Thermal Energy Transfer Key to Building Efficiency

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John Vastyan, Common Ground

Solar thermal, wind, biomass and biogas, hydrogen, photovoltaic, and geothermal technology—all are now among the renewable energy sources being developed at a greater pace than anticipated just a few years ago. Related to geothermal is one of the fastest growing trends in the commercial building industry: the use of water-source heat pumps, or water-loop heating and cooling systems.

Water-loop technology has been around for decades, though now, pushed by rising energy costs and a call-to-arms by the USGBC, Washington, and the advantages of LEED certification, interest in the technology is gaining rapidly, according to John Bailey, vice president of sales and marketing for ClimateMaster Inc., Oklahoma City. The company refers to the water-loop process as thermal energy transfer.

600% efficiency + 3-yr. paybacks

The newest generation of water-source heat pump heating and cooling technology for large buildings has pushed operational efficiencies into the 500% to 600% range. That is, for every unit of energy used to operate the equipment, the system delivers five to six units of energy in return. Add new and sophisticated controls, system integration with building-automation systems, and supplemental energy sources such as photovoltaics and hydrogen cells, and builders begin to see the potential.

Water-source heat pumps move heat very efficiently. The best models will extract 5 kWh of heat from the water loop for every 1 kWh of electricity used to power the compressor and fan, delivering all 6 kWh as heat into the air. This 6 to 1 ratio is called the COP (coefficient of performance), and can be equated to a 600% efficiency level.

By comparison, the very best fossil fuel furnaces and boilers produce heat at less than 100% efficiency. Heat is then removed from the air (cooling mode) at similar efficiencies, providing EER (energy efficiency ratio) levels higher than 20 BTU/W [5.86 W/W].

With the potential for off-the-charts efficiency performance, building owners are now at attention. When the design engineer can calculate a 3- to 4-yr. payback for new equipment, there is real incentive to install new technology. Many of these systems are suitable not only for new construction, but also for retrofit application.

Opposite page: As part of a thermal energy transfer system, boilers are ideally suited to provide additional BTUs. Right and below: Commercial water-loop or water-source heat pumps interact with systems such as these when additional BTUs are needed.

These horizontal-stacked boilers (right) are tied to a network of ClimateMaster heat pumps.

Thermal energy transfer

Water-source heat pump, or thermal energy transfer (TET) systems provide highly efficient, zone-controlled heating and cooling throughout a building by circulating water in a closed piping loop to move and exchange thermal energy. With such technology a building has, within it, many separate heat pumps, connected by closed-system water loops that transfer thermal energy with great efficiency.

Compared with traditional two-pipe, central chiller-based building systems, the installation of water-sourced equipment often saves 10% to 15% in the initial cost, or 20% to 30% of the installed cost when compared with a four-pipe system. A high-efficiency chiller is typically 10% to 15% less efficient than a water-source heat pump (TET) system, operationally, while a standard chiller performs 30% to 50% less efficiently. Maintenance costs are often 10% higher with chiller-based systems. Heat pump life expectancy is about 20 yr. while a chiller will typically serve for 20 to 25 yr. With a thermal-energy-transfer system, maintenance needs are also typically low.

Individual heat pumps add or remove heat from the air within each zone, as required to meet its unique heating or cooling load. During zone heating, they extract needed heat (thermal energy) from the common water loop.

During zone cooling, heat is rejected into the water loop where it can then be shared with all other heat pumps throughout the building. This way, rejected heat—which is wasted to the outdoors in most HVAC systems—is fully used before any new energy source is used to heat or cool the building.

All buildings contain year-round sources of thermal energy, or internal heat gains, that are recovered and recycled by a thermal-energy-transfer system, such as:

- lighting: the electrical energy used for lighting in most structures varies from 1 to 4 W/sq. ft. (11 to 13 W/sq. m)
- people: we emit thermal energy ranging from 300 to 500 BTU/hr. (88 to 147 W), depending upon our activity
- equipment: the energy consumed by equipment such as computers, printers, copiers, pumps, and motors is emitted as heat
- solar gain: perimeter zones with large glazed areas may require daytime cooling even during cold weather.

The cast-off thermal energy within the building envelope recovered in the water loop of a water-source heat pump system can be used for most purposes that require heat, including:

Space heating: Water-source heat pumps in zones that require heating will extract thermal energy from the water loop.

Water heating: Water-to-water heat pumps can be equipped to extract thermal energy from the water loop to heat domestic hot water, swimming pools and spas, or to serve hydronic

Water-source heat pumps easily reject unwanted heat through cooling towers.

A ClimateMaster vertical stack unit is discreetly mounted within a condominium unit's main living area.

loads such as radiant heat or snow-melt systems.

Ventilation: Dedicated outside air heat pumps extract thermal energy from the water loop to heat outside air used for ventilation.

The heat pumping concept

Water-source heat pumps use a simple vapor-compression refrigerant circuit to efficiently provide zone heating or cooling. During the cooling mode, heat is extracted from the air and rejected into the water loop. During heating mode, the process is reversed, with heat being extracted from the water loop and rejected into the air. Thus, thermal energy is transferred, or pumped, between the air and the water loop, in either direction, on demand.

Why water? In a word: efficiency. Water is the most efficient way to move thermal energy. A 2-in. water pipe can carry the same amount of cooling as a 24-in. air duct, requiring as much as 90% less transport energy in the process and taking up far less space. The mass of the water loop also provides thermal storage, allowing a substantial amount of heat to be carried from occupied periods into morning warm-up. The advantage of thermal storage is not a capability found with traditional HVAC systems.

Water-source heat pump heat exchangers are compact and efficient. This is because of the high mass and thermal conductivity of water. Water-source heat pumps—unlike traditional HVAC systems that are tied to outdoor dry bulb temperatures—operate at lower condensing temperatures because they are linked to the outdoor wet bulb temperature when using a cooling tower, or deep earth temperature when using a ground heat exchanger. This leads to higher efficiencies and longer service life.

Water-loop heat pump systems combine water-source heat pumps on a common piping loop with a heat rejector and boiler, which are used to maintain the circulating water temperature within a controlled range, typically 60 to 95 F. The most common heat rejectors are open cooling towers with isolating heat exchangers, closed-circuit evaporative coolers, or dry coolers.

Each zone heat pump uses the water loop to provide heating or cooling at any time, during or after hours, regardless of the operating mode of the other heat pumps. This is accomplished without the duplicate operation of heating or cooling systems, or the double waste inherent in reheat modes.

Water-to-water heat pump systems also operate very efficiently under part-load conditions, such as when a small portion of the building remains occupied after hours. Only the required zone heat pumps are used, unlike systems that must keep a large central plant in operation at an inefficient, scaled-back capacity in order to serve a small portion of the load.

A typical building has a perimeter with outside exposure that is directly affected by outdoor weather conditions, and a core without outside exposure that is virtually unaffected by the weather. To understand the energy-sharing benefits of a water-source heat pump system, the interaction of the loads in the core and perimeter zones must be studied throughout the year during occupied periods, with internal gains, and unoccupied periods with temperature setback/setup and little or no internal gains.

Four seasons

The main energy-consuming operating modes of an office building in a temperate climate are:

Summer, occupied: Typically, all zones require cooling and are rejecting heat into the water loop. The heat rejector maintains the maximum water-loop temperature according to a predetermined set point (fixed or outdoor reset). The boiler is off.

Winter warm-up: During recovery from night setback, most zones will require heating and will be extracting heat from the water loop. The boiler maintains the minimum water-loop temperature according to a predetermined set point. The heat rejector is off. The warm-up period is typically one hour or less/day.

Winter, occupied: Because of internal heat gain, most core zones require cooling. Most perimeter zones will require heating. Because heat is being simultaneously rejected into and extracted from the water loop, both the boiler and the heat rejector will remain in the off mode much of the time. This is the essence of thermal energy transfer: the inherent sharing of energy within the water loop minimizes boiler and heat rejector operation and provides maximum system efficiency.

The many advantages of water-to-water systems include:

- year-round individual control. Each zone heat pump provides individual temperature control. This allows each occupant to control heating or cooling regardless of the season, during or after hours, regardless of what other zones are doing. Zones served by single heat pumps can be as small as 200 sq. ft. or as large as many thousands of square feet.
- energy savings. Water-source heat pumps provide zone heating and cooling at the highest rated levels of efficiency. The water loop inherently recovers much of the energy needed for heating the building, minimizing boiler use. Water-loop heat pump systems operate efficiently under partial occupancy and at part-load conditions. They also eliminate the double energy waste of zone reheat (cooling with subsequent reheating), which is common in many HVAC systems.
- tenant metering. The majority of the system operating cost occurs at the zone heat pumps, which can be metered at the tenant level. Thus, each tenant pays for only what they use.
- quiet operation. Modern water-source heat pumps operate with great stealth, even though they are often located within occupied spaces. Sound levels produced by the latest models are greatly reduced by the use of new compressor technology, variable-speed fan motors, and sound-isolating designs.
- low initial cost. Water-source heat pumps are factory assembled and tested, usually incorporating all zone-level controls and hydronic accessories, greatly reducing on-site labor. They use basic low-pressure duct systems and, in some configurations, no ducts at all. The water loop is uninsulated and requires only two pipes, a supply and return, and can even be designed in a single-pipe configuration. The central aspects of the system (pump, boiler, heat rejector) require

a minimum of temperature controls and valves. These benefits lead to one of the lowest initial costs among HVAC systems.

- space is maximized; retrofitting is easy. Compact, zone heat pumps can be hidden within ceilings, installed in closets, or directly mounted within the occupied space. The space-saving attributes, or easy rezoning to permit tenant changes, also make water-loop heat pump systems ideal for the retrofit of existing buildings, especially for historic structures with limited space.
- downtime is minimized. Unlike large central systems, failure or maintenance operations on a water-source heat pump only affect the single zone served. Redundancy is usually provided for the minimal central components of a water-loop heat pump system.
- simpler design. With a wide variety of pre-engineered configurations, water-source heat pumps can easily be selected to fit varying locations and loads.
- simple control. Control can be as basic as a unit or wall-mounted thermostat for each zone heat pump. If desired, factory-mounted direct digital control (DDC) controllers allow zone heat pumps to be directly connected to a central building-management system. The only other controls necessary are those needed to maintain the water loop temperature.

Recent advancements also include the use of zero ozone-depleting HFC-410A refrigerant, further enhancing the operational efficiency of water-to-water heat pumps. Some units use 100% outside air. Other sophisticated systems offer a dehumidification option, allowing designers even greater flexibility when meeting more stringent building requirements.

Typical applications

Schools and dormitories

The systems are widely specified for new school construction and renovation. Benefits include protection from tampering and vandalism due to the sealed nature; individual control for each classroom or dormitory room; adaptability for fresh-air control; economy of operation with night setback controls and daytime programmed operation; and simplified design and operation for maintenance by custodians.

Office and commercial buildings

Water-source heat pumps are well suited for these applications. Most office and commercial buildings contain constant, internal heat sources that can be easily recovered. To attract tenants, owners and developers can offer individual year-round temperature control, with a minimal first cost and low maintenance and operating costs.

Additional tenant and owner advantages include minimal downtime; night setback controls; programmed daytime controls for energy savings; flexibility in partitioning; quiet, comfortable operation; flexibility in design, allowing spaces to be completed only as needed; separate metering; and the option of converting an existing two-pipe fan coil system to a water-source heat pump to provide the simultaneous heating of some spaces and cooling of others, which is impossible with a traditional two-pipe system.

> **"Pre-engineered water-source heat pumps can be selected to fit varying locations and loads. Space is maximized, retrofitting is easy."**

Computer centers

A large computer center, or areas with multiple computer workstations, can produce a significant amount of heat. This heat can be absorbed and reused in parts of the building or other buildings where heat may be needed. In some cases, enough heat can be recovered from computers to heat an entire complex without the need for any additional heat sources.

Medical buildings, nursing homes, and hospitals

The concept of de-centralized zoned units provides the diversity to meet many different patient, clinical service, laboratory, or diagnostic comfort levels. The systems are ideal because they provide isolation in air supply, preventing room-to-room contamination, as well as dependability and provision for almost instant replacement in case of malfunction.

Apartments and condominiums

The advantages over conventional systems for both multi-unit high-rise or garden-type complexes are individual metering, individual tenant control, lower initial cost, lower maintenance costs, diversity of operation due to tenant occupancy, and domestic water heating.

Hotels and motels

Typically the wide size and capability range that these systems provide offer total comfort for every size room, even large public spaces. Ducted or free-standing models are designed to be acoustically quiet for the comfort of guests. Individual units provide protection from complete shut downs; a risk with central system. The system maximizes economy of first cost, and minimizes operating and maintenance costs. The units can be installed a few at a time, ideal for renovation. They provide individual guest control, but the system can be designed with front desk control and low limit.

Shopping centers and malls

Central shopping centers and malls are much like office buildings in that they contain large internal areas from which heat can be recovered. Also, such areas often have multi-tenant use, each requiring its own control. Tenant spaces can be separately metered for cost control. The water-source heat pump system allows flexibility in design for comfort control, ventilation, and economy of operation, plus lower initial cost. Large mechanical rooms and big ducts are eliminated, thus providing more rentable space.

Restaurants and fast-food chains

Water-to-water systems will transfer heat for pre-heating incoming air required to replace air exhausted from kitchen hoods, or to make domestic hot water for dishwashing.

Indoor air quality

As important as the actual temperature of a building space is the quality of air within that space. ASHRAE's (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta) *Standard 62* requires significantly higher amounts of fresh outdoor air for buildings. The challenge now becomes how to properly introduce, condition, and deliver this fresh air into interior spaces. Traditional options, such as two- and four-pipe fan coil systems, must be up-sized significantly to handle the additional conditioning load. This means larger, more expensive units, piping, boilers, and chillers. In comparison, water-source systems offer a variety of options that will lower overall system size, introduce 100% outdoor air, and lower operational cost of the HVAC system.

Planning to build or renovate in the near future? If indoor air quality and energy savings are important considerations, perhaps it's time to consider a solution that incorporates thermal energy transfer. cbp

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