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A Tale of Two Systems

A cancer research facility employs heat pipe air-to-air energy recovery and innovative chiller specifications to maximize facility performance

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The Fox Chase Cancer Center in Philadelphia—renowned for its radiation oncology department and cancer prevention research—recently added a new structure to its campus: the five-story, 120,000-square-foot Cancer Prevention Pavilion. Touted as the first of its kind, the facility should take cancer research into the 21st century.

The project's design team shared goals for similar levels of innovation in the building's mechanical design. First, for state-of-the-art efficiency, a heat-pipe energy-recovery system would be specified for the laboratory's air-handling units (AHUs). Second, a new chilled-water plant—using a primary-secondary pumping scheme—would be installed to meet the center's current and future cooling-capacity needs.

WHY A HEAT PIPE?

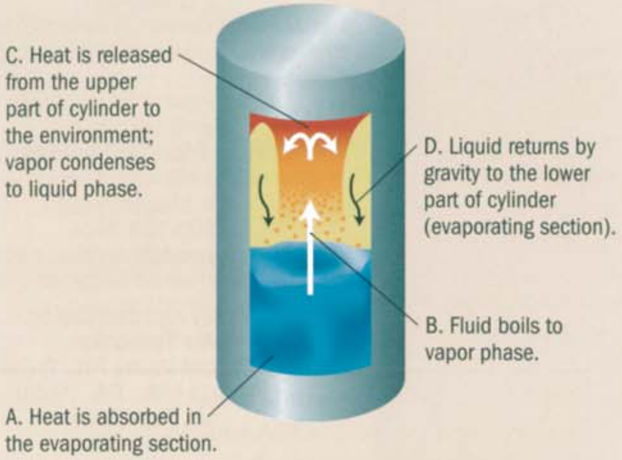
The main benefit of the heat pipe is that it has a high thermal-transfer effectiveness of approximately 65 percent at the coil velocities as designed. The units require virtually no maintenance, because there are no mechanical or electrical inputs required other than a simple bypass damper system. The pipes are filled with refrigerant R-22 that performs a "siphoning" effect between the two air streams, thereby moving thermal energy.

The R-22 operates continuously in a vacuum within each coated copper tube and unless punctured will outlast the AHU where it is installed. This thermal energy

The project team: Keith Cockerham, PE, Ewing Cole Cherry Brott (ECCB); Tom Garvey, vice president of facilities planning, Fox Chase Cancer Center; Jim Wilson, AIA president, ECCB, and Alan Mayzenberg, PE, project electrical engineer, ECCB. After construction, underground building systems were hidden well enough to return the facility and its courtyard (right) to its former serenity.

Heat Pipe System

A heat pipe is a hollow cylinder filled with a vaporizable liquid.



Note: Unit shown vertically for easy visualization. Applications have units spanning horizontally between airstreams.

The heat-pipe system was developed for use as a preheat coil and heat-recovery unit (above). A new central chilled-water plant (right) was built and buried underneath the facility's courtyard grounds.

transfer is continuous without the consumption of any outside energy.

A brief examination of the pavilion's overall heating, ventilation and air-conditioning (HVAC) system helps explain the heat pipe's role. The system includes one 50,000-cubic-foot-per-minute (cfm) central AHU for both clinical and outpatient areas with variable-air-volume (VAV) boxes that have hot-water reheat for zone control. The lab spaces are served by two 30,000-cfm AHUs interconnected to allow for 50-percent airflow in the case of unit failure. Laboratory spaces also have VAV boxes with reheat, and laboratory fume hoods are combined with the general lab exhaust, each also having VAV exhaust boxes.

Additionally, the exhaust system is split up so that each 30,000-cfm AHU receives 30,000 cfm of exhaust air in a side-by-side configuration. The separate exhaust unit includes the heat-pipe device, which is stretched over to the supply AHU. The exhaust system is also interconnected and includes a third stand-alone utility set fan for emergency backup to either of the main fans.

All systems are designed to be cooled by chilled water from an adjacent central plant. Critical functions, such as magnetic-resonance imaging, linear accelerators and dedicated equipment, are cooled by a year-round system consisting of a dual compressor and a roof-mounted rotary-screw air-cooled chiller with duty and standby pumps.

The systems are heated by one steam boiler located within the building's penthouse. The boiler directly feeds an autoclave and three steam-to-steam humidifiers as well as two hot-water heat exchangers for preheat hot water and reheat hot water. Redundancy—for building heating only—is achieved by piping hot water from an adjacent building in the event of a boiler failure.

THE HEAT PIPE SYSTEM

Installed within the pavilion laboratory's two central AHUs, the heat-pipe recovery unit consists of a bank of multiple, independent heat pipes that transfer thermal energy between two independent air streams. The combination of the unit's minimal moving parts and a bypass section that controls recovery capacity creates an advantage over other types of recovery devices. Built-in redundancy is another benefit, as the failure of one of the system's 120 tubes would only marginally affect performance.

The AHUs housing the heat pipe consist of a supply unit with prefilters, the heat pipe, a preheat coil, a cooling coil, a humidifier, a fan section, sound attenuators and final filters. The exhaust units contain filters, the heat pipe and fan section.

Whereas this configuration requires a custom AHU for both supply and exhaust air streams, other forms of recovery devices—such as plate-type exchangers or runaround-type coils—would have imposed high sheet-metal costs, space constraints and pumping and piping costs. Wheel-type heat recovery was also ruled out in the design phase due to cross-contamination concerns between air streams. In this case, air streams are separated by a sealed partition.

With a winter design temperature of 10°F, the heat pipe acts as a preheat coil by bringing the leaving-heat-pipe air temperature up to 50°F while recovering heat from the 75°F building exhaust air. Since the AHU design leaving-air temperature is 50°F, the heat pipe performs *all* preheat temperature performance 97 percent of the time in winter. The heat pipe's bypass damper opens incrementally according to temperature, which minimizes recovery and maintains a 50°F temperature.

There is a small penalty for using heat-pipe technology: between the outdoor temperatures of 50°F and 67°F, no heat transfer is needed. This "dead band" reduces performance in that the coils within each air stream do nothing more than add

The underground central chiller plant, shown during construction, was integrated with a primary-secondary pumping system.

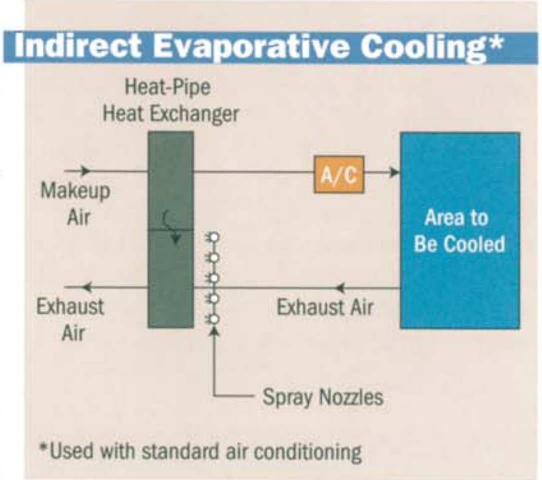
air stream resistance that increases horsepower requirements. This penalty, however, was already taken into account in the payback analysis.

In summer conditions, the heat pipe transfers energy in the opposite direction. On a design (peak) summer day of 93°F, the heat pipe can maintain a supply-leaving temperature of 84°F before the cooling coil. With water-spray evaporative cooling, the supply-leaving air temperature can be further reduced to about 77°F.

INDIRECT EVAPORATIVE COOLING

One of the most powerful applications of the heat pipe is water-spray evaporative cooling, also known as indirect evaporative cooling, or IEC (also "IDEC" in industry literature). This method captures most cooling energy normally lost when conditioned air is exhausted from a building, and can also cool building makeup air without adding humidity.

Specifically, the 100-percent outside AHUs cool incoming air by using the psychrometric potential of air exhausted from the building. Water is sprayed on the exhaust airside of the heat pipe, lowering the air stream temperature toward its wet-bulb temperature. In the case of the pavilion's lab, which has an air temperature of 75°F with 50-percent relative humidity, the air stream at the heat-pipe coil is expected to be 78°F dry bulb and 65°F wet bulb. The heat pipe then transfers this additional thermal energy to the supply air stream without adding humidity. This transfer takes effect by means of evaporative cooling that depresses the 78°F dry-bulb exhaust temperature much closer to the 65°F wet-bulb temperature. This significantly reduces mechanical air-conditioning and power requirements; it also cuts peak demand at higher outside-air temperatures by more than 100 tons on a design (93°F) day.



The indirect evaporative cooling system reduces mechanical loads and power requirements.

The IEC does more than cut power consumption, however: Its spray water also offered a second use for a softened-water system that supplies the facility's chemical-free, steam-to-steam humidifiers, which should minimize scale buildup and extend coil life.

Consisting of a submerged pump within the exhaust unit and near the main air stream, the IEC system is piped to spray manifolds in front of the heat-pipe coil. To minimize moisture carryover, a mist eliminator pad was installed on the downstream side of the heat-pipe coil that is easily replaceable and offers little static pressure resistance.

PERFORMANCE, VERIFIED

While Fox Chase officials initially expressed reservations about the installed performance of air-to-air energy recovery, a system that had not been used at their facility, the manufacturer tested the thermal effectiveness of the coil at the AHU's manufacturing facility, and the system performed in excess of design heat-recovery parameters.

The design also called for temperature sensors at all four points around the heat pipe, which would be tied into the campus' building-management system for remote logging, trending and performance verification. This data-trending capacity would allow the heat pipe to prove itself to the owners on an ongoing basis.

To further assure the owner of the technology's credibility, the manufacturer provided supervision and start-up services that included two days of instruction for operation and maintenance. Lastly, a performance bond was posted that was structured to pay for the cost of the heat pipe—approximately $100,000—if the thermal performance was not as specified for one heating and one cooling season.

To study performance, payback scenarios for the heat pipe were analyzed using a computer program with hourly bin weather data. Based on conservative assumptions, annual energy savings were calculated at 2,964,000 MBH heating, and 449,400 MBH cooling—roughly $72,510. With a $300,000 incremental first cost, the simple payback equaled 4.1 years, or a 25 percent rate of return on the initial capital outlay.

In addition to energy savings, the Fox Chase Cancer Center also benefits from a smaller load placed upon its central chiller plant. This allows the research organization to prioritize the plant's redundancy for backing up long-term studies or critical experiments.

Aside from heat-pipe technology, project engineers focused on developing a suitable and innovative chiller plant (see "A Chiller Plant Challenge," below). The design not only brought adequate and efficient supply for the new Pavilion, but it also helped solve limitations inherent in the existing HVAC and electrical systems.

PRIMARY-SECONDARY PUMPING

To maximize the efficiency of the new chilled-water plant, a primary-secondary pumping system was designed and installed. The variable-flow secondary pumping system required the replacement of three-way valves with new two-way valves at 16 existing AHUs throughout the campus. The requirements of each of the existing AHUs had to be verified and the placement of differential pressure transmitters had to be determined.

The transmitters are critical devices for determining if adequate chiller water pressure is available out in the system, and they are tied back into the panel that controls the three 150-horsepower secondary chilled-water pumps. This control panel was a stand-alone device, but it was connected to the new direct-digital-control (DDC) system. The DDC system changes lead pumps but does not interfere with the quantity of pumps on at any time or the speed at which they run.

While contract documents for the plant were finished in September of 1998, some quick and serious work was needed in order to throw the switch and start producing chilled water by May. The mechanical contractor worked closely with the entire design team, shop drawings were turned around in one day and a composite coordination drawing between all trades was reviewed simultaneously. The teaming led to the successful production of chilled water on schedule.

Fox Chase Cancer Center's commitment to advance cancer research into the 21st Century will be supported in part by the heat-pipe system. By starting a program of energy recovery on this scale, the Center consumes less natural gas each winter and less electricity each summer. These reductions help lower the amounts of greenhouse gases, primarily carbon dioxide, released into the atmosphere every day. |cse|

A Chiller Plant Challenge: Existing Electromechanical Systems

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Prior to the construction of the Cancer Prevention Pavilion, which would need 650 tons of new heating and cooling capacity, the Fox Chase Cancer Center suffered from a host of chilled-water challenges. Four chillers—two that were 30 years old—with 3,200 tons of capacity were located in a building without room for growth, and the existing electrical substation and systems were below par. Worse, all the equipment was located in a laboratory-animal facility where any shutdown would impact long-term experiments.

The Center's administration had already set aside money for chiller replacement, and the new facility was to double the size of the building and make redundancy an even higher priority. All of these issues led to the decision to build a new, high-efficiency central chilled-water plant.

The problem was where to put it. The campus was almost completely built out, and the plant would cost much less if it tied into existing mechanical assets, including the lab's six-year-old cooling towers—with a capacity of 3,800 tons—and three 450-ton chillers that were less than 10 years old.

The chillers were located in the nearby West Building, which also had an electrical infrastructure engineered for future growth. But to interface properly with the existing HVAC and electrical infrastructure, the new plant would have to be built in a lovely courtyard—an area of repose at the center of the wooded 30-acre campus.

The solution was to bury the new plant and replace the landscaping atop the new "bunker." The 3,800 tons of new capacity had to be engineered into the smallest footprint possible, however. Two choices were considered:

- **A hybrid plant** with natural gas-engine-driven chillers and electric centrifugals. While economic to operate, the footprint would be enormous and first costs would be high to bury the system.
- **Electric centrifugal chillers only.** Offering high electrical efficiency and reliability in a smaller footprint, an all-centrifugal, 3,800-ton plant would be hard to split into three-, two- or one-chiller configurations, however.

If three 480-volt units were specified, only one primary chilled-water pump and one condenser-water pump would be needed for each chiller. The two-chiller option meant 1,900-ton units at 4,160 volts; this system would minimize pump needs but also demand a larger electrical room to accommodate 480-volt equipment for pumps and ancillary equipment. The single-chiller alternative was quickly eliminated, as it did not offer any redundancy or good turndown capabilities.

The option that yielded the best footprint was the dual-compressor chiller. Two 1,900-ton dual-compressor chillers provided redundancy, excellent turndown capability—and two competitive manufacturers, one offering refrigerant R-123 and the second offering R-134a.

After awarding the contract for the R-134a unit, a single-pass chiller with a lower evaporator pressure drop was shown to offer only a slightly lower efficiency—0.61 kW/ton, as opposed to the 0.55 kW/ton originally specified.

An analysis of part-load perfor-

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