Potential (ODP) reduction goals —as well as planned replacement refrigerants.

Current and Future Refrigerants

Equipment Type	Traditional Refrigerant	Replacement Refrigerants
Rotary Screw- Chiller	HCFC-22	R407C, HFC-134a
Scroll Chiller	HCFC-22	R407C, R-410A
Reciprocating Chiller	HCFC-22	R-407C, R-410A
Absorption Chiller	R-718 (water)	R-718
Centrifugal Chiller	CFC-11, CFC-12	HFC-134a, HCFC-123
Packaged Air Conditioners	HCFC-22	R-407C, R-410A
Heat Pump	HCFC-22	R407C, R-410A
PTAC, PTHP	HCFC-22	R-407C, R-410A
Room Air Conditioning	HCFC-22	R-407C, R-410A

As each refrigerant is changed, equipment performance may also change due to the refrigerants' differing thermal and physical properties. Most cooling equipment presently manufactured with HCFC-22 is being or will be altered to HFC-134a, R-410A, or R-407C (R-410A and R407C are blends of HFC refrigerants). The new refrigerants help combat the growing ozone depletion in the earth's atmosphere, since they contain **no chlorine**. However, some of the newer refrigerants have a high global warming potential (GWP), which causes concern with environmentalists. As shown in Table below, R-410A has a slightly higher GWP than its predecessor, HCFC-22. However, GWP impacts must not be evaluated without consideration of a refrigerant's efficiency and potential emissions rate, since most of the global warming generated by an HVAC system will be associated

with CO₂ generated to supply its power demand rather than with the refrigerant emitted during the system life cycle. The concept of Total Warming Equivalent Impact (TEWI) is intended to reflect the full life cycle global warming impact of a refrigerant.

Environmental Impact and Performance of Refrigerants

Refrigerant	Global Warming Potential	Ozone Depletion Potential	Heat of Vaporization (Btu/lbm)
CFC-11	4000	1.0	81
CFC-12	7100	1.0	65
HCFC-22	1700	0.055	86
HCFC-123	93	0.016	77
HFC-134a	1300	0	83
R-407C	1600	0	95
R-410A	1890	0	95
R-290 (Propane)	~20	0	159
R-600a (Isobutane)	~20	0	151
R- 717 (Ammonia)	<1	0	536
R-744 (Carbon Dioxide)	1	0	94
R-718 (Water)	0	0	1070

Other Alternatives

Other alternatives have been considered, and are being more aggressively pursued, primarily because of the high direct global warming potential of HFC's. These alternatives are hydrocarbons, ammonia, and carbon dioxide.

Hydrocarbons have thermal and physical properties similar to traditional refrigerants, but they are flammable. Their use for HVAC applications is currently not actively considered because of safety and liability reasons.

Ammonia, used extensively for industrial refrigeration applications for many years, is being developed for commercial refrigeration and air-conditioning. Ammonia units must use more expensive steel, or stainless steel tubing (or aluminum for low-temperature components such as the evaporator) because ammonia is corrosive to copper and copper based alloys. The other drawback is that ammonia is somewhat flammable and toxic. Also, ammonia systems must use open-drive compressors, which can be more expensive, can require maintenance for the shaft seal, and allow some refrigerant leakage. Ammonia's advantages are low refrigerant cost, good efficiency, and good heat transfer characteristics.

Cooling systems using carbon dioxide are being developed primarily for mobile air-conditioning applications (cars, buses, etc.). This refrigerant must operate with a supercritical cycle for typical ambient conditions, at head pressures up to and above 100 atmospheres. Most of the development is occurring in Europe.

GREEN TIP # 9

COOLING TOWERS

A cooling tower is an auxiliary cooling device – it doesn't cool the building directly – but rather it helps other equipment do that job by rejecting unwanted heat from the condenser water loop to the air outside of the building. As an auxiliary device, the cooling tower lives to serve the connected chiller and is sized for the chiller evaporator load plus the chiller compressor heat, which is typically 20 to 25% above the evaporator load.

Tower Performance

Cooling towers remove heat by evaporation: when a pound of water evaporates, almost 1000 Btu's of cooling is associated with the process.

Two parameters must be noted:

1. Range - is the temperature difference between the entering water temperature and the leaving water temperature.
2. Approach - is the temperature difference between the ambient wet bulb temperature and the leaving water temperature.

Example

Nominal cooling tower tons is the capacity based on a 3 GPM flow per ton at 95°F entering water temperature, 85°F leaving water temperature, and 78°F entering wet bulb temperature. For these conditions, the range is 10°F (95°F-85°F) and the approach is 7°F (85°F-78°F).

The dominant factor in cooling tower performance is the outdoor **“wet bulb”** temperature, which indicates how dry the air is. From a technical standpoint, it can be said that the tower is sized for “X” tons of heat rejection, so the size is not questioned. However, this is not true. A tower rated at 500 tons at a 71°F wet-bulb might provide only about 340 tons of cooling if the wet-bulb is 78°F.

The wet-bulb conditions that are prevalent in a region must be well understood in order to properly size the tower. The higher the design wet-bulb temperature used for rating a particular tower, the more heat transfer surface that will be required (and, hence, the larger the tower will have to be) to provide the required amount of heat rejection.

The cooling tower “approach” tell us how close the water temperature can be lowered toward the wet bulb temperature. If the cooling tower were infinitely large, the leaving water temperature would be at the wet bulb air temperature. The larger the approach, the smaller and less expensive the cooling tower can be, which is nice on the day the cooling tower, is purchased. But the smaller the approach the greater the efficiency options for the equipment served by the cooling tower, which has benefits for years and years. Selecting towers with an approach of 5 -7 degrees will be cost effective relative to a more typical 10 degrees. Cooling towers are available with as low as 3% approach temperature, but the approach temperatures lower than 5 degrees encounter diminishing returns and require larger investment in fan horsepower for each additional degree.

Cooling Tower Efficiency

Tower efficiency (as defined in ASHRAE Standard 90.1-1999) is the ratio of the maximum tower flow rate (GPM) to the motor horsepower (hp) at standard Cooling Tower Institute (CTI) rating conditions (95°F to 85°F at 78°F wet bulb). The typical efficiency rating is put at 60 GPM/hp.

Unless there is a large premium, all towers should strive to achieve efficiency rating of 80 GPM/hp at CTI conditions, which would require larger cooling tower foot print and weight. The energy savings will soon outweigh the added cost to oversize the tower.

The optimum tower efficiency depends on the number of hours the tower operates under various load and weather conditions.

Fan Motor

To improve cooling tower efficiency, lower the cooling tower fan horsepower by adding surface area and free area within tower fill. These additions result in a five to ten time lower load on the cooling tower fans. The motors can therefore be resized. The tower performance goal should be .012 kw/ton or better.

Like chiller, the load on a cooling tower varies throughout the year, and there are many hours when it operates at partial load. To meet part loads efficiently, two-speed (1,800 rpm/900 rpm) or variable-speed fan control is more cost efficient.

When comparing the cost of VSDs with that of other approaches such as two-speed fan motors, keep in mind that the VSD allows you to purchase a less expensive single-speed motor, eliminates the more expensive two-speed starter, and gives more precise control of condenser water temperature. A VSD will normally reduce the wear and tear on the fan belt when compared to one- or two-speed fan motors.

Cooling Tower Selection

The design of the cooling tower has an impact on energy efficiency.

Mechanical cooling towers are available as forced draft and induced draft designs. The forced draft cooling tower blows air from the bottom whereas as an induced draft tower “pulls” the air in. Within induced draft cooling tower, there is counter-flow and cross-flow design. Cross flow tower are more prone to splash outs, spills and drift when there are strong winds.

The most efficient design is the induced draft, counter-flow design. For most applications, this is also the most cost-effective tower design if lifecycle costing is used. It may not be the lowest first-cost unit. In some instances, there may be site restrictions or conditions that would affect this choice.

Cooling Tower Placement

Tower efficiency is also dependent upon the physical placement and orientation of cooling tower cells at the facility. If the equipment is next to a wall, precipitation from the tower can cause building wall paint to peel, gutters to rust, or icicles to form. Recirculation of the wet air discharge, from the tower along a wall and back to the equipment, will result in raising the entering wet-bulb temperature and dramatically reducing system performance. In a similar situation, if the tower discharge enters a second tower cell that also has its intake facing the wall, airflow experiences restriction and poor performance follows.

Shutdown Vibration Switches

Most cooling towers use fans to push or pull air through the fill, and cool the water by evaporation. Fan blades are subject to fatigue, other mechanical stresses, and manufacturing defects. When a fan blade loses a blade tip or experiences abnormal wear, it becomes unbalanced. This causes excessive vibration in the gearbox, mounting, and other structures.

All cooling tower fans should be equipped with a shutdown vibration switch. In the event of an unbalanced situation, the fan will shut down before causing additional blade failure and the possibility of a safety hazard. Care should be taken to install the vibration switch in the correct plane for cooling towers. Switches installed in the wrong plane will not function. Switches should be checked regularly for correct operation.

The fan should preferably be constructed of FRP blades instead of cast aluminum or mild steel.

Cooling Tower Hot Deck Nozzles

To ensure efficient operation of a cooling tower, the tower must have the appropriate flow of water and air in the fill at all times. The most common disruption to adequate water flow is hot deck nozzle plugging (in towers with hot decks). This causes unbalanced and uneven water flow through the fill affecting the tower performance. This nozzle plugging is usually large pipe scale pieces and other debris in the system that cannot pass through deck nozzles. Regular monitoring of hot deck conditions is recommended.

Where frequent problems are encountered with nozzle plugging, install a line strainer on the return line to the tower. The perforations in the strainer should be one-half the size of the smallest opening in the hot deck nozzle. Install a 2-inch ball valve in a convenient location for blow down of the strainer, and check it frequently.

Cooling Tower Basins

Cooling tower basins usually collect a large amount of dirt and sludge from the solids washed out of the airflow. These solids create a sludge blanket on the bottom of the tower basin. When sludge thickness reaches 1-inch, the biocide and corrosion inhibitor used as cooling water treatment cannot reach the basin bottom. If the basin is

galvanized steel, rapid corrosion can cause severe damage in a short time. The most common form is anaerobic bacterial corrosion.

This is caused from the growth of bacteria, which thrives in an atmosphere with no oxygen. The first-line defense for this occurrence is the use of stainless steel basins and filtration with a basin sweeper system. Order new cooling towers with stainless steel basin for longer life and reduced maintenance costs. Use epoxy or elastomeric coatings to extend the life of galvanized cooling tower basins.

Controls

Cooling tower fans are controlled from a thermostat that senses water temperature. When the water temperature rises, the fan is started (or sped up). The most common form of control uses a fixed temperature setting of leaving water temperature. This is a major cause of wasted energy. Be mindful of the fact that chiller capacity will suffer if the tower cannot meet its heat rejection requirements or unable to supply water at lower temperatures close to wet bulb temperature.

Control cooling tower fans by sensing ambient wet bulb (wb) temperature. Adjust the set point for an approach of about 2°F (controller will measure outside wb and adjust set point to 2°F warmer).

A word of caution: Don't try this tip with old inefficient towers. The increase in fan kW will eat up chiller efficiency gains. The key concept is not to force a cooling tower to do something it wasn't made to do, but to capitalize on the low wet-bulb hours to make colder condenser water economically whenever possible. After making a control change like this it is always a good idea to check the combined chiller-tower energy consumption to verify the results are as predicted.

To summarize, here are some cooling tower hot buttons:

Reducing the entering condensing water temperature is one of the most effective ways to improve chiller efficiency. Note the following:

- Specify 7 degree approach max.
- Specify 0.05 kW/ton max.....light aerodynamic fans.

- Specify light aerodynamic fan blades and the high efficiency motor driven equipped with two-speed alternative or variable speed drive.
- Using colder tower water reduces chiller kW by 1 to 1.5 percent per degree – so the colder the better, as long as the chiller can accept it.
- Specify induced draft cooling tower – counter flow where possible.

PROS AND CONS

Pros

1. Cooling tower capacity is much less expensive (about \$120 to \$180/ton) compared to chillers (\$400–600/ton). A larger tower will provide cooler condenser water temperature to the chiller at very low cost and thus improve its efficiency at "off-design" conditions.
2. Fitting the cooling tower with variable-speed fans can take advantage of lower flow rates (more "free area") to reduce fan energy while providing the same temperature of condenser water.

Cons

1. In many projects, concerns about siting the cooling tower (physical appearance, biochemical control, water drift and risk of entraining condenser mist at air inlets, and noise) are the leading factors that discourage selection of water-cooled systems.
2. For cooling towers, in addition to the clearances for maintaining fans and pumps, space must be provided to ensure adequate airflow through the tower and prevent crossover from the tower discharge to the inlets.
3. If not maintained, tower water can be corrosive and may cause fouling of heat exchangers.
4. Water goes out of the tower and into the outdoor environment, not only in vapor form but also as aerosols. The aerosols could carry Legionnaires bacteria, which thrive in the warm water that the "cold water" basin of the tower houses.

5. Extreme care needed in discharging blowdown in environmental sensitive areas.
6. Tower discharge plumes must be located so that they will not damage building finishes or automobiles in adjacent parking lots.

GREEN TIP # 10

COOLING WATER TREATMENT

Fouling of the condenser tubes (e.g., scale formation, sedimentation, slime, and algae growth) results from poor water treatment and/or poor maintenance of the system's waterside. Fouling is an insulator that impedes transfer between the refrigerant and the water. It increases both the condensing temperature and the head pressure. Increasing head pressure increases compressor energy use. Fouling can increase the temperature difference needed between the leaving condenser water temperature and the refrigerant condensing temperature to maintain the same cooling load. Each increase in temperature of 1°F increases the full load energy consumed by 1%.

Good water treatment practices enhance energy efficiency and reduce maintenance. Steps include adopting chemical dosing to control scaling and corrosion, filtration to control suspended solids and passive non-chemical treatment methods mainly for micro-organisms growth.

Water Efficiency

Cooling towers consume water. Most of the water losses are:

Evaporation losses - In a typical cooling tower operation, only 1% of the recirculated water is evaporated. This evaporation will cool the remaining 99% of the water for reuse.

Drift losses - Drift is usually reported as a percentage of the recirculating water, though it is more accurately described in terms of the parts per million (ppm) of the air passing through the tower. Tower designs use drift eliminators to capture some of this entrained water. A typical value for drift from cooling towers is 0.005% of the recirculating water; many tower designs have drift values as low as 0.001%.

Blow down losses - The evaporation of water leaves behind mineral, etc that build up in the basin. These must be treated; otherwise they can form damaging scale and corrosion inside equipment and piping. An easy way is to simply bleed off (also called "blow down") a portion of the water and replace it with new, thereby continuously diluting the minerals. The parameter used to define the concentration of minerals is "total

dissolved solids (TDS) or conductivity of water. The blow down rate can be determined by the following formula:

$$B = \frac{E - [(C - 1) \times D]}{(C - 1)}$$

Where

- B – Blowdown rate (L/s)
- E – Design evaporative rate (L/s)
- C – Cycle of concentration
- D – Design drift loss rate (L/s)

The equation shows that as the concentration ratio increases the blow down requirement decreases. The equation also tells us that it is practically impossible to ever achieve a concentration ratio of 1, because to do so would require an infinite amount of water. As a rule of thumb, the minimum cycle of concentration shall be maintained at 5 to 6 for fresh water type cooling tower and 2 or less for seawater type cooling tower.

Example

A 400-ton cooling system would circulate approximately 1200 GPM through the cooling tower. At nominal rates, 12 GPM would be lost to evaporation (1%), 0.06 GPM would be lost to drift (0.005%), and, at four cycles of concentration, 4 GPM would be intentionally bled from the system. The drift and bleed will contain the same quantity of minerals and water treatment chemicals to the publicly owned treatment works.

Increasing the blow down is a simple way to reduce the levels of minerals in the water, but it is not in interests of water conservation.

Some amount of blow down is usually required, but this can be reduced by a variety of methods – the most common being chemical treatment. Through water treatment, the mineral content in the water can be allowed to rise somewhat without detriment to the connected equipment. Bleed water, instead of being sent to the publicly owned treatment works, could be used on-site for irrigation or other non-potable needs.

Chemical Water Treatment

The water in the evaporative cooling loop must be treated to minimize biological growth, scaling, and corrosion. Typically a combination of biocides, corrosion inhibitors, and scale inhibitors are added to the system.

Corrosion inhibitors are usually phosphate or nitrogen based (fertilizers) or molybdenum or zinc based (heavy metals). These inhibitors are more effective when added in combinations. Their only loss is through bleed and drift.

Most scaling inhibition is done by polymer-based chemicals, organic phosphorous compounds (phosphonates), or by acid addition. The acid reacts with the alkalinity in the water to release CO₂ and is used up. The polymer and phosphonate scale inhibitors remain in the solution to delay scaling; their major loss is through bleed and drift. Some polymers are designed to be biodegradable, easily broken down by bacteria in the environment, while others are not.

Biological growth is generally a larger problem for cooling systems. Chemical treatments with biocides such as chlorine and bromine at a constant level and slug feed a non-oxidizing biocide once a week have traditionally been used to control this growth. Alternatives to these chemicals include ozone and UV radiation.

Drift Elimination

Water lost through the cooling tower fan is called drift. The high drift losses causes higher water use, higher chemical costs and increased environmental damage from the water droplets.

Ensure drift eliminators in good condition. Drift eliminators affect the tower performance by increasing the pressure drop and, therefore, the airflow across the tower. There is a trade-off between energy, performance, and drift control. Use the type of drift eliminator that meets the requirements, not necessarily the best one available.

Cooling Tower Water Filtration

Cooling tower water filtration is the single most effective way to reduce fouling and maintenance on a cooling water system. The dirt particles typically found in cooling

water consist of airborne dust, pollen, dirt, bacteria, and other organic material ingested by the tower. The typical cooling tower moves millions of cubic feet of air each day. All of the foreign material in air is washed out into the cooling water. This material provides food for the bacteria normally present in cooling tower water. It also forms a sludge blanket in the basin or tower sump, which harbors bacteria and corrosion-causing conditions. If a sludge blanket becomes an inch or more thick, biocides can no longer penetrate it to kill bacteria.

Best Practices

The use of side-stream sand filters is the most effective way to remove the suspended solids in cooling tower water. Filters designed for this purpose can remove 90-95% of all suspend solids larger than 5 microns. This level of filtration, which is equal to or better than drinking water, will eliminate the problems associated with dirty cooling tower water. Selection and sizing is site-, equipment-, and location-dependant. If the solids are small and airborne (making them low in specific gravity), centrifugal separators are not effective for this application.

A filtration system should include a properly designed basin sweeper system to reduce or eliminate the sludge blanket that forms in tower basins.

Cooling Tower Hot Deck Covers

Algae cannot grow in cooling water without sunlight. The most common source of sunlight in cooling towers is uncovered hot decks. Installing cooling tower hot decks provide another defense against airborne solids and algae growth.

Non – chemical Water Treatment

Non-chemical water treatment has the potential to be a powerful method for water treatment; however, its success depends on the water chemistry, operating procedures, and degree of pollution of the specific system. There are several different technologies available: pulsed electric fields, mechanical agitation, and ultrasound to name a few. Each of these technologies offer the promise of eliminating the storage and handling of toxic chemicals at the site, eliminating the risk caused by any spills or leaks of cooling tower water, eliminating the issues of the bleed water, and eliminating much of the concerns with drift.

Pulse Powered Chemical Free Water Treatment

Pulse-powered physical water treatment uses pulsed, electric fields inside a PVC pipe fitted into the recirculating water system. The electric signal changes the way minerals in the water precipitate, totally avoiding hard-lime scale and instead producing a non-adherent mineral powder in the bulk water. The powder is readily filterable and easily removed. Bacteria are encapsulated into this mineral power and cannot reproduce, thereby resulting in low bacteria populations. The water chemistry maintained by pulse-powered technology is non-corrosive, operating at the saturation point of calcium carbonate (a cathodic corrosion-inhibiting environment).

This chemical-free approach to water treatment eliminates environmental and health-and-safety issues associated with water treatment chemicals. Pulse-powered systems do not require pumps or chemical tanks. Independent studies have shown not only that the method is effective for cooling towers but that the performance of pulse powered systems is superior to standard chemical treatment in biological control and water usage. The performance results of pulse-powered technology for chemical free water treatment, as documented by various independent evaluations, support the objectives of green buildings and have earned LEED points for certification in a number of projects.

WHEN/WHERE IT'S APPLICABLE

Pulse-powered technology is applicable on the recirculating lines of cooling towers, chillers, heat exchangers, boilers, evaporative condensers, fluid coolers, and fountains.

PROS AND CONS

Pros

1. The potential for lower bacterial contamination while providing scale and corrosion control.
2. Lower energy and water use than in traditional chemical treatment.
3. Blowdown water is environmentally benign and recyclable.
4. Life-cycle cost savings compared to chemical treatment.

5. Reduction or elimination of bio-film.
6. Removes health and safety concerns about handling chemicals.
7. Eliminates the environmental impact of blow down, air emissions, and drift from toxic chemicals.

Cons

1. It does not work effectively on very soft or distilled water, since the technology is based on changing the way minerals in the water precipitate.
2. Water with high chloride or silica content may limit the cycles of concentration obtainable to ensure optimum water savings since the technology operates at the saturation point of calcium carbonate.
3. Energy usage is still required to operate.

GREEN TIP # 11

HEAT RECOVERY FROM CONDENSER WATER

Water-cooled chillers reject a significant amount of heat through cooling towers. All of the building heat and the heat generated by the compressor work leave the building in this manner. Reclaiming this heat and using it to heat the building or the domestic hot water can potentially offer huge energy savings. For example, a 400-ton chiller can provide 500 tons or six million Btu of heat. Heat recovery systems can be added to utilize this free heat for generating hot water.

There are two main methods to accomplish this:-

Install an auxiliary double wall vented condenser in parallel with the standard chiller. This system can provide as much heat for heating water as would normally be rejected to the atmosphere or be sized to meet only the hot water demand of the building. The auxiliary condenser should be near and at the same level as the standard condenser. An oversized receiver is required for this system. The flow control of refrigerant (pressure) to the heat recovery water cooled condenser is very important to prevent high and low head pressure problems.

Alternatively a double wall vented desuperheater can be installed in the hot gas line and should be sized to desuperheat only. Little or no condensing should take place. If the desuperheater is oversized, it can act as an uncontrolled auxiliary condenser and cause operating problems such as low head pressure, low back pressure, and poor expansion valve control. Adequate hot water storage for the building's use must be provided for this system to work properly. Water temperatures from 105 to 135°F are normal for this system. The storage size will depend on building hot water use, the A.C. unit size, and its hours of operation.

WHEN/WHERE IT'S APPLICABLE

Heat recovery only occur when there is a source (a cooling load in the building) and a requirement (a heating load in the building).

Condenser water heat recovery can be used wherever there are simultaneous heating and cooling loads. The heating loads can be either domestic hot water or building

heating. Secondary systems such as fan coils, constant volume with reheat, and multi-zone are prime candidates. In general condenser heat recovery for service water heating or preheating is applicable if all of the following is true:

- The facility operates 24 hours day.
- The total installed heat rejection capacity of the water cooled system exceeds 6,000,000 Btu/h (1700 kW).
- The design service water heating load exceeds 1,000,000 Btu/h (300 kW).

Facilities with high domestic hot water usage, such as health care, hotels, etc., can benefit from condenser heat recovery.

PROS AND CONS

Pros

1. Free heat recovery for either building heat or domestic hot water heating possible that would otherwise be rejected from the building and then use it for.
2. Can be used with any kind of water-cooled chiller plant and any HVAC system that has simultaneous heating and cooling requirements.

Cons

1. When an auxiliary condenser is added to a system, the designer must design the refrigerant piping and physically locate the components of the system to prevent liquid slugging of the compressor and the production of flash gas ahead of the expansion valve. The designer must size and pitch the gas lines to promote the return of oil to the compressor.
2. Can increase chiller plant complexity and lower the performance of the chiller in heat recovery mode - typically, chillers send 95°F water to the cooling tower. By raising this design parameter to between 105°F and 140°F through one of two condenser heat recovery options, they work harder and their performance drops when compared to conventional chilled water production. This penalty must be weighed against the value of producing usable hot water.

3. When a auxiliary condenser or desuperheater is added to the hot gas line, the capacity of the air conditioning unit decreases because of the pressure drop in the desuperheater. Part of the decrease in capacity due to the pressure drop is recovered by the addition of the condenser surface of the desuperheater.

GREEN TIP # 12

PUMPING SYSTEM

The most common application for water pumps in commercial buildings is for fresh/raw water supply, cooling tower makeup, boiler makeup, chilled water systems, condenser water system, heating and steam systems, wastewater treatment and drainage. Although many pump types are available to the designer, the most common type of pump is the centrifugal pump. Among centrifugal pumps, there are many styles: single or double suction, in line or base mounted, close or flexible coupled and vertical turbine pumps. All have their specific uses and wide overlap. So in many applications, more than one pump style could be used. In general:

1. Higher flow rates are better served by double suction pump in which axial forces tend to balance one another.
2. Vertical split casing, double suction pumps might serve best where the installation footprint plus the access space required to service the pump is tight.
3. Using a vertical turbine pump is a way to avoid suction lift situation that can be difficult for a standard centrifugal pump. For example, a vertical turbine pump is particularly well suited to application such as a cooling tower where water from a tower basin must be elevated in relation to the condenser.

Pump Power

The pump system power consumption is defined by equation:

$$HP = \frac{GPM \times TDH (ft) \times SG}{3960 \times \text{Efficiency}}$$

In making a choice of pumping systems, engineers put emphasis on the efficiency. While this is OK to have the maximum possible efficiency, one must carefully look at other part of the formula; viz. the pump flow and the head. These two parameters are often neglected. The true energy savings can be found from the correct sizing of parameters (TDH in ft x flow in GPM).

For example, a pump efficiency of 70% will correlate to a system efficiency of 35%, if the pump is selected and operated at twice required pump head. If the flow requirements were similarly specified, system-pumping efficiency would decrease to the order of 17.5%. Small differences in efficiency between pumps are not as important as knowing and adjusting to the service conditions. Energy savings may be as high as 20% if pumps are sized based on reasonable system heads and capacity requirements.

As a generality, the larger the pump, the higher is the efficiency. While it is true that the large pumps offer higher efficiency, don't be misguided by this generic statement. It will almost always be true that a smaller pump matched to the system will operate at lowest cost-even though its efficiency as a pump is lower.

Energy Efficiency Strategies

Always size pumps based upon the actual pressure drop through each component in the system as well as the actual peak chilled water flow requirements, accurately itemizing the pressure losses through the system, and then applying a realistic safety factor to the total. The idea is not to design systems that are undersized, inflexible and ill-prepared for unforeseen changes to system operation, but rather to balance uncertainty about how a system will be used now and in the future with the resultant energy waste from oversizing.

The Darcy-Weisbach equation is a commonly used empirical expression for friction head loss in piping:

$$h = f \left(\frac{L}{D} \right) \left(\frac{v^2}{2g} \right)$$

Where

- h = head loss due to friction (ft)
- f = pipe friction coefficient
- v = fluid velocity (ft/sec)
- g = gravitational constant (ft/sec²)

- D = inner diameter of the pipe (ft)
- L = length of pipe (ft)

Some important conclusions arise from the Darcy-Weisbach relationship:

1. The velocity of the water: Friction increases as the square of fluid velocity, so keeping velocities low can substantially reduce pressure loss as fluid flows through the piping system. To keep frictional losses low, size pipes for a fluid velocity that does not exceed 4 feet per second and, depending on the pipe sizes involved, consider selecting the next larger pipe diameter that will result in acceptable pipe velocities. The longer the lengths of pipe, the greater will be the saving potential.
2. The size (inside diameter) of the pipe: Smaller pipe causes a greater proportion of the water to be in contact with the pipe, which creates friction. Pipe size also affects velocity. Installing larger diameter pipe results in reduction in fluid velocity and therefore results in lower friction losses.
3. The roughness of the inside of the pipe: Pipe inside wall roughness is rated by a “ f ” factor, which is provided by the manufacturer. The lower the “ f ” value or the rougher the inside, the higher will be the pressure loss due to friction.
4. The length of the pipe: The friction losses are cumulative as the water travels through the length of pipe. The greater the distance, the greater the friction losses will be.

Keep the Temperature Differential Up

A chilled water system that is designed based upon a 10° F temperature rise must circulate about 2.4 GPM/ton, whereas a system with a 20° F difference circulates only about 1.2 GPM/ton, resulting in a nominal savings of 50 percent of pumping energy. Select chillers and cooling coils at high delta T (14°F or 16°F recommended) - this will reduce the size of piping, pumps, motors, and piping accessories, which can offset some or all of the added cost of the coils. (Refer Green Tip #6, item “High Delta T chillers”).

Piping Layout

Shorter and straight piping paths mean less piping, less welding, and lower pressure loss. Minimize the use of unnecessary valves, flow control devices, turns, transitions, and other “pressure wasters.”

Use **pressure independent control valves** – this can eliminate the need for flow control devices that waste pumping energy while still ensuring that flow is balanced to each coil in the system.

Pump Control

A pump application might need to cover several duty points, of which the largest flow and/or head will determine the rated duty for the pump. Two field options are:

1. Throttling the pump discharge or putting a control valve near the terminal devices
2. Altering the speed of pump say by using variable frequency drive (VFD) motors

The other options include, “Trimming the impeller”, but that will lead to permanent reduction of capacity and head. The most efficient energy option is variable speed pumping, which we will discuss further in next section (Green tip 13).

Specify efficient pumps and premium efficiency motors

Select a pump where the design pressure and flow are as close to the point of highest efficiency as possible. This will minimize the brake horsepower requirements, and therefore the size of the motor required to drive the pump. Select a premium efficiency motor - premium efficiency motors can often be a couple of percentage points higher on the efficiency scale than motors that meet the “standard energy-efficient” rating.

Recommended Good Practices

1. Locate the pump as close to the source as possible. It is best to have your main (longest) run of pipe on the discharge side of the pump. The pump is designed to push water, not pull it.
2. Keep the suction piping as short as possible, and avoid air traps by ensuring that the pipe can be installed to rise uniformly to the pump suction. For example, try to avoid suction piping that “loops” vertically as it goes to the pump.

3. Try to avoid condenser fouling and pump air problems by including low pressure drop solids and air removal devices in the suction piping. Remember that there are limits to the amount of dynamic suction lift that a centrifugal pump can achieve. A good rule of thumb is to design for a maximum dynamic suction lift of 15 ft.
4. Air trapped in a piping system can make priming a centrifugal pump difficult. Therefore, the suction piping should slope gently upward to the pump or strainer inlet in order to remove unwanted air pockets.
5. Use eccentric reducers at the pump suction.
6. Consider installing unions on a pump to prevent priming problems. However, the location of the union should be between the pump's check valve and the pump, not between the check valve and the water source. Unions may be a source of a vacuum leak, which could cause the pump to lose its prime.
7. Locate the pump at an elevation as close to the suction source as possible to minimize suction lift and minimize priming problems.
8. Always have your inlet pipe diameter equal to, or larger than, the discharge line. This helps prevent cavitation.
9. Remember, the size of the pump's suction and discharge ports does not indicate your proper pipe size. Minimize friction losses by using large diameter pipe. Determine the approximate flow rate you want, and the total length of your pipe. Choose a pipe diameter that keeps your friction loss below about 4 feet per hundred feet of pipe.
10. Make sure all your pipe joints are airtight. This is especially important on the suction side. Use Teflon paste (not tape) for sealing threaded joints.
11. Do provide sufficient submergence over intake piping to prevent vortex formation.
12. Do not use suction elbows in a plane parallel to the shaft; place them in the plane perpendicular to the shaft.
13. Do not use the pump casing as an anchor for the piping. If you use expansion joints, supports and anchor them independently of the pump.

14. Do provide adequate flow, pressure and temperature instrumentation for each pump.
15. Pump and driver alignment must be rechecked under normal operating conditions.
16. Use a filtration system that does not require a lot of pressure. It costs money to create pressure. Biological filters work well and require very little pressure.
17. Fittings should be provided to permit the installation of vacuum and pressure gauges on each side of the pump if provision has not already been made in the pump for these gauges.
18. Install shut off valves before and after the pump, so you can easily remove it from the line without having to drain your system.
19. Quick-closing valves or nozzles should not be used on the discharge lines.
20. A check valve should be installed in the discharge line as close as possible to the pump when the static discharge head exceeds 25 feet.
21. On installations involving suction lift a good foot valve or line check, located at the beginning of the suction lift or an angle check valve at ground level will help insure flow as soon as pump is started.
22. If it is not possible to provide a flooded suction installation then:
 - Position the pump as low as possible, and as near the source as possible. (A pump one foot above the surface works better than one six feet above the surface.)
 - Install basket strainer on the inlet of the pump or provide some other priming source.
 - Suction piping should slope gently upward to the pump or strainer inlet.
 - Install a foot valve in the inlet line below the water level.
 - Always prime the entire inlet line, basket strainer, and pump before turning it on.

GREEN TIP # 13

VARIABLE SPEED PUMPING SYSTEMS

Most HVAC systems are designed to handle the maximum potential temperature extremes, keeping a building cool on the hottest days and warm on the coldest days. As a result, the HVAC system only needs to work at full capacity on the ten or so hottest and coldest days of the year. On the other 345 days, the system could be operated at reduced capacity.

Variable speed drives change the speed of a motor's rotation by changing the frequency of the power being applied to the motor. The relationship between a motor's speed and the frequency being applied to the motor is linear. For instance, a motor that is designed to turn at 1,800 revolutions per minute (RPM) when connected to a standard 60 Hz power supply will turn at 900 RPM when connected to a variable frequency drive supplying 30 Hz of power.

A variable speed drive allows precise control of motor speed based on actual demand, directly affecting pump output. In the case of centrifugal pumps, there is a significant reduction in the power required to handle the load. This power reduction is due to the fact that most pumps and all fans are variable torque loads.

The effect that reduced speed has on a variable torque pump is summarized by a set of rules known as the Affinity Laws. The basic interpretation of these laws is quite simple:

1. Flow produced by the pump is proportional to the speed (RPM).
2. Head produced by pump is proportional to the speed squared.
3. Horsepower required by the pump is proportional to the speed cubed.

For instance, a variable frequency drive running a variable torque load at 80 percent speeds needs to deliver only 50 percent of the horsepower required to run it at 100 percent speed. The reduction of horsepower means that it costs less to run that motor.

Example:

A cooling water pump is operating at a speed of 1800 rpm. Its flow rate is 400 GPM at a head of 48 ft. The power of the pump is 45 kW. Determine the pump flow rate, head, and power requirements if the pump speed is increased to 3600 rpm.

Solution:

$$\text{Flow rate} = 400 * (900 / 1800) = 800 \text{ GPM}$$

$$\text{Head} = 48 * (900 / 1800)^2 = 12 \text{ ft}$$

$$\text{Power} = 45 * (900 / 1800)^3 = 5.63 \text{ kW}$$

Pump horsepower varies as the CUBE of speed [or capacity (flowrate)], so cutting flow by one-half can reduce horsepower by one-eighth of its original value.

An effective way to achieve this is by installing variable frequency (i.e. variable speed) drives (VFDs). VFDs are electrical devices which adjust the rotational speed of pump motors in response to varying heating and cooling loads. This is the most efficient way to reduce the flowrate in comparison to alternative method of throttling the valves.

Looking at the equation that governs heat transfer, the capacity of a chiller is proportional to the product of flow rate and the temperature difference of entering and leaving chilled water, or

$$\text{The chiller capacity (BTU/hr)} = \text{GPM} \times 500 \times \Delta T$$

In constant-flow systems, flow rate (GPM) is established for peak design condition and ΔT varies to meet the load (BTU/hr) during lean periods. In air-conditioning applications, since the design conditions occur only during 1% of the operational hours in a year [i.e. 99% of the time the system runs on part load], some of the chilled water will always bypass through the three-way valve for most of coil's operational life. This is waste of energy.

In variable flow systems, the GPM changes and ΔT is kept constant. This saves energy as flow is reduced during lean periods. If the flow rate were half, the power necessary to provide the slower flow rate would be $(0.5)^3 = 0.125$ or 12.5 % of the power required for the higher flow rate. It means an energy saving of 87.5%.

Caution

The HVAC systems incorporating VFD must use 2-way valves. Use of 3-way valves will offset all benefits of VFD energy conservation features.

Unlike 3-way valves, two-way valves permit flow variation and do not divert or mix the supply-return streams. This is an obvious requirement since operating cost savings for variable primary flow result from flow variation.

WHEN/WHERE IT'S APPLICABLE

HVAC equipment offering opportunities for variable flow energy savings include:

- Centrifugal chilled water pumps
- Centrifugal hot water pumps
- Cooling tower pumps
- Centrifugal air handler fans
- Centrifugal exhaust fans
- Cooling tower fans

PROS AND CONS

Pros

1. Variable pumping schemes using variable speed drive provide significant energy savings.
2. Variable-speed drives on pumps provide a "soft" start, extending equipment life.
3. Variable-speed drives along with two-way valves are self-balancing.
4. Variable-speed systems are quieter than constant-speed systems.

Cons

1. Variable-speed drives add cost to the system. (They may not be cost-effective on hot-water systems.)
2. Not suitable for high static head pumping applications.
3. Demand-based supply pressure reset can only be achieved with DDC of the heating/cooling valves.
4. Variable flow on condenser-water systems with open towers requires supplementary measures be taken to keep the fill wet on the cooling towers.
5. Certain minimum flowrate must always be maintained through chiller evaporators and boiler tubes. Make sure the speed does not drop to absolute zero.

GREEN TIP # 14

CHILLED WATER DISTRIBUTION SCHEMES

Conventional chilled water plant designs circulate a constant volume of chilled water through the chillers and the building, no matter; the cooling load is large or small. If loads are small, the constant volume of chilled water is diverted around the cooling coils by three-way valves. As a result, energy is wasted. Variable-flow systems have become more economical in recent years and these offers attractive payback. There are two proven strategies to incorporate variable flow in system design.

Primary / Secondary System

In “primary/secondary system” the flow through the chiller (plant side) is maintained constant while flow through the cooling coils (building side) is varied according to demand for cooling. The beauty of the primary/secondary variable flow design is that the piping loop for chillers (the primary loop) is hydraulically independent (decoupled) from the piping loop for the system (the secondary loop) via a common “de-coupler” pipe.

The primary loop consists of constant volume pumps with flow rate matching the chiller’s evaporator. The secondary loop consists of variable speed pumps to deliver the variable flow to the building AHUs per the demand. These pumps are controlled from differential pressure sensors located remotely in the system or from cooling coil valve position.

PROS AND CONS

Pros

1. Variable speed pumping) is more energy efficient than the conventional constant volume chilled water designs. (Refer green tip 13)
2. Variable flow on the secondary loop reduces pipe size (capital savings) and pump work (operating savings).
3. Fixed flow for each chiller provides control stability.
4. Flow is only required when chiller is operating.

5. Dedicated condenser flow for each chiller is required only when it operates.
6. Chillers can be any size or type.

Cons

1. May require a large mechanical room.
2. More complicated to design and operate.
3. If the system delta T is not maintained (control valves problems, dirty coils, etc.) the system does not function properly and operating costs can rise.
4. When the secondary flow exceeds the primary, return water from the system flows back through the common pipe and mixes with the supply water from the chillers. This increases the temperature of the supply water to the secondary system, causing loss of dehumidification and also the warmer supply temperature causes the two-way valves at each cooling coil to open even more, creating an ever-increasing demand for secondary system flow.
5. If the secondary system return-water temperature is lower than the design temperature, the chillers cannot be loaded to their maximum capacity. This is called "low delta-T syndrome" and it results in greater pump, chiller, and cooling tower energy consumption, as well as a reduction in cooling plant capacity.
6. The primary-secondary system does not allow an increase in flow through the evaporator above design and; therefore, does not adjust to chilled water return temperatures that are lower than design. In addition, this pumping scheme can further exacerbate the problem during off-peak conditions. As the cooling load decreases, the secondary pump VFDs will ramp down to a lower speed, thus allowing these pumps to produce less flow. The constant volume circulation pumps will then over pump the primary loop causing supply water to flow through the neutral bridge and mix with return water. This mixing lowers the return water temperature and deteriorates the system ΔT .

7. Capital Investment: The greater quantity of pumps and the longer piping runs associated with this pumping scheme can yield a higher capital investment when compared to the direct-primary system.
8. Although energy savings is realized in secondary loop, the primary loop continues to consume higher energy. All variable primary loop is a better option (refer section below).
9. Requires More Plant Space: Two sets of pumps are needed to circulate chilled water through the chiller evaporator and the chilled water distribution system. This requires more floor space, more spare parts, and results in higher capital costs and pump maintenance costs when compared to the direct-primary system.

The other option that is somewhat more efficient and becoming increasingly popular is the variable-primary system, where flow through the chiller is also varied.

Variable Primary Flow System Design (VPF)

Engineers have traditionally avoided variable flow through chillers, but recent advancements in control technology permit variable flow through the chiller evaporator. This technique offers 5- 10% higher savings than the primary /secondary scheme discussed above.

PROS AND CONS

Pros

1. VPF controls permit flow through evaporators to be increased above design value, making it possible to adjust to less than ideal chilled water return temperature. This maximizes the output of a given chiller and eliminates the need to start additional chillers and pumps prior to reaching nameplate capacity. The combination of using less equipment more efficiently yields savings to the owner/operator.
2. Capital Investment: A VPF design uses fewer pumps and fewer piping connections than primary–secondary systems, which means fewer electrical lines and a smaller footprint for the plant. These factors reduce the initial cost of the chilled water system.

3. Energy savings are possible because no excess flow recirculates from supply to return through decoupling lines or three-way valves. In theory, every bit of supply water, without any mixing, must pass through a load before returning to the plant.
4. Energy savings are also possible when conditions permit flow to one or more chillers to exceed design flow. If outside wet bulb temperature is below the design value, as it is over 95 percent of the year, the condensing temperature will be also lower, giving each chiller additional capacity. If more water can be put through the chiller, this extra capacity can be tapped.
5. VPF systems are not prone to low ΔT syndrome. As a result, the pump flow rate is better matched to the cooling load within the distribution system and the absence of a neutral bridge prevents mixing of supply and return water.
6. Requires Less Plant Space: Constant flow pumps serving a production loop are not needed because the primary pumps circulate the water through the chillers as well as the distribution system. This requires less floor space, fewer spare parts, and can result in lower capital costs and pump maintenance costs.

Cons

1. System design is more involved and complex. To safeguard chiller against minimum flow, a separate by-pass loop with auto-modulating valve is necessary.
2. VPF system design is constrained by the range of flow rate permitted in the evaporator. Given the fluctuations and accuracy of controls, a good designer will choose a minimum flow rate that is not too close to the published minimum. Consult the manufacturer's literature for maximum and minimum flow rates.
3. Another issue in primary-only plant design is avoiding laminar flow in the evaporator tube. A fluid velocity of at least 3 feet per second is recommended to maintain good heat transfer.
4. Rapid flow variations in chiller can cause control instability and compressor flood-back or shutdown. DDC chiller plant controls will be needed.

5. Careful attention must be given to the design pressure of hydronic piping, and valves at the pump shut-off conditions. Because the total dynamic head is produced by a single set of pumps and there is no separation between the plant and distribution systems, VPF scheme will require larger motors.
6. When plant operators desire to bring additional chillers online, the sudden drop in flow through the lead chiller may cause it to trip offline on low flow.

GREEN TIP # 15

CHILLED WATER AND CONDENSER WATER PIPING

Traditionally, most designers size piping on following criteria:

- For closed systems (chilled water loop), the maximum friction loss shall be 1200 mm (4 ft) of water per 30 m (100 ft) of pipe with maximum velocity of 1.2 m/s (4 fps) for systems in occupied areas, and up to 2.4 m/s (8 fps) for mains and large branches.
- For open systems (condenser - cooling tower loop), the maximum friction loss shall be 1200 mm (4 ft) of water per 30 m (100 ft) of pipe and a maximum velocity of 2.4 to 3.0 m/s (8 to 10 fps). The minimum pipe size shall be 20-mm (3/4-inch).

These methods are expedient and reproducible, but they seldom result in an optimum design from either a first-cost or life-cycle cost perspective.

Recommendations:

Velocity is limited to minimize erosion of pipes based on common rules of thumb published in various handbooks (e.g. ASHRAE Handbook). These velocity limits are:

- 15 fps for systems operating less than 2000 hours/year;
- 14 fps for systems operating 2000 to 3000 hours/year;
- 13 fps for systems operating 3000 to 4000 hours/year;
- 12 fps for systems operating 4000 to 6000 hours/year; and
- 10 fps for systems operating more than 6000 hours/year.

The above limits only tend to apply to large pipe sizes; the small sizes are primarily selected by energy limitations with velocity in range of 4 to 6 fps. While these and similar maximum velocity guidelines have been around for years, they have never been corroborated by research. In fact, most of the research on this issue has indicated that

unless there are particles or air bubbles in the water, there is little erosion of piping regardless of velocity, within the normal velocity ranges found in commercial systems.

Looking again the Darcy-Weisbach pressure loss equation discussed in the Green Tip #12; the frictional loss is directly proportional to the square of velocity.

$$h = f \left(\frac{L}{D} \right) \left(\frac{v^2}{2g} \right)$$

Therefore keeping velocities low so that maximum friction loss is restricted to 4 ft per 100 ft length of piping should be the goal. For plants operating continuously for longer hours, select one pipe size higher than selected through the nomographs/ velocity equation.

Increase the Size of Distribution Piping

During renovation or expansion, consider increasing the size of distribution piping or, in the case of retrofit, adding parallel pipes to double the cross sectional area of the flow path. Note that "The energy required to move water (or air) through a pipe varies with the inverse fifth power of pipe diameter."

Rule of Thumb for Pipe Sizing

Steel Pipe				Copper Pipe		
Pipe Size	Flow Rate	Heating BTUH	Cooling Tons	Flow Rate	Heating BTUH	Cooling Tons
1/2"	1.8 GPM	18,000 BTUH	1.5 Tons	1.5 GPM	15,000 BTUH	1.3 Tons
3/4"	4 GPM	40,000 BTUH	3.3 Tons	3.5 GPM	35,000 BTUH	2.9 Tons
1"	8 GPM	80,000 BTUH	6.7 Tons	7.5 GPM	75,000 BTUH	6.3 Tons
1 1/4"	16 GPM	160,000 BTUH	13.3 Tons	13 GPM	130,000 BTUH	10.8 Tons
1 1/2"	24 GPM	240,000 BTUH	20 Tons	20 GPM	200,000 BTUH	16.7 Tons
2"	47 GPM	470,000 BTUH	39 Tons	45 GPM	450,000 BTUH	38 Tons
2 1/2"	75 GPM	750,000 BTUH	63 Tons	80 GPM	800,000 BTUH	67 Tons
3"	130 GPM	1,300,000 BTUH	108 Tons	130 GPM	1,300,000 BTUH	108 Tons

Steel Pipe				Copper Pipe		
Pipe Size	Flow Rate	Heating BTUH	Cooling Tons	Flow Rate	Heating BTUH	Cooling Tons
4"	270 GPM	2,700,000 BTUH	225 Tons	260 GPM	2,600,000 BTUH	217 Tons
5"	530 GPM	5,300,000 BTUH	442 Tons			
6"	850 GPM	8,500,000 BTUH	708 Tons			
	<ul style="list-style-type: none"> • Heating capacity BTUH based on a 20 degree F temperature differential • Cooling capacity Tons based on a 10 degree F temperature differential • Selection guide for water systems • Pipe sized for a maximum of 4 feet/100 feet pressure drop • $GPM = BTUH / 10,000$ • $Temperature\ differential = MBH / GPM / 500$ • $MBH = BTUH \times 1,000$ • Ton of cooling = 12,000 BTUH 					

Selecting Valves and Fittings for Energy Savings

To minimize the energy use of piping systems, piping system pressure drop must be minimized. Accessories such as valves, strainers, etc. also are major contributors to system pressure and must be optimized by proper selection. The following recommendations should be considered:

Valves

Use ball valves or butterfly valves for all isolation and balancing valves. These valves offer both very low pressure drop and low cost. Standard two-piece ball valves come in two types: full port (the opening in the ball is the same as the pipe size) and standard port (the hole is smaller than the pipe size). Full port ball valves have a lower pressure drop but cost more than standard port ball valves. It may be cost effective to use the full port valve for valves located in the "critical circuit" (the circuit that has the highest pressure drop and that determines the pump head).

Otherwise, standard port ball valves are the most cost effective. Gate valves also have a low pressure drop but they are more expensive, less reliable for tight shut-off, and cannot be used for balancing. Do not use globe valves, plug valves, or angle valves as isolation valves.

Use 2-port valves for variable speed applications

Never use 3-port valves for variable speed pumping applications. A two-way valve controls flow rate to the load through throttling, which causes pressure on the supply piping to rise. The rise in pressure is sensed by differential pressure sensor, which controls the variable frequency drive of the pump motor. In 3-way valve, because the water simply passes through the bypass line, it doesn't benefit the variable frequency drive.

GREEN TIP # 16

AIR HANDLING SYSTEMS

An air handler, or air handling unit (often abbreviated to AHU), is a device used to condition and circulate air as part of a HVAC system. Usually, an air handler is a large metal box containing a blower, cooling and/or heating coil, filter racks, sound attenuators, and dampers. Air handlers usually connect to ductwork that distributes the conditioned air through the building, and returns it to the AHU. Sometimes AHUs admit (*return*) air directly from the plenum space above false ceiling, without ductwork.

The amount of air delivered to a conditioned space is governed by one or more of the following:

- Heating and/or cooling load
- Delivery temperature
- Ventilation requirements (exhaust, people, infiltration)
- Air circulation (air changes)

The design of both comfort and many industrial air condition systems requires that, for good air circulation, the amount of supply air should provide an air change every 5 to 10 minutes. Many systems are designed for a 6- to 7-minute change. Reducing airflow will reduce fan horsepower (1.8 to 2 CFM per square foot, 10-foot high ceiling).

Air handling Units Configurations

Air handling units can be either blow-through or draw through.

Blow-through units add fan heat (usually equivalent to 2-3°F) before the cooling coil. This maximizes the temperature rise between the cooling air and the space design temperature or minimizes the amount of supply air needed to condition a space. Since the air is often saturated and moisture problems may occur, a blow-through design should not be used with final filters downstream of the coils.

Draw-through units add fan heat after the cooling coil and typically need 10% more supply air than blow-through units to achieve the same zone cooling effect. This added supply air increases the duct size requirement and fan operating costs. Moisture is less of an issue with draw through units because the fan heat helps to reduce the saturation of the supply air.

Air Handling Unit Components

Fans

The electrical energy used to drive the fan motors is often the largest part of the total energy cost. Efficient fans and motors will obviously reduce energy cost.

There are two main types of fans: centrifugal and axial. Centrifugal fans are most prevalent for air handling applications whereas axial fans are most commonly employed for ventilation and exhaust applications.

Centrifugal fans incorporate several types of fan blades – forward curved, backward curved aerofoil blades, radial etc. Backward-curved Airfoil impellers provide the highest efficiencies for centrifugal fans. Their efficiencies range from 70 to 80% and can be as much as 30% more efficient than the typical forward curved fan.

When selecting the fan, estimate the static pressure accurately. Anything that contributes to the obstruction of the free flow of air imposes a resistance to flow, which the fan has to overcome. Filter, coil, ducting and distribution system all impose resistance and all restrict flow to a degree. This restriction is known as system resistance (or pressure drop), and a vital part of the fan selection. The chosen fan must overcome this system resistance and still move the required volume of air. Of course, it would be easy to fit an oversize fan but, cost, size, efficiency, noise levels and energy consumption will suffer.

The method used in reducing the system's airflow has a great influence on the amount of horsepower saved. Three methods normally used are:

- Fan discharge damper
- Fan vortex damper (fan inlet)

- Fan speed change

Of these fan speed change is most efficient (refer HVAC tip # 17 for description).

Fan Drive Motor

Electric motors are generally most efficient when operating from 75 to 100 percent of full-load capability. An oversized motor is often needlessly inefficient because of light-load operation—particularly if it is operating at less than 50 percent of full load.

When it comes to efficiency, all motors are not created equal. The difference between two seemingly identical motors can be vast, especially in the case of small, single-phase motors. Motors for fans 1 horsepower or greater should meet NEMA premium efficiency motor guidelines when available as an option (see www.nema.org).

There are no LEED points specifically associated with drive power. However, LEED points are available for beating the ASHRAE 90.1 energy specification. In this regard, efficient drive power system design, the selection of premium-efficiency motors, and the use of VFDs can contribute to LEED certification.

Belt Drives

Belts are often used to transfer power from the drive motor to the equipment being driven.

1. Standard V-belt drives can be found in the majority of belt applications, as they are the lowest cost option of the belt family. The trade-off, as usual, is in energy efficiency.
2. V-belts, when new, can typically achieve efficiencies in the 90 to 95% range. A worn belt, however, can considerably reduce the efficiency due to slip caused by slackening and worn grip surfaces.
3. Cogged V-belts are similar to standard V-belts, except that the normally flat underside has longitudinal grooves in it, allowing better grip and less slip than standard V-belts. They typically offer a 2% to 5% efficiency bonus.

4. Synchronous belts combine toothed belts with grooved pulleys, minimizing slip and improving efficiency, typically to a range of 97% to 99%.

Filters

Filtration has a substantial impact on energy efficiency. With static pressure drops of up to 0.072 pounds per square inch (psi), filters can consume an enormous amount of fan power. As with other air-handling components, the key to energy efficiency is the face velocity (airflow per unit area of filter media). Don't confuse this to the filter efficiency. The *efficiency* of a filter refers NOT to energy efficiency, but to how well it removes particles from the airstream. Pressure drop is the measure that determines how much fan power is required to move air through the filter, and it varies by the square of the air speed through it. For typical HVAC-duty filters (30 percent ASHRAE dust-spot efficiency) a reasonable target pressure drop is 0.0036 psi. Dirty, thick, or poorly designed filters can have pressure drops as high as 0.072 psi—as much as the entire frictional drag of the duct system.

Always use a filter differential pressure gauge to monitor the pressure drop across the filters. The gauge should be checked on a routine basis as well as a visual inspection of the filters. Include a monitor to send an alarm when the filter pressure drop exceeds a predetermined maximum pressure drop.

Cooling/Heating Coils

To improve coil heat transfer performance and reduce air-side pressure drop, select coils with a low face velocity of 300 to 400 fpm (instead of conventional 500 fpm), and low approach temperatures of 5°F to 8°F instead of 10°F to 15°F.

Mixing Box

Each air-handling system should have an outdoor air connection through which ventilation air is introduced and mixes with the return air. The outdoor air can be mixed with the return air either in the ductwork prior to the air conditioning unit or at the unit's mixing plenum. In either case, the damper and duct/plenum should be arranged to promote mixing and minimize stratification.

A typical commercial HVAC system has numerous dampers that alter the flow of outside air, return air, exhaust air, and supply air. An efficient air-handling system minimizes the number of dampers necessary overall and eliminates dampers or uses low-loss dampers at branch takeoffs, reducing the fan power needed to blow air past them but maintaining the capability for minor balancing adjustments. Using variable-speed drives for fan regulation can eliminate the need for fan inlet or discharge dampers.

Return and Relief Air

Relief (rather than return) fans should be used when necessary to maintain building pressurization during economizer operation. However, where return duct static pressure exceeds 0.5 in. of water, return fans should be used.

Balancing of the System

Testing and balancing should be performed in accordance with applicable standards as published by the Associated Air Balance Council (AABC) or ASHRAE. The balancing must be carried out by skilled personnel who have training and experience in working with such systems. The contractor should be prepared to show proof of the competence of personnel used for balancing. All balancing reports need to be documented and typed for projects striving for LEED certification.

Cooling and Heating Airflow

For cooling systems, airflow rate is generally 400 CFM/ton. If airflow is greater, condensation might blow off the cooling coil. If airflow is less than 350 CFM/ton, the cooling capacity will drop and reduced airflow can also contribute to coil icing, comfort problems and a reduction in cooling efficiency by approximately 10 percent or more.

For heating-only systems, a good target is 25 CFM per kBtu/hr of heating capacity, providing about 105°F supply air. Heating airflow should not be lower than 15 CFM per kBtu/hr because supply air temperature will exceed 135°F. Excessive airflow creates more noise and can cause uncomfortable drafts.

Ventilation Airflow

Makeup air should be provided to all spaces in accordance with ASHRAE standard 62-89 "Ventilation for Acceptable Indoor Air Quality." Depending upon the space application it is usually 15 CFM per person. The revised ASHRAE standard 62-2004, provides guidelines in terms of occupancy and sq-ft covered area.

The location of air intakes shall be remote from any pollution sources and the building air intake and exhaust outlets shall be remotely located from each other to prevent contamination.

How many Air Handling Units - Their Distribution

The number of air handling units shall be decided by the number of thermal zones.

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 perimeter spaces of the building have variations in load as compared to the interior core areas. East facing zone will normally peak at 10 to 12 AM while most building loads will peak at 3 to 4 PM. South facing zones are similar but will peak usually at noon to 2 PM and may peak in winter. Therefore the building shall be divided into smaller zones to control comfort levels in each zone. The buildings may be zoned into individual floors, rooms, or spaces with distinct loads, such as exterior (perimeter) and interior 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 exterior 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.

Office buildings should be divided into thermal zones based on building size, part-load performance requirements, space layout and function, number of tenants, and the needs of the user. In an office building with similar internal loads throughout, a minimum of one zone for each of the perimeter exposures, one for the top floor building core area, one for the bottom floor building core area, and one for the interior would be ideal; for small buildings, this may be impractical. Zoning can also be accomplished using multiple air-

handling units or by having multiple zone control with a single air-handling unit. The temperature sensor for a zone should be located in a room representative of that entire zone.

Noise Control

Acoustical requirements may necessitate attenuation of the supply and/or return air, but the impact on fan energy consumption should also be considered and, if possible, compensated for in other duct or fan components. Acoustical concerns may be particularly critical in short, direct runs of ductwork between the fan and supply or return outlet. Avoid installation of the air handling units above occupied spaces. Consider locations above less critical spaces such as storage areas, toilet rooms, corridors, etc.

Raise the Cold Air Temperature Set Point at the Thermostat

Raise the cold air temperature set point at the thermostat. Higher temperatures and slightly higher humidity levels can be maintained without noticeable discomfort to the room occupants. Higher dry bulb temperatures are acceptable with lower RH – note that the comfort levels at 73.4°F and 55% RH and at 78.8°F and 35- 40% RH are about the same. Increasing room conditions from 74°F dry-bulb and 50 percent RH to 78°F dry-bulb and 55 percent RH will save approximately 13 percent of the energy required for cooling.

GREEN TIP # 17

VARIABLE AIR VOLUME (VAV) SYSTEMS

By using a variable air volume HVAC system controlled by variable speed drives, air flows can be matched to actual heating and cooling demands. Because motor speeds are reduced when full flow is not required, the electrical energy used to operate the fan is reduced.

In contrast, a constant volume air handling system without variable speed drives runs at full speed all the time, creating hot or cold air regardless of need. This wasted air is either dumped outside or into the mechanical room, wasting not only the air but also the energy that was required to heat or cool it.

VAV systems Eliminate Reheat

When humidity control is required, the conventional method is to cool the air to the required dew point temperature to remove the excess moisture and then reheat the air to deliver it at the desired humidity and temperature. The process of cooling and then reheating is inefficient, and is not considered justified in today's energy situation for comfort air conditioning systems.

VAV systems work either by opening or closing dampers or by modulating the airflow through VAV mixing boxes as loads in various zones of the building change. If, for example, more cooling in an area is required, the damper to that area is opened wider, increasing the flow of cold air until the desired temperature is reached. Conversely, if the area is too cool, the damper is slowly closed, reducing the flow of cold air.

When properly designed, the VAV system ensures that at any given instant the system do not heat and cool at the same time. VAV with reheat system is sometimes used for critical internal spaces but is not recommended for normal air conditioning systems. Energy experts are advocating to discontinue setting any standards for humidity levels for comfort air conditioning systems.

The other inherent benefit of VAV system is the fan energy savings. When the damper closes in a VAV box, the fan in the air handling unit can run at a slower speed (through the use of a variable speed drive) and the amount heating and cooling mediums running

through the coil can be reduced (through electric or pneumatic control valves). Varying the supply air volume reduces fan work, a major use of building energy.

Let's see how?

The power a fan consumes is dependent upon on the volume of air moved, the resistance against which the fan works, and the fan efficiency. For the same volume of air, the horsepower will decrease as resistance goes down and efficiency goes up. Resistance is also known as the "pressure drop" that the fan must overcome. The relation between work, air flow, and pressure drop can be expressed by the following equation:

Fan Power $\propto P \times V$

Where:

- Fan Power = horsepower or kilowatts
- P = pressure rise fan must produce
- V = volume of air or gas moved

Pressure drop or rise is usually measured in inches of water. This is because air at a certain pressure will push up a column of water in a U-shaped tube (manometer). The higher the pressure, the higher the water is pushed up. Static pressure is the force per unit area exerted on walls, ducts and piping and is what overcomes the resistance of ducts, bends, and obstructions like filters and grates. Total pressure is the combined effect of static pressure and velocity pressure. Velocity pressure is that pressure over and above static pressure caused by the movement of the air.

$$HP = \frac{V \times P}{6350 \times Eff.}$$

Where:

- HP = horsepower (divide HP by 1.34 (or multiply by 0.75) to convert to KW)
- V = volume of air or gas moved, cubic feet per minute (CFM)

- P = pressure drop overcome by fan, inches of water
- Eff. = fan efficiency (%)

Fan Laws

The effect that reduced speed has on a fan is summarized by a set of rules known as the Affinity Laws. The basic interpretation of these laws is quite simple:

1. Flow varies as fan speed
2. Pressure rise varies as fan speed squared
3. Horsepower (HP) varies as fan speed cubed

Example:

Assume you find that your fan is oversized. It is supplying 10,000 cfm at a pressure of 4in-wg and requires 9 HP. You have determined that you need only 5000 cfm. By installing a variable speed drive, you can reduce the speed by 50%. The corresponding reduction in fan static pressure and horsepower can be worked out as:

$10,000 \text{ cfm} \times 50\% = 5,000 \text{ cfm}$ and $4 \text{ in. water} \times (50\%)^2 = 4 \text{ in.} \times 0.25 = 1 \text{ in. wg}$ and

$9 \text{ HP} \times (50\%)^3 = 9 \text{ HP} \times 0.125 = 1.1 \text{ HP}$

(Assuming the fan efficiency stays the same. It would probably drop somewhat, slightly increasing power consumption. It would also be a good idea to purchase a smaller motor more suited to this power range.)

Assuming that your HVAC system operates 3000 hours per year, and cost of electricity is 8 cents per kWh (kilowatt-hour), you would save:

$(9\text{HP} - 1.1\text{HP}) \times 0.746 = 5.93 \text{ kW}$

$5.93 \text{ kW} \times 3,000 \text{ hr} = 17,790 \text{ kWh}$

$17,790 \text{ kWh} \times 8 \text{ ¢/kWh} = \$ 1,423$

This example illustrates the effects of the CUBE LAW, wherein right sizing of the fan saves considerable energy.

WHEN/WHERE IT'S APPLICABLE

VAV systems are very useful in offices, conference rooms, auditoriums, schools etc. because of their efficiency and ability to grant independent temperature control. A VAV system is also rather flexible, as the boxes can easily be moved into new ductwork branches to accommodate office renovations. Offices are usually not as pressure sensitive as other scenarios (such as hospitals or laboratories), so the deficiencies in pressure associated with a VAV system are not a large concern.

PROS AND CONS

Pros

1. Very efficient because the minimal amount of air required is used to keep a space at its design temperature. Only the necessary amount of primary air is used, conserving primary fan power.
2. Diversity is applied to supply air volume, reducing duct and fan sizes.
3. Air- or water-side economizers can be added easily to the design to minimize mechanical cooling during cooler weather.
4. Air handling unit can maintain minimum outside air amounts, avoiding the need for dedicated ventilation equipment.
5. Since a VAV box is linked to a thermostat, the ability to control temperature in a space is independent of other spaces. Rooms with similar loading patterns are often placed on the same VAV box, and through the use of a VAV system, areas with very different loading patterns can be placed on the same air handling unit.

Cons

1. As a VAV system reaches its design setpoint, the volume of air delivered to a room is decreased. This decrease in air volume is a problem because the outdoor air requirements of 20 cfm/person are not met, the velocity of air is decreased resulting

in discomfort, and if a space requires positive pressure the needs cannot be met with a VAV system.

2. Requires sophisticated controls.
3. The installation of a VAV box requires considerable space, both in the vertical and horizontal directions. As a rule of thumb, the linear duct length before a VAV box should be three times the diameter of the inlet. This length is required for the air profile in the duct to even out before entering the box. In the vertical direction, the VAV box can require up to 18", which can be a problem if above ceiling heights are relatively small.
4. A separate, distributed heating system is needed for cooler climates.

GREEN TIP # 18

DEDICATED OUTDOOR AIR HANDLING SYSTEMS

The amount of ventilation air depends upon the largest demand caused by the following:

- Ventilation for people
- Satisfaction of exhaust air
- Pressurization to overcome infiltration

In many systems, the bullet no. 2 and 3 dictates the amount of makeup air required. When this is the case, the amount of air being exhausted should be reviewed to determine, if it is excessive. Minimizing infiltration requires that all openings between conditioned and non-conditioned spaces be closed and that doors and windows fit tightly. The ventilation rate for people can vary between 5 to 20 CFM and sometimes higher depending on the use of the room.

In most buildings, HVAC systems combine fresh outdoor air with re-circulated air in the main air handler for conditioning and distribution into the interior space. Studies indicated that the ventilation becomes less efficient when the mixed air system serves multiple spaces with differing ventilation needs. If the percentage of outdoor air is simply based on the critical space's need, then all other spaces are over ventilated. Some new buildings are using a different configuration called a dedicated outdoor air system (DOAS). In this design, the outdoor air is conditioned separately from the return air before it enters the building. This system is the reliable way to meet the true intent of ASHRAE Standard 62.

What is Dedicated Outdoor Air handling (OA) System?

A dedicated outdoor air system is a 100% separate air handler used to deliver conditioned outdoor air to the space. These are especially good for buildings with multiple spaces with varying ventilation requirements. Typically these are designed to remove latent load and decouple from sensible cooling load.

This technique ensures that every conditioned space receives the required minimum ventilation air.

How Does It Work?

A DOAS doesn't rely on new technology. It uses conventional HVAC equipment configured to condition outdoor ventilation air separately from return air. A DOAS requires two sets of equipment, one for outdoor air and one for return air, whereas a conventional system requires just one.

Whether a building conditions air with a DOAS or a conventional system, there are two different types of cooling loads that the HVAC system must control:

- *Sensible cooling load.* This is the energy required to cool air to the desired temperature.
- *Latent cooling load.* This is the energy required to remove the moisture in air to reduce humidity to a target level.

By conditioning the outdoor air and return air in two separate HVAC systems, a DOAS effectively separates the two cooling loads. The outdoor-air HVAC unit removes the latent load to control humidity, and the return-air unit removes the sensible load to produce a comfortable temperature. It is possible to decouple the two loads because the primary source of building humidity in most climate areas is fresh outdoor ventilation air. The outdoor air unit can also handle the smaller amount of latent load from the building interior by providing air that is slightly drier than the target humidity level. The ventilation air is introduced into the space via its own high aspiration diffusers, independent of any other mechanical system used to thermally condition the space.

The outdoor-air unit typically cools and dehumidifies air in the summer and humidifies and heats or cools it in the winter. Therefore, the simplest unit consists of a preheating coil, a cooling coil, a reheating coil, and a humidifier.

ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) standards also require that a DOAS use energy recovery, which can be accomplished with a device called an energy-recovery wheel. Latent and sensible energy wheels transfer heat and moisture between building exhaust air and incoming air, thereby recovering energy that would have been lost to the outdoors and providing humidification or dehumidification.

How much airflow rate?

Airflow rates generally are dictated by

- Indoor air quality needs (based on ASHRAE Std. 62.1-2004 or better)
- Make-up air for toilets and kitchen exhausts (when needed)
- Latent load (dehumidified supply air provides humidity control)
- Building pressurization to prevent infiltration which allows for reduction of heating/cooling and moisture loads.

WHEN/WHERE IT'S APPLICABLE

This design strategy applies mainly to areas with expected high occupant density and is most beneficial in a facility with multiple spaces served with VAC system and having differing ventilation needs.

When evaluating whether your building is a good candidate for DOAS, it is useful to know that savings are most likely to occur for facilities found in humid climates or those that need tight humidity control, such as libraries and museums or buildings that require a large volume of outdoor air. Because there is no comprehensive set of case study data, however, these guidelines are really the only ones that exist, so it is not simple to pick a good candidate for cost-effective application.

Some of the buildings that are currently incorporating this strategy include all new U.S. federal government buildings designed in 2004 or later.

PROS AND CONS

Pros

1. A DOAS ensures compliance with 62.1-2004 for proper multiple space ventilation and ensures proper ventilation, improving air quality and occupant well-being.
2. Dedicated outdoor air systems are a useful tool for improving humidity (mold) control and delivering precise amounts of ventilation air.

3. Compared to conventional HVAC systems, they eliminate restrictions on the different types of HVAC components that designers can specify, and they often use energy more efficiently.
4. It reduces a building's energy use when compared to mixed air systems that require over ventilation of some spaces.
5. It allows the designer to decouple the latent load from the sensible load, hence providing more accurate space humidity control.
6. It allows easy airflow measurement and balance and keeps ventilation loads off main HVAC units.
7. Simplify the ventilation needs for variable air volume (VAV) systems. A DOAS system is not affected by modulating VAV boxes which otherwise would require complex control sequence to keep outdoor air constant.
8. DOAS systems are easily adaptable to economizer cycle.

Cons

1. Add first cost. The amount of operating cost savings varies widely in different applications and isn't always necessary to make a DOAS application cost-effective.
2. Depending on overall design, it may require additional materials with their associated embodied energy costs.
3. Depending on overall design, there may be more systems to maintain.
4. With two airstreams, proper mixing may not occur when distributed to the occupied space.
5. The total airflow of two airstreams may exceed airflow of a single system.

GREEN TIP # 19

OPTIMAL AIR DISTRIBUTION

Conventional air handling system design use supply air @ 55°F to maintain a room at 75°F using chilled water at 44°F. There is nothing sacrosanct about these figures; one may as well go for supply air temperature at 48°F, while maintaining the room at 75°F.

As the supply air temperature is reduced, the amount of airflow required to provide the same cooling effect is reduced proportionally. That is, a 10% increase in supply air ΔT (space setpoint minus the supply air temperature) will result in a 10% drop in required supply air volume. Any resulting decrease in air volume reduces the air handler, fan motor and duct sizes to match the lower supply air volume resulting in first capital cost savings and recurring operational savings. Other advantages include:

- Lower capacity air handler means lesser footprint of the equipment or more leasable space.
- Lower capacity fan reduces noise resulting in a quieter system.
- Lower duct sizes means less plenum space. Alternatively, sizing the air handler and ductwork as if the system is providing 55°F supply air results in lower static pressure and reduced energy consumption of fan motors.

WHEN/WHERE IT'S APPLICABLE

This approach is ideal for new buildings where there are no preexisting conditions affecting the design. The key design parameter is to identify the optimal balance point i.e. the lowest supply air temperature that can be used without increasing the annual operating cost of the building. While it is typically 48°F to 52°F, every building is different and annual energy analysis is required to determine this point. The amount of time and effort on finding the balance point depends on the complexity of the project.

The practice of reducing supply air temperature is common in grocery stores to improve humidity control, and it is gaining popularity in comfort cooling applications.

PROS AND CONS

Pros

1. The lower supply air temperature lowers the relative humidity in the space. This should allow the room set-point to be raised while still maintaining acceptable conditions as detailed in ANSI/ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. The lower RH, which come with cold air systems achieve better IAQ since, bacteria find it harder to survive at lower RH.
2. The airside can be specified with a blow-through (fan before coil) vs. a draw-through (fan after coil) configuration to eliminate the additional airflow required to compensate for fan heat in the air stream (typically a 2°F to 3°F [1°C to 1.5°C] temperature rise).

Cons

1. The penalty for achieving these reductions is that the colder supply air temperature requires more refrigeration work and reduces the number of hours in a year where economizer operation can be used. For example, lowering the supply air setpoint from 55°F to 50°F removes the opportunity to cool the building with outdoor air when the ambient dry bulb is between 55°F and 50°F.
2. Cold air system may be prone to condensation problems on the surfaces if badly engineered.

GREEN TIP # 20

DUCTWORK

The supply duct system conveys conditioned air from an AHU to the spaces of the building to be conditioned. The power that causes the air to move through the supply ducts is supplied by the fan in the AHU unit and the motor that drives the fan.

Ductwork categories

Supply duct systems are designed and constructed in many different ways. They may be categorized as follows:

Round vs. rectangular

They may be either round or rectangular. Both types have advantages and disadvantages, and both find applications where one is definitely superior to the other. A round duct, however, is more efficient than a rectangular duct in performing the same task; it is also smaller in cross-sectional area, has less duct wall exposed to moving air, lower static pressure drop and thus lower operating costs. An 18" diameter duct, for example, has the same air-carrying capacity as a 26" wide and 11" high rectangular duct. The round duct has a cross-sectional area 254.5 sq-in and a perimeter of 4.7 ft, while the rectangular duct has 286 sq-in area and a perimeter of 6.2 ft. The rectangular duct has 32% more metal in it, and should cost proportionately more. One big disadvantage of round duct is its height. If the net clear height of a furred space above suspended ceiling is, for example, 14 in, an 18 in diameter duct cannot be installed therein; however, its equivalent 26 in wide by 11 in high rectangular duct will fit the space easily.

Metallic vs. nonmetallic

Supply ducts may be further categorized according to the materials of which the ducts are made. A great majority of metallic ducts are made of galvanized steel. Next in popularity in metal ducts is aluminum. Aluminum ducts are light in weight, but basic cost per pound is higher than galvanized steel. Other metals used under special circumstances are copper and stainless steel: appearance, resistance to some types of

chemical attack. Use of glass fiber, compressed paper, plastic, cement-asbestos, vitrified clay, and concrete as non-metallic ducts is also popular.

Low velocity vs. high velocity

A duct system may also be categorized by air velocities. Low-velocity ducts are characterized by air velocities in the range of 400 to 2500 fpm, but not usually in excess of 2000 fpm. The vast majority of supply ducts, over 90%, are designed for low-velocity performance. Low velocity systems are lower in initial cost, have lower energy consumption, and, consequently, lower in operating costs.

The design of LV duct systems is very simple. It is done on the basis of restricting static pressure loss to 0.1 in - wg per 100 ft of equivalent length. Reducing the design friction rate to 0.05 in - wg per 100 ft increases the duct size and costs by 15 percent, but cuts the portion of the total pressure drop attributable to the ductwork by 50 percent. Upsizing the duct system can provide fan energy savings on the order of 15 to 20 percent.

High-velocity duct systems are characterized by air velocities in the range of 2500 to 7000 fpm, although velocities normally do not exceed 6000 fpm. HV ducts are smaller for a given air quantity and require less space for their installation, but they have a higher initial cost and even greater operating cost.

Duct frictional resistance

Any type of duct system offers frictional resistance to the movement of supply air. The frictional resistance of a supply duct varies in proportion to the square of the ratio of the velocity at two different velocities, and the fan power varies as the cube of this ratio. If a supply duct, for example, is carrying 5000 cfm of air at 1000 fpm, and a second supply duct is carrying the same quantity of air at 2000 fpm, the frictional resistance of the second duct per foot of duct length will be four times higher than that of the first duct: $(2000/1000)^2$; and the power required to overcome this frictional resistance will be eight times as much: $(2000/1000)^3$.

The AHU fan must develop a pressure equivalent to the frictional resistance of the ductwork in order to supply air in the spaces to be conditioned. This pressure is measured in terms of inches of water. The total pressure in the duct system is the sum of static and velocity pressures. Static pressure is the outward push of air against duct

surfaces as a result of the compressive force applied by the fan; velocity pressure is the directional thrust of supply air due to its velocity. A decrease in duct size increases velocity pressure and decreases static pressure; an increase in duct size decreases velocity pressure, increases static pressure.

Duct equivalent length

The fittings (elbows, tees, branch connections, etc.) and accessories (dampers, extractors, etc.) in the ductwork offer additional frictional resistance. An additional length has to be added to the actual measured length of the ductwork to take care of the resistance offered by these items to supply air. This additional length is called equivalent length, and the sum of actual measured length and equivalent length is known as total equivalent length (TEL).

$$TEL = L + (C \cdot L)$$

Where

- L = actual measured length
- C = a coefficient of duct system complexity (0.4 for simple duct systems, 1 for very complex duct systems).

One fitting can add from 5 feet to more than 60 feet to the length of the path. Designing air distribution systems to avoid excessive duct lengths/fittings, high air velocities, and pressure drop can reduce significant fan energy.

Duct layout

The ductwork should be as direct as possible, minimizing the number of elbows, abrupt contractions and expansions, and transitions. Long radius elbows and 45-degree lateral take-offs should be used wherever possible. Where variable air volume systems are used, they should have single-duct air terminal units to control the volume of air to the zone based on the space temperature sensor.

In general, the following sizing criteria should be used for the duct system components:

1. Diffusers and registers should be sized with a static pressure drop no greater than 0.08 in.

2. Supply and return ductwork should be sized with a pressure drop no greater than 0.08 inches-WG per 100 linear feet of duct run.

Other recommendations include:

1. Use smooth WYE branch fittings instead of right angle fittings for branch takeoffs, and avoid turns immediately before a supply or return air register.
2. Avoid duct connection details at the unit that degrade fan performance (called the “system effect”).
3. Provide at least two feet of straight duct before the first turn to minimize noise and loss of fan capacity.
4. Install turning vanes in supply ducts at the first turn after entering the building.
5. The ductwork shall have adequate provision for balancing airflow.

Duct Location

Ductwork should not be installed outside the building envelope in order to minimize heat gain to, or heat loss from the ductwork due to outdoor air temperatures and solar heat gain. Ductwork on rooftop units should enter or leave the air-conditioning or heat pump unit through an insulated roof curb around the perimeter of the air-conditioning or heat pump unit's footprint. Other recommendations include:

1. Locate ductwork within conditioned space whenever possible.
2. Plan locations to minimize duct lengths, turns and fittings.
3. Avoid locating ductwork in exterior walls where the ductwork may displace wall insulation.
4. With the exception of ceiling return plenums and under-floor air delivery, building cavities should not be used for air distribution.
5. When chases, furred spaces or other cavities (except ceiling return plenums) are used for air pathways, provide sealed ductwork within the cavity to convey the air.

6. Ceiling spaces should only be used as return-air plenums when the thermal insulation is located above the plenum.
7. Ducts in unconditioned spaces and outside the building should be well insulated.
8. Locate away from sources of heat and in shaded areas when possible.
9. Unconditioned attic spaces containing ducts should be well ventilated.

Use of flex duct

Flex duct, which is used extensively in light commercial construction, has more than a 60 percent higher pressure drop than galvanized metal duct of the same diameter. Flex duct runs should be limited to five feet or less. Flex duct should also be fully extended and well supported at five-foot intervals to minimize pressure losses. The bend radius should be greater than one times the duct diameter to avoid kinking. Flexible ductwork should be of the insulated type and should be

1. Limited to connections between duct branch and diffusers
2. Limited to connections between duct branch and variable air volume terminal units
3. Limited to 5 ft or less
4. Installed without any kinks, and
5. Installed with a durable elbow support when used as an elbow.

Duct Insulation

All supply air ductwork should be insulated. All return air ductwork located above the ceiling immediately below the roof should be insulated. Any outdoor air ductwork should be insulated. All exhaust and relief air ductwork between the motor-operated damper and penetration of the building exterior should be insulated.

Most duct systems are insulated with one inch of fiberglass insulation (R- 4.2). Duct wrap and duct liner two inches thick are commonly available, and improve the insulation level to R-8. Include a vapor retardant on the outside of the insulation where condensation is possible.

Exception: In conditioned spaces without a finished ceiling, only the supply air duct mains and major branches should be insulated. Individual branches and runouts to diffusers in the space being served do not need to be insulated, except where it may be necessary to prevent condensation.

Duct Sealing and Leakage

The ductwork should be sealed for Seal Class B and leak tested at the rated pressure. The leakage should not exceed the allowable CFM/100 ft² of duct area for the seal and leakage class of the system's air quantity apportioned to each section tested.

Supply and Return Air Diffusers

Recommended Elements:

1. Supply outlets (grilles and registers) shall be the appropriate style and size for the application and shall be in an appropriate location for the application.
2. Supply outlets shall not produce objectionable noise. Design guides and manufacturers' information establish limits for face velocity.
3. Supply outlets shall provide the appropriate throw for the installed location. Floor outlets shall throw the supply air to the ceiling; ceiling outlets shall throw the supply air to the wall, etc. Size depends on product performance, the supply CFM value and the face velocity limitation.
4. Never blow supply air directly into the occupied zone. Occupants will complain about drafts.
5. Floor outlets that blow air straight up the exposed wall are best for cold-climate heating; and if properly selected, adequate for cooling.
6. The relation between supply CFM, throw, face velocity and drop is established by manufacturer performance data. Performance is very sensitive to size and devices that appear to be generally similar can have substantially different performance characteristics.

7. A low resistance return path shall be provided for every room that receives supply air - a wall opening with no door, a transfer grille or a ducted return. Door undercuts are not acceptable).
8. Return grilles shall be the correct size for the grille flow rate. Filter grilles have a lower face velocity than plain grilles.
9. The location of the return grille does not affect room air patterns which are controlled by the supply outlets and will not have a significant affect on pockets of stagnate air. Low returns do “pull” warm air down to the floor and high returns do not “pull” cool air up into the occupied zone.

GREEN TIP # 21

AIR SIDE ECONOMIZERS

An airside economizer is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE Standard 90.1-2004 states an airside economizer is a "duct-and-damper arrangement and automatic control system that together allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather."

As you can see from this definition, the primary function of an airside economizer is to conserve energy by using cool outside air as a means of cooling the indoor space. When the enthalpy of the outside air is less than the enthalpy of the recirculated air, conditioning the outside air is more energy efficient than conditioning recirculated air. When the outside air is sufficiently cool, no additional conditioning of it is needed; this portion of the air-side economizer control scheme is called free cooling.

At some upper outside temperature limit, it is no longer economical to bring in 100 percent outdoor air because the energy to cool it will be greater than cooling the building return air mixed with the minimum quantity of outdoor air. This point is called the economizer changeover point and, depending on the climate, there are several ways to determine and control the changeover.

1. **Fixed temperature setpoint** economizers close to minimum position when outdoor air exceeds a fixed temperature setpoint, typically 72° to 74°F.
2. **Differential temperature** economizers will operate whenever the temperature of the outside air is below the temperature of the return air.
3. **Differential enthalpy** economizers compare the enthalpy of the outside air and return air streams and operate whenever the outside air has less heat content. Enthalpy economizers are most important in humid climates.

Air-side economizers can reduce HVAC energy costs in cold and temperate climates while also potentially improving indoor air quality, but are most often not appropriate in hot and humid climates.

Good controls, and valves or dampers, as well as maintenance, are needed to ensure proper operation of the air- and water-side economizers.

WHEN/WHERE IT'S APPLICABLE

The use of the economizer varies with climate, being greater where there are larger daily temperature swings and generally cooler temperatures. Where humidity at moderate temperatures may be very high (e.g., the Southeast), "enthalpy" controls prevent the introduction of relatively cool but humid air that will make the indoors uncomfortable.

Economizers make the most difference for systems serving spaces with low occupant density, such as libraries, administration, and other areas. In those spaces, the normal ventilator rate is fairly low and little free cooling occurs without an economizer. In classrooms and assembly areas, where high occupant density will dictate a large minimum position on the outside air damper (30% or above), economizers controls will have less impact. However, they will still be cost effective due to higher cooling loads in these spaces.

PROS AND CONS

Pros

1. Economizers save energy by cooling buildings with outside air rather than using refrigeration equipment to cool recirculated air. A properly operating economizer can cut energy costs by as much as 10 percent of a building's total energy consumption (up to 20 percent in mild, coastal climates), depending mostly on local climate and internal cooling loads.
2. As a bonus, during economizer operation abundant outside air is brought into the space, diluting and exhausting contaminants generated there.

Cons

1. A poorly designed system will have high pressure drop that at part load they require more electricity for their fans than they save in cooling.
2. Poorly fabricated economizer systems don't work properly, and their problems increase as they age. To make matters worse, there's a good chance that

malfunctioning economizers waste much more energy than they were intended to save.

3. For retrofit applications, care must be taken to protect the direct exchange coil and compressor from damage during low loads. With existing direct exchange systems, either non-integrated economizers should be installed or controls should be added to prevent compressor cycling and cutout on low evaporator temperatures. Economizer retrofits are likely to be cost effective only for larger systems (above 7.5 tons).
4. Misapplication may cause coil and/or compressor damage.
5. May increase indoor humidity levels.

GREEN TIP # 22

WATERSIDE ECONOMIZERS

Use a water-side economizer system instead of the more common air-side economizer when the air supplied to the space must be kept within tight humidity limits. Using an air-side economizer would introduce low humidity air to the space that would then have to be humidified. A water-side economizer means that chilled water is cooled by the cooling tower without mechanical refrigeration when outdoor temperatures are low enough. Minimum outdoor air is introduced to the space by using this method.

Some examples include:

1. Minimum humidity requirements - bringing in additional cold, dry outdoor air can increase humidification loads.
2. System limitations - some air handling units are easily equipped with economizers while others are not. This can be related to space, distance to the outside air intake, increased return or exhaust fan sizing, duct routing, or duct space.
3. Applications include laboratories, hospitals, data processing centers and other areas where specific minimum humidity levels are required.

Savings will be highest when electric humidification must be used and when the ambient conditions are very dry. Savings from this measure will vary based on local conditions, but the cost of humidification must be considered when making system selections.

The most common method is indirect free cooling that uses a separate plate-and-frame heat exchanger between condenser and the cooling tower. The plate-and-frame type heat exchanger configuration is typically used because it can achieve high heat-transfer efficiency without cross contamination. With the addition of a second condenser-water pump and proper piping modifications, this heat exchanger can operate simultaneously with the chiller.

The other method is direct cooling where the condenser and chilled-water systems are connected. When the outdoor wetbulb temperature is low enough, cold water from the

cooling tower is routed directly into the chilled-water loop. Although the strainer cycle is the most efficient water economizer option, it greatly increases the risk of fouling in the chilled-water system and cooling coils with the same type of contamination that is common in open cooling-tower systems. A strainer or filter can be used to minimize this contamination, but the potential for fouling prevents widespread use of the strainer-cycle system.

Alternatively for water-cooled, self-contained direct-expansion (DX) systems, a precooling coil upstream of the refrigerant coil is supplied with cold water from the cooling tower. This indirect evaporative precooling-coil circuit is similar to the strainer cycle because it interfaces an open circuit directly with the air delivered to the zones.

WHEN/WHERE IT'S APPLICABLE

Facilities that require year-round cooling from high sensible heat gains would most likely benefit from direct free cooling provided the ambient wet bulb temperature in the region gets low.

PROS AND CONS

Pros

1. Under the right conditions, free cooling or a water side economizer system can generate significant energy savings.
2. When ambient outdoor conditions are ideal (that is, when the wet-bulb temperature is low enough), the chiller can be shut off and the cooling load may be served exclusively by the cooling tower without the energy-intensive mechanical refrigeration. The resulting reduction in energy consumption can be dramatic.

Cons

1. In cooler, drier climates, water side economizers can provide over 75 percent of the cooling requirements; in warmer climates they may provide only 20 percent.
2. If direct cooling is used, without a heat exchanger, the sludge and bacteria present in the cooling tower water system may contaminate your chilled water circuit.

GREEN TIP # 23

NIGHT PRE- COOLING

ASHRAE Standard 62.2-1999 (1999) requires that the ventilation system provide fresh air @ of at least 15 cfm per person in office buildings. However, there are circumstances when greater ventilation rates lead to lower energy usage. The most obvious example is an economizer, where the goal is to maximize the amount of ventilation air when the ambient enthalpy is less than the zone return air enthalpy and there is a call for cooling.

Night pre-cooling involves the circulation of cool air within a building during the night time hours with the intent of cooling the structure. Night cooling can be done with either air or water cooling systems. For air systems, late night and early morning outdoor air temperatures allow use of the economizer cycle for much of the year, greatly reducing compressor run-time and energy. Similarly, for water systems, the chiller can be bypassed to use water from the cooling tower. For greatest demand cost savings, ensure that the HVAC systems start before the onset of higher demand charges.

The nighttime ventilation leads to lower building surface temperatures, which tends to reduce the heat gains to the air during the daytime and the associated energy and peak power consumption for the mechanical cooling equipment.

The night ventilation pre-cooling strategy can be implemented using the same sensors and control hardware employed within an economizer controller. Therefore, it should be cost effective to integrate night ventilation control with economizers. Even greater savings should be possible for packaged units that use variable speed fan control.

WHEN/WHERE IT'S APPLICABLE

Night pre-cooling would be applicable in the following circumstances:

1. A hot, dry environment, such as the southwestern United States, is an ideal potential area for this concept.
2. Night pre-cooling and night ventilation can reduce both HAVC peak demand and energy consumption in heavy mass buildings, but not in light buildings.

3. Since commercial buildings such as offices, restaurants, and retail stores are not occupied at night, they are better candidates for use of night ventilation as compared to residential buildings, which are occupied at night. Furthermore, there is also a greater opportunity for savings in large commercial buildings than smaller ones because of a smaller ratio of external area to thermal mass, the use of heavier weight materials, and the availability of more favorable electrical rate structures.
4. The cost-effectiveness of night ventilation is increased when night electricity rates are lower than daytime rates.

PROS AND CONS

Pros

1. Night ventilation pre-cooling has good potential for net energy savings because the power required to circulate the cooler nighttime air through the building is relatively low compared to the power required to mechanically cool the space during the daytime hours.
2. Mechanical pre-cooling could lead to net energy savings, although there will likely be a net increase in total energy use due to the less-than-100% TES efficiency in the building mass.
3. Both variations require only minor, if any, change to the overall building and system design. Any changes required are primarily in the control scheme.
4. Night ventilation can provide a better IAQ environment due to increased circulation of air during the night. A greater potential exists with the ventilation pre-cooling concept. Both will be better than if the system were completely shut off during unoccupied hours.

Cons

1. Night ventilation is usually not effective in humid climates.
2. The major drawback of night cooling is the potential for cold space temperatures at the beginning of the occupied period. Stopping night cooling an hour before occupancy typically ensures comfortable conditions for early arrivals.

3. The system designer needs to be aware of the introduction of additional humidity into the space with the use of night ventilation. Thus, the concept of night ventilation pre-cooling is better suited for drier climates.
4. A mechanical nighttime pre-cooling system will prevent the introduction of additional humidity into the space by the natural dehumidification it provides, but at the expense of greater energy usage compared to night ventilation alone.
5. Both variations (night ventilation and night mechanical pre-cooling) are not 100% efficient in the thermal energy storage (TES) in the building mass, particularly if the building is highly coupled (thermally) with the outside environment.
6. Temperature control should be monitored carefully. The potential exists for the building environment to be too cool for the occupant's comfort during the early hours of the occupied period.

GREEN TIP # 24

DESICCANT DEHUMIDIFICATION

Desiccant dehumidifiers are primarily aimed at reducing the humidity factor in the atmosphere. Whether a place is conditioned or unconditioned, there is a need to keep the level of humidity at a comfortable level at all times. The principle of indoor air-conditioning is guided by factors like:

- Bringing in enough air from outside the premise (outdoor air exchange)
- Allowing the outdoor air in after a certain level of purification i.e. filtration
- Controlling the airflow i.e. by keeping the air pressure inside the premise positive (so that when doors are opened, airflow takes place from indoors to outdoors and not the other way round).

In a conditioned space, temperature is kept at a definite level and a constant process of condensation takes place. Due to this, the level of moisture keeps on rising, which is not conducive for conditioned areas. The need for climate control in commercial buildings with centralized air-conditioning calls for active humidity control such as desiccant dehumidifiers.

Desiccants dehumidify by principle of adsorption. Desiccant materials can adsorb between 20% and 40% of their dry weight in water vapor from humid air. Both solid and liquid desiccants are used in cooling systems, but solid desiccants are much more common in commercial buildings. Liquid desiccants employ solutions such as glycol or salts such as lithium chloride (LiCl_2). In solid desiccant systems, desiccant is formed in place in a honeycomb matrix wheel mounted between the process air stream and the reactivation air stream; air seals separate the air streams from each other. The desiccant wheel rotates slowly (6 to 20 rph) between the two air streams. The process airflows through the wheel, gives up its moisture to the desiccant and increases dry-bulb temperature (up to 120°F), and finally is cooled by coils for comfort supply. After drying the air, the desiccant wheel is saturated with moisture and rotates slowly into the reactivation air. The hot reactivation air (with temperature up to 250°F typically required) heats the honeycomb, absorbs moisture released by the hot desiccant, and is released as exhaust air from the building. Desiccants are also available that can be regenerated

at temperatures as low as 120°F, allowing a greater range of options for heat sources such as heat pumps or solar sources.

While installing dehumidifier units, one should also consider the area of coverage of the units. It is wise not to put dehumidifiers in areas where sufficient airflow takes place. The system of dehumidification is essentially for trapped spaces.

WHEN/WHERE IT'S APPLICABLE

Desiccant dehumidification is recommended for applications demanding large dehumidification and low space humidity levels, which would be difficult to achieve with cooling-type dehumidification. Desiccant systems are applicable to clean rooms, supermarkets, refrigerated warehouses, ice rinks, schools, restaurants, theaters, hotels, hospital/healthcare facilities, and situations where one or more of the following situations apply:

- Low indoor humidity (dew point below 50°F)
- High latent load fraction (greater than 25%)
- High outside air fraction (greater than 20%)
- High electrical cost and low gas costs
- Available heat source from waste heat, steam, hot water or gas for regeneration of desiccant

Costs of desiccant systems are typically given in terms of \$/cfm. For large commercial systems, the cost is approximately \$5/cfm, while smaller units (less than 1000 cfm) may cost up to \$8/cfm. The higher initial cost of desiccant systems may be offset by lower operating costs and improved productivity because of increased comfort and enhanced indoor air quality.

PROS AND CONS

Pros

1. Dehumidifiers offer three basic benefits - fresh air, optimum humidity limit and energy conservation.
2. In large buildings where non-electric heat is available for reactivation of desiccants, desiccant systems can reduce HVAC electricity use by 30% to 60% and peak electricity demand by 65% to 70%. The maintenance requirements of desiccant systems can be modest compared to conventional cooling-based dehumidification systems.
3. Desiccant systems improve an air conditioning system by removing moisture from ventilation air. Since the cooling system no longer has to remove moisture, it operates more efficiently in sensible cooling mode.
4. Desiccant equipment tends to be very durable.
5. Often this is the most economical means to dehumidify below a 40°F dew point.
6. It eliminates condensate in the air stream, in turn, limiting the opportunity for mold growth.

Cons

1. Desiccant usually must be replaced, replenished, or reconditioned every five to ten years.
2. The process is not especially intuitive and the controls are relatively complicated. The choice of a desiccant system affects the selection and sizing of the cooling coil, because the cooling coil only needs to handle the sensible load of the supply air, which allows for higher chilled water temperature and efficient operation. The sensible cooling load will be higher because of the hot dry air leaving from the desiccant wheel (due to heat of adsorption).
3. The addition of a desiccant wheel will increase the pressure drop, fan power and maintenance, and an additional motor is required to rotate the wheel. This extra energy usage must be counted accordingly.

GREEN TIP # 25

HEAT RECOVERY DEVICES

ENTHALPY & HEAT WHEELS

The heat recovery systems for the HVAC industry use the heat of exhaust air to pre-heat fresh air. Or, on hot days, colder exhaust air will pre-cool the hot fresh air.

ASHRAE Standard 90.1 – 2001 sets minimum design requirement for heat recovery devices that encourage energy efficiency. This standard requires the use of exhaust-air energy recovery when an individual fan system meets both of the following conditions:

- Design supply airflow equals or exceeds 5000 CFM
- Minimum outdoor airflow \geq 70 %design supply airflow

Three most common types of heat recovery devices are 1) Rotary heat exchangers also known as sensible heat wheels and total enthalpy wheels, 2) Heat pipes and 3) Run-around coils.

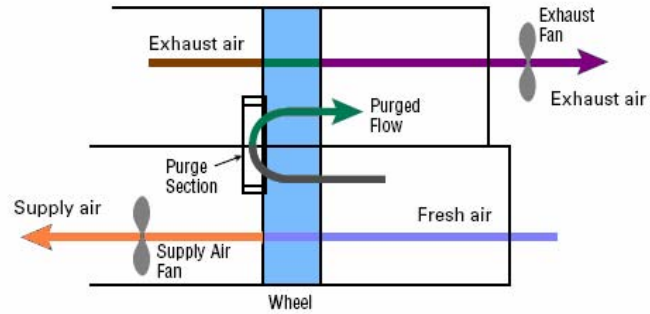
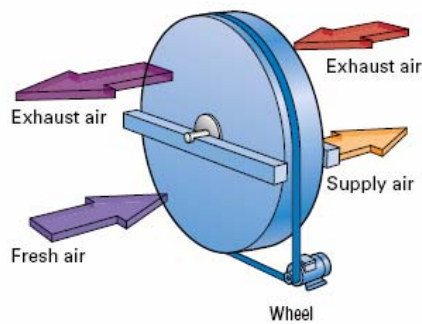
Enthalpy Wheels

The enthalpy wheels filled with desiccant materials work in two applications 1) effective dehumidification of indoor spaces and 2) for recovering energy from building exhaust air.

We have discussed the first item “effective dehumidification” system in Green Tip #24.

Heat wheels or thermal wheels consist of a rotor with permeable storage mass fitted in a casing. The rotor is driven by a motor so that the exhaust air and fresh air are alternately passed through each section. Sometimes a purge sector is created to reduce cross contamination between the two airflows. A unique advantage of heat wheels is the capability of recovering both sensible and latent heat, meaning; it does not only recover heat, but also moisture.

Thermal efficacy is between 65% and 75%.



Technology Types

A small motor and belt drive rotates the wheel and its fill medium. Sensible heat is transferred as the hot air stream passes through the fill which picks up and stores heat and then releases it as the fill rotates into the cold air stream.

Latent heat is transferred as the wheel fill:

- Condenses moisture from the air stream with the higher humidity (either due to a fill temperature below the air dewpoint or because the fill includes a desiccant) and heat is released, and
- Releases the moisture through evaporation (and picks up heat) as the fill rotates into the air stream with the lower humidity ratio. Both latent and sensible heat is transferred simultaneously as the moist air is dried and the dry air is humidified.

Fill for total heat recovery is made from a number of different materials and treated with a hygroscopic material such as lithium chloride, alumina, or aluminum oxide, each of which has specific moisture pickup properties.

[* Note that the heat wheels have a fill that transfers only sensible heat while an enthalpy wheel's fill transfers total heat].

WHEN/WHERE IT'S APPLICABLE

Heat wheels are preferred if:

- Both heat and humidity recovery is desirable.
- High heat recovery efficacy is called for.

- High airflows (generally >10000 CFM) and small casing dimensions are required.

Possible Applications

- Existing buildings where codes require it or they have "sick building" syndrome and the amount of outdoor air intake must be increased,
- New buildings where the required amount of ventilation air causes excess loads or where the desired equipment does not have sufficient latent capacity.

Applications to Avoid

- Where the intake or exhaust air ducts must be rerouted extensively, the benefits are likely not to offset the higher fan energy and first cost.
- Use of an enthalpy wheel where there are contaminants in one of the air streams. Corrosion, scale, and fouling of the wheel and its fill where a wetted condition can occur are all needs to be addressed carefully.

PROS AND CONS

Pros

1. The total HVAC system installed cost may be lower because central heating and cooling equipment may be reduced in sized.
2. These wheels are quite compact and can achieve high heat transfer effectiveness
3. The cooling or heating equipment size can be reduced in some cases.
4. With a total energy wheel, humidification costs may be reduced in cold weather and dehumidification costs may be lowered in warm weather
5. Heat wheel heat exchanger enhancement can improve system latent capacity. For example, a 1°F dry bulb drop in air entering a cooling coil can increase the latent capacity by about 3%. Both cooling and reheating energy is saved by the heat wheel's transfer of heat directly from the entering air to the low-temperature air leaving the cooling coil. It can also be used to precool or preheat incoming outdoor air with exhaust air from the conditioned spaces.

6. The other systems listed are suitable for installations that are unable to bring the exhaust outlet duct and ventilation air inlet duct close together. This can be the case for existing building A/C systems.

Cons

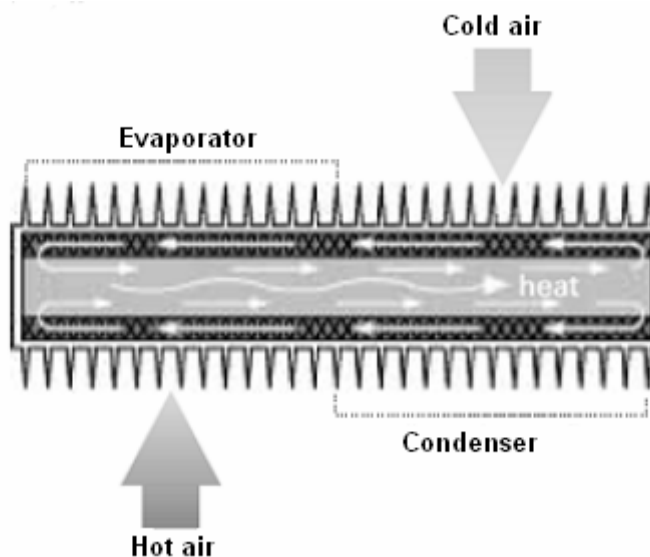
1. Adds to the first cost and to the fan power to overcome its resistance
2. Requires that the two air streams be adjacent to each other
3. Requires that the air streams must be relatively clean and may require filtration
4. Requires a rotating mechanism that requires it be periodically inspected and maintained, as does the cleaning of the fill medium and any filtering of air streams
5. In cold climates, there may an increase in service needs
6. Results in some cross-contamination (mixing) of the two air streams, which occurs by carryover and leakage
7. Energy wheel adds pressure drop to the system.

GREEN TIP # 26

HEAT PIPE SYSTEMS

Heat pipes are finned tubes, evacuated and charged with a refrigerant. The tubes are placed in both exhaust air and fresh air streams. Exhaust air will boil and evaporate the refrigerant inside the tube, cooling down the exhaust air. The fresh air heats up as the refrigerant condensates inside the heat pipe. Due to the phase change of the refrigerant, a huge amount of thermal energy can be transferred at small temperature differences.

The heat pipe system is hermetically sealed, uses a wicking action, and requires no pump. The thermal efficacy of heat pipes is between 45% and 55%.



Heat transfer along a heat pipe is 1000 times faster than through copper and this allows the coil to more effectively cool the air to a point below the dew-point temperature and to extract more moisture. Heat pipes typically have zero cross-contamination, but constructing a vented double-wall partition can provide additional protection. Changing the slope or tilt of a heat pipe controls the amount of heat it transfers. Operating the heat pipe on a slope with the hot end below (or above) the horizontal improves (or retards) the condensate flow back to the evaporator. By utilizing a simple temperature sensor-controlled actuator, the output of the exchanger can be modulated by adjusting its tilt angle to maintain a specific leaving temperature.

Heat pipes systems can also be used for energy recovery from the building exhaust similar to enthalpy wheels. Energy recovery is most economical when there are large temperature differences between the airstreams.

WHEN/WHERE IT'S APPLICABLE

Reclaiming heat from exhaust air and returning it to the fresh supply stream saves energy and money in a huge range of buildings such as hospitals, swimming pools, supermarkets, schools and colleges, restaurants, and social clubs. In every case, the running cost of the heat pipe heat recovery system is virtually nil, and maintenance is minimal.

A wrap-around heat pipe enhances the performance of a dehumidifier and improves the quality of the recycled air. The Heat Pipe provides a more comfortable environment for living and working in applications such as shopping malls, call centers, supermarkets for example.

The installation cost of a heat pipe loop for a cooling system is approximately \$2.50/cfm.

Possible Applications

1. Use of a dry heat pipe coupled with a heat pump in humid climate areas.
2. Heat pipe heat exchanger enhancement used with a single-path or dual-path system in a supermarket application.
3. Existing buildings where codes require it or they have "sick building" syndrome and the amount of outdoor air intake must be increased,
4. New buildings where the required amount of ventilation air causes excess loads or where the desired equipment does not have sufficient latent capacity.

PROS AND CONS

Pros

1. Passive heat exchange with no moving parts
2. Relatively space efficient

3. The cooling or heating equipment size can be reduced in some cases
4. The moisture removal capacity of existing cooling equipment can be improved
5. No cross-contamination between air streams
6. Heat pipes increase the effectiveness of air conditioning systems by helping to decrease the total cooling load of the air.
7. They require little maintenance and are simple to operate.

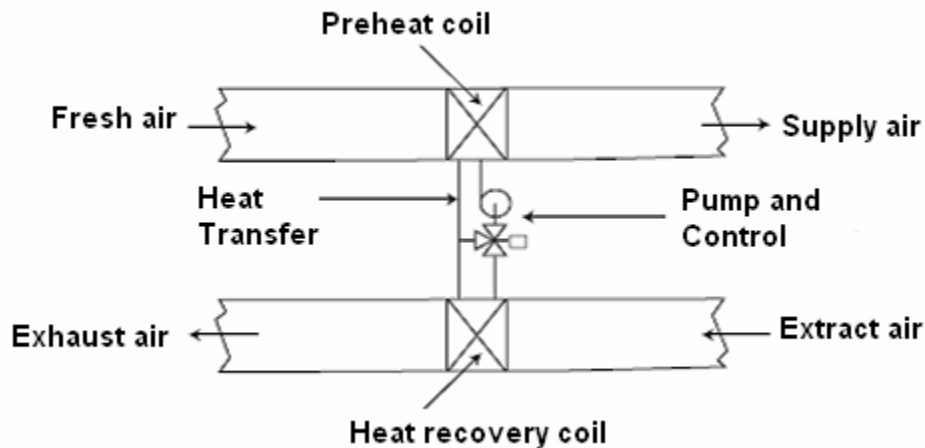
Con

1. Adds to the first cost and to the fan power to overcome its resistance
2. Requires that the two air streams be adjacent to each other
3. Requires that the air streams must be relatively clean and may require filtration
4. The cost effectiveness of heat pipes depends on the system it is replacing. When used instead of a dehumidifying system requiring reheat, the simple payback is two to three years. However, when the system replaces a system without reheat (that is, no humidity control), there are additional benefits including increased comfort and enhanced indoor air quality, which are difficult to quantify.
5. Decomposition of the thermal fluid can deteriorate performance.

GREEN TIP # 27

RUN - AROUND SYSTEMS

Run-around coils use two physically separated heat exchangers (coils) in the air supply and exhaust ducts to recover and transfer heat between them. The heat is transferred from the exhaust to supply air using an intermediate heat transfer fluid, such as water. This system operates for sensible heat recovery only.



The coil in the exhaust air and the coil in the fresh air are linked with a closed water (or water-glycol mixture if frost is expected) circuit and a circulation pump. The heat is first transmitted from the exhaust coil to the water circuit and then to the fresh air coil via the second coil. The thermal efficacy is usually 45% to 55%.

Coil energy recovery loop systems are highly flexible and well suited to renovation and industrial applications. The system accommodates remote supply and exhausts ducts and allows the simultaneous transfer of energy between multiple sources and uses. An expansion tank must be included to allow fluid expansion and contraction. A closed expansion tank minimizes oxidation when ethylene glycol is used.

Standard finned tube water coils may be used; however, these need to be designed using an accurate simulation model if high effectiveness values and low costs are to be realized. Integrating runaround loops in buildings with variable loads to achieve maximum benefits may require combining the runaround simulation with building energy simulation.

Moisture must not freeze in the exhaust coil air passage. A three-way temperature control valve should be used that prevents the exhaust coil from freezing. The valve is controlled to maintain the temperature of the solution entering the exhaust coil at 30°F or above. This condition is maintained by bypassing some of the warmer solution around the supply air coil. If a dual- purpose valve is used, it can also ensure that a prescribed air temperature from the supply air coil is not exceeded.

WHEN/WHERE IT'S APPLICABLE

Run-around coils are preferred if:

- The exhaust air and fresh air ducts are far away.
- Exhaust air and fresh air must be absolutely isolated
- Small unit dimensions are required with high airflow rates

PROS AND CONS

Pros

1. The main advantage of this system is that the supply and extract ducts can be physically separated, even in different parts of the building. This provides maximum possible flexibility, as well as no possibility of cross contamination between air streams.
2. Easily turned off when energy recovery is not beneficial.
3. Runaround loops allow the simultaneous transfer of energy between multiple sources and uses.
4. Lower cooling load contributes to a smaller cooling system and less pumping energy use, but fan energy increases due to extra air pressure drop through the run-around coils.
5. The run-around loop can either be applied to existing systems or can be installed at the factory. The run-around loop requires a fractional horsepower pump, a 120V–

60HZ single-phase electrical circuit, and a three-way valve or a variable-speed drive (VSD) for the pump.

6. The total HVAC system installed cost may be lower because central heating and cooling equipment may be reduced in sized.
7. The loop accommodates remote supply and exhaust duct locations.
8. Cross-contamination is not a concern.

Cons

1. The main disadvantage of this system is that, because an intermediate fluid is used as a heat transfer medium, the system's efficiency is reduced and electricity is required for pumping fluid.
2. It adds pressure drop to the system.
3. Relative to passive air-to-air heat exchangers (i.e., heat wheels or heat pipes); it requires extra maintenance for the two coils and the loop. Air trapped in the coils, pump and piping must be vented upon initial startup to ensure effective fluid flow and heat transfer.
4. The initial cost of a run-around system is about double that of a conventional system, but if the downsizing of the chiller and cooling tower is counted, the total initial cost will be very close. The total installation cost is approximately \$4.50 to \$5.00/cfm.
5. For bigger systems, requires field installation of piping, pump, an expansion tank with air vent, a mixing valve or variable speed drive.

GREEN TIP # 28

EVAPORATIVE COOLING

An evaporative cooling system uses the physics of water evaporation and is an alternative way to provide air conditioning in dry climates. When a pound of water evaporates, almost 1000 Btu's of cooling is associated with the process.

When warm dry air is blown across a medium thoroughly wetted with water, the air is cooled and its humidity is raised. If the process were 100% efficient, the temperature drop of the air would be the difference between dry bulb and wet bulb temperatures. In practice, efficiencies of 80-90% are routinely achieved.

Two terms are important here:

Wet Bulb Depression - The difference between the Dry Bulb and Wet Bulb temperatures, i.e. if Dry Bulb is 100 degrees (F) and the Wet Bulb is 70 degrees (F), the Web Bulb Depression is 30 degrees (F). The Wet Bulb Depression is used to determine the percent of efficiency of the cooling media.

Cooling Efficiency - The percent of the temperature drop across the media compared to the Wet Bulb Depression i.e. if the Wet Bulb Depression is 30 degrees (F) (as in the above example) and the actual temperature drop measured across the cooling media is 27 degrees (F), the cooling efficiency of the media is 90%. ($27/30 = .90$). The cooling efficiency is also referred to as "Saturation Efficiency" because it refers to the amount of moisture that is packed into the air. 100% Saturation Efficiency would indicate a temperature drop of 30 degrees (F) in the above example of wet bulb depression.

Evaporative cooling can be direct or indirect.

Direct Evaporative Cooling

Direct evaporative cooling (open circuit) is used to lower the temperature of air by using latent heat of evaporation, changing water to vapor. In this process, the energy in the air does not change i.e. this process lowers the dry-bulb temperature of the supply air stream while the wet bulb temperature remains constant; it also increases the air

moisture content. Warm dry air is changed to cool moist air. Heat in the air is used to evaporate water.

The effectiveness can reach 80% to 90% meaning that the dry bulb temperature drops 80% - 90% of the difference between the dry bulb and wet bulb temperature of the entering air. For example, if entering air temperature is 80°F dry bulb and 50°F wet bulb, then the leaving air is cooled to 56°F dry bulb at 80% effectiveness and 53°F dry bulb at 90% effectiveness.

Indirect Evaporative Cooling

Indirect evaporative cooling (closed circuit) is similar to direct evaporative cooling, but uses some type of heat exchanger. The cooled moist air never comes in direct contact with the conditioned environment. Indirect evaporative cooling results in lowering both dry bulb and wet bulb temperatures

Indirect evaporative cooling is not as effective as direct evaporative cooling, but adds no moisture to the supply air. Indirect evaporative cooling can be approximately 60% effective in reducing the dry bulb temperature of the entering air to its wet bulb temperature. While direct cooling provides 53°F to 56°F air in the example above, indirect cooling could provide 62°F air.

WHEN/WHERE IT'S APPLICABLE

Evaporative cooling is especially well suited for hot and dry climates. For example, in the United States, the western/mountain states are good locations; with swamp coolers are prevalent in cities like Denver, Salt Lake City, Albuquerque, El Paso and Phoenix.

Consider evaporative cooling for spaces with high outside air ventilation requirements and dry outdoor conditions.

In highly humid climates, evaporative cooling may have little thermal comfort benefit beyond the increased ventilation and air movement it provides. But indirect evaporative cooling can be applied during non-peak seasons. It is especially applicable for loads that operate 24 hours a day for many days of the year. Sometimes both evaporative cooling and vapor-compression air conditioning are sometimes used in combination to yield optimal performance.

PROS AND CONS

Pros

1. Less expensive to install - Estimated cost for installation is 1/8 to 1/2 that of refrigerated air conditioning
2. Less expensive to operate – Evaporative coolers use only a fraction (about 1/4th) of the energy of vapor-compression or absorption air conditioning systems.
3. Ventilation air - The constant and high volumetric flow rate of air through the building reduces the age-of-air in the building dramatically. Evaporative cooling increases humidity, which, in dry climates, may improve thermal comfort.
4. Some evaporative coolers may also serve as humidifiers in the heating season.

Cons

1. Evaporative coolers increase the humidity levels.
2. High temperature, high humidity outside conditions decrease the cooling capability of the evaporative cooler.
3. The air supplied by the evaporative cooler is typically 80–90% relative humidity. Very humid air reduces the evaporation rate of moisture from the skin, nose, lungs, and eyes.
4. High humidity in air accelerates corrosion. This can considerably shorten the life of electronic and other equipment.
5. High humidity in air may cause condensation. This can be a problem for some situations (e.g., electrical equipment, computers, paper/books, old wood).
6. Evaporative coolers require a constant supply of water to wet the pads. On site water consumption increases.
7. Larger ducts are required compared to a typical compressor cooling system, and duct size may be consideration in the architectural and structural design.

8. The water supply line needs protection against freeze bursting during off-season, winter temperatures. The cooler itself needs to be drained too, as well as cleaned periodically and the pads replaced.
9. Pollen, odors, and other outdoor contaminants may be blown into the building unless sufficient filtering is in place.
10. The vents that allow air to exit the building may pose a physical security risk.
11. Asthma patients may need to avoid evaporatively cooled environments.

GREEN TIP # 29

DEMAND CONTROL VENTILATION USING CO₂ SENSORS

The amount of ventilation air is based on the ASHRAE Standard 62, which calls for 15 cfm of outside air per person. However, providing ventilation strictly on the peak occupancy will result in over ventilation and therefore higher energy costs during lean periods.

Demand-controlled ventilation modulates ventilated air to keep CO₂ levels less than or equal to 1000ppm [600ppm + the outdoor air CO₂ concentration*] in all spaces with CO₂ sensors. The outdoor air CO₂ concentration can be assumed to be 400ppm without any direct measurement, or the CO₂ concentration can be monitored using a CO₂ sensor located near the position of the outdoor air intake.

Simply put, the amount of CO₂ present in the air is an indicator of the number of people in the space and, in turn, the amount of ventilation air that is required. CO₂-based ventilation control does not affect the peak design ventilation capacity required to serve the space as defined in the ventilation rate procedure, but it does allow the ventilation system to modulate in sync with the building's occupancy.

The key components of a CO₂ demand-based ventilation system are CO₂ sensors and a means by which to control the outdoor fresh air intake, i.e., a damper with a modulating actuator. The number and location of carbon dioxide sensors for demand-control ventilation can affect the ability to accurately reflect the building or zone occupancy. A minimum of one CO₂ sensor per zone is recommended for systems with greater than 500 cfm of outdoor air. Multiple sensors may be necessary if the ventilation system serves spaces with significantly different occupancy expectations. Where multiple sensors are used, the ventilation should be based on the sensor recording the highest concentration of CO₂.

Sensors used in individual spaces with high outdoor air requirements (e.g., conferences rooms) should be installed on a wall within the space; for multiple spaces of similar occupancy (i.e., private offices), a return air duct-mounted sensor may be more cost-effective and provide an average CO₂ measure for the zone. For sensors mounted in return air duct, adequate access for sensor calibration and field test must be provided.

The number and location of sensors should take into account the sensor manufacturer's recommendations for their particular products.

CO₂ sensors should be certified by the manufacturer to have an accuracy of no less than 75 ppm, factory calibrated and calibrated periodically as recommended by the manufacturer.

WHEN/WHERE IT'S APPLICABLE

CO₂ demand control is best suited for buildings designed for large number of people and which are frequently partially occupied. The savings will be greatest in spaces that have a wide variance, such as gymnasiums, large meeting rooms, and auditoriums. For buildings with a constant occupancy rate, such as an office building or school, a simple nighttime setback scenario may be more appropriate for ventilation demand control, but CO₂ monitoring may still be utilized for verification that high IAQ is achieved.

LEED 2.2 Indoor Environmental Air Quality (IEQ) credit 1 states that when the indoor CO₂ levels rise 10% above the ASHRAE 62-2004 requirements, then the mechanical control system shall be able to send an alarm to the occupants so that they will be informed and can take corrective action. The spaces that should be included in the application of this credit are all densely populated areas such as those with a design occupant density greater than or equal to 25 people per 1,000 ft². This would typically include all K-12 and higher education classrooms, restaurants, conference rooms, auditorium, courtrooms, gymnasiums, etc (refer to table 6-1 in ASHRAE 62-2004 for a complete list).

PROS AND CONS

Pros

1. DCV saves energy by avoiding the heating, cooling, and dehumidification of more ventilation air than is needed.
2. Improved IAQ—By increasing ventilation if CO₂ levels rise to an unacceptable level
3. Improved humidity control—in humid climates, DCV can prevent unnecessary influxes of humid outdoor air that makes occupants uncomfortable and encourages mold and mildew growth.

4. It assists in maintaining adequate ventilation levels regardless of occupancy.

Cons

1. There is an added first cost associated with the sensors and additional controls.
2. Evolving sensor technology may not be developed to full maturity.
3. Carbon dioxide sensor calibration and maintenance considerations need to address.
4. Inability to appropriately address non-human pollutants

GREEN TIP # 30

DISPLACEMENT VENTILATION

The conventional air distribution systems generally supply air in a manner that the air in the entire room is fully mixed. In cooling mode, the cool supply air, typically around 55°F (saturated) at design conditions, exits an outlet at high velocity, inducing room air to provide mixing and temperature equalization. Because the entire room is near-fully mixed, temperature variations are small while the contaminant concentration is fairly uniform throughout the entire room. To enhance the mixing, diffusers are normally used as the air outlets. Most often, the air outlets and inlets are placed in the ceiling.

In displacement systems, supply air is purposely not uniformly mixed throughout the space. It is intentionally stratified vertically to provide a better quality of air in the occupied part of the facility. Air is typically supplied at or near the floor in the space at extremely low velocity, which results in no “throw” of air and subsequently little risk of “drafts”. The supply air moves horizontally across the floor until it naturally rises, driven by convective currents as it warms due to internal heat from the process, people, lights, computers, etc. By doing so, the air quality in the occupied zone is generally superior to that achieved with mixing room air distribution.

Since the conditioned air is supplied directly into the occupied space, supply air temperatures must be higher than mixing systems (usually above 63°F) to avoid cool temperatures at the floor. By introducing the air at elevated supply air temperatures and low outlet velocity a high level of thermal comfort can be provided at lower energy.

If air mixing is encouraged at the floor level, this type of floor-to-ceiling room air distribution is known as under floor air distribution (UFAD); if mixing is discouraged, it is displacement.

WHEN/WHERE IT'S APPLICABLE

Displacement ventilation is most appropriate for spaces with ceiling height of at least 9 ft to permit stratification: higher ceilings of 12 ft will improve stratification and reduce energy requirements. It is typically used in industrial plants and data centers, but it can be applied in almost any application where a conventional overhead forced air distribution system could be utilized and the load permits.

Some associate displacement ventilation solely with underfloor air distribution and the perceived higher costs associated with it. In fact, most underfloor pressurized plenum, air distribution systems do not produce true displacement ventilation but, rather, well-mixed airflow in the lower part of the space. It can, however, be a viable alternative when considering systems for modern office environments where data cabling and flexibility concerns may merit a raised floor.

PROS AND CONS

Pros

1. Less Fan Horsepower Needed. In this design approach, supply airflows needed to achieve adequate temperature control and provide adequate ventilation are often lower than conventional system. Thus, typically lower fan horsepower than conventional mixing type systems is needed.
2. Less Room Noise: Low velocity supply of air cannot be accomplished using conventional ceiling mounted mixing type diffusers, conventional heating ventilators (air make-up units), or non-ducted fan coils. With reduced total air flow quantities and low exit velocities, there is reduced noise when compared to mixing type systems because there is no need to forcefully mix air in the room and less total airflow is needed.
3. Reduced Cooling Capacity Needed. Thermal stratification also allows for some reduction of internal cooling requirements, because about 50% of the heat from the lights and other sources located above the occupants does not reach the occupied zone and, in this design, is exhausted outdoors when not needed.
4. More effective pollutant removal. The vertical air flow eliminates lateral air mixing. Pollutants are drawn up in a vertical plume to the ceiling rather than being swirled around with room air.
5. Since air is delivered at about 65°F, there are greater hours of free cooling, where the compressor is not required to run. With 65°F supply air temperature, the required cooling capacity will usually be lower with displacement ventilation.

6. Extended economizer range. Using warmer supply air significantly extends conditions for free cooling (using outside air directly for cooling, with no chiller operation), especially in mild climates.
7. Flexible space arrangements. The raised floor, with its modular panels, makes it easy to relocate diffusers, wiring, and even plumbing to accommodate changes in occupancy.

Cons

1. It may add complexity to the supply air ducting.
2. It is more difficult to address high heating or cooling loads.
3. There are perceived higher first costs.
4. Heating performance may be worse than systems providing air at greater velocities. Mixing is desirable for heating.
5. Lack of available design tools makes this a less attractive option at the design stage.
6. Some floor area or low wall area is required for supply air outlets.
7. The required supply airflow can be up to 20-25% higher than a comparable overhead mixing system.
8. Because the range of supply air temperatures and discharge velocities is limited to avoid discomfort to occupants, displacement ventilation has a limited ability to handle high heating or cooling loads. Some designs use chilled ceilings or heated floors to overcome this limitation.

GREEN TIP # 31

HYBRID VENTILATION

A hybrid ventilation system allows the controlled introduction of outdoor air ventilation into a building by both mechanical and passive means. It has built-in strategies to allow the mechanical and passive portions to work in conjunction with one another so as to not cause additional ventilation loads compared to what would occur using mechanical ventilation alone. It thus differs from a passive ventilation system, consisting of operable windows alone, which have no automatic way of controlling the amount of outdoor air load.

Two variants of hybrid ventilation are the changeover (or complementary) type and the concurrent (or zoned) type. With the former, spaces are ventilated either mechanically or passively, but not both simultaneously. With the latter variant, both methods provide ventilation simultaneously, though usually to zones discrete from one another.

Control of hybrid ventilation is obviously an important feature. With the changeover variant, controls could switch between mechanical and passive ventilation seasonally, diurnally, or based on a measured parameter. In the case of the concurrent variant, appropriate controls are needed to prevent “fighting” between the two ventilation methods.

WHEN/WHERE IT’S APPLICABLE

A hybrid ventilation system may be applicable in the following circumstances:

1. When the owner and design team are willing to explore employing a non-conventional building ventilation technique that has the promise of reducing ongoing operating costs as well as providing a healthier, stimulating environment.
2. When it is determined that the building occupants would accept the concept of using the outdoor environment to determine (at least, in part) the indoor environment, which may mean greater variation in conditions than with a strictly controlled environment.

3. When the design team has the expertise and willingness—and has the charge from the owner—to spend the extra effort to create the integrated design needed to make such a technique work successfully.
4. Where extreme outside conditions—or a specialized type of building use—do not preclude the likelihood of the successful application of such a technique. Buildings with atriums are particularly good candidates.

PROS AND CONS

Pros

1. Hybrid ventilation is an innovative and potentially energy-efficient way to provide outdoor air ventilation to buildings and, in some conditions, to cool them, thus reducing energy otherwise required from conventional sources (power plant).
2. Corollary to the above, it could lead to a lower building life-cycle cost.
3. It could create a healthier environment for building occupants.
4. It offers a greater sense of occupant satisfaction due to the increased ability to exercise some control over the ventilation provided.
5. There is more flexibility in the means of providing ventilation; the passive variant can act as backup to the mechanical system and vice versa.
6. It could extend the life of the equipment involved in providing mechanical ventilation since it would be expected to run less.

Cons

1. Failure to integrate the mechanical aspects of a hybrid ventilation system with the architectural design could result in a poorly functioning system. Some architectural design aspects could be constrained in providing a hybrid ventilation system, such as building orientation, depth of occupied zones, or grouping of spaces.

2. Additional first costs could be incurred since two systems are being provided where only a single one would be provided otherwise, and controls for the passive system could be a major portion of the added cost.
3. If automatic operable window openers are utilized, these could result in security breaches if appropriate safeguards and overrides are not provided.
4. If integral building openings are utilized in lieu of, or in addition to, operable windows, pathways for the entrance of outside pollutants and noise or of unwanted insects, birds, and small animals would exist. If filters are used to prevent this, they could become clogged or could be an additional maintenance item to keep clear.
5. Building operators may have to have special training to understand and learn how best to operate the system. Future turnovers in building ownership or operating personnel could negatively affect how successfully the system performs.
6. Occupants would probably need at least some orientation so that they would understand and be tolerant of the differences in conditions that may prevail with such a system. Future occupants may not have the benefit of such orientation.
7. Special attention would need to be given to certain safety issues, such as fire and smoke Propagation in case of a fire.
8. Although computer programs (such as computational fluid dynamics) exist to simulate, predict, and understand airflow within the building from passive ventilation systems, it would be difficult to predict conditions under all possible circumstances.
9. Few codes and standards in the US recognize and address the requirements for hybrid ventilation systems. This would likely result in local code enforcement authorities having increased discretion over what is acceptable or not.

GREEN TIP # 32

RADIANT COOLING

Radiant cooling offers a means of transporting cooling to occupied space with much less energy than conventional air circulation. The conventional practice for removing excess heat gain from an occupied space is to circulate air that has been cooled well below room temperature from a cooling source to the occupied space. The chilled air then absorbs heat from the space as it warms to room temperature. The air is then transported back to the cooling source where it is cooled again to repeat the cycle.

With radiant cooling, the heat transport medium is liquid, usually water, and the transfer of heat from room to the medium is by both radiant and convective means. Because of the higher mass and greater specific heat of the water, it conveys significantly greater heat per unit of energy required for circulation. Radiant cooling systems, furthermore, rely upon large surface areas for heat transfer, rather than large temperature differences between the space and the heat transport medium. As a result, temperature extremes within the space typically are reduced compared with spaces cooled by air circulation, which typically utilize large temperature differences to avoid excessive energy consumption for air circulation. A room radiant cooling source will typically operate at temperatures above 60°F in order to avoid condensation, while air cooling systems may well operate at temperatures as low as 50°F. Despite this decreased temperature difference with the space, transport energy for hydronic energy conveyance will typically be less than a quarter of that with air conveyance systems. The decrease in temperature difference, furthermore, between the space and the transport medium reduces the prevalence of discomfort brought about by imperfect mixing of the cold supply air and the warm room air.

Radiant cooling systems are generally of two types, independent radiant panels, most commonly ceiling and integrated radiant building structure, most often floor slabs. Radiant panel systems are usually constructed of sheet metal plates with metal tubing mechanically attached to the backside of the panel.

Basic ceiling panel design consists of a metal sheet with copper tubing attached to the upper side and covered with insulation/acoustical inlay material. The panels are able to absorb roughly 30 Btu/hr·ft²; use very little plenum space; are modular and easily

reconfigured with ever changing building use patterns. The system can be suspended, recessed, or placed in a grid configuration.

WHEN/WHERE IT'S APPLICABLE

Consider the use of radiant cooling systems in applications with modest cooling loads to reduce transport energy required to remove heat gain from the occupied space as compared to an air system.

Most applicable in areas with low latent heat load (dry), but can also work in more humid climates with a proper dehumidifying system. Panels can also be used for heating, generally as a substitution for radiators around building parameter.

PROS AND CONS

Pros

1. Radiant cooling offers a means of transporting cooling to occupied space with much less energy than conventional air circulation.
2. Provide even temperature throughout the space.

Cons

1. Radiant cooling systems do not provide required ventilation air and do not assist in humidity control. These functions must be met by a separate and independent ventilation and dehumidification system.
2. Sophisticated controls for the dedicated outdoor air system are necessary to insure that indoor air dew point temperature never approaches the radiant panel or slab temperature so that condensation may be avoided.

GREEN TIP # 33

ELECTRICAL SPACE HEATING

Electric Resistance Heating

Electric resistant heating uses electricity to heat a wire filament that provides heat. The one main benefit of electric resistance heating is that it is one of the lowest up front cost heating systems available.

1kW of electric resistance delivers 3413 BTU's of heat energy at almost 100% transformation efficiency. Transformation efficiency means that it converts into heat all the electric power it gets. However even at 100% transformation efficiency electric heat is still very expensive because of high costs of electricity. [The energy cost to deliver one Therm (100,000 BTU's) of heat is \$2.4 per Therm at \$0.08 per kWh - the highest compared to all other choices available for heating].

Transformation efficiencies should not be confused with heating efficiency. The overall efficiency of resistance heating is much less to the tune of about 35%, when including the electric power plant and transmission lines that bring the electricity to the building. To compliment the green building initiative, electric resistance heating should not be used for large spaces; our goal is to eliminate the environmental impact at macro level.

Heat Pumps

A heat pump does not convert electricity to heat. Rather, heat pumps move (or pump) heat (BTU's) from one environment to another. These are available in two major types: conventional packaged (air-source) and water-source (conventional or geothermal).

Air source heat pumps

Air source heat pumps are the type of air-cooled air-conditioners that extract heat from a cooler, conditioned space and reject it to a warmer space (i.e., the outdoors). In fact, a heat pump really is an air conditioner with a reversing valve that allows it to pump heat into the space in the winter and pump heat out in the summer. Although heat pumps are significantly more expensive than standard combustion furnace systems, the investment

includes air conditioning. Also, some heat pumps have the ability to provide hot water for domestic use.

The efficiency of a heat pump is determined by how much heat is available at the source it pumps heat from. *The more heat content at the source, the higher the heat pump's efficiency.*

An electric heat pump is generally much more efficient than electric resistance since it takes much less electricity to move a BTU of heat versus the electricity required to create a BTU of heat. In fact, a typical air to air (air-coupled) heat pump can move almost 2.5 times as much heat for a kilowatt (kW) of power than a 1 kW electric resistance heater can deliver. Since electric resistance heating has a transformation rate of nearly 100%, an electric heat pump that can deliver 2.5 times the heat, would appear to be 250% efficient. Is this possible? Sure, the difference is that the heat pump is not creating heat it is merely transferring it. Therefore, heat pumps are typically rated by a coefficient of performance (COP), which is the ratio of BTU's of delivered heat to the BTU input of the electric heat pump (based on it's electricity consumption to pump the heat).

One particular problem with air coupled heat pumps is that when the temperature outside falls below 30 degrees or so, there is not enough heat content in the air for the heat pump to pump heat efficiently. Therefore, most air-coupled heat pumps have back-up electric resistance filaments that come on when the temperature plummets below freezing. Unfortunately, during times of cold snaps, air-coupled heat pumps can become quite expensive. In fact, there is a tremendous spike in energy use during peak winter months (January and February) when the *increased heating need* is met with a *rapidly falling efficiency* for delivering that heat.

Ground-source heat pump (GSHP)

If it is possible to tap into a more constant heat source rather than the outside air, the efficiency of the heat pump could be dramatically improved, not just during the very cold winter months, but also throughout the year including summertime cooling. Fortunately, you don't have to go far for a reliable constant source of heat. In fact, just 36 inches below the earth's surface the ground is a more constant 55°F temperature year round. By drilling bore-holes and circulating water or a refrigerant underground, you can deliver

this constant heat source to a geothermal (earth-coupled) heat pump. The COP of earth-coupled heat pumps can be as high as 4.0 - 4.5 year round that equates into heating cost savings of 30-75%. The savings vary depending on your current systems efficiency (you can save more if you're upgrading from an older natural gas system or even more so if you currently use heating oil) and the electricity rates in your area (electricity is cheapest in the Northwest and most expensive in the Northeast.) Unlike with an air source heat pump, savings do not vary much depending on the winter climate.

Visit the Geoexchange Geothermal Heat Pump Consortium Web site (www.geoexchange.org/about/how.htm) for a more detailed description.

WHEN/WHERE IT'S APPLICABLE

The most economical application of heat pumps is in buildings that require significant space/water heating and cooling over extended hours of operation. Building types that not well suited to the technology are buildings where space and water heating loads are relatively small or where hours of use are limited.

PROS AND CONS

Pros (Heat Pumps)

1. Efficiency – An air source heat pump produces 2.5 kW of heat per every 1 kW of electricity spent. Compared to regular electric heaters, you get only 1 for 1, this is 250% efficiency.
2. Year-round use - Heat pumps can be used in year-round for places with milder winter. Air conditioners are only used for a few short weeks of summer.
3. Better comfort - Heat produced by heat pumps is less intense than heat from the furnace. It makes the heating cycle longer and heat distribution more even.
4. Safe to use - Since heat pumps use electricity, not fuel no reason to worry about carbon monoxide poisoning or fuel (gas, propane, oil) escape.

Cons (Heat Pumps)

1. Heat pumps are more expensive than air conditioners.
2. Heat pumps need supplemental heat at low temperatures. There are two main reasons for that.
3. Requires additional site coordination and supervision
4. Heat pumps are powered by electricity. This can be expensive when used on a peak tariff during the day.

GREEN TIP # 34

SPACE HEATING THROUGH COMBUSTION OF FOSSIL FUELS

Fuel sources such as oil, natural gas and propane are regularly used for the heating system. The direct combustion of fossil fuels releases the stored BTU content in the form of heat with varying efficiency and BTU content depending on the fuel source and combustion method. Oil fired boilers are perhaps the least efficient form of combustion heating releasing significant emissions relative to other heating systems. Natural gas and propane are much cleaner-burning fuels, but propane is expensive, making it generally more costly than oil. Natural gas is probably the least costly (although recent price increases have made natural gas heating expensive) best choice for clean combustion heating, but it is subject to the availability of gas pipelines.

The most common form of combustion heating is called continuous combustion, where the fuel is burned under a continuous steady state assuming the fuel-air mixture is kept within the flammability limits. Under continuous combustion, the average efficiency of the heating equipment is in the 80 percent range. A gallon of propane, which costs \$1.00 or more, has a heating content value of up to 73,000 BTU's. Thus average heating costs using propane are in the range of \$1.60 - \$1.80 per Therm.

A newer methodology for combustion heating is pulse combustion where the furnace operates like an internal combustion engine with discreet bursts of fuel air mixtures firing at 30 to 100 times per second. The pulses produce high convective heat transfer rates that can achieve efficiencies of 97%. Thus a propane heating system using a pulse furnace costs \$1.30 - \$1.50 per Therm. Pulse furnaces use a tiny amount of electricity for firing a spark plug, but this can be easily provided through a modest solar power system.

Forced Air Heating Systems

A forced-air heating system is one which uses air as its heat transfer medium. These systems use ductwork and vents as a means of air distribution. The return plenum carries the air from several large return grills (vents) to a central air handler for re-heating. The supply plenum directs heated air from the central unit to the rooms which the system is designed to heat. Regardless of type, all air handlers consist of an air filter,

blower, heat exchanger/element/coil, and various controls. Like any other kind of central heating system, thermostats are used to control forced air heating systems.

Furnaces

The forced heating systems use a furnace to heat the air, which is then sent through a system of ducts to heat your house. Most furnaces are gas fired and are made up of several important components: the burners, a heat exchanger, and a blower. The burners function is to burn the natural or propane gas in the heat exchanger. The exchanger is a metal enclosure that separates the burners flames from the air stream. The blower moves the air stream. The blower forces the heated air throughout the ducts to heat registers in each room. An electric forced air furnace uses electrical elements rather than burners to heat the heat exchanger.

The size or heating capacity, of a furnace is quantified in terms of British thermal units per hour (Btu/h) of gas input. The furnaces for residential use come in a wide range of capacities—generally from 40,000 Btu/h to 150,000 Btu/h for natural gas and from 10 kW to 50 kW for electrical resistance furnaces. To accommodate different types of spaces, there are three main furnace designs for use with forced-air systems. The designs are named according to the way air travels through the system.

- **Up flow** furnaces are recommended for basement floor locations.
- **Horizontal flow** furnaces are particularly suited for crawl space installations.
- **Down flow** furnaces are recommended for installations in mobile homes or on the main floor of buildings on concrete slabs.

The efficiency of furnaces is expressed as annual fuel utilization efficiency (AFUE), which is defined as the ratio of output energy of heating equipment to the annual input energy in consistent units and including all pilot losses. Typical values are 80-85%. For example, if a furnace has an AFUE of 80 per cent, then 80 per cent of the heat value in the fuel is available. The other 20 per cent is lost, mostly up the chimney. Thus, additional fuel must be consumed to make up for these losses. Improving the efficiency of the heating equipment reduces energy use and cost. The minimum AFUE available is set by federal law for most furnace types at 78 percent. The highest AFUE units available are slightly less than 97 percent efficient.

Making the best choice

There are numerous choices available with diverse efficiencies (refer table below). Note the efficiency figures in the column titled "Seasonal Efficiency". By using these figures, you can calculate the savings you can achieve by upgrading your present system to a newer, more energy-efficient model, or by choosing a more efficient appliance that uses another energy source.

Heating System Efficiencies and Energy Savings

Energy Source	Technology	Seasonal Efficiency (AFUE) %	Energy Savings % of Base**
Oil	Cast-iron head burner (old furnace)	60	Base
	Flame-retention head replacement burner	70-80	14-23
	High-static replacement burner	74-82	19-27
	New standard model	78-86	23-30
	Mid-efficiency model	83-89	28-33
	Integrated space/tap water system (mid-efficiency)	83-89	28-33 40-44
Natural Gas	Conventional	60	Base
	Vent damper with non-continuous pilot light	62-67	3-10
	Mid-efficiency model	78-84	23-28
	High-efficiency condensing furnace	89-97	33-38
	Integrated space/tap water system (mid-efficiency)	89-96	33-38 44-48
Propane	Conventional model	62	Base
	Vent damper with non-	64-69	3-10

Energy Source	Technology	Seasonal Efficiency (AFUE) %	Energy Savings % of Base**
	continuous pilot light		
	Mid-efficiency model	79-85	21-27
	Condensing model	87-94	29-34
Wood	Central furnace	45-55	
	Conventional stove (properly located)	55-70	
	"High-tech" stove (properly located)	70-80	
	Advanced combustion fireplace	50-70	
	Pellet stove	55-80	

1. Pick a size that's just right. Don't oversize; an oversized furnace is noisier, less efficient, and more expensive than an accurately sized one.
2. Premium efficiency furnaces feature both sealed combustion and variable-speed blowers. They cost more but quick payback on energy efficiency.
3. Use dedicated heating system. Instead of burning gas in a central location and distributing heated air throughout the building, multiple gas furnaces, each designed to heat just a small space are more efficient.

Hydronic Systems - Boilers

Hydronic hot water heating systems are very popular in large building complexes due to its ability to carry large amount of heat in small volume. Hot water can be transported from a heat source over great distances using insulated pipelines and the heat is delivered at the point of use in many ways – forced air handler, finned pipes fan coil units or unit heaters.

Hydronic systems rely on the availability of hot water and typically the hot water comes from a boiler system. Because the boiler is where the action of converting your fuel into

heat energy takes place, it's important that you consider purchasing the most efficient boiler for your particular needs.

The two most common types of boilers are fire tube and water tube.

1. **Fire-tube boilers**—Combustion gases pass through tubes, transferring heat to boiler water flowing over the tubes on the shell side. Benefits of this type of boiler include low initial costs as well as efficiency and durability. The boilers are limited, however, to lower pressure steam production temperatures, generally not exceeding 300 psig, due to the steam being contained in the shell.
2. **Water-tube boilers**—Boiler water passes through tubes while hot gases contained on the shell side circulate over the outside of the tubes, transferring heat. The fact that the steam is contained in the tubes and not the shell allows for much higher pressure steam production, on the order of up to 3000 psig is practical. For this reason, and due to their high efficiency, water-tube boilers are ideal for applications that require saturated or superheated steam, especially those applications insisting on dry, high pressure, high heat energy steam.

Energy Efficiency

Boiler efficiency is defined as how much of the heating value of the fuel is being converted to useful heat. The term “boiler efficiency” is often substituted for thermal efficiency or fuel-to-steam efficiency. Both are not same. Let's see some efficiency reporting terms:

Combustion Efficiency - Combustion efficiency is an indication of the burner's ability to burn fuel completely without generating carbon monoxide or without un-burnt carbon. Complete combustion efficiency would extract all the energy available in the fuel. However 100% combustion efficiency is not realistically achievable. Common combustion processes produce efficiencies from 90% to 95%. Combustion efficiency calculations assume complete fuel combustion and are based on three factors:

- The chemistry of the fuel -combustion efficiency is not the same for all fuels and, generally, gaseous and liquid fuels burn more efficiently than solid fuels.

- The net temperature of the stack gases – higher the temperature lower the efficiency.
- The percentage of oxygen or CO₂ by volume after combustion – well designed burners firing gaseous fuels operate at excess air levels of 10 -15% corresponding to equivalent O₂ level of 1-2% and 10 - 11% CO₂ in stack gasses.

Thermal Efficiency – Thermal efficiency is a measure of the effectiveness of the heat exchanger of the boiler. It is solely a measurement of the effectiveness of the heat exchanger of the boiler and does not account for radiation and convection losses due to the boiler's shell, water column, or other components. It is therefore not a true indication of the boilers fuel usage and should not be used in economic evaluations.

Fuel to Steam Efficiency – Fuel-to-steam efficiency is a measure of the overall efficiency of the boiler. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses.

Condensing and Non-condensing Boilers

1. **Condensing boilers** absorb more heat from combustion gases, allowing the water vapor to condense and therefore providing increased efficiency. Any hydrocarbon fuel burned in a boiler, whether it is propane, natural gas, or fuel oil, produces water vapor during the combustion process. A condensing boiler captures latent heat from flue gases by condensing water vapor that normally goes up the flue.
2. **Conventional boilers** are non-condensing boilers with materials that cannot tolerate the corrosive properties of condensing flue or stack gases.

When looking to optimize fuel costs, consider a condensing boiler. Condensing boilers will capture more heat from the combustion gases than conventional boilers and offer efficiencies above 90% compared to around 80% of the conventional boilers.

An important factor in maximizing condensing boiler efficiency is maintaining a relatively low return water temperature (85-100°F) whenever possible. A lower return water temperature allows the boiler to extract more of the heat of combustion because of the larger temperature difference between the return water and the combustion gases in the boiler.

Condensing boilers are not typically available in larger sizes and are found in sizes from 500,000 to 2,000,000 Btu per hour (15-60bhp). To accommodate larger heating loads, multiple condensing boilers can be installed.

Size

Boiler size is a measure of boiler heat capacity in Btu per hour for smaller units or boiler horsepower (bhp) for larger units. One boiler horsepower is equal to 33,475 Btu per hour. The table below shows sizing ranges for different facility types:

Typical Facility	Size – Btu/hr (bhp)
Small commercial or residential	67,000-3,400,000 (2-100)
Medium commercial or small industrial	2,500,000-10,000,000 (100-300)
Large commercial or large industrial	10,000,000-33,500,000 (300-1000)

A common rule of thumb is one bhp per 1,000 square feet. Most often the designers oversize boilers two to three times the required heating capacity, which can decrease the efficiency and operating life of a boiler because of short cycling (frequent on-off cycles). It is good practice to select multiple smaller sized boilers to best accommodate fluctuating heating loads and provide redundancy. A single smaller boiler can be used to handle the lighter loads and minimize cycling of the boiler and additional boilers can be brought on-line during periods of higher heating loads.

Making the best choice

The table below gives general selection guidelines for implementing some of the energy efficiency options detailed below and described further in tip # 35.

Facility Requirements	Condensing Boiler	Stack Gas Economizers	O ₂ Trim	Supply Water Temp. Reset
Small facility space heating (2-100hp)	X			X
Medium facility space heating (100-300hp)		X	X	X
Large facility space heating (300-1000hp)		X	X	X
High pressure steam (100hp or greater)		X	X	

PROS AND CONS

Pros (Forced air heating using furnaces)

1. The heating and cooling come through the same set of ducts, giving you comfortable temperatures no matter what season.
2. Air may be filtered
3. Air may be humidified or dehumidified
4. Furnace can attain highest AFUE

Cons (Forced air heating using furnaces)

1. Since the heating isn't continuous (the furnace switches on and off), you do not always get constant heat. It will be hot when the furnace is running, and gradually cool down until it kicks in again.

2. Need large space for ductwork
3. Requires ductwork and takes space in walls
4. Furnace fan system can be noisy
5. May cause discomfort, drafts and dry air

PROS AND CONS

Pros (Hot water heating using boilers)

1. Easy to zone
2. Quiet
3. Can be used as forced heating or radiant heating system

Cons (Hot water heating using boilers)

1. Higher cost
2. High mass boilers have high stand-by heat loss
3. Water may need chemical treatment

GREEN TIP # 35

BOILER CONTROLS & AUXILIARIES

There is a broad array of options in boiler equipment and controls that can enhance energy performance: stack gas heat recovery equipment, such as air preheaters and economizers; condensing heat exchangers, which also utilize stack gas waste heat; turbulators (fin enhancers) to improve heat transfer and balance of gas flows between tube banks; water recovery equipment, to re-use heat from blowdown and water return condensate; outdoor temperature controls, which control the system loop temperature in accordance with outside temperatures; electronic ignition devices; increased boiler and piping insulation; and high performance (including "power") burners.

Controls

Hot water boilers control the burner based on a water temperature set-point, typically 140-180F, where steam boilers used for space heating are controlled based on a pressure set-point, typically 5-10 psi.

Efficient boiler control minimizes the number of on-off cycles. When a boiler is cycled on or off; some purging of the combustion chamber takes place before and after firing to prevent explosions of combustible gases that may have accumulated in the boiler. This process wastes heat; in addition, frequent cycling of a boiler decreases its useful life because of the thermal stresses associated with each on-off cycle.

Most boiler burner combustion controls fall into 3 categories:

1. **On-off control** is the least expensive but also typically the least efficient because of the losses associated with each cycle. Often boilers are oversized causing frequent on-off cycling. The associated pre and post-purge losses can be substantial.
2. **Low-high-low combustion control** is also fairly inexpensive but more efficient and effective than on-off control. The boiler starts and stops with the typical pre and post purge and then cycles between a low-fire and max-fire condition to meet the heating load.

3. **Modulating control** is generally more expensive but also the most efficient and most effective at handling varying heating loads. Modulating control turns down the firing rate of the burners to meet the heating load. Modulating control is specified by the turndown ratio, which is the ratio of the full firing output to low fire output. Most modulating control boilers will have a turndown ratio of 5 to 1 and up to 10 to 1 for expensive burners.

At low fire conditions the flow of combustion gases through the boiler is less and more heat can be captured before the combustion gases exit the boiler.

Another method to improve overall efficiency of a boiler is called hot water temperature reset. Hot water temperature reset decreases the temperature of the hot water depending on outdoor conditions. Along with improving the overall efficiency of the boiler system, temperature reset also provides better temperature control and reduces other problems like overheating spaces.

A primary-secondary decoupled system can be used to allow for resetting the temperature in the secondary or distribution loop, while still maintaining the required return water temperature for the boiler.

Minimize Excess Air in Boiler Operations (O₂ trim)

Minimize "excess air" in boiler operations. In order to ensure complete combustion, most boilers are designed to operate with excess air (more air than is theoretically required for the combustion process). However, this excess air reduces the boiler's efficiency. If excess air can be minimized, efficiency gains of 1 to 2 percent can be realized. Excess air controllers (sometimes called "O₂ trimmers") are available. They control excess air by sampling combustion products and adjusting the amount of air supplied to the burner accordingly. For a 250 hp boiler running 2,000 hours per year, the installation of an O₂ trim system would result in an increase in efficiency of 1 to 2 percent, which is equivalent to an energy cost savings of about \$1,700. Initial cost of a unit for a package boiler of this size is approximately \$9,000. If the boiler ran for more than 2,000 hours per year, the savings would be correspondingly higher.

Low-NOx burners

Low-NOx burners are natural gas burners with improved energy efficiency and lower emissions of nitrous oxides (NOx).

When fossil fuels are burned, nitric oxide and nitrogen dioxide are produced. These pollutants initiate reactions that result in the production of ozone and acid rain. The NOx come from two sources: high-temperature combustion (thermal NOx) and nitrogen bound to the fuel (fuel NOx). For clean-burning fuels such as natural gas, fuel NOx generation is insignificant.

In most cases, NOx levels are reduced by lowering flame temperature. This can be accomplished by modifying the burner to create a larger (and therefore lower temperature) flame, injecting water or steam into the flame, recirculating flue gases, or limiting the excess air in the combustion Process. In many cases a combination of these approaches is used. In general, reducing the flame temperature will reduce the overall efficiency of the boiler. However, recirculating flue gases and controlling the air-fuel mixture can improve boiler efficiency, so that a combination of techniques may improve total boiler efficiency.

Circulating pumps for hot-water boilers

The circulating pumps in a hot water system distribute the water to spaces and processes where it is needed.

Typically, a hot water system is designed with a primary and secondary loop. The primary loop pump continuously circulates water through the boiler while the secondary loop pump circulates hot water to individual spaces and processes.

Along with using efficient pump motors, one can implement variable speed drives (VSDs) to decrease the speed of the motor driving the pump depending on the heating load or demand.

Savings for variable speed pumping will be greatly reduced if hot water temperature reset is implemented; reset should be provided first if the boiler and system allow for it.

Minimize Leaks

While leakage in the condensate return system is inevitable, such leaks should be kept to a minimum. It takes approximately 150 Btu/lb to heat make-up water from 50°F to 200°F. One leak at one drop per second represents almost 3 million Btu wasted annually, or \$16.50 in wasted fuel, assuming the fuel is gas costing 44 cents a therm.

Combustion Air Control

A couple valuable tips which will insure proper combustion air are:

1. If louvers are used as a combustion air source, they must have one square inch of free area for each 1000 BTU burned. Louver dimensions do not guarantee equivalent free space. Metal louvers normally provide 60% free space. Example: A 20 by 20 louver would have a free area of 240 sq-inches. (20 x 20 x .60)
2. If mechanical combustion air fans are used, provide 15 to 20 cu. Ft. Of combustion air for each 1000 BTU burned.

GREEN TIP # 36

BOILER WASTE HEAT RECOVERY

Maximizing boiler efficiency means minimizing the waste heat energy losses in the stack gases. A 100°F reduction in stack gas temperatures can result in a 2.5 percent increase in efficiency.

There are three common heat recovery devices – 1) economizers, 2) recuperators and 3) regenerators.

Economizers

Economizers are heat exchangers that capture heat from the exhausting gases and transfer it to the return water going into the boiler.

Recuperators

Recuperators increase the efficiency of a boiler by transferring some of the heat from the exhaust combustion gases to the intake combustion air.

Regenerators

Regenerators include two or more separate heat storage sections. Flue gases and combustion air take turns flowing through each regenerator, alternatively heating the storage medium and then withdrawing heat from it. For uninterrupted operation, at least two regenerators and their associated burners are required: one regenerator is needed to fire the furnace while the other is recharging.

WHEN/WHERE IT'S APPLICABLE

A stack gas temperature greater than 400°F on a larger boiler of 300hp or greater is typically required to make these technologies worthwhile. Financial justification is based on energy saved rather than on temperature differential.

PROS AND CONS

Pros

1. Lowers energy costs.
2. Increasing thermal efficiency lowers CO₂ emissions.

Cons

1. There are additional material and equipment costs.
2. Some processes produce dirty or corrosive exhaust gases that can plug or attack an exchanger, so material selection is critical.
3. Corrosion and condensation can add to maintenance costs.
4. Low specific heat of air results in relatively low U-factors and less economical heat exchangers.
5. Increasing combustion temperature also increases NO_x emissions.

GREEN TIP # 37

RADIANT FLOOR HEATING SYSTEM

Forced air systems typically blow heated air into a room to warm it. Radiant heat operates by heating the objects in the room first and then those objects in turn warm the air around them. A radiant floor heating system simply radiates heat upward from the floor to provide a comfortable environment to individuals in a room. Heat spreads more evenly around the room, eliminating cold spots and cold blasts of air from registers.

Radiant Heating is considered to be the most comfortable and healthiest heating solution. There are different types of radiant heating such as, electric and hydronic systems.

Electric cable radiant heating – The electrical radiant floor heating system involves placing heating elements (coils, cables or mats) under the floors. When the electric input is turned on, heat is forced through the heating element to the conductive floor. The heating elements heat the flooring until it reaches the set temperature. The heat then passes through the floor to the cold objects in the room.

The heating element is usually made with fluoropolymer insulated heating cables sandwiched between two layers of specially reinforced aluminum foil. Depending on your heating requirement, they are available in nominal heat outputs of 80 W/m² and 140 W/m². Most of them are available in predetermined lengths with cold tail - prefabricated & tested in a carefully controlled factory environment.

Hydronic slab heating – In a hydronic system, water is heated by a boiler or water heater and circulated through flexible tubes buried in the floor. The floor absorbs this energy, and then gives it off as radiant heat, which warms people and objects in the room. Hydronic system is advantageous over electric cable radiant heating in a way that these can provide radiant cooling as well as radiant heating. Another big advantage of hydronic systems is the flexibility of the fuel source. You can use gas, oil, electricity and even solar energy. Plus, you can change fuels for the price of a new boiler.

Two basic configurations exist. The first option involves the placement of pipes in the foundation slab itself, referred to as “slab-on-grade”. The second, called “thin-slab” consists of piping placed in a thinner slab layer that is situated on top of the foundation

slab or on suspended floors. Each consists of a loop of tubing (normally cross-linking polyethylene, PEX) that is imbedded in concrete or a similar material, such as gypcrete.

Hydronic flooring systems are a closed loop, which means the water circulated is heated and then reheated. The temperature in each space is controlled by regulating the flow of hot water through each tubing loop.

WHEN/WHERE IT'S APPLICABLE

Radiant floor heat is used to warm up our floors in cold or winter season with bone-chilled weather outside. Depending on your application, a hydronic system may be more beneficial than an electric system, or vice-versa. Generally, electric cable systems are more applicable in situations where only floor warming is desired or the area to be heated is relatively small. Hydronic systems tend to be more desirable when primary heating is the goal and/or the area to be heated is relatively large. Radiant cooling is limited to areas with low latent cooling load due to concerns about the condensation on the surfaces that may result in potential water dripping.

Hydronic systems are more commonly used in commercial, while electric radiant heat systems are more commonly used in smaller applications.

PROS AND CONS

Pros

1. Radiant hydronic systems both provide heating and cooling.
2. All radiant hydronic systems impact many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.
3. This system can be integrated into a facility-wide hydronic heating and cooling system including baseboards and ceiling panels.
4. Quiet operation.
5. Better perceived comfort. Radiant slabs heat occupants from the bottom up and are purported to increase comfort. Allows for lower thermostat settings.

6. Lower boiler temperatures of 90°F to 120°F compared to 140°F to 200°F for other heating systems. These temperatures can be accomplished by a geothermal heat pump or solar thermal system.
7. Can provide fuel savings when compared to forced-air systems.
8. Aesthetically pleasing; no heat registers or visible radiators.

Cons

1. Hard to set back temperatures because of lag.
2. Ground losses can reduce efficiency, if insulation is not properly installed.
3. The electric draw of an electric cable system can be a limiting factor in designing a system if your electric service is not sized to accommodate it.
4. When hydronic systems are used for cooling as well as heating, care must be taken to account for humidity control. If surface temperatures fall below the dew-point of the air, condensation can occur, resulting in dripping water and slippery surfaces.
5. Hydronic systems can leak and precautions needed to lay this system in skillful manner. [Before pouring the concrete, tubing should be laid out and pressurized to 100 psi for 24 hours to ensure no leakage. The tubing should remain pressurized throughout the pouring and curing process].
6. The slab is a large thermal mass and care must be taken to avoid under or over shooting the prescribed temperature. Water should be delivered to the slab at a temperature that can maintain surface temperatures between 80°F and 85°F. The required inlet water temperature is dependent upon the thermal resistance of the slab and any floor finishing material.

GREEN TIP # 38

RADIANT PANEL HEATING SYSTEMS

Compared to conventional baseboard resistance heaters, which first warm the air and then warms the occupants, the radiant technologies directly warm occupants and furnishings, which then reradiate heat to the surrounding air. *The electric resistance heating requires higher space temperatures to achieve the same level of comfort that can be achieved at lower temperatures with radiant heaters.* Radiant heaters are available in both electric and gas-fired versions.

Electric radiant heating panels are designed to be mounted directly on the surface of a ceiling or wall, but they can also be made as replacements for drop-in ceiling panels. Electric radiant heating panels are available in a variety of sizes, typically ranging from about 2 feet by 2 feet up to 4 feet by 8 feet. Heating capacity is proportional to the panel area and power densities varying from about 50 to 125 watts per square foot (170 to 425 Btu per hour per square foot). The low-intensity panels (50 watts per square foot) are self-supporting, requiring only a metal frame to maintain their integrity. The following choices are available:

- Low-temperature graphite or Ni-chrome wire for use in electric ceilings or floors.
- Medium-temperature, metal sheath with nickel-chromium alloy resistor wire (60 watts/inch).
- High-temperature, quartz tube with nickel-chromium alloy resistor wire (75 watts/inch).

Low-intensity radiant heaters are typically used where total heating of a large area is required. High-intensity radiant heaters can be used both for spot or localized heating and for heating large areas.

Electric radiant heaters transfer 58 to 90 percent of their heat as radiation.

Gas-fired radiant heaters use gas burner to heat the surface of ceramic or stainless-steel materials. The heated surface radiates thermal energy to the warm other nearby surfaces and objects in the vicinity. Reflector-focused heaters combust fuel and the hot

combusted gases flow through a series of exhaust tubes suspended above the area that is to be heated. The tubes are usually shrouded with a reflector that directs the radiated energy to the desired area and may be 4-inch steel tube, 20 to 30 foot long, either straight or U-shaped configuration.

Several configurations of gas-fired radiant heaters are available. Some are linear units consisting of a long steel pipe with a reflector above. Another option is a smaller unit with heated ceramic surface design to cover a rectangular area of floor. Gas-fired radiant heating is commonly used to heat industrial facilities and to provide heat and drying for manufacturing processes.

Gas-fired radiant heaters transfer 35 to 70 percent of their heat as radiation.

WHEN/WHERE IT'S APPLICABLE

Radiant heating is appropriate in spaces with high ceilings because it helps to overcome thermal stratification. Much of the heat is delivered directly to objects and occupants at floor level.

Radiant heating is also useful in areas with high traffic where infiltration can be a problem. Appropriate spaces include gyms, shops, greenhouses, and high-traffic entrances or lobbies. Radiant heaters can provide spot heating in large open spaces such as workshops or warehouses.

PROS AND CONS

Pros

1. Fan energy and/or pumping energy required for heating distribution is eliminated.
2. The use of radiant heating can also reduce or eliminate the inefficiencies that result from the excessive air changes that can occur with poorly balanced forced-air heating systems.
3. Gas-fired radiant heaters are usually a cost-effective choice for spot heating in large open spaces. They may also be cost effective for general heating in spaces like gymnasiums when energy savings are considered.

4. In new, heating-dominated commercial buildings, radiant heating may eliminate the need for air ducts or allow ducts to be downsized, which, in turn, may make it possible to reduce floor-to-floor height.
5. When used as a supplement to, or replacement for, electric resistance heaters, radiant heating allows for lower thermostat settings that translate directly into reduced peak demand for a given building.
6. Maintenance and associated costs are virtually nonexistent with electric radiant heating panels. These units have no pumps, blowers, compressors, or burners to fail, and there are no filters to change.

Cons

1. Radiant heat must be delivered precisely when and where it is needed; the overall efficiency of radiant heating systems varies widely with heater design, reflector design, and response time.
2. Occupants may experience some discomfort due to warm heads and cool feet.
3. The effectiveness of radiant heating decreases in the presence of substantial winds or drafts. To minimize discomfort from the movement of cold air, pressurize the building or take steps to block winds.
4. Radiant systems also require a direct line between the heater and the person or object being heated. Care must be taken not to obstruct the path or place furniture where it might interfere with the heater's ability to warm the room's occupants.
5. Radiant systems can't be controlled by conventional thermostats, because comfort doesn't correspond to air temperature alone; thermostats that sense both temperature and radiation need to be used.
6. Require space for routing of combustion air and venting flue gas for a gas-fired radiant heater.

GREEN TIP # 39

COMBINATION SPACE WATER HEATERS

In many commercial buildings, the main boiler is used both for space conditioning and water heating. The system consists of a storage water heater, a heat delivery system (for example, a fan coil or hydronic baseboards), and associated pumps and controls. The water heater is installed and operated as a conventional water heater. When there is a demand for domestic hot water, cold city water enters the bottom of the tank, and hot water from the top of the tank is delivered to the load. When there is a demand for space heating, a pump circulates water from the top of the tank through fan coils or hydronic baseboards.

The storage tank is maintained at the desired temperature for domestic hot water (e.g., 140°F). Because this temperature is cooler than conventional hydronic systems, the space heating delivery system needs to be slightly larger than typical. Alternatively, the storage tank can be operated at a higher water temperature; this requires tempering valves to prevent scalding at the taps.

The water heater can be either a conventional storage type water heater (either naturally venting or power vented) or a recuperative (condensing) gas boiler. Conventional water heaters have an efficiency of approximately 60%. By adding the space heating load, the energy factor increases because of longer runtimes and reduced standby losses on a percentage basis. Recuperative boilers can have efficiencies approaching 90%.

WHEN/WHERE IT'S APPLICABLE

These units are best suited to buildings that have similar space and water heating loads, including dormitories, apartments, and condos. They are suited to all climate types.

PROS AND CONS

Pros

1. Reduces floor space requirements.
2. Lowers capital cost.

3. Improves energy efficiency.
4. Increases tank life.

Con

1. They are only available in small sizes.
2. All space heating piping has to be designed for potable water.
3. No ferrous metals or lead-based solder can be used.
4. All components must be able to withstand prevailing city water pressures.

GREEN TIP # 40

THERMAL ENERGY STORAGE

Demand for heating, cooling, or power is seldom constant over time, and the excess generation available during low demand periods can be used to charge the energy storage apparatus in order to increase capacity during high demand periods. Thermal energy storage (TES) systems offer the potential for substantial operating cost savings by using off-peak electricity to produce chilled water or ice for use in cooling during peak hours. The idea is to run chiller equipment off-peak and store cooled water or ice, then draw on this cooling during the peak times of the day.

These systems take one of three forms: chilled water, ice or a salt-water hybrid of both—called a eutectic system.

1. Sensible heat storage - Chilled-water systems use the sensible heat capacity of water—1 Btu per pound (lb) per degree Fahrenheit (F)—to store cooling capacity. They operate at temperature ranges compatible with standard chiller systems and are most economical for systems greater than 2,000 ton-hours in capacity.
2. Latent heat storage - Ice thermal storage systems use the latent heat of fusion of water—144 Btu/lb—to store cooling capacity. Storing energy at the temperature of ice requires refrigeration equipment to cool charging fluid below the normal operating range of conventional air-conditioning equipment.
3. Thermo-chemical heat storage - Eutectic salts use thermo-chemical combination of inorganic salts, water, and other elements to create a mixture that freezes at a desired temperature. The material is encapsulated in plastic containers that are stacked in a storage tank through which water is circulated.

Selecting the most appropriate system depends on the availability of space for storage media, cooling load profile, rate schedule and current equipment, if any. Chilled-water systems require the large tanks, but they can interface with most existing chiller systems. Ice systems use smaller tanks and offer the potential for the use of low-temperature air systems, but they require more complex (and typically less efficient) chillers that are designed for low-temperature operation. Eutectic salts can use existing chillers but usually operate at the warmest temperatures.

Systems can be sized to eliminate compressor energy use during periods when electricity is most expensive, but most systems are designed to simply augment mechanical cooling in order to limit peak demand.

WHEN/WHERE IT'S APPLICABLE

TES systems are most likely to be cost-effective in situations where any one or more conditions exist:

1. A facility's maximum cooling load is much greater than the average load
2. The utility rate structure has high demand charges, ratchet charges, or a high differential between on- and off-peak energy rates
3. An existing cooling system is being expanded
4. An existing tank is available
5. Limited electric power is available at the site
6. Backup cooling capacity is desirable
7. Cold air distribution would be advantageous

PROS AND CONS

Pros

1. TES allows a smaller refrigeration equipment to be installed (or to add capacity without purchasing additional units) and results in a higher load factor on the units. Reduced refrigeration equipment size means corresponding reduction in connected power requirement and lower first cost on electrical system.
2. TES systems can store low-cost energy that is generated off-peak as an electrical demand cost-control measure. It's not that TES saves energy as such in any big way, but it shifts the consumption from – typically, the peak hours of the day to some other part of the 24 hour-day – typically again – to the off-peak hours.

3. Some utility rate structures offer lower energy prices during off-peak periods when the demand for power is less and the demand for cooling or heating is usually lower. TES reduces operating costs by taking advantage of the lower utility energy rates.
4. Factors increasing energy efficiency. Because TES allows operation of the refrigeration system at or near peak efficiency during all operating hours, the annual energy usage may be lower than non-storage systems that must operate at lower part-load ratios to meet instantaneous loads. In addition, since off-peak hours are usually at night when lower ambient temperatures prevail, lower condensing temperatures required for heat rejection would tend to increase refrigeration efficiency.
5. Electric power infrastructure. Because TES systems shift the consumption of site energy from on-peak to off-peak periods, it contributes to the demand side management of electric utility plants.
6. Related high-efficiency technologies. TES enables the practical incorporation of other high-efficiency technologies such as cold-air distribution systems and nighttime heat recovery.
7. TES will almost certainly increase system reliability.

Cons

1. Capital cost - Compared to a conventional system, the thermal storage element proper (water tank or ice tank) and any associated pumping, piping accessories, and controls add to the incremental capital cost. If the system's refrigeration equipment can be reduced in size sufficiently (see Pros 1), this burden may be mitigated substantially or balanced out.
2. Factors decreasing energy efficiency - The need to generate cooling at evaporator temperatures lower than conventional ones tends to decrease refrigeration efficiency. This reduction may be overcome, however, by factors that increase efficiency.
3. Engineering - Successful TES systems require additional efforts in the design phase of a project.

4. Space - TES systems will require increased site space usage. The impact of site space usage can be mitigated by considering ice storage technologies.
5. Operations - Because a thermal storage system departs from the norm of system operation, continued training of facility operations staff is required as well as procedures for propagating system knowledge through a succession of facilities personnel.
6. Controls - Ice requires special control of melt rate to prevent uneven melting and to maximize performance.
7. Treatment - Calcium chloride brine needs management to prevent corrosion. Glycol needs management to prevent corrosion and toxicity.

GREEN TIP # 41

ENERGY MANAGEMENT SYSTEMS

An energy management and control system (EMS) supports the efficient operation of HVAC equipments by continuously managing and optimizing HVAC system energy consumption while also providing valuable diagnostic data for energy consumption and identifying potential HVAC system problems.

Most new chillers are equipped with direct digital controller (DDC), but for some reason their local “brain” is not usually networked with the computer-based “Energy Management System” (EMS) that controls other HVAC system components. This is usually because the chiller and the EMS follow different communication protocols and therefore cannot communicate directly without additional hardware or software.

Modern chiller control panels pull together a wealth of detailed operating data for the chiller, but these data can be used only if intelligent decisions are made about how to operate the rest of the system. For example, raising the chilled water temperature setpoint improves chiller efficiency and capacity, but may increase the amount of water that is circulated to the cooling coils or the amount of air delivered to the building. This leads to a net increase in energy use. Therefore, networking the chiller controls together with the rest of the EMS is very important to obtain the overall HVAC system efficiency.

Strategies to Integrate Chiller Controls with EMS

1. **Specify an “open” communications Protocol** - If all HVAC control components are specified to comply with an established “open” Protocol (BacNET, LonWorks), then achieving networked operation and data sharing should be as simple as connecting the devices together on a common network.
2. **Use a hardware gateway-** All is not lost when the chiller control panel follows a different protocol than the house EMS. A hardware device called a “gateway” can be installed that serves as a translator between the two languages, allowing most data to be shared between the foreign devices.
3. **Measure the power of ancillary equipment** - If it is not measured and recorded, it can be difficult to get a handle on how much energy is used by pumps and fans in

the chiller plant—and if this information can't be measured, then it is difficult to manage it effectively. To make these data available, specify that kW transmitters be installed on chilled and condenser water pump motors as well as cooling tower fan motors. Rather than installing simple current transformers that may not be accurate when used to measure power drawn by inductive loads such as motors, specify that true RMS-reading kW sensors be installed. Many of these devices are available in a standard signal output configuration in which a 4-20 mA signal corresponds to kW, but some are now available in a network-enabled version that makes far more data (power, plus volts, Amps, power factor) available to the house EMS.

4. **Analyze the resultant data** - Collecting data from the chiller plant is of no benefit unless this information is analyzed and ultimately used to draw useful conclusions about how to improve chiller plant operation. Though it is not the ongoing responsibility of the design team, it is worthwhile to specify that the eventual operators of the chiller plant receive training in the use of EMS so that they can take advantage of it.

What to include?

Modern EMS will typically include features such as:

1. **Start/stop** – Control needless operation after hours and on weekends.
2. **General scheduling** - Typically accommodate weekly and holiday schedules as well as one-time events.
3. **Zone-by-zone scheduling** – Capable to shut down HVAC and lighting system in unoccupied areas.
4. **Override control**– Capable to activate lighting and HVAC via card-readers, when workers need to work in the building outside of normal schedules.
5. **Night setup/setback** - Change setpoints during unoccupied hours to save energy by reducing the differential between inside and outside temperatures.
6. **Optimum start** - Optimum start by starting equipment only as early as required to bring the building to setpoint at the time it will be occupied.

7. **Optimum stop** - Optimum stop strategy determines the earliest possible time equipment can be turned off before unoccupied periods begin while still maintaining occupant comfort.
8. **Morning warm-up/cool-down** - Morning warm-up strategies shall be used in conjunction with optimum start to bring the building to the desired temperature before occupancy after a night setup or setback with the least amount of energy, by closing outside air dampers.
9. **Night ventilation purge** – Capable of purging or flushing the building with cool outside air in the early morning hours – this can delay the need for cooling until later in the morning.
10. **Lockouts** - Lockouts ensure that equipment does not come on when it is not needed.
11. **Chiller system** - The chiller and associated pumps can be locked out below a set outside air temperature, by calendar date, or when building cooling requirements fall below a minimum.
12. **Outside air damper** - The modulation of the outside air damper can be locked out when the outside air conditions are not conducive to “free cooling.”
13. **Economizer Control** - When the outside air temperature is less than two degrees lower than the inside air temperature (sensed in the return air duct), the economizer will be enabled, and outside air and return air dampers will modulate together to maintain the supply air setpoint. When the outside air is equal to the return air temperature, the economizer is disabled and the outside air dampers return to minimum. When the economizer is unable to maintain the supply air temperature setpoint, the cooling coil chilled water valve modulates open, using a proportional integral control loop to maintain the supply air setpoint. The economizer remains enabled if outside conditions permit.
14. **Temperature of condenser water entering the chiller** - Often, the setpoint for condenser water entering the chiller from the cooling tower is set at a fixed value around 80°F. Less frequently, it is set to a low value such as 70°F. Both fixed settings may be inefficient. The 80°F setting does not take advantage of conditions

during which the cooling tower can easily make cooler water, which increases chiller efficiency. The 70°F setting sometimes wastes energy trying to make 70°F water when outside conditions will not allow it. Resetting the condenser water to the lowest value that is practical for the tower to make (given the outside wet-bulb and dry-bulb conditions) saves chiller energy with the smallest possible increase in tower fan energy. This can be done by having the entering condenser water setpoint equal to the outdoor wet-bulb plus 10° to 15°F.

15. **Secondary chilled water loop pressure** - Instead of controlling the secondary chilled water loop to a fixed differential pressure setpoint under all conditions (the typical method), this strategy resets the pressure down as the load decreases (as the chilled water valves close), so that one cooling coil valve will always be 100 percent open.
16. **Chiller staging** - For multiple chiller systems, BMS shall determine the total cooling load on the system, compare the part-load efficiencies and capacities of all available chillers and determine the most efficient mix of chillers to have on-line.
17. **Position of outside air dampers in accordance with carbon dioxide levels** - Controls the amount of fresh air that is brought in by the HVAC system based on indoor carbon dioxide level, which is a measure of building occupancy at any given time. When CO₂ levels are low, outdoor air ventilation rates are reduced to save energy, and, when CO₂ levels are high, outdoor air rates are increased to reduce occupant-related contaminants. Because demand controlled ventilation using CO₂ sensors does not account for other sources of pollution, it is important to be aware of other sources that may create indoor air quality problems.
18. **Demand limiting or load shedding** - When the demand (based on kilowatts or current amps) on a building meter or piece of equipment approaches a predetermined setpoint (it may be different each month), the EMS will not allow a predetermined piece of equipment—a chiller, for example—to load up any further.
19. **Sequential startup of equipment** - Eliminate demand spikes by Programming time delays between the startups of major electrical load-generating equipment so that the startup peak loads stay below the peak demand later in the day.

20. Maximizing the amount of load curtailment - Ability to quickly and reliably cut back on the maximum amount of electric demand at any time.

Contemporary HVAC controls automatically regulate system output. At minimum, these controls maintain indoor temperature as interior loads and outdoor conditions change. In a small heating-only building, this is done with a thermostat that "compares" indoor temperature with an occupant-selected "setpoint," or desired value. When the indoor temperature drops enough, the thermostat activates the furnace or boiler, and then turns it off when the space reaches the setpoint. The difference between the "start" and setpoint temperatures is the "dead band." If it is set too large, temperatures will vary too much for comfort and if it is too small, the equipment will tend to run in very short cycles, which is very inefficient.

This equipment may also include an economizer that brings in large amounts of outdoor air when it is sufficiently cooler than the indoor air, thus providing cooling at lower cost than operating the refrigeration system. Economizers are crucial, except where the daily and seasonal temperature swings are very small.

PROS AND CONS

Pros

1. Modern energy management systems are much more sophisticated and able to optimize performance.
2. They allow simultaneous protection of equipment and maximum energy efficiency and are mandatory for complex chiller-based systems.

Con

1. High on first cost.
2. Require skilled work force in trouble shooting.

GREEN TIP # 42

TESTING, ADJUSTING & BALANCING

Most of today's newest HVAC systems are being designed with many more individually controlled temperature zones to improve occupant comfort. Variable speed fans and pumps are becoming more commonplace to provide the exact amount of heating and cooling system capacity in a manner that minimizes overall energy usage. New occupant air ventilation codes are much more restrictive and at the same time building envelopes are becoming much tighter. The combination of constantly changing HVAC airflow rates and increased demand for fresh- and filtered-ventilation air for all occupants is placing more emphasis on fine tuning HVAC system operation.

The purpose of testing, adjusting, and balancing (TAB) is to assure that an HVAC system is providing maximum occupant comfort at the lowest energy cost possible. The following tips are included for initial planning.

Pre-planning for TAB work includes making certain that all the necessary parties and individuals to conduct the work are onboard. The type of building and systems to be tested and a realistic evaluation of what skills the TAB technician possesses are key planning elements.

- Often, a controls specialist will be needed to operate the system for the TAB technician.
- The representatives from the original equipment suppliers may be needed as a resource, at a minimum, but for complex equipment and systems or in a new building startup a manufacturer's representative may be required at the site to operate the mechanical equipment.
- If the building has a facilities manager that individual is typically the most important participant with which the on-site TAB technicians will work. Facility managers have a substantial vested interest in ongoing customer satisfaction—the people who work or live in the building are actual end-use customers—and their satisfaction will ultimately be the key measure of success.

Occasionally, a system cannot be balanced or made to perform in accordance with the contract's design specifications regardless of the number of balancing dampers or valves that can be installed. Competent TAB technicians should be prepared for this possibility and work with the appropriate individuals to formulate recommendations as part of the final TAB report.

Airflow Measuring Instruments

- Manometers—used to measure pressure drops which can be translated into flow rates. Available in tube types, both U-Tube and inclined-vertical use a fluid in a tube to represent the difference in pressure between two points.
- Digital manometers—can provide very accurate readings at very low pressure differentials, such as across air filters and expansion cooling coils. Can automatically adjust for barometric pressure, store readings with recall in average or total numbers, and some can provide additional functions such as temperature measurements.
- Anemometers—Available in several configurations—rotating vane, deflecting vane, thermal—and used primarily to measure air velocities at registers, grilles, hoods, coils, etc.
- Flow measuring hoods—directly measures CFM of air distribution devices.

Temperature Measuring Instruments

- Glass tube and dial thermometers—Measurement of air and fluid temperatures
- Thermocouples—Measures surface temperatures
- Psychrometers and electronic thermo-hygrometers—Determines relative humidity.

Elements of TAB

1. Balance air and water distribution systems
2. Adjust the total system to provide specific quantities

3. Perform accurate electrical measurements
4. Establish quantitative performance of all equipment
5. Verify automatic controls
6. Measure sound and vibration with complete confidence

And much more.....

Refer to following link for further reading.

www.nebb.org/tabspec.htm

Note that the TAB work is not "commissioning." Most commissioning services are completed by firms having technicians experienced with each of the individual building systems—HVAC, lighting, plumbing, electrical, and security systems.

GREEN TIP # 43

HVAC COMMISSIONING

Keeping HVAC systems running at optimal efficiency can save operating dollars. The fact that commissioning can help make HVAC systems run correctly in the first place or restore them to proper operation is recognized by both the United States Green Building Council's LEED® Green Building Rating Systems and the Green Building Initiative's Green Globes Rating System.

What is Commissioning?

Most chiller plants have the potential to operate reasonably efficiently, but many never reach this potential due to installation problems, poor control system programming, or lack of coordination between the design team and the contractor. In particular, the advanced control systems that now pervade most building systems can be problematic if their programming is not carefully implemented.

Commissioning (Cx) is a systematic process of verifying and documenting that building energy systems or subsystems perform interactively according to the design intent and the owner's operational needs. Recommissioning (ReCx) involves "tuning up" an existing energy system to improve its performance, so that, ideally, the system functions "like new." Retrocommissioning is essentially the same process as recommissioning, but applied to buildings that have never gone through any formal type of commissioning or quality assurance process. Commissioning is concerned with sequence of operations and optimization of flow, temperature, and the system's overall performance. System efficiency is the focus.

Commissioning is **not**:

- Construction observation (inspection, workmanship, correction of punch list deficiencies)
- TAB (testing, adjusting, and balancing)

Completion Requirements

Of prime importance to successful long-term energy efficiency are the steps taken at the time of project completion to assure that the packaged equipment and systems are working properly and that an orderly transition occurs from the contractor to the owner.

Activities include:

1. Startup and testing of all equipment
2. Owner training on operation

Reports documenting these activities include:

1. Testing, adjustment, and balancing (TAB) reports
2. Drawings of the as-built installation
3. Narrative descriptions of all systems (may not be required on through-the-wall and single-zone systems)
4. Complete operation and maintenance manuals including:
 - a. locations of qualified service agencies
 - b. data on each piece of equipment (i.e., capacities, options, etc)
 - c. operating instructions for each piece of equipment
 - d. preventative maintenance measures
 - e. electrical wiring diagrams
 - f. spare parts list
 - g. control sequences

Reasons why commissioning is necessary:

- Owner reduces design fees - Value Engineering
- Design team neglects input from O&M staff

- Construction cost and schedules dominate, not quality of work
- Design team has limited field review and little knowledge of existing operations.
- Problem identification can be a conflict of interest
- Sub-contractors do not understand intended system operation.
- Building complexity - Automated controls not properly calibrated, tuned, and programmed

Typical problems discovered during commissioning:

- AHU control wiring is "Jumpered"
- Electric motors running backwards, dampers and valves stroke wrong direction - Incorrect wiring
- Improper sequencing of HVAC - HVAC control systems sequenced for current weather conditions only
- Failure of electric reheat coils due to insufficient air-flow
- Improper placement of isolation/by-pass valves on piping in central plants, valves fail closed causing pump failures.
- VAV Zone dampers fail to work properly
- Outside air dampers fail - freeze protection

Lawrence Berkeley Laboratory conducted a study of 60 new buildings and found that 50% suffer from problems with the controls system and the largest source of complaints. The study also discovered the following:

- 15% of the buildings had missing equipment
- 25% of the buildings did not have functioning Energy Management Systems/economizers/VFD's

- 60% of the insurance claims involved the HVAC

Commissioning will provide:

- Visible owner's advocate for long-term savings and improved relationship with administration and O&M staff
- Ensure energy projects realize maximum return
- Fewer start-up problems, smaller punch lists, and systems training for design engineers and O&M staff
- More accurate documentation

Commissioning a HVAC system—that is, functionally testing it under all anticipated operating modes to ensure that it performs as intended—can improve efficiency and reliability and ensure that the owner's are getting the level of efficiency they paid for. Ideally, commissioning starts early in the design process and is performed by an independent third party (that is, an entity who is not part of the design or construction team).

Average savings for commissioning a building is 5% to 15% of energy costs. *(ASHRAE)*

RESOURCES FOR FURTHER INFORMATION

ASHRAE (American Society of Heating Refrigeration and Air conditioning Engineers)
www.ashrae.org

AABC (Associated Air Balance Council) www.aabchq.com

ABMA (American Boiler Manufacturers Association) www.abma.com

AMCA (Air Movement and Control Association International Inc.) www.amca.org

AFE (Association for Facilities Engineering) www.afe.org

BI (BACnet International) www.bacnetassociation.org

BPI (Building Performance Institute) www.bpi.org

CABA (Continental Automated Buildings Association) www.caba.org

CTI (Cooling Technology Institute) www.cti.org

GreenMech (Green Mechanical Council) www.greenmech.org

GridWise Architecture Council www.gridwise.org

HARDI (Heating, Airconditioning & Refrigeration Distributors International)
www.hardinet.org

HVI (Home Ventilation Institute) www.hvi.org

IAQA (Indoor Air Quality Association) www.iaqa.org

IIAR (International Institute of Ammonia Refrigeration) www.iiar.org

LMA (LonMark Americas) www.lonmarkamericas.org

MCAA (Mechanical Contractors Association of America) www.mcaa.org

MSCA (Mechanical Service Contractors of America) www.mcaa.org/msca

NADCA (National Air Duct Cleaners Association) www.nadca.com

NAFA (National Air Filtration Association) www.nafahq.org

NEBB (National Environmental Balancing Bureau) www.nebb.org

PHCC (Plumbing-Heating-Cooling Contractors Association) www.phccweb.org

RPA (Radiant Panel Association) www.radiantpanelassociation.org

REHVA (Federation of European Heating and Air-conditioning Associations)
www.rehva.com

RETA (Refrigerating Engineers & Technicians Association) www.reta.com

RSES (Refrigeration Service Engineers Society) www.rses.org

SMACNA (Sheet Metal and Air Conditioning Contractors' National Association)
www.smacna.org

SPIDA (Spiral Duct Manufacturers Association) www.spida.org

TABB (Testing, Adjusting and Balancing Bureau) www.tabbcertified.org

USGBC (U.S. Green Building Council) www.usgbc.org

ZigBee Alliance www.zigbee.org
