ASHRAE Building-Type GreenTip #1: Performing Arts Spaces

GENERAL DESCRIPTION

Performing arts spaces include dance studios, black box theaters, recital halls, rehearsal halls, practice rooms, performance halls with stage and fixed seating, control rooms, back-house spaces, and support areas.

HIGH-PERFORMANCE STRATEGIES

Acoustics

1. Clearly understand different criteria for noise criteria levels to be achieved in different type of spaces.
2. Consider 2 and 4 in. liners for large ducts serving spaces with noise criteria levels of 25 and lower.
3. Locate equipment as far away from low noise criteria spaces as practical.
4. Work closely with the acoustic consultant, structural engineer, architect, and construction manager to integrate strategies that eliminate the distribution of vibration and equipment noise from the HVAC systems to the performance spaces.
5. Design duct distribution to eliminate noise transfer between acoustically sensitive spaces. This can be done by using duct liner, additional elbows to isolate sound travel, sound attenuators, etc.
6. Do not route piping systems through or above spaces that are acoustically sensitive.

Energy Considerations

1. Demand-control ventilation for high-occupancy spaces.
2. Heat recovery for spaces served by air-handling units (AHUs) with 100% outdoor air capability or over 50% outdoor air component.
3. Consider strategies that allow the significant heat gain from the theatrical lighting equipment to stratify rather than handling all of the equipment heat gain within the “conditioned space” zones in the building.
4. Because of the significant variation in the cooling load throughout the day, incorporating a thermal energy storage (TES) system into the central plant design will reduce the size of the chiller plant equipment, saving capital costs, along with energy and operational costs.

Occupant Comfort

1. Consider underfloor supply air/displacement air strategies for large halls with fixed seating.

2. Consider stage air distribution separately from seating air distribution.
3. Consider CO_2 sensors in all spaces that have infrequent, dense occupancy.
4. Consider humidification control for all spaces where musical instruments and vocalists will practice, store equipment, and perform.

KEY ELEMENTS OF COST

1. If properly integrated, an underfloor distribution system should not add significant capital costs to the project.
2. Heat recovery strategies should be assessed using life-cycle analyses. All components of the strategy must be taken into account, including the negative aspects, such as adding fan static pressure and, therefore, using more fan energy when heat wheel or heat pipe strategies are considered.

SOURCES OF FURTHER INFORMATION

Bauman, F.S., and A. Daly. 2003. *Underfloor Air Distribution Design Guide*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE Building-Type GreenTip #2: Health Care Facilities

GENERAL DESCRIPTION

Health care facilities are infrastructure-intensive and include many different types of spaces. The HVAC systems for these different types of spaces must be designed to address the specific needs of the spaces being served. The first considerations should always be safety and infection control. In addition, optimizing energy efficiency and positively affecting the patient experience should also be important design team goals.

HIGH-PERFORMANCE STRATEGIES

Safety and Infection Control

1. Consider HEPA filtration for all air-handling equipment serving the facility.
2. Consider air distribution strategies in operating rooms and trauma rooms that zone the spaces from most clean to least clean. Start with the most clean zone being the operation/thermal plume location at the patient, the zone around the doctors, the zone around the room, and then the zone outside the room.
3. Pressurize rooms consistent with AIA and/or ASHRAE guidelines.
4. Provide air exchange rates in excess of AIA guidelines in operating rooms, intensive care units (ICUs), isolation rooms, trauma rooms, and patient rooms.
5. Redundancy of equipment should be designed for fail-safe operation and optimal full- and part-load energy-efficient operation.
6. Intake/exhaust location strategies should be modeled to ensure no reintroduction of exhaust into the building.

Energy Considerations

1. Heat recovery for spaces served by AHUs with 100% outdoor air capability.
2. Utilize variable-air-volume (VAV) systems in noncritical spaces working in conjunction with lighting occupancy sensors.

Occupant Comfort

1. Acoustics of systems and spaces must be designed with patient comfort in mind.
2. Daylight and views should be provided while minimizing the HVAC load impact of these benefits.
3. Provide individual temperature control of patient rooms with the capability of adjustment by patient.

4. Building pressurization relationships/odor issues should be carefully mapped and addressed in the design and operation of the building.

KEY ELEMENTS OF COST

1. HEPA filtration costs are significant in both first cost and operating cost. The engineer should work closely with the infection control specialists at the health care facility to determine cost/benefit assessment of the filtration strategies.
2. Heat recovery strategies should be assessed using life-cycle analyses. All components of the strategy must be taken into account, including the negative aspects, such as adding fan static pressure and, therefore, using more fan energy when heat wheel or heat pipe strategies are considered.

SOURCES OF FURTHER INFORMATION

AIA. 2006. *Guidelines for Design and Construction of Health Care Facilities.* Washington, DC: American Institute of Architects.

ASHE. *Green Guide for Health Care.* American Society of Healthcare Engineering. Available from www.gghc.org.

ASHRAE. 2003. *HVAC Design Manual for Hospitals and Clinics*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

The Center for Health Design, www.healthdesign.org.

NFPA. 2005. *NFPA 99, Standard for Health Care Facilities*. Quincy, MA: National Fire Protection Agency.

ASHRAE Building-Type GreenTip #3: Laboratory Facilities

GENERAL DESCRIPTION

Laboratory facilities are infrastructure-intensive and include many different types of spaces. The HVAC systems for these different types of spaces must be designed to address the specific needs of the spaces being served. The first considerations should always be safety and system redundancy to ensure the sustainability of laboratory studies. Life-cycle cost analyses for different system options is critical in developing the right balance between first costs and operating costs.

HIGH-PERFORMANCE STRATEGIES

Safety

1. Fume hood design and associated air distribution and controls must be designed to protect the users and the validity of the laboratory work.
2. Pressurize rooms consistent with the *ASHRAE Laboratory Design Guide* and any other code-required standards. Utilize building pressurization mapping to develop air distribution, exchange rate, and control strategies.
3. Optimize air exchange rates to ensure occupant safety while minimizing energy usage.
4. Chemical, biological, and nuclear storage and handling exhaust and ventilation systems must be designed to protect against indoor pollution, outdoor pollution, and fire hazards.
5. Intake/exhaust location strategies should be modeled to ensure that lab exhaust air is not reintroduced back into the building’s air-handling system.

Redundancy

1. Consider a centralized lab exhaust system with a redundant ($n + 1$) exhaust fan setup.
2. Redundant central chilled-water, steam or hydronic heating, air-handling, and humidification systems should be designed for fail-safe operation and to optimize full-load and part-load efficiency of all equipment.

Energy Considerations

1. Heat recovery for spaces served by AHUs with 100% outdoor air capability or over 50% outdoor air component.
2. Utilize VAV systems to minimize air exchange rates during unoccupied hours.

3. Consider low-flow fume hoods with constant volume controls where this concept can be properly applied.

Occupant Comfort

1. Air systems should be designed to allow for a collaborative working environment. Acoustic criteria should be adhered to in order to maintain acceptable levels of noise control.
2. Daylight and views should be considered where lab work will not be adversely affected.

KEY ELEMENTS OF COST

1. Heat recovery strategies should be assessed using life-cycle analyses. All components of the strategy must be taken into account, including the negative aspects, such as adding fan static pressure and, therefore, using more fan energy when heat wheel or heat pipe strategies are considered.
2. Low-flow fume hoods should be evaluated considering the impact of reducing the sizes of air-handling, heating, cooling, and humidification systems.

SOURCES OF FURTHER INFORMATION

Labs 21 Environmental Performance Criteria, www.labs21century.gov.

McIntosh, I.B.D., C.B. Dorgan, and C.E. Dorgan. 2002. *ASHRAE Laboratory Design Guide.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

NFPA. 2004. *NFPA 45, Standard on Fire Protection for Laboratories using Chemicals*. Quincy, MA: National Fire Protection Association.

ASHRAE Building-Type GreenTip #4: Student Residence Halls

GENERAL DESCRIPTION

Student residence halls are made up primarily of living spaces (bedrooms, living rooms, kitchen areas, common spaces, study spaces, etc.). Most of these buildings also have central laundry facilities, assembly/main lobby areas, and central meeting/study rooms. Some of these spaces also include classrooms, central kitchen and dining facilities, etc. The strategies outlined below can also be applied to hotels and multi-unit residential complexes, including downtown luxury condominium developments.

HIGH-PERFORMANCE STRATEGIES

Energy Considerations

1. Heat recovery for spaces served by AHUs with 100% outdoor air capability serving living units (exhaust from toilet rooms/supply air to occupied spaces).
2. Utilize VAV systems or induction systems for public/common spaces.
3. Natural ventilation and hybrid natural ventilation strategies. (See Figure 4-4 for an example of natural ventilation use.)
4. Utilize electronically commutated motors (ECMs) for fan-coil units.
5. Utilize GSHP where feasible.

Occupant Comfort

1. Systems should be designed to appropriately control noise in occupied spaces.
2. Daylight and views should be optimized while minimizing load impact on the building.
3. Consider providing occupant control in all bedrooms

KEY ELEMENTS OF COST

1. While there is a premium to be paid in first costs for ECMs, many utility companies have energy rebate programs that make this concept acceptable, even on projects with tight budgets.
2. Heat recovery strategies should be assessed using life-cycle analyses. All components of the strategy must be taken into account, including the negative aspects, such as adding fan-static pressure and, therefore, using more fan energy when heat wheel or heat pipe strategies are considered.
3. Hybrid natural ventilation strategies could be utilized using operable windows, properly designed vents using the venturi effect to optimize natural airflow through the building, and shutdown of mechanical ventilation and cooling

systems during ambient temperature ranges between 60°F and 80°F. This will save significant operating costs. The costs of the operable windows and vents will need to be weighed against the energy savings.

SOURCES OF FURTHER INFORMATION

ASHRAE. 2005. *2005 ASHRAE Handbook—Fundamentals*. Chapter 27, pp. 25.10–25.12. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

BRESCU, BRE. 1999. *Natural Ventilation for Offices Guide and CD-ROM*. ÓBRE on behalf of the NatVent Consortium, Garston, Watford, UK, March.

Svensson C., and S.A. Aggerholm. 1998. Design tool for natural ventilation. *Proceedings of the ASHRAE IAQ '98 Conference, New Orleans, October 24–27.*

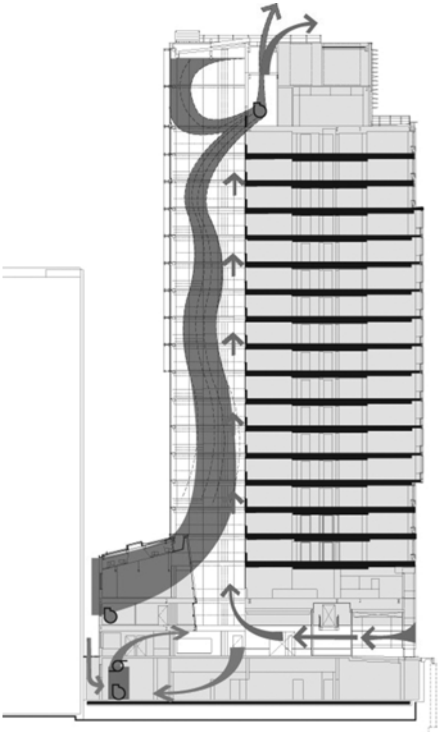


Figure 4.4 Suffolk University 10 Sommer Street Residence Hall (Boston, MA)—natural ventilation in atrium optimizes views while minimizing solar heat gain.

ASHRAE Building-Type GreenTip #5: Athletic and Recreation Facilities

GENERAL DESCRIPTION

Athletic and recreational spaces include pools, gymnasiums, cardio rooms, weight-training rooms, multipurpose rooms, courts, offices, and other support spaces, etc.

HIGH-PERFORMANCE STRATEGIES

Energy Considerations

1. Demand control ventilation for high-occupancy spaces.
2. Heat recovery for spaces served by AHUs with 100% outdoor air capability or over 50% outdoor air component. (See Figure 4-5 for an example of heat recovery use.)
3. Consider strategies that allow the significant heat gain in high volume spaces to stratify rather than handling all of the heat gain within the "conditioned space" zones in the building.
4. Consider heat recovery/no mechanical cooling strategy for the pool area in moderate climates.

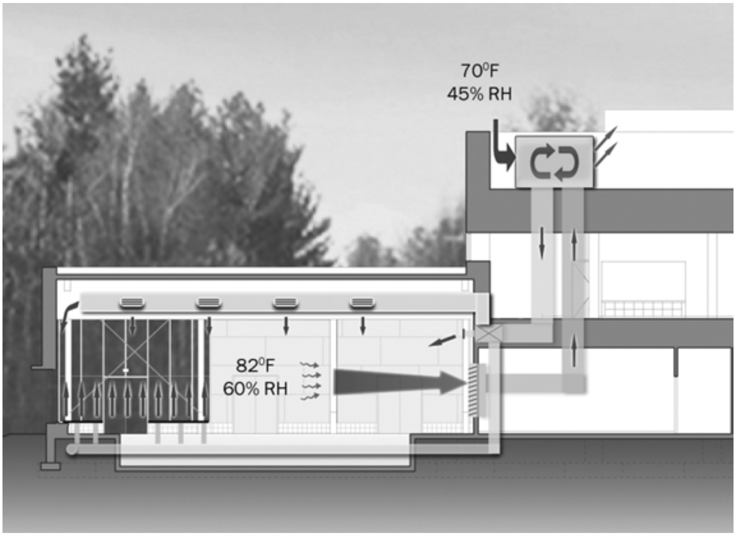


Figure 4.5 University of Maine Pool HVAC system with heat recovery.

5. Consider occupied/unoccupied mode for large locker room and toilet room areas to set back the air exchange rate in these spaces during unoccupied hours and save fan energy.
6. Consider heating pool water with waste heat from pool dehumidification system.

Occupant Comfort

1. Consider CO_2 sensors in all spaces that have infrequent, dense occupancy.
2. Consider high-occupancy and low-occupancy modes for air-handling equipment in gymnasiums utilizing a manual switch and variable-frequency drives (VFDs).
3. Consider hybrid natural ventilation strategies in areas that do not have humidity control issues (i.e., pools, training rooms, etc.)

KEY ELEMENTS OF COST

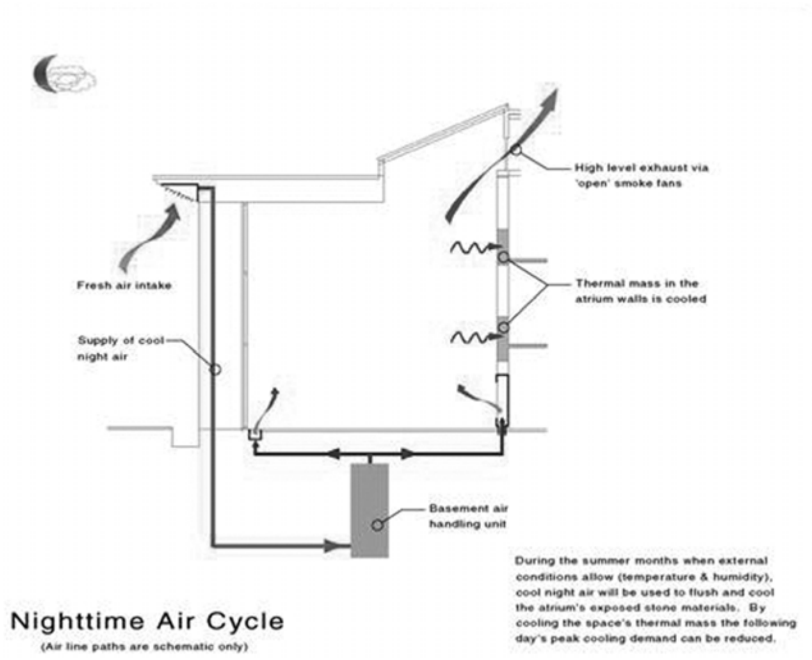
1. The pool strategy described above should reduce first costs and operating costs.
2. Heat recovery strategies should be assessed using life-cycle analyses. All components of the strategy must be taken into account, including the negative aspects, such as adding fan static pressure and, therefore, using more fan energy when heat wheel or heat pipe strategies are considered.
3. Demand control ventilation adds minimal first costs and often provides paybacks in one to two years.

ASHRAE GreenTip #6: Night Precooling

GENERAL DESCRIPTION

Night precooling involves the circulation of cool air within a building during the nighttime hours with the intent of cooling the structure (see Figure 7-5). The cooled structure is then able to serve as a heat sink during the daytime hours, reducing the mechanical cooling required. The naturally occurring thermal storage capacity of the building is thereby utilized to smooth the load curve and for potential energy savings. More details on the concept of thermal mass on building loads are included in Chapter 4, “Architectural Design Impacts.”

There are two variations on night precooling. One, termed *night ventilation precooling*, involves the circulation of outdoor air into the space during the naturally cooler nighttime hours. This can be considered a passive technique except for any fan power requirement needed to circulate the outdoor air through the space. The night ventilation precooling system benefits the building IAQ through the cleansing effect of introducing more ventilation air. With the other variation, *mechanical*



During the summer months when external conditions allow (temperature & humidity), cool night air will be used to flush and cool the atrium's exposed stone materials. By cooling the space's thermal mass the following day's peak cooling demand can be reduced.

Buro Happold-Hamilton College Science Center (2002)

Figure 7-5 Schematic example of nighttime air cycle.

precooling, the building mechanical cooling system is operated during the nighttime hours to precool the building space to a setpoint usually lower than that of normal daytime hours.

Consider these key parameters when evaluating either concept:

- local diurnal temperature variation
- ambient humidity levels
- thermal coupling of the circulated air to the building mass

The electric utility rate structure for peak and off-peak loads also is important to determine the cost-effectiveness, in particular for a mechanical precooling scheme.

A number of published studies show significant reductions in overall operating costs by the proper precooling and discharge of building thermal storage. The lower overall costs result from load shifting from the day to the nighttime with its associated off-peak utility rates. For example, Braun (1990) showed significant energy cost savings of 10% to 50% and peak power requirements of 10% to 35% over a traditional nighttime setup control strategy. The percent savings were found to be most significant when lower ambient temperatures allowed night ventilation cooling to be performed.

For a system incorporating precooling to be considered a truly green design concept, the total energy used through the entire 24-hour day should be lower than without precooling. A system that uses outdoor air to do the precooling only requires the relatively lower power needed to drive the circulation fans, compared to a system that incorporates mechanical precooling. Electrical energy provided by the utility during peak demand periods also may be “dirtier” than that provided during normal periods, depending on the utility and circumstances.

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 precooling is better suited for drier climates. A mechanical nighttime precooling 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.

Both variations (night ventilation and night mechanical precooling) 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. Certain building concepts used in Europe are designed to increase the exposure of the air supply or return with the interior building mass (see, for example, Andersson et al. [1979]). This concept will increase the overall efficiency of the thermal storage mass.

For either type of system, the designer must carefully analyze the structure and interaction with the HVAC system air supply using transient simulations in order to assess the feasibility with their particular project. A number of techniques and commercially available computer codes exist for this analysis (Balaras 1995).

WHEN/WHERE IT'S APPLICABLE

Night precooling would be applicable in the following circumstances:

- When the ambient nighttime temperatures are low enough to provide sufficient opportunity to cool the building structure through ventilation air. Ideally, a low ambient humidity level would also occur. A hot, dry environment, such as the southwestern United States, is an ideal potential area for this concept.
- When the building occupants would be more tolerant of the potential for slightly cooler temperatures during the morning hours.
- When the owner and design team are willing to include such a system concept and to commit to (1) a proper analysis of the dynamics of the building thermal performance and (2) the refinement of the control strategy upon implementation to fine-tune the system performance.
- More massive buildings, or those built with heavier construction materials such as concrete or stone as compared to wood, have a greater potential for benefits. Just as important is the interaction of the building mass with the building internal and HVAC system circulating air. This interaction may allow for more efficient transfer of thermal energy between the structure and the airspace.

PROS AND CONS

Pro

1. Night ventilation precooling 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 precooling 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 precooling concept. Both will be better than if the system were completely shut off during unoccupied hours.

Con

1. 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. This will result in increased service calls or complaints and may end with the night precooling being bypassed or turned off.

2. The increased runtime on the equipment could lead to lower equipment life expectancy or increased frequency in maintenance. Careful attention should be given to the resulting temperature profile through the day during the commissioning process. Adjustments may be needed to the control schedule to keep the building within the thermal comfort zone.
3. Proper orientation must be given to the building operator to understand how the control concept affects the overall system operation throughout the day.
4. Future turnovers in building ownership or operating personnel could negatively affect how successfully the system performs.
5. 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.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a nighttime precooling scheme from a conventional one and gives an indication of whether the net cost for the precooling option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Mechanical ventilation system elements	S
• Architectural design features	S
• System controls	H
• Analysis and design fees	H

Recurring Cost

• Energy for mechanical portion of system	
Ventilation precooling	L
Mechanical precooling	S/H
• Total cost to operate cooling systems	L
• Maintenance of mechanical ventilation and cooling system	S/H
• Training of building operators	H
• Orientation of building occupants	H
• Commissioning cost	H
• Occupant productivity	S

SOURCES OF FURTHER INFORMATION

The following is a sampling of representative papers that can provide further background information.

Andersson, L.O., K.G. Bernander, E. Isfält, and A.H. Rosenfeld. 1979. Storage of heat and coolth in hollow-core concrete slabs. Swedish experience and application to large, American style buildings. Second International Conference on Energy Use and Management, Lawrence Berkeley National Laboratory, LBL-8913.

Balaras, C.A. 1995. The role of thermal mass on the cooling load of buildings. An overview of computational methods. *Energy and Buildings* 24(1):1–10.

Braun, J.E. 1990. Reducing energy costs and peak electrical demand through optimal control of building thermal storage. *ASHRAE Transactions* 96(2):876–88.

Keeney, K.R., and J.E. Braun. 1997. Application of building precooling to reduce peak cooling requirements. *ASHRAE Transactions* 103(1):463–69.

Kintner-Meyer, M., and A.F. Emery. 1995. Optimal control of an HVAC system using cold storage and building thermal capacitance. *Energy and Buildings* 23:19–31.

Ruud, M.D., J.W. Mitchell, and S.A. Klein. 1990. Use of building thermal mass to offset cooling loads. *ASHRAE Transactions* 96(2):820–29.

ASHRAE GreenTip #7:
Air-to-Air Energy Recovery—Heat Exchange Enthalpy Wheels

GENERAL DESCRIPTION

There are several types of air-to-air energy systems for recovering energy from building exhaust air, and consideration should be given to using the type most appropriate for the application. The table at the bottom of the page indicates typical ranges in performance.

A heat exchange enthalpy wheel, also known as a *rotary energy wheel*, has a revolving cylinder filled with an air-permeable medium with a large internal surface area. Adjacent airstreams pass through opposite sides of the exchanger in a counterflow pattern. Heat transfer media may be selected to recover heat only or sensible plus latent heat. Because rotary exchangers have a counterflow configuration and normally use small-diameter flow passages, they are quite compact and can achieve high transfer effectiveness.

Cross-contamination, or mixing, of air between the airstreams occurs in all rotary exchangers by one of two methods: carryover or leakage. Carryover occurs as air is entrained within the medium and is carried into the other airstream. Leakage occurs because the differential pressure across the two airstreams drives air from the high-pressure to the low-pressure airstream. Because cross-contamination can be detrimental, a purge section can be installed to reduce carryover.

Two control methods are commonly used to regulate wheel energy recovery. In the first, an air bypass damper controlled by a wheel supply air temperature sensor regulates the proportion of air that is permitted to bypass the exchanger. The second,

Type	Cross Leakage, %	Pressure Drop, %	Effective Sensible, %	Effective Latent, %
Plate—dry air streams	0–5	100–400	50–75	—
Plate—wetted exhaust air[a]	0–5	100–500	50–75	50–85
Plate—membrane[b]	0–5	100–500	50–75	50–85
Heat wheel	0.5–10	100–300	50–75	—
Enthalpy wheel[c]	0.5–10	100–300	50–75	50–85
Heat pipe	0–1	100–500	50–65	—
Runaround loop	0	100–500	50–65	—
Thermosyphon	0	100–500	50–65	—
Twin towers	0	100–300	50–65	—

a. Indirect evaporative—total energy transfer.
b. Porous membrane—total energy transfer.
c. Desiccant coated—total energy transfer.

and more common, method regulates the energy recovery rate by varying the wheel's rotational speed.

WHEN/WHERE IT'S APPLICABLE

In general, rotary air-to-air energy recovery systems can be used in process-to process, process-to-comfort, and comfort-to-comfort applications, where energy in the exhaust stream would otherwise be wasted. Regions with higher energy costs favor higher levels of energy recovery; however, the economics of scale often favor larger installations. Energy recovery is most economical when there are large temperature differences between the airstreams, the source of supply is close to the exhaust, and they are both relatively constant throughout the year. Applications with a large central energy source and a nearby waste energy use are more favorable than applications with several scattered waste energy sources and uses. Rotary energy wheels are best applied when cross-contamination is not a concern.

PROS AND CONS

Pro

1. The total HVAC system installed cost may be lower because central heating and cooling equipment may be reduced in sized.
2. With a total energy wheel, humidification costs may be reduced in cold weather and dehumidification costs may be lowered in warm weather.
3. Plate energy exchangers are the simplest type due to having no moving parts (compared to rotary types). Some are sealed to prevent leakage and cross-contamination and have plates made from hygienic materials in a cleanable cross-flow arrangement.
4. Rotary type exchangers have cross-contamination because they rotate between the exhaust and supply air ducts. Cross-contamination may be reduced by inserting a purge section in the wheel between entering and leaving the ducts. This uses some supply air.
5. Rotary wheels require little maintenance and are simple to operate.
6. Heat pipe systems have variable tilt for performance control. This requires some maintenance and allows minor cross-contamination.
7. 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.

Con

1. Energy recovery requires that the supply and exhaust airstreams be within close proximity.
2. Cross-contamination can occur between the airstreams.
3. Energy wheel adds pressure drop to the system.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate the above system from a conventional one and an indication of whether the net cost for the alternative option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Central equipment costs	L
• Co-locating exhaust and supply sources	S/H
• Ductwork	S/H
• Design fees	S

Recurring Cost

• Overall energy cost	L
• Maintenance of system	S/H
• Training of building operators	S/H
• Filters	H

SOURCES OF FURTHER INFORMATION

ASHRAE. 2004. *2004 ASHRAE Handbook—HVAC Systems and Equipment,* chapter 44, Air-to-Air Energy Recovery. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Trane Company. 2000. Energy conscious design ideas—Air-to-air energy recovery. *Engineers Newsletter* 29(5). Publication ENEWS-29/5. Lacrosse, WI: Trane Company.

ASHRAE GreenTip #8:
Air-to-Air Energy Recovery—Heat Pipe Systems

GENERAL DESCRIPTION

A heat pipe heat exchanger is a completely passive energy recovery device with an outward appearance of an ordinary extended surface, finned tube coil. The tubes are divided into evaporator and condenser sections by an internal partition plate. Within the permanently sealed and evacuated tube filled with a suitable working fluid, there is an integral capillary wick structure. The working fluid is normally a refrigerant, but other fluorocarbons, water, and other compounds are used in applications with special temperature requirements.

Heat transfer occurs when hot air flowing over the evaporator end of the heat pipe vaporizes the working fluid. A vapor pressure gradient drives the vapor to the condenser end of the heat pipe tube, where the vapor condenses, releasing the latent energy of vaporization. The condensed fluid is wicked back to the evaporator where it is revaporized, thus completing the cycle. Using this mechanism, heat transfer along a heat pipe is 1000 times faster than through copper.

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.

WHEN/WHERE IT'S APPLICABLE

In general, air-to-air energy recovery systems can be used in process-to process, process-to-comfort, and comfort-to-comfort applications, where energy in the exhaust stream would otherwise be wasted. Regions with higher energy costs favor higher levels of energy recovery; however, the economics of scale often favor larger installations. Energy recovery is most economical when there are large temperature differences between the airstreams, the source of supply is close to the exhaust, and they are both relatively constant throughout the year. Applications with a large central energy source and a nearby waste energy use are more favorable than applications with several scattered waste energy sources and uses.

PROS AND CONS

Pro

1. The total HVAC system installed cost may be lower because central heating and cooling equipment may be reduced in sized.

2. They require little maintenance and are simple to operate.
3. Cross-contamination is not a significant concern.

Con

1. The system requires that the supply and exhaust airstreams be within close proximity.
2. Heat pipe adds pressure drop to the system.
3. Decomposition of the thermal fluid can deteriorate performance.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building with a heat pipe system from one without and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Central equipment costs	L
• Co-locating exhaust and supply sources	S/H
• Ductwork	S/H
• Design fees	S

Recurring Cost

• Overall energy cost	L
• Maintenance of system	S/H
• Training of building operators	S/H
• Filters	H

SOURCES OF FURTHER INFORMATION

ASHRAE. 2003. *2003 ASHRAE Handbook—HVAC Systems and Equipment*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Trane Company. 2000. Energy conscious design ideas—Air-to-air energy recovery. *Engineers Newsletter* 29(5). Publication ENEWS-29/5. Lacrosse, WI: Trane Company.

ASHRAE GreenTip #9:
Air-to-Air Energy Recovery—Run-Around Systems

GENERAL DESCRIPTION

A typical coil energy recovery loop places extended surface, finned tube coils in the supply and exhaust airstreams of a building or process. The coils are connected in a closed loop via counterflow piping through which an intermediate heat transfer fluid (typically water or an antifreeze solution) is pumped. An expansion tank must be included to allow fluid expansion and contraction.

The coil energy recovery loop cannot transfer moisture from one airstream to another. However, indirect evaporative cooling can reduce the exhaust air temperature, which significantly reduces cooling loads. And in comfort-to-comfort applications, the energy transfer is seasonally reversible. Specifically, the supply air is preheated when the outdoor air is cooler than the exhaust and precooled when the outdoor air is warmer.

Complete separation of the airstreams eliminates cross-contamination as a concern, but freeze protection must be considered. A dual-purpose three-way control valve can prevent freeze-ups by controlling the temperature of the solution entering the exhaust coil to 30°F or above. This condition is maintained by bypassing some of the warmer solution around the coil. This valve can also ensure that a prescribed air temperature from the supply coil is not exceeded.

WHEN/WHERE IT'S APPLICABLE

In general, air-to-air energy recovery systems can be used in process-to process, process-to-comfort, and comfort-to-comfort applications, where energy in the exhaust stream would otherwise be wasted. Regions with higher energy costs favor higher levels of energy recovery; however, the economics of scale often favor larger installations. Energy recovery is most economical when there are large temperature differences between the airstreams, the source of supply is close to the exhaust, and they are both relatively constant throughout the year. Runaround loops are highly flexible and well suited to renovation and industrial applications. The loop accommodates remote supply and exhaust ducts and allows the simultaneous transfer of energy between multiple sources and uses.

PROS AND CONS

Pro

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

Con

1. It requires a pump, which offsets some energy recovery savings.
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 more maintenance and controls.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building with a run-around coil system from one without and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Central equipment costs	L
• Hydronics (piping, pumps, and controls)	H
• Ductwork	S
• Design fees	S

Recurring Cost

• Overall energy cost	L
• Maintenance of system	S/H
• Training of building operators	S/H
• Filters	H

SOURCES OF FURTHER INFORMATION

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Trane Company. 2000. Energy conscious design ideas—Air-to-air energy recovery. *Engineers Newsletter* 29(5). Publication ENEWS-29/5. Lacrosse, WI: Trane Company.

ASHRAE GreenTip #10: Displacement Ventilation

GENERAL DESCRIPTION

With a ceiling supply and return air system, the ventilation effectiveness may be compromised if sufficient mixing does not take place. While there are no data suggesting that cold air supplied at the ceiling will short circuit, it is possible that a fraction of the supply air may bypass directly to the return inlet without mixing at the occupied level when heating from the ceiling. For example, when heating with a typical overhead system with supply temperatures exceeding 15°F (8.3°C) above room temperature, ventilation effectiveness will approach 80% or less. In compliance with Table 6.2, ASHRAE Standard 62.1-2004, zone air distribution effectiveness is only 0.8, so ventilation rates must be multiplied by 1/0.8 or 1.25. While proper system design and diffuser selection can alleviate this problem, another potential solution is displacement ventilation.

In displacement ventilation, conditioned air with a temperature slightly lower than the desired room temperature is supplied horizontally at low velocities at or near the floor. Returns are located at or near the ceiling. The supply air is spread over the floor and then rises by convection as it picks up the load in the room. Displacement ventilation does not depend on mixing. Instead, you are literally displacing the stale polluted air and forcing it up and out the return or exhaust grille. Ventilation effectiveness may actually exceed 100%, and Table 6.2 of ASHRAE Standard 62.1-2004 indicates a zone air distribution effectiveness of 1.2 shall be used.

Displacement ventilation is common practice in Europe, but its acceptance in North America has been slow primarily because of the conventional placement of ductwork at the ceiling level and more extreme climatic conditions.

WHEN/WHERE IT'S APPLICABLE

Displacement ventilation 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.

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 if the space served is occupied. Some designs use chilled ceilings or heated floors to overcome this limitation. When chilled ceilings are used, it is critical that building relative humidity be controlled to avoid condensation. Another means of increasing cooling capacity is to recirculate some of the room air.

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

Pro

1. Displacement ventilation offers improved thermal comfort and IAQ due to increased ventilation effectiveness.
2. There is reduced energy use due to extended economizer availability associated with higher supply temperatures.

Con

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 costs.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a system utilizing displacement ventilation from one that does not and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Controls	S
• Equipment	S
• Distribution ductwork	S/H
• Design fees	S

Recurring Cost

• Energy cost	L
• Maintenance of system	S
• Training of building operators	S/H
• Orientation of building occupants	S/H
• Commissioning cost	S

SOURCES OF FURTHER INFORMATION

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ASHRAE. 2004. *2004 ASHRAE Handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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ASHRAE GreenTip #11: Dedicated Outdoor Air Systems

GENERAL DESCRIPTION

ASHRAE Standard 62 describes in detail the ventilation required to provide a healthy indoor environment as it pertains to IAQ. Traditionally designers have attempted to address both thermal comfort and IAQ with a single mixed air system. But 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 overventilated. In turn, providing a separate dedicated outdoor air system (DOAS) may be the only reliable way to meet the true intent of ASHRAE Standard 62.

A DOAS uses a separate air handler to condition the outdoor air before delivering it directly to the occupied spaces. The air delivered to the space from the DOAS should not adversely affect thermal comfort (i.e., too cold, too warm, too humid); therefore, many designers call for systems that deliver neutral air. However, there is a strong argument for supplying cool dry air and decoupling the latent conditioning as well as the IAQ components from the thermal comfort (sensible only) system.

The only absolute in a DOAS is that the ventilation air must be delivered directly to the space from a separate system. Control strategy, energy recovery, and leaving air conditions are all variables that can be fixed by the designer.

WHEN/WHERE IT'S APPLICABLE

While a DOAS can be applied in any design, it is most beneficial in a facility with multiple spaces with differing ventilation needs. A DOAS can be combined with any thermal comfort conditioning system, including, but not limited to, all-air systems, fan-coil units, and hydronic radiant cooling. Note, however, that a design incorporating a separate 100% outdoor air unit delivering air to the mixed air intakes of other units is not a DOAS as defined here. While this type of system may have benefits, such as using less energy or providing more accurate humidity control, it still suffers from the multiple space dilemma described above.

PROS AND CONS

Pro

1. A DOAS ensures compliance with ASHRAE 62.1-2004 for proper multiple space ventilation and adequate IAQ.
2. It reduces a building's energy use when compared to mixed air systems that require overventilation of some spaces.
3. It allows the designer to decouple the latent load from the sensible load, hence providing more accurate space humidity control.
4. It allows easy airflow measurement and balance and keeps ventilation loads off main HVAC units.

Con

1. Depending on overall design (thermal comfort and IAQ), it may add additional first cost associated with providing parallel systems.
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.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building with a DOAS from one with another system and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Controls	H
• Equipment	S/H
• Distribution ductwork	S/H
• Design fees	S/H

Recurring Cost

• Energy cost	S/L
• Maintenance of system	S/H
• Training of building operators	S/H
• Orientation of building occupants	S
• Commissioning cost	S/H

SOURCES OF FURTHER INFORMATION

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Coad, W.J. 1999. Conditioning ventilation air for improved performance and air quality. *Heating/Piping/Air Conditioning*, September.

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ASHRAE GreenTip #12: Ventilation Demand Control Using CO_2

GENERAL DESCRIPTION

A significant component of indoor environmental quality (IEQ) is the indoor air quality (IAQ). ASHRAE Standard 62.1-2004 describes in detail the ventilation required to provide a healthy environment. However, providing ventilation based strictly on the peak occupancy using the ventilation rate procedure (Section 6.1) will result in overventilation during periods. Any positive impact on IAQ brought on by overventilation will be outweighed by the costs associated with the energy required to condition the ventilation air.

CO_2 can be used to measure or control the per-person ventilation rate and, in turn, allow the designer to introduce a ventilation demand control strategy. Simply put, the amount of CO_2 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. CO_2-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 CO_2 demand-based ventilation system are CO_2 sensors and a means by which to control the outdoor fresh air intake, i.e., a damper with a modulating actuator. There are many types of sensors, and the technology is evolving while, at the same time, costs are dropping. Sensors can be wall-mounted or mounted in the return duct, but it is recommended that the sensor be installed within the occupied space whenever possible.

WHEN/WHERE IT'S APPLICABLE

CO_2 demand control is best suited for buildings with a variable occupancy. 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 CO_2 monitoring may still be utilized for verification that high IAQ is achieved.

PROS AND CONS

Pro

1. CO_2 demand control reduces a building's energy use as it relates to overventilation.
2. It assists in maintaining adequate ventilation levels regardless of occupancy.

Con

1. There is an added first cost associated with the sensors and additional controls.

2. There are additional materials and their associated embodied energy costs.
3. Evolving sensor technology may not be developed to full maturity.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building utilizing a CO_2 ventilation demand control strategy from one that does not and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Controls	H
• Design fees	S/H

Recurring Cost

• Energy cost	L
• Maintenance of system	S/H
• Training of building operators	S/H
• Orientation of building occupants	S/H
• Commissioning cost	S/H

SOURCES OF FURTHER INFORMATION

Advanced Buildings Technologies and Practices, www.advancedbuildings.org.

ASHRAE. 2004. *ANSI/ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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ASHRAE GreenTip #13: Hybrid Ventilation

GENERAL DESCRIPTION

A hybrid ventilation system allows the controlled introduction of outdoor air ventilation into a building by both mechanical and passive means; thus, it is sometimes called mixed-mode ventilation. 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 has no automatic way of controlling the amount of outdoor air load.

Two variants of hybrid ventilation are the *changeove*r (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:

- When the owner and design team are willing to explore employing a nonconventional building ventilation technique that has the promise of reducing ongoing operating costs as well as providing a healthier, stimulating environment.
- 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.
- 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.
- 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

Pro

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.

Con

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.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a hybrid ventilation system from a conventional one and an indication of whether the net cost for the hybrid option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Mechanical ventilation system elements	S
• Architectural design features	H/L
• Operable window operators	H
• Integral opening operators/dampers	H
• Filters for additional openings	H
• Controls for passive system/coordination with mechanical system	H
• Design fees	H

Recurring Cost

• Energy for mechanical portion of system	L
• Maintenance of above	L
• Energy used by controls, mechanical operators	H
• Maintenance of passive system	H
• Training of building operators	H
• Orientation of building occupants	H
• Commissioning cost	H
• Occupant productivity	H

SOURCE OF FURTHER INFORMATION

Kosik, W.J. 2001. Design strategies for hybrid ventilation. *ASHRAE Journal* 43(10). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE GreenTip #14:
Pulse-Powered Chemical-Free Water Treatment

TECHNOLOGY DESCRIPTION

Pulse-powered physical water treatment uses pulsed, electric fields (a technology developed by the food industry for pasteurization) to control scaling, biological growth, and corrosion. 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. Pulse-powered systems tend to be forgiving of operational upsets and promote cooling tower operation at higher cycles of concentration (therefore, less blowdown and less water usage) than standard chemical treatment. 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.

The technology produces a pulsed, time-varying, induced electric field inside a PVC pipe that is fit into the recirculating water system. The electric signal changes the way minerals in the water precipitate, totally avoiding hard-lime scale by 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 noncorrosive, operating at the saturation point of calcium carbonate (a cathodic corrosion-inhibiting environment). The low bacteria count and reduction or elimination of biofilm reduces concern about microbial influenced corrosion. The absence of aggressive oxidizing biocides eliminates the risk of other forms of corrosion.

PROS AND CONS

Pro

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 biofilm.
6. Removes health and safety concerns about handling chemicals.
7. Eliminates the environmental impact of blowdown, air emissions, and drift from toxic chemicals.

Con

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.

KEY ELEMENTS OF COST

The following economic factors list the various cost elements associated with traditional chemical treatment that are avoided with chemical-free water treatment. This is a general assessment of what might be likely, but it may not be accurate in all situations. There is no substitute for a detailed cost analysis as part of the design process.

- *Direct Cost of Chemicals.* This item is the easiest to see and is sometimes considered the only cost. For cooling towers in the US, this direct cost usually runs between $8.00 and $20.00 per ton of cooling per year.
- *Water Softener.* Water softeners have direct additional costs for salt, media, equipment depreciation, maintenance, and direct labor.
- *OSHA and General Environmental Requirements.* Many chemicals used to treat water systems are OSHA-listed hazardous materials. Employees in this field are required to have documented, annual training on what to do in the event of a chemical release or otherwise exposed contamination.
- *General Handling Issues.* Chemical tanks, barrels, salt bags, etc., take space. A typical chemical station requires 100 ft (9.3 m) of space.
- *Equipment Maintenance.* Lower overall maintenance for the systems as a whole may be possible.
- *Water Savings.* Cooling towers are often a facility’s largest consumer of water. Most chemically controlled cooling towers operate at two to four cycles of concentration. Cycles of concentration can often be changed to six to eight cycles with chemical-free technology, with an annual reduction in water usage costs and the associated environmental impacts.
- *Energy Savings.* Energy is required to operate the pulse-powered system, but overall energy usage can be lower. The reduction or elimination of biofilm (a

slime layer in a cooling tower) results in energy savings versus chemical treatment due to improved heat transfer. Biofilm has a heat transfer resistance four times that of scale and is also the breeding ground for *Legionella* amplification. Preventing this amplification thus saves costs.

SOURCES OF FURTHER INFORMATION

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ASHRAE GreenTip #15:
Variable-Flow/Variable-Speed Pumping Systems

GENERAL DESCRIPTION

In most hydronic systems, variable flow with variable-speed pumping can be a significant source of energy savings. Variable flow is produced in chilled- and hot-water systems by using two-way control valves and in condenser-water cooling systems by using automatic two-position isolation valves interlocked with the chiller machinery's compressors. In most cases, variable flow alone can provide energy savings at a reduced first cost since two-way control valves cost significantly less to purchase and install than three-way valves. In condenser-water systems, even though two-way control valves may be an added first cost, they are still typically cost-effective, even for small (1 to 2 ton [3.5 to 7 kWR]) heat pump and air-conditioning units. (ASHRAE Standard 90.1-1999 requires isolation valves on water-loop heat pumps and some amount of variable flow on all hot-water and chilled-water systems.)

Variable-speed pumping can dramatically increase energy savings, particularly when it is combined with demand-based pressure reset controls. Variable-speed pumps are typically controlled to maintain the system pressure required to keep the most hydraulically remote valve completely open at design conditions. The key to getting the most savings is placement of the differential pressure transducer as close to that remote load as possible. If the system serves multiple hydraulic loops, multiple transducers can be placed at the end of each loop, with a high-signal selector used to transmit the signal to the pumps. With direct digital control (DDC) control systems, the pressure signal can be reset by demand and controlled to keep at least one valve at or near 100% open. If valve position is not available from the control system, a "trim-and-respond" algorithm can be employed.

Even with constant-speed pumping, variable-flow designs save some energy, as the fixed-speed pumps ride up on their impeller curves, using less energy at reduced flows. For hot-water systems, this is often the best life-cycle cost alternative, as the added pump heat will provide some beneficial value. For chilled-water systems, it is typically cost-effective to control pumps with variable-speed drives. It is very important to "right size" the pump and motor before applying a variable-speed drive in order to keep drive cost down and performance up.

WHEN/WHERE IT'S APPLICABLE

Variable-flow design is applicable to chilled-water, hot-water, and condenser-water loops that serve water-cooled air-conditioning and heat-pump units. The limitations on each of these loop types are as follows:

- Chillers require a minimum flow through the evaporators. (Chiller manufacturers can specify flow ranges if requested.) Flow minimums on the evaporator side can be achieved via hydronic distribution system design using either a primary/secondary arrangement or primary-only variable flow with a bypass line and valve for minimum flow.

- Some boilers require minimum flows to protect the tubes. These vary greatly by boiler type. Flexible bent-water-tube and straight-water-tube boilers can take huge ranges of turn-down (close to zero flow). Fire-tube and copper-tube boilers, on the other hand, require a constant flow primary pump.

Variable-speed drives on pumps can be used on any variable-flow system. As described above, they should be controlled to maintain a minimum system pressure. That system pressure can be reset by valve demand on hot-water and chilled-water systems that have DDC control of the hydronic valves.

PROS AND CONS

Pro

1. Both variable-flow and variable-speed control save significant energy.
2. Variable-speed drives on pumps provide a “soft” start, extending equipment life.
3. Variable-speed drives and two-way valves are self-balancing.
4. Application of demand-based pressure reset significantly reduces pump energy and decreases the occurrence of system overpressurization, causing valves near the pumps to lift.
5. Variable-speed systems are quieter than constant-speed systems.

Con

1. Variable-speed drives add cost to the system. (They may not be cost-effective on hot-water systems.)
2. Demand-based supply pressure reset can only be achieved with DDC of the heating/cooling valves.
3. Variable flow on condenser-water systems with open towers requires that supplementary measures be taken to keep the fill wet on the cooling towers. Cooling towers with rotating spray heads or wands can accept a wide variation in flow rates without causing dry spots in fill. 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.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a variable-flow/variable-speed system from a conventional one and an indication of whether the net cost for the hybrid option is likely to be lower

(L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

Hydronic system terminal valves: two-way vs. three-way (applicable to hot-water and chilled-water systems)	L
Bypass line with two-way valve or alternative means (if minimum chiller flow is required)	H
Hydronic system isolation valves: two-position vs. none (applicable to condenser-water systems)	H
Cooling tower wet-fill modifications (condenser-water systems)	H
Variable-speed drives and associated controls	H
DDC system (may need to allow demand-based reset) or pressure transducers	H
Design fees	H

Recurring Cost

Pumping energy	L
Testing and balancing (TAB) of hydronic system	L
Maintenance	H
Commissioning	H

SOURCES OF FURTHER INFORMATION

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ASHRAE GreenTip #16: CHP Systems

GENERAL DESCRIPTION

CHP stands for combined heating and power. Other abbreviations that have been used to describe such integrated energy systems are CCHP (includes *cooling*) and BCHP (building cooling, heating, and power). The goal, regardless of the abbreviation, is to improve system efficiencies or source fuel utilization by availing of the low-grade heat that is a by-product of the power generation process for heating and/or cooling duty. Fuel utilization efficiencies as high as 80% were reported (Adamson 2002). The resulting savings in operating cost, relative to a conventional system, are then viewed against the first cost, and simple paybacks under four years have been anticipated (LeMar 2002). This is particularly important from a marketing perspective, for both the distributed-generation and the thermal equipment provider. This is because, by themselves, a microturbine manufacturer and an absorption chiller manufacturer, for example, would find it difficult to compete with a utility and an electric chiller manufacturer, respectively, as the provider of low-cost power and cooling. Last, but by no means least, the higher (fossil-)fuel utilization rates result in reduced emissions of CO_2, the greenhouse gas with over 55% contribution to global warming (Houghton et al. 1990).

Gas engines, microturbines, and fuel cells have been at the center of CHP activity as the need for reliable power and/or grid independence has recently become evident. These devices are also being promoted to reduce the need for additional central-station peaking power plants. As would be expected, however, they come at a first cost premium, which can range from \$1000–\$4000/kW (Ellis and Gunes 2002). At the same time, operating (thermal) efficiencies have remained in the vicinity of those of the large, centralized power plants, even after the transmission and distribution losses are taken into account. This is particularly true of engines and microturbines (25%–35% thermal efficiency), while fuel cells promise higher efficiencies (~50%), albeit at the higher cost premiums (\$3000–\$4000/kW).

On the thermal side, standard gas-to-liquid or gas-to-gas heat exchanger equipment can be used for the heating component of the CHP system. This transfers the heat from the exhaust gases to the process/hydronic fluid or air, respectively. For the cooling component, the size ranges of distributed power generators offer a unique advantage in terms of flexibility in the selection of the chiller equipment. These can be smaller-end (relative to commercial) water-lithium bromide single- or double-effect absorption chillers or larger-end (relative to residential) single-effect or GAX ammonia-water absorption chillers (Erickson and Rane 1994). Such chillers have a typical COP of 0.7 and, as a rule of thumb, for thermal-to-electrical load matching, for every 4 kW of power generated, 1 ton of cooling may be achieved (Patnaik 2004).

Figure 11-5 illustrates typical operating conditions that an absorption chiller would see with a reciprocating engine.

WHEN/WHERE IT'S APPLICABLE

CHP is particularly suited for applications involving distributed power generation. Buildings requiring their own power generation, either due to a stringent power reliability and/or quality requirement or remoteness of location, must also satisfy various thermal loads (space heating or cooling, water heating, dehumidification). A conventional fossil-fuel-fired boiler and/or electric chiller can be displaced, to some extent if not entirely, by a heat recovery device (standard heat exchanger) and/or an absorption chiller driven by the waste heat from the power generator. Since the source of heating and/or cooling is waste heat that would ordinarily have been rejected to the surroundings, the operating cost of meeting the thermal demand of the building is significantly mitigated if not eliminated.

Economic analyses suggest that CHP systems are ideally suited for base-loaded distributed power generation and steady thermal (heating and/or cooling) loading. This is also the desirable mode of operation for the absorption chiller. Peak-loading is then met by utility power. Alternatively, if utility power is used for base-loading

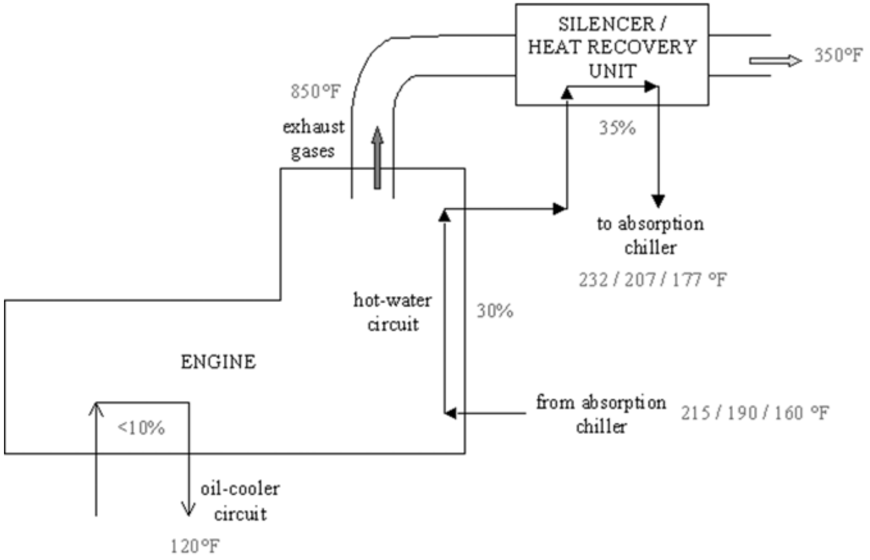

Figure 11-5 Schematic of CHP system consisting of a gas-fired reciprocating engine showing typical operating temperatures (Patnaik 2004).

and the DG meets the peaking demand, the thermal availability may be intermittent and require frequent cycling of the primary thermal equipment (boiler and/or chiller).

PROS AND CONS

Pro

- One of the primary advantages of CHP systems is the reduction in centralized (utility) peak-load generating capacity. This is especially true since one of the biggest contributors to summer peak loads is the demand for air conditioning. If some of this air-conditioning demand can be met by chillers fired by essentially free energy (waste heat), there is a double benefit.
- Additionally, DG-based CHP systems enabled the following:
  - Brought the power generation closer to the point of application/load (“distributed generation”), eliminating transmission and distribution losses, etc.
  - Removed or reduced the normal electric and primary fuel consumption by independent pieces of equipment providing cooling, heating, and/or dehumidification (e.g., separate electric chiller and boiler), thereby improving substantially overall fuel utilization rates inclusive of the power generation process.
  - Removed or reduced emissions of CO_2 and other combustion by-products associated with the operation of the cooling, heating, and/or dehumidification equipment.

Con

- If the CHP system is to entirely replace a conventional boiler/electric chiller system, the ratio of electrical to thermal load of the building must match closely the relative performance (efficiencies) of the respective equipment.
- Start-up times for absorption chillers are relatively longer than those for vapor-compression chillers, particularly when coupled to microturbines, which themselves have large time constants. Such systems would require robust and sophisticated controls that take these transients into account.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a CHP system from a conventional one and an indication of whether the net cost for the alternative system is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

Distributed power generator	H
Heat recovery device/heat exchanger	L
Absorption chiller	H
Integrating control system	H

Recurring Cost

Distributed power generator (engine/microturbine/fuel cell)	S/H/L
Heat recovery device/heat exchanger	None
Absorption chiller	None
Integrating control system	H

SOURCES OF FURTHER INFORMATION

In keeping with the spirit of cross-cutting themes being promoted by ASHRAE, a number of technical sessions in recent meetings have been devoted to CHP, generally sponsored by technical committees on cogeneration systems (TC 1.10) and absorption/sorption heat pumps and refrigeration systems (TC 8.3). Presentations from these should be available on the ASHRAE Web site. The following is a link to recently sponsored programs by TC 8.3, including a couple of viewable presentations: http://tc83.ashraetcs.org/programs.html.

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Houghton, J.T., G.J. Jenkins, and J.J. Ephraums, eds. 1990. *Climate Change: The IPCC Scientific Assessment.* Intergovernmental Panel on Climate Change. New York: Cambridge UP.

LeMar, P. 2002. Integrated energy systems (IES) for buildings: A market assessment. Final report by Resource Dynamics Corporation for Oak Ridge National Laboratory, Contract No. DE-AC05-00OR22725, September 2002.

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ASHRAE GreenTip #17: Low-NO_x Burners

GENERAL DESCRIPTION

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

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 NO_x come from two sources: high-temperature combustion (thermal NO_x) and nitrogen bound to the fuel (fuel NO_x). For clean-burning fuels such as natural gas, fuel NO_x generation is insignificant.

In most cases, NO_x 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.

Natural-gas-fired burners with lowered NO_x emissions are available for commercial and residential heating applications. One commercial/residential boiler has a burner with inserts above the individual burners; this design reduces NO_x emissions by 30%. The boiler also has a "wet base" heat exchanger to capture more of the burner heat and reduce heat loss to flooring.

NO_x production is of special concern in industrial high-temperature processes because thermal NO_x production increases with temperature. These processes include metal processing, glass manufacturing, pulp and paper mills, and cement kilns. Although natural gas is the cleanest-burning fossil fuel, natural gas can produce NO_x emissions as high as 100 ppm or more.

A burner developed by MIT and the Gas Research Institute combines staged introduction combustion air, flue gas recirculation, and integral reburning to control NO_x emissions. These improvements in burner design result in a low-temperature, fuel-rich primary zone, followed by a low-temperature, lean secondary zone; these low temperatures result in lower NO_x formation. In addition, any NO_x emission present in the recirculated flue gas is reburned, further reducing emissions. A jet pump recirculates a large volume of flue gas to the burner; this reduces NO_x emissions and improves heat transfer.

The low-NO_x burner used for commercial and residential space heating is larger in size than conventional burners, although it is designed for ease of installation.

WHEN/WHERE IT'S APPLICABLE

Low NO_x burners are best applied in regions where air quality is affected by high ground-level ozone and where required by law.

PROS AND CONS

Pro

1. Lowers NO_x and CO emissions, where that is an issue.
2. Increases energy efficiency.

Con

1. High cost.
2. Higher maintenance.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a low-NO_x system from a conventional one and an indication of whether the net cost for the alternative system is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Conventional burner	L
• Low NO_x burner	H

Recurring Cost

• Maintenance	H
• Possible avoidance of pollution fines	L

SOURCE OF FURTHER INFORMATION

American Gas Association, www.aga.org.

ASHRAE GreenTip #18: Combustion Air Preheating

GENERAL DESCRIPTION

For fuel-fired heating equipment, one of the most potent ways to improve efficiency and productivity is to preheat the combustion air going to the burners. The source of this heat energy is the exhaust gas stream, which leaves the process at elevated temperatures. A heat exchanger, placed in the exhaust stack or ductwork, can extract a large portion of the thermal energy in the flue gases and transfer it to the incoming combustion air.

With natural gas, it is estimated that for each 50°F the combustion air is preheated, overall boiler efficiency increases by approximately 1%. This provides a high leverage boiler plant efficiency measure because increasing boiler efficiency also decreases boiler fuel usage. And, since combustion airflow decreases along with fuel flow, there is a reduction in fan-power usage as well.

There are two types of air preheaters: recuperators and regenerators. Recuperators are gas-to-gas heat exchangers placed on the furnace stack. Internal tubes or plates transfer heat from the outgoing exhaust gas to the incoming combustion air while keeping the two streams from mixing. 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

While theoretically any boiler can use combustion preheating, flue temperature is customarily used as a rough indication of when it will be cost-effective. However, boilers or processes with low flue temperatures but a high exhaust gas flow may still be good candidates and must be evaluated on a case-by-case basis. Financial justification is based on energy saved rather than on temperature differential. Some processes produce dirty or corrosive exhaust gases that can plug or attack an exchanger, so material selection is critical.

PROS AND CONS

Pro

1. Lowers energy costs.
2. Increasing thermal efficiency lowers CO_2 emissions.

Con

1. There are additional material and equipment costs.
2. Corrosion and condensation can add to maintenance costs.
3. Low specific heat of air results in relatively low U-factors and less economical heat exchangers.
4. Increasing combustion temperature also increases NO_x emissions.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building with a combustion preheat system from one without and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Equipment costs	H
• Controls	S
• Design fees	H

Recurring Cost

• Overall energy cost	L
• Maintenance of system	H
• Training of building operators	H

SOURCES OF FURTHER INFORMATION

DOE. 2002. *Energy Tip Sheet #1*, May. Office of Industrial Technologies, Energy Efficiency and Renewable Energy, US Department of Energy.

Fiorino, D.P. 2000. Six conservation and efficiency measures reducing steam costs. *ASHRAE Journal* 42(2):31–39.

ASHRAE GreenTip #19: Combination Space/Water Heaters

GENERAL DESCRIPTION

Combination space and water heating systems consist of a storage water heater, a heat delivery system (for example, a fan coil or hydronic baseboards), and associated pumps and controls. Typically gas-fired, they provide both space and domestic water heating. 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 [60°C]). 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

Pro

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.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a combination space and water heating system from a conventional one and an indication of whether the net cost for the hybrid option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Conventional heating equipment	L
• Combination space/domestic water heater	H
• Sanitizing/inspecting space heating system	H
• Piping and components able to withstand higher pressures	H
• Floor space used	L

Recurring Cost

• Heating energy	L
• Maintenance	L

SOURCES OF FURTHER INFORMATION

EERE. *A Consumer's Guide to Energy Efficiency and Renewable Energy*, EERE, US DOE, www.eere.energy.gov/consumerinfo/refbriefs/ad6.html.

Sustainable Sources, www.greenbuilder.com.

UG. *Combo Heating Systems: A Design Guide*. Union Gas, Chatham ON, CAN N7M5M1.

ASHRAE GreenTip #20: Ground-Source Heat Pumps

GENERAL DESCRIPTION

A ground-source heat pump (GSHP) extracts solar heat stored in the upper layers of the earth; the heat is then delivered to a building. Conversely, in the summer season, the heat pump rejects heat removed from the building into the ground rather than into the atmosphere or a body of water.

GSHPs can reduce the energy required for space heating, cooling, and service-water heating in commercial/institutional buildings by as much as 50%. GSHPs replace the need for a boiler in winter by utilizing heat stored in the ground; this heat is upgraded by a vapor-compressor refrigeration cycle. In summer, heat from a building is rejected to the ground. This eliminates the need for a cooling tower or heat rejector and also lowers operating costs because the ground is cooler than the outdoor air. (See Figure 11-6 for an example GSHP system.)

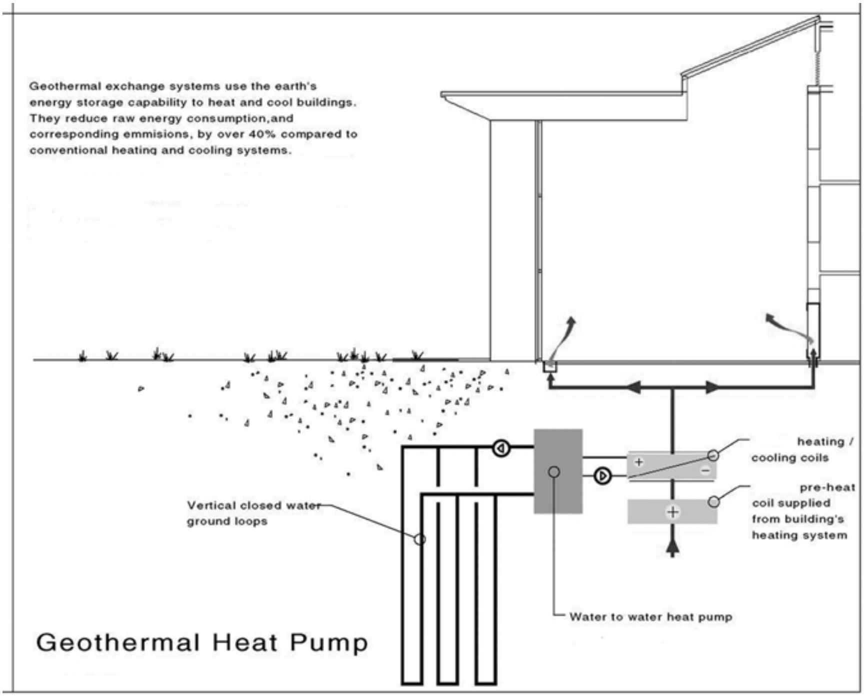

Figure 11-6 Schematic example of GSHP closed-loop system.

There are numerous types of GSHP loop systems. Each has its advantages and disadvantages. Visit the Geoexchange Geothermal Heat Pump Consortium Web site (www.geoexchange.org/about/how.htm) for a more detailed description of the loop options.

Water-to-air heat pumps are typically installed throughout a building with ductwork serving only the immediate zone; a two-pipe water distribution system conveys water to and from the ground-source heat exchanger. The heat exchanger field consists of a grid of vertical boreholes with plastic U-tube heat exchangers connected in parallel.

Simultaneous heating and cooling can occur throughout the building, as individual heat pumps, controlled by zone thermostats, can operate in heating or cooling mode as required.

Unlike conventional boiler/cooling tower-type water-loop heat pumps, the heat pumps used in GSHP applications are generally designed to operate at lower inlet-water temperature. GSHP are also more efficient than conventional heat pumps, with higher COPs and EERs. Because there are lower water temperatures in the two-pipe loop, piping needs to be insulated to prevent sweating; in addition, a larger circulation pump is needed because the units are slightly larger in the perimeter zones requiring larger flows.

GSHPs reduce energy use and, hence, atmospheric emissions. Conventional boilers and their associated emissions are eliminated since no supplementary form of energy is usually required. Typically, single packaged heat pump units have no field refrigerant connections and, thus, have significantly lower refrigerant leakage compared to central chiller systems.

GSHP units have life spans of 20 years or more. The two-pipe water-loop system typically used allows for unit placement changes to accommodate new tenants or changes in building use. The plastic piping used in the heat exchanger should last as long as the building itself.

When the system is disassembled, attention must be given to the removal and recycling of the HCFC or HFC refrigerants used in the heat pumps themselves and the antifreeze solution typically used in the ground heat exchanger.

WHEN/WHERE IT’S APPLICABLE

The most economical application of GSHPs is in buildings that require significant space/water heating and cooling over extended hours of operation. Examples are retirement communities, multi-family complexes, large office buildings, retail shopping malls, and schools. Building types 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

Pro

1. Requires less mechanical room space.
2. Requires less outdoor equipment.
3. Does not require roof penetrations, maintenance decks, or architectural blends.
4. Has quiet operation.
5. Reduces operation and maintenance costs.
6. Requires simple controls only.
7. Requires less space in ceilings.
8. Loop piping, carrying low-temperature water, does not have to be insulated.
9. Installation costs are lower than for many central HVAC systems.

Con

1. Requires surface area for heat exchanger field.
2. Higher initial cost overall.
3. Requires additional site coordination and supervision.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a GSHP system from a conventional one and an indication of whether the net cost for it is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Conventional heating/cooling generators	L
• Heat pumps	H
• Outside piping system	H
• Heat exchanger field	H
• Operator training	H
• Design fees	H

Recurring Cost

• Energy cost (fossil fuel for conventional)	L
• Energy cost (electricity for heat pumps)	H
• Maintenance	L

SOURCES OF FURTHER INFORMATION

ASHRAE. 1995. *Commercial/Institutional Ground-Source Heat Pump Engineering Manual*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Canadian Earth Energy Association, Ottawa ON, CAN K1P 6E2, www.earthenergy.org.

Caneta. GS-2000TM (a computer program for designing and sizing ground heat exchangers for these systems). Caneta Research Inc., Mississauga, ON, CAN L5N 6J7.

Kavanaugh, S.P., and K. Rafferty. 1997. *Ground-Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

RETScreen (software for renewable energy analysis), Natural Resources Canada, www.retscreen.net.

ASHRAE GreenTip #21:
Water-Loop Heat Pump Systems

GENERAL DESCRIPTION

A water-loop heat pump system consists of multiple water-source heat pumps serving local areas within a building and tied into a neutral-temperature (usually 60°F–90°F [15.5°C–30°C]) water loop that serves as both heat source and heat sink. The loop is connected to a central heat source (e.g., small boiler) and a central heat dissipation device (e.g., closed-circuit evaporative condenser or open-circuit cooling tower isolated from building loop via heat exchanger). These operate to keep the temperature of the loop water within range.

The water-source heat pump itself is an electric-driven, self-contained, water-cooled heating and cooling unit with a reversible refrigerant cycle (i.e., a water-cooled air-conditioning unit that can run in reverse). Its components include heat exchanger, heating/cooling coil, compressor, fan, and reversing controls, all in a common casing. The heat exchanger and coil are designed to accept hot and cold refrigerant liquid or gas. The units can be located either within the space (e.g., low, along outside wall) or remotely (e.g., in a ceiling plenum or in a separate nearby mechanical room).

Piping all of the water-to-refrigerant heat exchangers together in a common loop yields what is essentially an internal source heat recovery system. In effect, the system is capable of recovering heat energy (through the cooling process) and redistributing it where it is needed.

During the cooling mode, heat energy is extracted from room air circulated across the coil (just like a room air conditioner) and rejected to the water loop. In this mode, the unit’s heat exchanger acts as a condenser and the coil as an evaporator. In the heating mode, the process is reversed: specifically, a reversing valve allows the heat exchanger to function as the evaporator and the coil as the condenser so that heat extracted from the water loop is “rejected” to the air being delivered to the occupied space, thus heating the space.

In addition to the components mentioned above, the system includes equipment and specialties normally associated with a closed hydronic system (e.g., pumps, filters, air separator, expansion tank, makeup system, etc.)

WHEN/WHERE IT’S APPLICABLE

A water-source heat pump system is well qualified for applications where simultaneous heating and cooling needs/opportunities exist. (An example might be a building where, in certain seasons, south-side or interior rooms need cooling at the same time north-side rooms require heating.) Appropriate applications may include office buildings, hotels, schools, apartments, extended care facilities, and retail stores.

The system's characteristics may make it particularly suitable when a building is to be air conditioned in stages, perhaps due to cost constraints; once the basic system is in, additional heat pumps can be added as needed and tied into the loop. Further, since it uses low-temperature water, this system is an ideal candidate for mating with a hydronic solar collection system (since such solar systems are more efficient the lower the water temperature they generate).

PROS AND CONS

Pro

1. It can make use of energy that would otherwise be rejected to atmosphere.
2. Loop piping, carrying low-temperature water, does not have to be insulated.
3. When applied correctly, the system can save energy. (*Note:* Some factors tend to decrease energy cost, and some tend to increase it; which prevails will determine whether savings result.)
4. It is quieter than a system utilizing air-cooled condensers (i.e., through-the-wall room air conditioners).
5. Failure of one heat pump unit does not affect others.
6. It can condition (heat or cool) local areas of a building without having to run the entire system.

Con

1. Multiple compressors located throughout a building can be a maintenance concern because of their being noncentralized and sometimes difficult to access (e.g., above the ceiling).
2. Effective water filtration is critical to proper operation of heat exchangers.
3. There is an increased potential for noise within the conditioned space from heat pump units.
4. Some of the energy used in the heating cycle is derived from electricity (used to drive the heat pump compressors), which may be more expensive than energy derived from fossil fuel.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a water-loop heat pump system from a conventional one and an indication of whether the net incremental cost for the alternative option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

Equipment costs (will vary depending on what type of conventional system would otherwise be used)	S/L
Controls	S
Design fees	S

Recurring Cost

Overall energy cost	L
Maintenance of system	H
Training of building operators	H

SOURCES OF FURTHER INFORMATION

Geoexchange Geothermal Heat Pump Consortium, www.geoexchange.org.

Tri-State. Closed water-loop heat pump. Tri-State Generation and Transmission Association, Inc. http://tristate.apogee.net/cool/cchc.asp.

Trane. 1994. *Trane Water-Source Heat Pump System Design Application Engineering Manual*, SYS-AM-7. Lacrosse, WI: Trane Co.

ASHRAE GreenTip #22: Thermal Energy Storage for Cooling

GENERAL DESCRIPTION

There are several suitable media for storage of cooling energy, including:

1. Chilled water
2. Ice
3. Calcium chloride solutions (brine)
4. Glycol solutions
5. Concentrated desiccant solutions

Active thermal storage systems utilize a building's cooling equipment to remove heat, usually at night, from an energy storage medium for later use as a source of cooling. The most common energy storage media are ice and chilled water. These systems decouple the production of cooling from the demand for cooling, i.e., plant output does not have to match the instantaneous building cooling load. This decoupling increases flexibility in design and operations, thereby providing an opportunity for a more efficient air-conditioning system than with a non-storage alternative. Before applying active thermal storage, however, the design cooling load should be minimized.

Although many operating strategies are possible, the basic principle of a TES system is to reduce peak building cooling loads by shifting a portion of peak cooling production to times when the building cooling load is lower. Energy is typically charged, stored, and discharged on a daily or weekly cycle. The net result is an opportunity to run a chiller plant at peak efficiency during the majority of its operating period. A non-storage system, on the other hand, has to follow the building cooling load, and the majority of its operation is at part-load conditions. Part-load operation of chiller plants comes at the expense of efficiency.

Several buildings have demonstrated site energy reductions with the application of thermal energy storage (TES) as discussed in both the "Pro" and "Sources of Further Information" sections following.

In addition to the potential of site energy reduction, operation of TES systems can reduce energy resource consumption. This reduction is due to a shift toward using energy during periods of low aggregate electric utility demand. As a result, transmission and distribution losses are lower and power plant generating efficiencies can be higher because the load is served by base-load plants. Thermal storage can also have beneficial effects on CHP systems by flattening thermal and electric load profiles.

The ASHRAE *Design Guide for Cool Thermal Storage* (Dorgan and Elleson 1993) covers cool storage application issues and design parameters in some detail.

WHEN/WHERE IT'S APPLICABLE

TES systems tend to perform well in situations where there is variability in loads. Successful applications of TES systems have included commercial office buildings, schools, worship facilities, convention centers, hotels, health care facilities, industrial processes, and turbine inlet air cooling.

PROS AND CONS

Pro

1. *Capital cost savings.* Because TES allows downsizing the refrigeration system, the resulting cost savings (which may include *avoiding* having to add such equipment on an existing project) may substantially or entirely cover the added incremental cost of the storage system proper (see also Con 1 below). However, if the first cost is more than another design option, there are still life-cycle cost benefits due to a significant reduction in utility costs.
2. *Reduced size of refrigerating equipment.* The addition of aTES system allows the size of refrigerating equipment to be reduced since it will have to meet an average cooling load rather than the peak cooling load. Reduced refrigeration equipment size means less on-site refrigerant usage and lower probability of environmental impacts due to direct effects.
3. *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. A number of carefully documented examples of energy savings can be found in the literature, including Bahnfleth and Joyce (1994), Fiorino (1994), and Goss et al. (1996).
4. *Reduced environmental impacts.* Because TES systems shift the consumption of site energy from on-peak to off-peak periods, the total energy resources required to deliver cooling to the facility will be lower (Reindl et al. 1995; Gansler et al. 2001). In addition, in some electric grids, the last generation plants to be used to meet peak loads may be the most polluting per kW of energy produced (Gupta 2002); in such cases, emissions would be further reduced by the use of TES.
5. *Related high-efficiency technologies.* TES enables the practical incorporation of other high-efficiency technologies such as cold-air distribution systems and nighttime heat recovery.

6. *Electric power infrastructure.* TES can be effective at preventing or delaying the need to construct additional power generation and transmission equipment.
7. *Reduced first cost.* Liquid desiccant can be circulated in plastic pipes and does not need insulation.

Con

1. *Capital cost increases.* 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 Pro 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 (see Pro 3 above).
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.
8. *Added components.* Liquid desiccant needs small resistant heating to be above 77°F (25°C) to prevent crystallization (similar to compressor sumpts to prevent condensation).

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a TES system above from a conventional one and an indication of whether the net cost for the alternative option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

Storage element (CHW, ice, glycol, and brine tanks) (Desiccant cost is higher than CHW and brine but similar to glycol)	H
Additional pumping/piping re storage element	H
Chiller/heat rejection system	L
Controls	H
Electrical (regarding chiller/heat rejection system)	S/L
Design fees	H
Operator training	H
Commissioning	S/H
Site space	H

Recurring Cost

Electric energy	L
Gas supply with low electrical demand	H
Operator training (ongoing)	H
Maintenance training	L

SOURCES OF FURTHER INFORMATION

Bahnfleth, W.P., and W.S. Joyce. 1994. Energy use in a district cooling system with stratified chilled water storage. *ASHRAE Transactions* 100(1):1767–78.

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Gansler, R.A., D.T. Reindl, T.B. Jekel. 2001. Simulation of source energy utilization and emissions for HVAC systems. *ASHRAE Transactions* 107(1):39–51.

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Mathaudhu, S.S. 1999. Energy conservation showcase. *ASHRAE Journal* 41(4):44–46. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

O'Neal, E.J. 1996. Thermal storage system achieves operating and first-cost savings (Technology Award case study). *ASHRAE Journal* 38(4).

Reindl, D.T., D.E. Knebel, and R.A. Gansler. 1995. Characterising the marginal basis source energy and emissions associated with comfort cooling systems. *ASHRAE Transactions* 101(1):1353–63.

Links to Other Efficient Buildings Utilizing TES

Centex—Most efficient building in U.S. in 1999, www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showProfile&profile_id=1306.

LEED Gold Building Hewlett Foundation, www.usgbc.org/Docs/Certified_Projects/Cert_Reg67.pdf.

ASHRAE GreenTip #23:
Double-Effect Absorption Chillers

GENERAL DESCRIPTION

Chilled-water systems that use fuel types other than electricity can help offset high electric prices, whether those high prices are caused by consumption or demand charges. Absorption chillers use thermal energy (rather than electricity) to produce chilled water. A double-effect absorption chiller using high-pressure steam (115 psig) has a COP of approximately 1.20. Some double-effect absorption chillers use low-pressure steam (60 psig [414 kPa]) or 350°F–370°F (177°C–188°C) hot water, but with lower efficiency or higher cost.

Double-effect absorption chillers are available from several manufacturers. Most are limited to chilled-water temperatures of 40°F (4.3°C) or above, since water is the refrigerant. The interior of the chiller experiences corrosive conditions; therefore, the manufacturer's material selection is directly related to the chiller life. The more robust the materials, the longer the life.

WHEN/WHERE IT'S APPLICABLE

Double-effect absorption chillers can be used in the following applications:

- When natural gas prices (used to produce steam) are significantly lower than electric prices.
- When the design team and building owner wish to have fuel flexibility to hedge against changes in future utility prices.
- When there is steam available from an on-site process; an example is steam from a turbine.
- 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.
- At sites that have limited electric power available.
- In locations where district steam is available at a reasonable price (e.g., New York City).

PROS AND CONS

Pro

1. Reduces 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.

Con

1. Cost of an absorption chiller will be roughly double that of an electric chiller of the same capacity as opposed to 25% more for a single-effect absorption machine.
2. Size of an absorption chiller is larger than an electric chiller of the same capacity.
3. Although absorption chiller efficiency has increased in the past decade, the amount of heat rejected is significantly higher than that of an electric chiller of similar capacity. This requires larger cooling towers, condenser pipes, and cooling tower pumps.
4. Few plant operators are familiar with absorption technology.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate an absorption chiller system from a conventional one and an indication of whether the net cost for the hybrid option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Absorption chiller	H
• Cooling tower and associated equipment	H
• Electricity feed	L
• Design fees	H
• System controls	H

Recurring Cost

• Electric costs	L
• Chiller maintenance	S
• Training of building operators	H

SOURCES OF FURTHER INFORMATION

ASHRAE. 2000. *2000 ASHRAE Handbook—HVAC Systems and Equipment*, p. 4.1. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2002. *2002 ASHRAE Handbook—Refrigeration*, Chapter 41. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Trane Co. 1999. *Trane Applications Engineering Manual, Absorption Chiller System Design*, SYS-AM-13. Lacrosse, WI: Trane Co.

ASHRAE GreenTip #24:
Gas-Engine-Driven Chillers

GENERAL DESCRIPTION

Chilled-water systems that use fuel types other than electricity can help offset high electric prices, whether those high prices are caused by consumption or demand charges. Gas engines can be used in conjunction with electric chillers to produce chilled water.

Depending on chiller efficiency, a gas-engine-driven chiller may have a cooling COP of 1.6 to 2.3.

Some gas engines are directly coupled to a chiller's shaft. Another option is to use a gas engine and switchgear. In such cases, the chiller may either be operated using electricity from the engine or from the electric utility.

WHEN/WHERE IT'S APPLICABLE

A gas engine is applicable in the following circumstances:

- When natural gas prices are significantly lower than electric prices.
- When the design team and building owner wish to have fuel flexibility to hedge against changes in future utility prices.
- At sites that have limited electric power available.

PROS AND CONS

Pro

1. Reduces electric charges.
2. Allows fuel flexibility if installed as a hybrid system (part gas engine and part electric chiller, so the plant may use either gas engine or electricity from utility).
3. Allows system expansion even at sites with limited electric power.
4. When the system is designed and controlled properly, allows versatile use of various fuel sources.
5. May be used in conjunction with an emergency generator if switchgear provided.

Con

1. Added cost of gas engine.
2. Additional space required for engine.
3. Due to amount of heat rejected being significantly higher than for similar capacity electric chiller, larger cooling towers, condenser pipes, and cooling tower pumps may be required.
4. Site emissions are increased.
5. Noise from engine may need to be attenuated, both inside and outside.
6. Significant engine maintenance costs.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a gas-engine-driven chiller from a conventional one and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Gas engine	H
• Cooling tower and associated equipment	H
• Electricity feed	L
• Site emissions	H
• Site acoustics	H
• Design fees	H
• System controls	H

Recurring Cost

• Electric costs	L
• Engine maintenance	H
• Training of building operators	H
• Emissions costs	H

SOURCE OF FURTHER INFORMATION

NBI. 1998. *Gas Engine Driven Chillers Guideline*. Fair Oaks, CA: New Buildings Institute and Southern California Gas Company. www.newbuildings.org/downloads/guidelines/GasEngine.pdf.

ASHRAE GreenTip #25: Gas-Fired Chiller/Heaters

GENERAL DESCRIPTION

Chilled-water systems that use fuel types other than electricity can help offset high electricity prices, whether those high prices are caused by consumption or demand charges. Absorption chillers use thermal energy (rather than electricity) to produce chilled water. Some gas-fired absorption chillers can provide not only chilled water but also hot water. They are referred to as *chiller-heaters*.

A gas-fired absorption chiller has a cooling COP of approximately 1.0 and heating efficiency in the range of about 80%.

Gas-fired chiller-heaters are available from several manufacturers. Most are limited to chilled water supply temperatures of 40°F (4.3°C) or above, since water is the refrigerant. Some manufacturers offer dual-fuel capability (natural gas or No. 2 fuel oil).

WHEN/WHERE IT'S APPLICABLE

Gas-fired chiller-heaters are applicable in the following circumstances:

- When natural gas prices are significantly lower than electric prices.
- At sites where a boiler can be eliminated by using the chiller-heater.
- When the design team and building owner wish to have fuel flexibility to hedge against changes in future utility prices.
- At sites that have limited electric power available.

PROS AND CONS

Pro

1. Reduces electric charges.
2. Allows fuel flexibility, since either natural gas or No. 2 fuel oil may be used to supply thermal energy for the absorption chiller.
3. May allow a boiler to be eliminated.
4. Uses water as the refrigerant, making it environmentally friendly.
5. Allows system expansion even at sites with limited electric power.
6. When the system is designed and controlled properly, allows versatile use of various fuel sources.

Con

1. Cost will be roughly double that of the same capacity electric chiller.
2. Size of absorption chiller will be larger than the same capacity electric chiller and added space is required.

3. The amount of heat rejected is significantly higher than from an electric chiller of similar capacity, approximately double that of a single-stage absorption machine, 50% greater for a two-stage unit.
4. Larger cooling towers, condenser pipes, and cooling tower pumps are required compared with electric-drive machines.
5. Few plant operators are familiar with absorption technology.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate the gas-fired chiller/heater system from a conventional system and an indication of whether the net cost for the hybrid option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Absorption chiller	H
• Possible boiler elimination	L
• Cooling tower and associated equipment	H
• Electricity feed	L
• Design fees	H
• System controls	H

Recurring Cost

• Electric costs	L
• Chiller maintenance	S
• Training of building operators	H

SOURCES OF FURTHER INFORMATION

AGCC. 1994. *Applications Engineering Manual for Direct-Fired Absorption*. American Gas Cooling Center.

ASHRAE. 2000. *2000 ASHRAE Handbook—HVAC Systems and Equipment*, p. 4.1. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2002. *2002 ASHRAE Handbook—Refrigeration*, Chapter 41. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Trane. 1999. *Trane Applications Engineering Manual, Absorption Chiller System Design*, SYS-AM-13. Lacrosse, WI: Trane Co.

ASHRAE GreenTip #26:
Desiccant Cooling and Dehumidification

GENERAL DESCRIPTION

There are two basic types of open-cycle desiccant process: solid and liquid desiccant. Each of these processes has several forms, and these should be investigated to determine the most appropriate for the particular application.

All systems have in common the need to have air contact the desiccant, during which moisture is absorbed from the air and the temperatures of both the air and desiccant are coincidently raised.

The moisture absorption process is caused by desiccant having a lower surface vapor pressure than the air. As the temperature of the desiccant rises, its vapor pressure rises and its useful absorption capability lessens. Some systems, particularly liquid types, have cooling of air and desiccant coincident with dehumidification. This can allow the need for less space and equipment.

The dehumidified air has then to be cooled by other means. Two supply air arrangements are available. One has the dehumidified air that is supplied to the building being the mixture of recycled and ventilation air that contacts the desiccant. Moisture as well as contaminants such as VOCs can be absorbed by the desiccant and recycled; particles of solid or liquid desiccant may also be carried over into the ducts and to building occupants.

The other arrangement combines energy recovery from building exhaust air that is typically much cooler and less humid than outdoor ventilation air. By dehumidifying the exhaust air to a sufficiently low humidity ratio (moisture content), it can be used to indirectly cool outdoor air for supply to the building that has not contacted desiccant. Using the recovered energy, this arrangement can be used either for processing only the ventilation air needed or the total supply air being 100% from outside.

So that desiccant can be reused, it has to be re-dried by a heating process generally called *reactivation* or *regeneration* in the case of solid types and reconcentration if a liquid. The re-drying can be either direct by contact of heated outdoor air with the desiccant or indirect. Indirect may be preferred, particularly in high humid climates due to the higher temperature needed to maximize the vapor difference and drying potential.

The energy storage benefit for liquid desiccant has been discussed previously in GreenTip #22.

Rotary desiccant dehumidifiers use solid desiccants such as silica gel to attract water vapor from the moist air. Humid air, generally referred to as *process air*, is dehumidified in one part of the desiccant bed while a different part of the bed is dried for reuse by a second airstream known as reactivation air. The desiccant rotates slowly between these two airstreams so that dry, high-capacity desiccant leaving the reactivation air is available to remove moisture from the moist process air.

Process air that passes through the bed more slowly is dried more deeply, so for air requiring a lower dew point, a larger unit (slower velocity) is required. The reactivation air inlet temperature changes the outlet moisture content of the process air. In turn, if the designer needs dry air, it is generally more economical to use high reactivation temperatures. On the other hand, if the leaving humidity need not be especially low, inexpensive low-grade heat sources such as waste heat or rejected cogeneration heat can be used.

The process air outlet temperature is higher than the inlet temperature primarily because the heat of sorption of the moisture removed is converted to sensible heat. The outlet temperature rises roughly in proportion to the amount of moisture that is removed. In most comfort applications, provisions must be made to remove excess sensible heat from the process air following reactivation. Cooling is accomplished with cooling coils, and the source of this cooling affects the operating economics of the system.

WHEN/WHERE IT'S APPLICABLE

In general, applications that require a dew point at or below 40°F (4.3°C) may be candidates for active desiccant dehumidification. Examples include facilities handling hygroscopic materials; film drying; the manufacture of candy, chocolate, or chewing gum; the manufacture of drugs and chemicals; the manufacture of plastic materials; packaging of moisture-sensitive products; and the manufacture of electronics. Supermarkets often use desiccant dehumidification to avoid condensation on refrigerated casework. And when there is a need for a lower dew point and a convenient source of low-grade heat for reactivation is available, rotary desiccant dehumidifiers can be especially economical.

PROS AND CONS

Pro

1. Desiccant equipment tends to be very durable.
2. Often this is the most economical means to dehumidify below a 40°F dew point.
3. It eliminates condensate in the airstream, in turn, limiting the opportunity for mold growth.

Con

1. Desiccant usually must be replaced, replenished, or reconditioned every five to ten years.
2. In comfort applications, simultaneous heating and cooling may be required.
3. The process is not especially intuitive and the controls are relatively complicated.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building with a rotary desiccant dehumidification system from one without and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Equipment costs	H
• Regeneration (heat source and supply)	H
• Ductwork	S
• Controls	H
• Design fees	S

Recurring Cost

• Overall energy cost	S/H
• Maintenance of system	H
• Training of building operators	H
• Filters	H

SOURCE OF FURTHER INFORMATION

ASHRAE. 2000. *2000 ASHRAE Handbook—HVAC Systems and Equipment*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE GreenTip #27: Indirect Evaporative Cooling

GENERAL DESCRIPTION

Evaporative cooling of supply air can be used to reduce the amount of energy consumed by mechanical cooling equipment. Two general types of evaporative cooling—direct and indirect—are available. The effectiveness of either of these methods is directly dependent on the extent that dry-bulb temperature exceeds wet-bulb temperature in the supply airstream.

Direct evaporative cooling introduces water directly into the supply airstream, usually with a spray or wetted media. As the water absorbs heat from the air, it evaporates. While this process lowers the dry-bulb temperature of the supply airstream, it also increases the air moisture content.

Two typical forms of *indirect evaporative cooling* (IEC) are described below.

1. *Coil/cooling tower type of IEC.* This type uses an additional water-side coil to lower supply air temperature. The added coil is placed ahead of the conventional cooling coil in the supply airstream and is piped to a cooling tower where the evaporative process occurs. Because evaporation occurs elsewhere, this method of "precooling" does not add moisture to the supply air, but it is somewhat less effective than direct evaporative cooling. A conventional cooling coil provides any additional cooling required.
2. *Plate heat exchanger (PHE) type of IEC*. This comprises sets of parallel plates arranged into two sets of passages separated from each other.

   In a typical arrangement, exhaust air from a building is passed through one set of passages, during which it is wetted by water sprays. A stream of outdoor air is coincidently passed through the other set of passages and is cooled by heat transfer through the plates by the wetted exhaust air before being supplied to the building. Alternatively, the exhaust air may be replaced by a second stream of outdoor air.

   The wetted air is reduced in dry-bulb temperature to be close to its wet-bulb temperature. The stream of dry air is cooled to be close to the dry-bulb temperature of the wetted exhaust air.

   In some applications, the cooled stream of outdoor air is passed through the coil of a direct expansion refrigeration unit, where it is further cooled before being supplied to the building. This system is an efficient way for an all outdoor air supply system.

   The plates in the heat exchanger can be formed from various metals and polymers. Consideration needs to be given to preventing the plate material from corroding.

WHEN/WHERE IT'S APPLICABLE

In climates with low wet-bulb temperatures, significant amounts of cooling are available. In such climates, the size of the conventional cooling system can be reduced as well.

In more humid climates, 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.

PROS AND CONS

Pro

1. Indirect evaporative cooling can reduce the size of the conventional cooling system.
2. It reduces cooling costs during periods of low wet-bulb temperature.
3. It does not add moisture to the supply airstream (in contrast, direct evaporative cooling does add moisture).
4. It may be designed into equipment such as self-contained units.
5. There is no cooling tower or condenser piping in the PHE type of IEC described.

Con

1. Air-side pressure drop (typically 0.2 to 0.4 in. w.c. [50 to 100 kPa]) increases due to an additional coil in the airstream.
2. To make water cooler in the coil/cooling tower type of IEC, the cooling tower fans operate for longer periods of time and consume more energy.
3. For the coil/cooling tower type of IEC, condenser piping and controls must be accounted for during design process.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate an indirect evaporative cooling system from a conventional one and an indication of whether the net cost for the hybrid option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Indirect cooling coil	H
• Decreased conventional cooling system capacity	L
• Condenser piping, valves, and control	H

Recurring Cost

• Cooling system operating cost	L
• Supply fan operating cost	H
• Tower fan operating cost	H
• Maintenance of indirect coil	S

SOURCES OF FURTHER INFORMATION

ASHRAE. 1999. *1999 ASHRAE Handbook—HVAC Applications*, pp. 50.1–3. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2000. *2000 ASHRAE Handbook—Systems and Equipment*, p. 19.3–4; 44.7. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE GreenTip #28: Passive Solar Thermal Energy Systems

GENERAL DESCRIPTION

Passive solar thermal energy systems utilize solar energy, mainly for space heating, via little or no use of conventional energy or other mechanisms than the building design and orientation. All abovegrade buildings are “passive solar”; making buildings collect, store, and use solar energy wisely is then the challenge to building designers. A building that intentionally optimizes passive solar heating can visually be a “solar building,” but many reasonably sized features that enhance energy collection and storage can be integrated into the design without dominating the overall architecture.

To be successful, a well-designed passive solar building needs (1) an *appropriate thermal load* such as space heating; (2) *aperture*, such as clear, glazed windows; (3) *thermal storage* to minimize overheating and to use the heat at night; (4) *control*, either manual or automatic, to address overheating; and (5) *night insulation* of the aperture so that there is not a net heat loss.

HIGH-PERFORMANCE STRATEGIES

The following strategies are general in nature and are presented as a guideline to help maximize the performance of a passive thermal solar design.

Do conservation first. Minimizing the heating load will reduce conventional and renewable heating systems’ sizes and yields the best economics. Insulate, including the foundation, and seal the building well. Use quality exterior windows and doors.

In the northern hemisphere, the aperture must face due south for optimal performance. If not possible, make it within ±10 degrees of due south. In the southern hemisphere, this solar aperture looks north.

Minimize use of east- and west-facing glazing. They admit solar energy at non-optimal times, at low angles that minimize storage, and are difficult to control by external shading. Also reduce north glazing in the colder regions of the northern hemisphere, due to high heat loss rates.

Use optimized and/or moveable external shading devices, such as overhangs, awnings, and side fins. Internal shading devices should not be relied upon for passive solar thermal control—they tend to cause overheating.

Use high-mass “direct gain” designs. The solar collector (windows) and storage (floors and potentially walls) are part of the occupied space and typically have the highest solar savings fraction, which is the percent of heating load met by solar. “Directly irradiated” thermal masses are much more effective than indirect, thus floors or trombe walls are often best.

Use vertical glazing. Horizontal or sloped windows and skylights are hard to control and insulate.

Calculate the optimal thermal mass—it is often around 8 in. thick (about 20 cm) high-density concrete for direct-gain floors over conditioned basements. The optimization should direct the designer to a concept that will capture and store the highest amount of solar energy without unnecessarily increasing cost or complexity. For all direct-gain surfaces, make sure they are of high-absorptivity (dark color) and are *not* covered by floor carpet, tile, much furniture, or other ways that prevent or slow solar energy absorption. Be sure the thermal mass is highly insulated from the outdoor air or ground.

Seeking a very high annual solar savings fraction (f_S) often leads to disappointment and poor economics, so keep expectations reasonable. Even a 15% annual fraction represents a substantial reduction in conventional heating energy use. A highly optimized passive solar thermal single-family house, in an appropriate climate, often only has about a 40% solar fraction. Combining passive with active solar, PVs, wind, and other renewable energy sources is often the most satisfactory way to achieve a very high annual solar savings fraction.

An old solar saying, of unknown origin, is “the more passive a building, the more active the owner.” Operating a passive solar building to optimize collection has thus been called *solar sailing* and requires time and experience. Be sure that passive solar and the building operator are good matches for each other.

KEY ELEMENTS OF COST

Passive solar energy systems must be engineered, otherwise poor performance is likely.

Window sizes are typically larger than for conventional design. Some operable windows and/or vents, placed high and low, are needed for overheat periods. Proper solar control must also be foreseen.

Concrete floors and walls are commonly thicker in the storage portion of a passive solar building. A structural engineer’s services are likely required.

Conventional backup systems are still needed. They *will be used* during cloudy and/or cold weather, so select high-efficiency equipment with low-cost fuel sources.

Night insulation *must* be used consistently or else there will be a net heat loss. Making the nightly installation and removal automatic is recommended, but costly.

SOURCES OF FURTHER INFORMATION

ASHRAE. 2003. *2003 ASHRAE Handbook—Applications*, Chapter 33, “Solar Energy Use.” Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Balcomb, J.D. 1984. *Passive Solar Heating Analysis: A Design Manual*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Crosbie, M.J., ed. 1998. *The Passive Solar Design and Construction Handbook*, Steven Winter Associates. New York: John Wiley & Sons.

ASHRAE GreenTip #29: Active Solar Thermal Energy Systems

GENERAL DESCRIPTION

Both passive and active solar thermal energy systems rely on capture and use of solar heat. *Active solar thermal energy systems* differ from *passive* systems in the way they utilize solar energy, mainly for space and water heating, by also using some conventional energy. This can allow for a greatly enhanced collection, storage, and use of the solar energy.

To be successful, a well-designed active solar system needs (1) an *appropriate thermal load* such as potable water, space air, or pool heating; (2) *collectors* such as flat-plate "solar panels;" (3) *thermal storage* to use the heat at a later time; and (4) *control*, typically automatic, to optimize energy collection and storage and for freeze and overheat protection.

The "working fluid" or "coolant" that moves heat from the collectors to the storage device is typically water, a water/glycol solution, or air. The heat storage medium is often water but could be a rock-bed or a high-mass building itself for air-coolant systems.

The solar energy collectors are most often of "fixed" orientation and nonconcentrating, but they could be "tracking" and/or concentrating. "Flat-plate" collectors are most common and are typically installed as fixed and nonconcentrating. Large surface areas of collectors, or mirrors and/or lens for concentration, are needed to gather heat and to achieve higher temperatures.

There are many different types of active solar thermal energy systems. For example, one type often used for potable water heating is flat-plate, pressurized water/glycol coolant, and two-tank storage. An internal double-wall heat exchanger is typically employed in one tank, known as the "preheat tank," and the other tank, plumbed in series, is a conventional water heater. These preheat tanks are now widely available due to nonsolar use as "indirect water heaters." One-tank systems typically have an electric-resistance heating element installed in the top of the special tank.

HIGH-PERFORMANCE STRATEGIES

The following strategies are general in nature and are presented as a guideline to helping maximize the performance of an active thermal solar design.

Do conservation first. Minimizing the heating load will reduce conventional and renewable heating systems' sizes, and yields the best economics.

In the northern hemisphere, the solar collectors must face due south for optimal performance. If not possible, make them within ±10 degrees of due south. In the southern hemisphere, the solar collectors look north.

When using flat-plate collectors for space heating, mount them at an angle equal to the local latitude plus 15 to 20 degrees. For water heating, use the local latitude plus 10 degrees.

Calculate the optimal thermal storage—about one day's heat storage (or less) often yields the best economics. Place the thermal storage device within the heated space and be sure it is highly insulated, including under its base.

Seeking a very high annual solar savings fraction (f_s) often leads to disappointment and poor economics, so keep expectations reasonable. Even a 25% annual fraction represents a substantial reduction in conventional energy use. A highly optimized active solar thermal domestic water heating system, in an appropriate climate, often has about a 60% solar fraction. Combining active solar with passive, PVs, wind, and other renewable energy sources is often the most satisfactory way to achieve a very high annual solar savings fraction.

KEY ELEMENTS OF COST

Active solar energy systems must be engineered; otherwise poor performance is likely. Fortunately, good design tools, such as F-Chart software, are readily available.

Well-designed, factory-assembled collectors are recommended, but are fairly expensive. Site-built collectors tend to have lower thermal performance and reliability.

Storage tanks must be of high quality and be durable. Water will eventually leak, so proper tank placement and floor drains are important. For rock storage, moisture control and air-entrance filtration are important for mold growth prevention.

Quality and appropriate pumps, fans, and controls can be somewhat expensive. Surge protection for all the electrical components is highly advised. Effective grounding, for lightning and shock mitigation, is normally required by building code. For liquid coolants in sealed loops, expansion tanks and pressure relief valves are needed. For domestic water heating, a temperature-limiting mixing valve is required for the final potable water to prevent scalding; even nonconcentrating systems can produce 180°F (80°C) or so water at times. All thermal components require insulation for safety and reduced heat loss.

Installation requires many trades: a contractor to build or install the major components, a plumber to do the piping and pumps (water systems), an HVAC contractor to install ducts (air systems) and/or space-heating heat exchangers, an electrician to provide power, and a controls specialist.

Conventional backup systems are still needed. They *will be used* during cloudy and/or cold weather, so select high-efficiency equipment with low-cost fuel sources.

SOURCES OF FURTHER INFORMATION

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Howell, J., R. Bannerot, and G. Vliet. 1982. *Solar-Thermal Energy Systems: Analysis and Design.* New York: McGraw-Hill.

Klein, S., and W. Beckman. 2001. *F-Chart Software.* Madison, WI: The F-Chart Software Company. Available from www.fchart.com/index.shtml.

ASHRAE GreenTip #30: Solar Energy System—Photovoltaic

GENERAL DESCRIPTION

Light shining on a PV cell, which is a solid-state semiconductor device, liberates electrons that are collected by a wire grid to produce direct current electricity.

The use of solar energy to produce electricity means that PV systems reduce greenhouse gas emissions, electricity cost, and resource consumption. Electrical consumption can be reduced. Because the peak generation of PV electricity coincides with peak air-conditioning loads (*if* the sun shines then), peak electricity demands (from the grid) may be reduced, though it is unlikely without substantial storage capacity.

PV can also reduce electrical power installation costs where the need for trenching and independent metering can be avoided. The public appeal of using solar energy to produce electricity results in a positive marketing image for PV-powered buildings and, thus, can enhance occupancy rates in commercial buildings.

While conventional PV design has focused on the use of independent applications in which excess electricity is stored in batteries, grid-connected systems are becoming more common. In these cases, electricity generated in excess of immediate demand is sent to the electrical grid, and the PV-powered building receives a utility credit. Grid-connected systems are often integrated into building elements. Increasingly, PV cells are being incorporated into sunshades on buildings for a doubly effective reduction in cooling and electricity loads.

PV power is being applied in innovative ways. Typical economically viable commercial installations include the lighting of parking lots, pathways, signs, emergency telephones, and small outbuildings.

A typical PV module consists of 33 to 40 cells, which is the basic block used in commercial applications. Typical components of a module are aluminum, glass, tedlar, and rubber; the cell is usually silicon with trace amounts of boron and phosphorus.

Because PV systems are made from a few relatively simple components and materials, the maintenance costs of PV systems are low. Manufacturers now provide 20-year warranties for PV cells.

PV systems are adaptable and can easily be removed and re-installed in other applications. Systems can also be enlarged for greater capacity through the addition of more PV modules.

WHEN/WHERE IT'S APPLICABLE

PV is well suited for rural and urban off-grid applications and for grid-connected buildings with air-conditioning loads. The economic viability of PV depends on the distance from the grid, electrical load sizes, power line extension costs, and incentive programs offered by governmental entities or utilities.

PV applications include prime buildings, outbuildings, emergency telephones, irrigation pumps, fountains, lighting for parking lots, pathways, security, clearance, billboards, bus shelters or signs, and remote operation of gates, irrigation valves, traffic signals, radios, telemetry, or instrumentation.

Grid-connected PV systems are better suited for buildings with peak loads during summer cooling operation but are not as well suited for grid-connected buildings with peak wintertime loads.

Note that a portion of a PV electrical system is direct current, so appropriate fusing and breakers may not be readily available. A PV system is also not solely an electrical installation; other trades, such as roofing and light steel erectors, may be involved with a PV installation. When a PV system is installed on a roof or wall, it will likely result in envelope penetrations that will need to be sealed.

PROS AND CONS

Pro

1. Reduces greenhouse gas emissions.
2. Reduces nonrenewable energy demand, with the ability to help offset demand on the electrical grid during critical peak cooling hours.
3. Enhances green-image marketing.
4. Lowers electricity consumption costs and may reduce peak electrical demand charges.
5. Reduces utility infrastructure costs.
6. Increases electrical reliability for the building owner; may be used as part of an emergency power backup system.

Con

1. Relatively high initial capital costs.
2. Requires energy storage in batteries or a connection to electrical utility grid.
3. May encounter regulatory barriers.
4. High-capacity systems require large-building envelope areas that are clear of protuberances and have uninterrupted access to sunshine.
5. Capacity to supply peak electrical demand can be limited, depending on sunshine during peak hours.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a PV system from a conventional one and an indication of whether the net cost for this system is likely to be lower (L), higher (H), or the same

(S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• PV modules	H
• Wiring and various electrical devices	H
• Battery bank	H
• Instrumentation	H
• Connection cost (if grid-connected)	H

Recurring Cost

• Electricity	L

SOURCES OF FURTHER INFORMATION

California Energy Commission, Renewable Energy Program, www.energy.ca.gov/renewables/.

Canadian Renewable Energy Network, www.canren.gc.ca.

National Renewable Energy Laboratory (NREL), *PV for Buildings*, www.nrel.gov/buildings/pv/index.html.

NRC. *Photovoltaic Systems Design Manual*. Natural Resources Canada, Office of Coordination and Technical Information, Ottawa ON CAN K1A 0E4.

NRC. RETSCREEN (renewable energy analysis software), Natural Resources Canada, Energy Diversification Research Laboratory, Varennes PQ CAN J3X 1S6; tel 1 450 652 4621; www.retscreen.gc.ca.

Photovoltaics, Solar Energy Technologies Program, Energy Efficiency and Renewable Energy, US Department of Energy, www1.eere.energy.gov/solar/photovoltaics.html.

PV Power Resource Site, www.pvpower.com.

Renewable Energy Deployment Initiative (REDI) (a Canadian federal program that supports the deployment of renewable technologies; some technologies qualify for incentives), www.nrcan.gc.ca/redi.

School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, www.pv.unsw.edu.au.

Solar Energy Industries Association (SEIA), Washington, DC, www.seia.org/.

Sustainable Sources, www.greenbuilder.com.

WATSUN-PV (simulation software), University of Waterloo, Waterloo ON CAN.

ASHRAE GreenTip #31: Solar Protection

GENERAL DESCRIPTION

Shading the building's transparent surfaces from solar radiation is mandatory during summer and sometimes even necessary during winter. This way, it is possible to prevent solar heat gains when they are not needed and to control daylighting for minimizing glare problems. Depending on the origin of solar radiation (direct, diffuse, reflected), it may be possible to select different shading elements that provide more effective solar control.

Depending on the specific application and type of problem, there may be different options for selecting the optimum shading device. The decision can be based on several criteria, from aesthetics to performance and effectiveness or cost. Different types of shading elements are suitable for a given application, result in varying levels of solar control effectiveness, and have a different impact on indoor daylight levels, natural ventilation, and overall indoor visual and thermal comfort conditions.

There are basically three main groups of solar control devices: (1) *External shading devices* can be fixed and/or movable elements. They have the most apparent impact on the aesthetics of the building. If properly designed and accounted for, they can become an integral part of the building's architecture, integrated into the building envelope. *Fixed types* are typically variations of a horizontal overhang and a vertical side fin, with different relative dimensions and geometry. Properly designed and sized, fixed external shading devices can be effective during summer, while during winter they allow the desirable direct solar gains through the openings. This is a direct positive outcome given the relative position of the sun and its daily movement in winter (low solar elevation) and summer (high solar elevation). *Movable types* are more flexible, since they can be adjusted and operated either manually or automatically for optimum results and typically include various types and shapes of awnings and louvers. (2) *Interpane shading devices*, are usually adjustable and retractable louvers, roller blinds, screens, or films, which are placed within the glazing. This type of a shading device is more suitable for solar control of scattered radiation or sky diffuse radiation. Given that the incident solar radiation is already absorbed by the glazing, thus increasing its temperature, one needs to take into account the heat transfer component to the indoor spaces. (3) *Internal shading devices* are very common because of indoor aesthetics, offering privacy control, and their easy installation, accessibility, and maintenance. Although on the interior, they are very practical and, most of the time, necessary; their overall thermal behavior needs to be carefully evaluated, since the incident solar radiation is trapped inside the space and will be absorbed and turn into heat if not properly controlled (i.e., reflecting solar radiation outward through the opening). Numerous types or combinations of the various shading devices are also possible, depending on the application.

HIGH-PERFORMANCE STRATEGIES

Natural shading: Deciduous plants, trees, and vines offer effective natural shading. It is critical for their year-round effectiveness not to obstruct solar radiation during winter in order to increase passive solar gains. Plants also have a positive impact on the immediate environment surrounding the building (microclimate) by taking advantage of their evaporative cooling potential. However, the plants need some time to grow, may cause moisture problems if they are too close to opaque elements, and can suffer from plant disease. The view can be restricted and some plants, especially large leafless trees, can still obstruct solar radiation during winter and may reduce natural ventilation. In general, for deciduous plants, the shading effect is best for east and west orientations, along with southeast and southwest.

Louvers: Also referred to as *venetian blinds* and can be placed externally (preferable) or internally (easier maintenance and installation in existing buildings). The external louvers can be fixed in place with rotating or fixed tilt of the slats. The louvers can also be retractable. The slats can be flat or curved. Slats from semitransparent material allow for outdoor visibility. The louvers can be operated manually (slat tilt angle, up or down movement) or they can be electrically motor driven. Adjusting the tilt angle of the slats or raising/lowering the panel can change the conditions from maximum light and solar gains to complete shading. Louvers can also be used to properly control air movement during natural ventilation. Slat curvature can be utilized to redirect incident solar radiation before entering into the space. Slat material can have different reflective properties and can also be insulated. During winter, fully closed louvers with insulated slats can be used at night for providing additional thermal insulation at the openings.

Awnings: External or internal awnings can be fixed in place, operated manually, or driven electrically by a motor that can also be automated. A preference lies with light-colored materials for high solar surface reflectivity. Awnings are easily installed on any type and size of opening and may also be used for wind protection during winter to reduce infiltration and heat losses.

KEY ELEMENTS OF COST

Natural shading: Natural shading is usually low cost, reduces glare, and, depending on the external building facade, can improve aesthetics. Plants should be carefully selected to match local climatic conditions in order to optimize watering needs.

Louvers: External electrically driven and automated units have a higher cost and need to account for maintenance costs of motors but are more flexible and effective. Louvers are difficult to clean on a regular basis. Nonretractable louvers somewhat obstruct outward vision.

Awnings: Awning fabric needs periodic replacement depending on local wind conditions. Electrically driven and automated units have a higher cost and need to account for maintenance costs of motors.

SOURCES OF FURTHER INFORMATION

Argiriou, A., A. Dimoudi, C.A. Balaras, D. Mantas, E. Dascalaki, and I. Tselepidaki. 1996. *Passive Cooling of Buildings*. M. Santamouris and A. Asimakopoulos, eds. London: James & James Science Publishers Ltd.

Baker, N. 1995. *Light and Shade: Optimising Daylight Design*. European Directory of sustainable and energy efficient building. London: James & James Science Publishers Ltd.

Givoni, B. 1994. *Passive and Low Energy Cooling of Buildings*. New York: Van Nostrand Reinhold.

Stack, A., J. Goulding, and J.O. Lewis. *Solar Shading*. European Commission, DG TREN, Brussels. http://erg.ucd.ie/down_thermie.html.

ASHRAE GreenTip #32: Light Conveyors

GENERAL DESCRIPTION

A light conveyor is large pipe or duct with reflective sides that transmits artificial or natural light along its length.

There are two types of such light-directing devices. The first is a square duct or round pipe made of plastic. By means of how the inside of the duct or pipe is cut and configured, light entering one end of the pipe is both reflected off these configurations (just as does light through a prism) and transmitted through. That reflected light continues to travel down the pipe, but the relatively small amount of light transmitted through the pipe provides continuous lighting along the pipe. Because some light is absorbed and escapes along the length of the pipe (i.e., is “lost”), the maximum distance that light can be “piped” into a building is about 90 ft (27.4 m).

There are a few installations where sun-tracking mirrors concentrate and direct natural light into a light pipe. In most applications, however, a high-intensity electric light is used as the light source. Having the electric light separate from the space where the light is delivered isolates the heat, noise, and electromagnetic field of the light source from building occupants. In addition, the placement of the light source in a maintenance room separate from building occupants simplifies replacement of the light source.

A second light-directing device is a straight tube with a highly reflective interior coating. The device is mounted on a building roof and has a clear plastic dome at the top end of the tube and a translucent plastic diffusing dome at the bottom end. The tube is typically 12 to 16 in. (300 to 400 mm) in diameter. Natural light enters the top dome, is reflected down the tube, and is then diffused throughout the building interior. The light output is limited by the amount of daylight falling on the exterior dome.

WHEN/WHERE IT’S APPLICABLE

The first light conveyor system is best suited to building applications where there is a need to isolate electric lights from the interior space (for example, operating rooms or theaters) or where electric light replacement is difficult (for example, swimming pools or tunnels). For the reflective tube system, each device can light only a small area (10 ft^2 [1 m^2]) and is best suited to small interior spaces with access to the roof, such as interior bathrooms and hallways.

PROS AND CONS

Pro

1. A light conveyor transports natural light into building interiors.
2. The first type of light conveyor isolates the electric light source from the lighted space.

3. The first type of light conveyor reduces lighting glare.
4. It lowers lighting maintenance costs.

Con

1. A light conveyor may have greater capital costs than traditional electric lighting.
2. The tube type may increase roof heat loss.
3. The tube type runs the risk of poor installation, resulting in leaks.
4. The effectiveness may not be worth the additional cost.

KEY ELEMENTS OF COST

Because of the specialized nature of these techniques, it is difficult to address specific cost elements. As an alternative to conventional electric lighting techniques, it could add to or reduce the overall cost of a lighting system—and the energy costs required—depending on specific project conditions. A designer should not incorporate any such system without thoroughly investigating its benefits and applicability and should preferably observe such a system in actual use.

SOURCE OF FURTHER INFORMATION

Preliminary Evaluation of Cylindrical Skylights
McKurdy, Harrison and Cooke
23rd Annual SESCI Conference
Solar Energy Society of Canada, Inc.
116 Lisgar, Suite 702
Ottawa ON
Canada K2P 0C2
tel: 613-234-4151
fax: 613-234-2988
www.solarenergysociety.ca

ASHRAE GreenTip #33:
Water-Conserving Plumbing Fixtures

GENERAL DESCRIPTION

Water conservation strategies save building owners both consumption and demand charges.

Further, municipal water and wastewater treatment plants save operating and capital costs for new facilities. As a general rule, water conservation strategies are very cost-effective when properly applied.

The Energy Policy Act of 1992 set reasonable standards for the technologies then available. Now there are plumbing fixtures and equipment capable of significant reduction in water usage. For example, a rest stop in Minnesota that was equipped with ultra-low-flow toilets and waterless urinals has recorded a 62% reduction in water usage.

Tables 14-1, 14-2, and 14-3 list the maximum water usage standards established by the Energy Policy Act of 1992 for typical fixture types. Also listed is water usage for flush-type and flow-type fixtures. Listing of conventional fixture usage allows comparison to the low-flow and ultra-low-flow fixture usage.

Table 14-1 EPCA Maximum Flows

Fixture Type	Energy Policy Act of 1992 Maximum Water Usage
Water closets, gpf* (L/f)	1.6 (6.1)
Urinals, gpf (L/f)	1.0 (3.8)
Shower heads, gpm* (L/s)	2.5 (0.16)
Faucets, gpm (L/s)	2.5 (0.16)
Replacement aerators, gpm (L/s)	2.5 (0.16)
Metering facets, gal/cycle (L/cycle)	0.25 (0.95)

* Note: gpf = gallons per fixture (L/f = liters per fixture); gpm = gallons per minute (L/s = liters per second). The gpm (L/s) value is at flowing water pressure of 80 psi (552 kPa).

Table 14-2 Flush-Fixture Flows

Flush-Fixture Type	Water Use, gpf (L/f)
Conventional water closet	1.6 (6.1)
Low-flow water closet	1.1 (4.2)
Ultra-low-flow water closet	0.8 (3.0)
Composting toilet	0.0
Conventional urinal	1.0 (3.8)
Waterless urinal	0.0

Table 14-3 Flow-Fixture Flows

Flow-Fixture Type	Water Use, gpm (L/s)
Conventional lavatory	2.5 (0.16)
Low-flow lavatory	1.8 (0.11)
Kitchen sink	2.5 (0.16)
Low-flow kitchen sink	1.8 (0.11)
Shower	2.5 (0.16)
Low-flow shower	1.8 (0.11)
Janitor sink	2.5 (0.16)

WHEN/WHERE IT'S APPLICABLE

Applicable state and local codes should be checked prior to design as some of them have "approved fixture" lists; some code officials have not approved the waterless urinal and low-flush toilet technologies. Waterless urinals and low-flow lavatory fixtures usually pay back immediately. Toilet technology continues to evolve rapidly, so be sure to obtain test data and references before specifying; some units work very well, while others perform marginally.

Options that should be considered in design of water-conserving systems include:

- Infrared faucet sensors
- Delayed action shutoff or automatic mechanical shutoff valves (metering faucets at 0.25 gal per cycle [0.95 L/cycle])
- Low-flow or ultra-low-flow toilets
- Lavatory faucets with flow restrictors
- Low-flow kitchen faucets
- Domestic dishwashers that use 10 gal (38 L) per cycle or less
- Commercial dishwashers (conveyor type) that use 120 gal (455 L) per hour
- Waterless urinals
- Closed cooling towers (to eliminate drift) and filters for cleaning the water.

PROS AND CONS

Pro

1. Water conservation reduces a building's potable water use, in turn reducing demand on municipal water supply and lowering costs and energy use associated with water.

2. It reduces a building’s overall waste generation, thus putting fewer burdens on the existing sewage system.
3. It may save capital cost since some fixtures, such as waterless urinals and low-flow lavatories, may be less expensive to install initially.

Con

1. Some states and municipalities have “approved fixture” lists that may not include certain newer and more efficient fixtures. However, the design engineer would likely have the option to go to a review process in order to get new fixture technologies put on the approved fixture list.
2. Maintenance of these fixtures is different and will require special training of staff.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building utilizing water-conserving plumbing fixtures from one that does not and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listing below may also provide some assistance in identifying the cost elements involved.

First Cost

• Low-flow and ultra-low-flow flush water closets	S/H
• Waterless urinals	S/L
• Low-flow shower heads	S
• Metering faucets	S
• Electronic faucets	M
• Dual-flush water closets	S/H
• Water-conserving dishwashers	S/H

Recurring Cost

• Potable water	L
• Sewer discharge	L
• Maintenance	L/S
• Training of building operators	S/H
• Orientation of building occupants	S
• Commissioning	S

SOURCES OF FURTHER INFORMATION

The American Society of Plumbing Engineers, www.aspe.org.

Del Porto, D., and C. Steinfeld. 1999. *The Composting Toilet System Book*. The Center for Ecological Pollution Prevention.

Public Technology, Inc., US Department of Energy and the US Green Building Council. 1996. *Sustainable Building Technical Manual—Green Building Design, Construction and Operations*. Public Technology, Inc.

US Environmental Protection Agency, *How to Conserve Water and Use It Effectively*, www.epa.gov/OW/you/chap3.html.

US Green Building Council, www.usgbc.org.

ASHRAE GreenTip #34: Graywater Systems

GENERAL DESCRIPTION

Graywater is generally wastewater from lavatories, showers, bathtubs, and sinks that is not used for food preparation. Graywater is further distinguished from blackwater, which is wastewater from toilets and sinks that contains organic or toxic matter. Local health code departments have regulations that specifically define the two kinds of waste streams in their respective jurisdictions.

Where allowed by local code, separate blackwater and graywater waste collection systems can be installed. The blackwater system would be treated as a typical waste stream and piped to the water treatment system or local sewer district. However, the graywater would be "recycled" by collecting, storing (optional), and then distributing it via a dedicated piping system to toilets, landscape irrigation, or any other function that does not require potable water.

Typically, for a commercial graywater system, such as for toilet flushing in a hotel, a means of short-term on-site storage, or, more appropriately, a surge tank, is required. Graywater can only be held for a short period of time before it naturally becomes blackwater. The surge tank would be provided with an overflow to the blackwater waste system and a potable makeup line for when the end-use need exceeds stored capacity.

Distribution would be accomplished via a pressurized piping system requiring pumps and some low level of filtration. Usually, there will be a requirement for the graywater system to be a supplemental system. Therefore, systems will still need to be connected to the municipal or localized well service.

WHEN/WHERE IT'S APPLICABLE

Careful consideration should be given before pursuing a graywater system. While a graywater system can be applied in any facility that has a nonpotable water demand and a usable waste stream, the additional piping and energy required to provide and operate such a system may outweigh any benefits. Such a system is best applied where the ratio of demand for nonpotable water to potable water is relatively high and consistent, as in restaurants, laundries, and hotels.

Some facilities have a more reliable graywater volume than others. For example, a school would have substantially less graywater in the summer months. This may not be a problem if the graywater was being used for flushing since it can be assumed that toilet use would vary with occupancy. However, it would be detrimental if graywater were being used for landscape irrigation.

PROS AND CONS

Pro

1. A graywater system reduces a building's potable water use, in turn reducing demand on the municipal water supply and lowering costs associated with water.
2. It reduces a building’s overall wastewater generation, thus putting less tax on the existing sewage systems.

Con

1. There is an added first cost associated with the additional piping, pumping, filtration, and surge tank required.
2. There are additional materials and their associated embodied energy costs.
3. There is negative public perception of graywater and health concerns regarding ingestion of nonpotable water.
4. Costs include maintenance of the system, including the pumps, filters, and surge tank.
5. Local health code authority has jurisdiction, potentially making a particular site infeasible due to that authority’s definition of blackwater versus graywater.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building utilizing a graywater system from one that does not and an indication of whether the net incremental cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Collection systems	H
• Surge tank	H
• Water treatment	H
• Distribution system	H
• Design fees	H

Recurring Cost

• Cost of potable water	L
• Cost related to sewer discharge	L
• Maintenance of system	H

• Training of building operators	H
• Orientation of building occupants	S
• Commissioning cost	H

SOURCES OF FURTHER INFORMATION

Advanced Buildings Technologies and Practices, www.advancedbuildings.org.

The American Society of Plumbing Engineers, www.aspe.org.

Del Porto, D., and C. Steinfeld. 1999. *The Composting Toilet System Book*. The Center for Ecological Pollution Prevention.

Ludwig, A. 1997. Builder's Greywater Guide and Create an Oasis with Greywater. Oasis Design.

Public Technology Inc., US Department of Energy and the US Green Building Council. 1996. *Sustainable Building Technical Manual—Green Building Design, Construction and Operations*. Public Technology, Inc.

US Green Building Council. *LEED Reference Guide*, *Version 2.0*, June 2001.

ASHRAE GreenTip #35: Point-of-Use Domestic Hot-Water Heaters

GENERAL DESCRIPTION

As implied by the title, point-of-use domestic hot-water heaters provide small quantities of hot water at the point of use, without tie-in to a central hot water source. A cold water line from a central source must still be connected, as well as electricity, for heating the water.

There is some variation in types. Typically, such as for lavatories, the device may be truly instantaneous, or it may have a small amount of storage capacity. With the instantaneous type, the heating coil is sized such that it can heat a normal-use flow of water up to the desired hot-water temperature (120°F [49°C], say). When a small tank (usually three to ten gallons) is incorporated in the device, the electric heating coil is built into the tank and can be sized somewhat smaller because of the small amount of stored water available.

The device is usually installed under the counter of the sink or bank of sinks.

A similar type of device boosts the water supply (which is cold water) up to near boiling temperature (about 190°F [88°C]). This is usually used for purposes of quickly making a cup of coffee or tea without having to brew it separately in a coffeepot or teapot.

WHEN/WHERE IT'S APPLICABLE

These devices are applicable wherever there is a need for a hot-water supply that is low in quantity and relatively infrequently used *and* it is excessively inconvenient or costly to run a hot-water line (with perhaps a recirculation line as well) from a central hot-water source. Typically, these are installed in lavatories or washrooms that are isolated or remote, or both. However, they can be used in any situation where there is a hot-water need but where it would be too inconvenient and costly to tie in to a central source. (There must, of course, be available a source of incoming water as well as a source of electricity.)

PROS AND CONS

Pro

1. A point-of-use device is a simple and direct way to provide small amounts of domestic hot water per use.
2. Long pipe runs—and, in some cases, a central hot-water heating source—can be avoided.
3. Energy is saved by avoiding heat loss from hot-water pipes and, if not needed, from a central water heater.

4. In most cases where applicable, it has lower first cost.
5. It is convenient—especially as a source of 190°F–210°F (88°C–99°C) water supply.
6. When installed in multiple locations, central equipment failure does not knock out all user locations.
7. It may save floor space in the central equipment room if no central heater is required.
8. Water is saved by not having to run the faucet until the water warms up.

Con

1. This is a more expensive source of heating energy (though cost may be trivial if usage is low and may be exceeded by heat losses saved from central heating method).
2. Water impurities can cause caking and premature failure of electrical heating coil.
3. It cannot handle changed demand for large hot-water quantities or too-frequent use.
4. Maintenance is less convenient (when required) since it is not centralized.
5. Temperature and pressure (T&P) relief valve and floor drain may be required by some code jurisdictions.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a point-of-use domestic hot-water heater from a conventional one and an indication of whether the net incremental cost for the system is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Point-of-use water heater equipment	H
• Domestic hot-water piping to central source (including insulation thereof)	L
• Central water heater (if not required) and associated fuel and flue gas connections	L
• Electrical connection	H
• T&P relief valve and floor drain (when required by code jurisdiction)	H

Recurring Cost

• Energy to heat water proper	H
• Energy lost from piping not installed (and perhaps central heater)	L
• Maintenance/repairs, including replacement	H

SOURCES OF FURTHER INFORMATION

The American Society of Plumbing Engineers, www.aspe.org.

Domestic Water Heating Design Manual. 1998. Chicago: American Society of Plumbing Engineers.

Fagan, D. 2001. A comparison of storage-type and instantaneous heaters for commercial use. *Heating/Piping/Air Conditioning Engineering*, April.

ASHRAE GreenTip #36: Direct-Contact Water Heaters

GENERAL DESCRIPTION

A direct-contact water heater consists of a heat exchanger in which flue gases are in direct contact with the water. It can heat large quantities of water for washing and/or industrial process purposes. Cold supply water enters the top of a heat exchanger column and flows down through stainless steel rings or other devices. Natural gas is burned in a combustion chamber, and the flue gases are directed up the heat exchanger column. As the gases move upward through the column, they transfer their sensible and latent heat to the water. A heat exchanger or water jacket on the combustion chamber captures any heat loss from the chamber. The gases exit only a few degrees warmer than the inlet water temperature. The heated water may be stored in a storage tank for "on-demand" use. Direct-contact water heaters can be 99% efficient when the inlet water temperature is below 59°F (15°C).

The low-temperature combustion process results in low emissions of NO_x and CO; thus, the system is in effect a low-NO_x burner. It is also a low-pressure process since heat transfer occurs at atmospheric pressure.

Although there is direct contact between the flue gases and the water, there is very little contamination of the water. Direct-contact systems are suitable for all water-heating applications, including food processing and dairy applications; the water used in these systems is considered bacteriologically safe for human consumption.

WHEN/WHERE IT'S APPLICABLE

The high cost of direct-contact water heaters (due to stainless steel construction) restricts their use to where there is a large, almost continuous, demand for hot water. Appropriate applications include laundries, food processing, washing, and industrial processes. The system can also be used for closed-loop (or recirculating) applications such as space heating. However, efficiency—the primary benefit of direct-contact water heating—will be reduced because of the higher inlet water temperature resulting from recirculation.

PROS AND CONS

Pro

1. Increases part-load and instantaneous efficiency.
2. Reduces NO_x and CO emissions.
3. Increases safety.
4. Increases system response time.

Con

1. High cost.
2. Less effective in higher-pressure or closed-loop applications or where inlet water temperatures must be relatively high.
3. Results in considerable water usage beyond that required for the process itself due to high evaporation rate.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a direct-contact water heater from a conventional one and an indication of whether the net cost for the alternative option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Water heater	H
• Operator training (unfamiliarity)	H

Recurring Cost

• Water heating energy	L

Direct-contact boilers are two to three times the price of indirect or conventional boilers, primarily because of the stainless steel construction. In high and continuous water use applications, however, the payback period can be under two years.

SOURCES OF FURTHER INFORMATION

NSF. 2000. *NSF/ANSI 5-2000e: Water Heaters, Hot Water Supply Boilers, and Heat Recovery Equipment*. Ann Arbor, MI: National Sanitation Foundation and American National Standards Institute.

QuikWater, High Efficiency Direct Contact Water Heaters, www.quikwater.com

ASHRAE GreenTip #37: Rainwater Harvesting

GENERAL DESCRIPTION

Rainwater harvesting has been around for thousands of years. Rainwater harvesting is a simple technology that can stand alone or augment other water sources. Systems can be as basic as a rain barrel under a downspout or as complex as a pumped and filtered graywater system providing landscape irrigation, cooling tower makeup, and/or building waste conveyance.

Systems are generally composed of five or less basic components: (1) a catchment area, (2) a means of conveyance from the catchment, (3) storage (optional), (4) water treatment (optional), and (5) a conveyance system to the end use.

The catchment area can be any impermeable area from which water can be harvested. Typically this is the roof, but paved areas such as patios, entries, and parking lots may also be considered. Roofing materials such as metal, clay, or concrete-based are preferable to asphalt or roofs with lead-containing materials. Similarly, care should be given when considering a parking lot for catchment due to oils and residues that can be present.

Conveyance to the storage will be gravity fed like any stormwater piping system. The only difference is that now the rainwater is being diverted for useful purposes instead of literally going down the drain.

Commercial systems will require a means of storage. Cisterns can be located outside the building (above grade or buried) or placed on the lower levels of the building. The storage tank should have an overflow device piped to the storm system and a potable water makeup if the end-use need is ever greater than the harvested volume.

Depending on the catchment source and the end use, the level of treatment will vary. For simple site irrigation, filtration can be achieved through a series of graded screens and paper filters. If the water is to be used for waste conveyance, then an additional sand filter may be appropriate. Parking lot catchments may require an oil separator. The local code authority will likely decide acceptable water standards, and, in turn, filtration and chemical polishing will be a dictated parameter, not a design choice.

Distribution can be via gravity or pump depending on the proximity of the storage tank and the end use.

WHEN/WHERE IT'S APPLICABLE

If the building design is to include a graywater system or landscape irrigation—and space for storage can be found—rainwater harvesting is a simple addition to those systems.

When a desire exists to limit potable water demand and use, depending on the end-use requirement and the anticipated annual rainfall in a region, harvesting can be provided as a stand-alone system or to augment a conventional makeup water system.

Sites with significant precipitation volumes may determine that reuse of these volumes is more cost-effective than creating stormwater systems or on-site treatment facilities.

Rainwater harvesting is most attractive where municipal water supply is either nonexistent or unreliable, hence its popularity in rural regions and developing countries.

PROS AND CONS

Pro

1. Rainwater harvesting reduces a building's potable water use, in turn reducing demand on the municipal water supply and lowering costs associated with water.
2. Rainwater is soft and does not cause scale buildup in piping, equipment, and appliances. It could extend the life of systems.
3. It can reduce or eliminate the need for stormwater treatment or conveyance systems.

Con

1. There is added first cost associated with the cisterns and the treatment system.
2. There are additional materials and their associated embodied energy costs.
3. The storage vessels must be accommodated. Small sites or projects with limited space allocated for utilities would be bad candidates.
4. Costs include maintenance of the system, including the catchments, conveyance, cisterns, and treatment systems.
5. There is no US guideline on rainwater harvesting. The local health code authority has jurisdiction, potentially making a particular site infeasible due to backflow prevention requirements, special separators, or additional treatment.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a building utilizing rainwater harvesting from one that does not and an indication of whether the net cost is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Catchment area	S
• Conveyance systems	S
• Storage tank	H
• Water treatment	S/H
• Distribution system	S/H
• Design fees	H

Recurring Cost

• Cost of potable water	L
• Maintenance of system	H
• Training of building operators	H
• Orientation of building occupants	S
• Commissioning cost	H

SOURCES OF FURTHER INFORMATION

The American Society of Plumbing Engineers, www.aspe.org.

American Water Works Association, WaterWiser, The Water Efficiency Clearinghouse, www.waterwiser.org.

Gerston, J. *Rainwater Harvesting: A New Water Source*.

Irrigation Association, www.irrigation.org.

Public Technology Inc., US Department of Energy and the US Green Building Council. 1996. *Sustainable Building Technical Manual—Green Building Design, Construction and Operations*. Public Technology, Inc.

US Green Building Council. 2001. *LEED Reference Guide, Version 2.0*.

Waterfall, P.H. 1998. *Harvesting Rainwater for Landscape Use*, http://ag.arizona.edu/pubs/water/az1052/.

ASHRAE GreenTip #38: Mixed Air Temperature Reset

GENERAL DESCRIPTION

Mixed air temperature (MAT), in this case, refers to the temperature of the mix of outdoor and return (recirculated) air that exists on an operating supply AHU prior to any “new” thermal energy being added to the airstream. In the days when constant air volume (CAV) systems were prevalent, it was customary to set the MAT controls to maintain a constant 55°F (13°C) nominally. (The controls would adjust the relative positions of outdoor and return air dampers to apportion the relative quantities of each airstream to satisfy the MAT setpoint, but never allowing less than the code-required minimum outdoor air.) In the “wintertime”—or heating season—when the outdoor air temperature was generally below 55°F (13°C), the MAT would be the “cooling” airstream or cold deck—the lowest-temperature air available for zones that needed cooling in this season. As heating was required, heat would be added at some point, either through a “hot deck” airstream within the AHU or through reheat by downstream coils.

The reset technique is based on the premise that the MAT from a supply air-handling system is colder than any one zone requires to maintain the set conditions of that zone. To the extent that this condition prevails, it means that the mixed (or cold) airstream must be mixed with some warm (hot deck) air to yield the proper supply air temperature to satisfy even the zone requiring the *lowest* temperature air supply. Since warmer air would need to be mixed in to do this, that would require “new” energy and is thus somewhat wasteful of heating energy (a form of simultaneous heating and cooling). In the heating season, cooling—being derived from outdoor air—is free.

The idea is to reset the MAT to a temperature that just satisfies the space with the lowest cold air demand. Reset controls involve raising the setpoint of the MAT controls based on input that indicates the demand of that zone needing the coldest air—limited still by the need to main the *minimum* quantity of outdoor air. This, in turn, requires sensors that can monitor that and other zone demands continuously; this input could come from hot deck/cold deck mixing dampers, mixing box damper positions, or thermostat output signals that indicate zone temperature demands. The goal would be to raise the MAT just enough so that the zone with the lowest supply air temperature demand was satisfied on a continuing basis. (As conditions change over time, that zone may change.)

WHEN/WHERE IT’S APPLICABLE

As stated above, this technique, in most cases, *should only be used on CAV systems*. If it is used with VAV systems, it can often backfire since other energy variables (such as fan energy, in the case of air systems) may change in the opposite direction from heating energy saved, possibly resulting in a net increase in energy use or cost. Thus, if it *is* applied to VAV systems, it should come into play when any other affected variable is already at its minimum (e.g., fan already at its minimum turndown rate).

As the season becomes warmer and the outside temperature rises, this technique may become less and less effective, especially since the served zones may require more cooling and ever lower supply air temperatures.

Although there may not be a lot of CAV systems installed in new designs, there are still plenty operating in existing buildings (though it should not be applied to CAV systems converted to variable volume). This technique does lend itself well to retrofit, and since the controls are basically the same for large- or small-sized air-handling systems, the savings can be large for a relatively low capital cost.

PROS AND CONS

Pro

1. MAT reset saves heating energy and the associated operating cost.
2. It can yield a low payback, especially on larger air-handling systems.
3. It is relatively low in capital cost in the full spectrum of energy retrofits.

Con

1. MAT reset may require greater attention to periodic controls calibration.
2. To be effective, there must be evidence that worst-zone demands will allow sufficient upward reset of temperature to realize appreciable savings.
3. Sampling of zone demands may be difficult to do in remote or scattered locations.
4. It is relatively easy to do as a retrofit on existing systems.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a mixed air temperature (MAT) reset system from a conventional one and an indication of whether the net cost for the alternative is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Reset controls and installation	H
• Zone input sensors and connection to reset controls	H

Recurring Cost

• Heating energy (heating coil)	L
• Maintenance	H
• Operator training	H

SOURCE OF FURTHER INFORMATION

ASHRAE. 2003. *2003 ASHRAE Handbook—HVAC Applications*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE GreenTip #39:
Cold Deck Temperature Reset with Humidity Override

GENERAL DESCRIPTION

Cold deck temperature (CDT) reset is very similar to MAT reset, but it applies to the air temperature leaving a cooling coil—or CDT of a CAV AHU during "summertime," or the season when mechanical cooling is required. In this situation, the object is to save cooling energy supplied at the cooling coil by allowing the set CDT to "ride up" above a nominal design level (e.g., 55°F [13°C]) as long as all zone cooling needs are met.

The control needs and techniques are similar to MAT reset (reviewing GreenTip #38 is a prerequisite to considering this one) with one addition: a humidity override. When in the mechanical cooling mode in moderate-to-humid climates, mechanically cooled air serves the function of dehumidification (latent cooling) as well as sensible cooling. The degree of humidification achieved in the occupied zones served depends largely on the CDT being maintained. Thus, if CDT is allowed to ride up for cooling purposes, it should not be allowed to rise beyond the temperature needed to maintain comfortable humidity conditions. Thus, the occupied zone humidity parameter sets an upper limit for the reset function.

Zone humidity input can be sensed from a sampling of served zones themselves, or one could sense the return airstream at the AHU. The latter would yield an *average* humidity of all spaces served rather than the highest humidity of any one space. However, given that return air humidity would probably be a lot easier and less expensive to sense than that of several remote zones, it may be good enough to serve the purpose.

The upper limit of humidity chosen as the limiting factor for this reset technique would depend on what the building operator feels is within the comfort tolerance of the occupants. While a nominal relative humidity level of 50% is often the goal for cooling season comfort, higher levels can be tolerated, and sometimes an upper limit of 55% to 60% may be selected. Whatever is chosen, however, is easily adjustable. High-quality humidity-sensing equipment is recommended.

Reducing the CDT off the cooling coil can also result in savings at other "upstream" components of the building's cooling system, such as not-as-cold temperatures off a central chiller or reduced chilled-water flow in a variable-flow pumping system. (In fact, this is where the cost savings would actually be realized.) If considering this technique, the designer should ensure that the piping, valves, and control configurations are such that "up-the-line" energy and cost savings are indeed achievable.

WHEN/WHERE IT'S APPLICABLE

The same constraints apply here as with MAT reset. Again, before doing this, the designer should be sure that there are likely to be opportunities for significant upward reset to take place. If it is found that there is just one space that is likely to always need the design CDT during the cooling season, regardless of weather or other changing conditions, then this technique is probably not a good bet.

PROS AND CONS

Pro

1. CDT reset saves cooling energy and associated operating cost.
2. It can yield a good payback when the situation is right, although not as low as MAT reset.
3. Capital cost is still relatively low (though more controls are required than with MAT reset).

Con

1. There are the same drawbacks as with MAT reset, plus.
2. There could be added problems with excessive space humidity if the humidity sensing is not accurate.

KEY ELEMENTS OF COST

The following provides a possible breakdown of the various cost elements that might differentiate a CDT reset system from a conventional one and an indication of whether the net incremental cost for the alternative option is likely to be lower (L), higher (H), or the same (S). This assessment is only a perception of what might be likely, but it obviously may not be correct in all situations. **There is no substitute for a detailed cost analysis as part of the design process.** The listings below may also provide some assistance in identifying the cost elements involved.

First Cost

• Same elements as for MAT reset, plus	H
• Humidity sensor(s) and connection reset controls	H

Recurring Cost

• Cooling energy	L
• Maintenance	H
• Operator Training	L

SOURCE OF FURTHER INFORMATION

ASHRAE. 2003. *2003 ASHRAE Handbook—HVAC Applications.* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.