Single-Pipe Systems

for Commercial Applications

Cost-competitive and energy-efficient, single-pipe systems finally can be extended to commercial buildings

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Imagine an optimal hydronic HVAC system for a commercial building. What benefits would it deliver? First, it would provide comfort to all building zones. Second, it would be easy to install, operate, and maintain. Third, it would be competitive on a first- and operating-cost basis. Lastly, it would conserve the use of raw materials and be energy-efficient, a must in the "green" environment.

Since the 1950s, a system providing all of these benefits has been available—the single-pipe hydronic system.[1] Single-pipe systems employ venturi tees, providing differential pressure to force water through terminal units. They are easy to design and install, use less materials, mostly are self-balancing, are easy to maintain, and are affordable to operate. These systems, however, traditionally have been limited to residential applications because of their inability to provide individual-zone control. But with an innovative application of proven hydronic technology, single-pipe systems now can be applied readily to commercial buildings.

THE SINGLE-PIPE COMMERCIAL SYSTEM

This recent advance revolves around an idea that has been around for years: primary-secondary pumping. A single-pipe system—in addition to having a single-pipe primary main—utilizes terminal units configured with decoupled secondary piping circuits. In addition, maintenance-free wet-rotor circulators take the place of control valves, providing temperature control for each zone. Circulators also provide differential pressure to direct water through a secondary system. There is no need for control valves or venturi tees (Figure 1).

With a primary system, a single constant-size pipe circulates all of the flow for an entire system throughout a

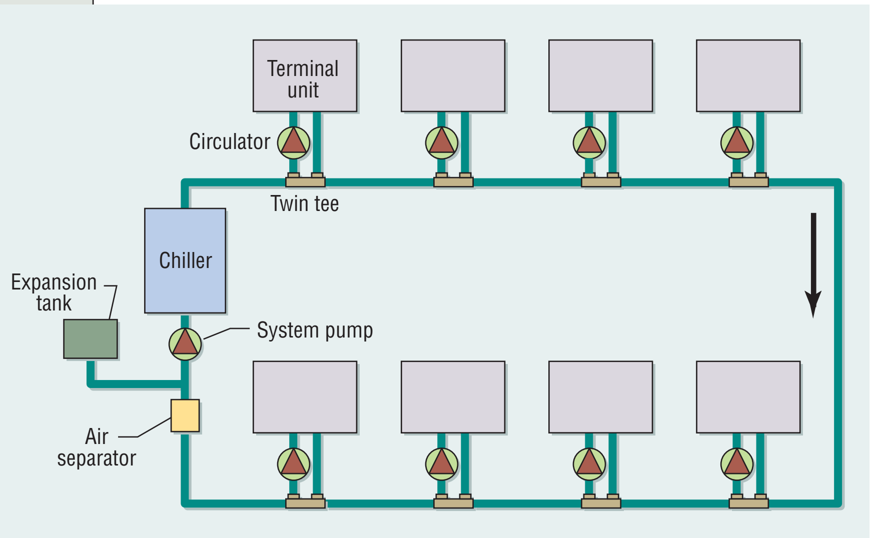

FIGURE 1. A single-pipe system.

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building, floor, or wing. Each terminal unit has its own decoupled secondary piping circuit with a dedicated wet-rotor circulator for its zone. A circulator is controlled based on zone temperature with either a variable-speed drive or an on/off arrangement. This allows for accurate temperature control in a zone.

A single-pipe hydronic system is self-balancing because of the use of wet-rotor circulators in a decoupled secondary piping circuit. Because the flow in all secondary circuits is independent of the flow in the primary circuit, the need for balancing valves at the terminal unit is eliminated (Figure 2).

With a self-balancing system, correct flow to each zone is achieved, so there is no need to tweak balancing valves to satisfy building occupants' desire for comfort. In a single-pipe system, the total volume of fluid and the required heating and cooling energy are available at any time to any terminal unit in the system and are not short-circuited to another terminal unit.

SINGLE-PIPE-SYSTEM DESIGN

A single-pipe primary circuit (or loop) has multiple secondary circuits attached to it, adding to the system's simple design. Each of these secondary circuits is a decoupled secondary piping circuit providing flow in the secondary circuit independent of the flow in the primary circuit. Circulators in each secondary circuit are sized for the correct flow and head of that circuit. As a circulator operates, the correct flow and head satisfy the requirements for the circulator's zone at all times. The flow for each terminal unit cannot be diverted to any other terminal unit.

For example, let's look at a typical cooling system designed with a standard 10-F difference between the supply and return. Let's assume conditions for that 10-F difference are 40-F supply water from the chiller and 50-F return water to the chiller. The main pumps are sized to provide the flow necessary to satisfy the cooling capacity in the system at the 10-F design temperature difference. Therefore, the maximum temperature difference in the system is no more than 10 F at any time. At full load, water leaving the chiller is 40 F, and water returning to the chiller is 50 F. In this cooling system, each terminal unit rejects heat to the single-pipe primary circuit to satisfy its needs.

In this example, the primary circuit has to increase in temperature as water flows through it. Despite the fact that the entering temperature on each terminal unit is going to change, it does not pose a problem as long as the temperature cascade is known for each unit. The entering-water temperature at each terminal unit can be calculated, and the coil can be sized for the appropriate entering-water temperature to provide the capacity necessary to satisfy the zone.

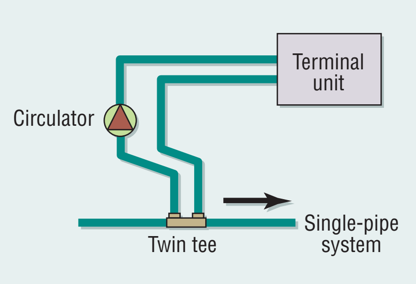

FIGURE 2. A decoupled secondary-piping circuit. Balancing valves no longer are necessary at the terminal unit.

A conventional two-pipe system requires a supply and return pipe in the primary circuit. In some applications, this could be a problem, as there may not be enough space, and additional holes with firestop material may have to be cut in walls, floors, etc. But in a single-pipe system, only one pipe has to be installed. This translates into space, material, and labor savings. Only one pipe has to be installed, and if it is a single-pipe circuit, the pipe will be the same size throughout. There is no need for reducers, increasers, etc.

ENGINEERING CONSIDERATIONS

When presented with a single-pipe system for the first time, design engineers typically are most concerned with the temperature cascade. Because water temperature in the primary loop changes, it would appear that the terminal units at the end of the primary loop are not going to be able to provide the necessary heating and cooling energy for the heating or cooling loads. A typical engineer would ask, "How is a cooling system able to provide the same capacity, including dehumidification, at the end of a primary loop that is experiencing 50-F entering water when other units at the beginning of the primary loop are experiencing 40-F entering water?" This is a legitimate question.

An examination of basic heat-transfer fundamentals provides the answer. Consider the single-dimensional steady-state heat-transfer form of the following Navier-Stokes equation:

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

where:
delta Q = heat-transfer rate
U = heat-transfer coefficient
A = surface area
delta T = temperature difference[2]

Let's take a room that needs to be maintained at 70 F. If the room is at the beginning of the primary loop, there is a 40-F water supply, so the temperature difference between the water supply and the room is 30 F (70 F minus 40 F). However, at the end of the primary loop, the water is 50 F, so now the temperature difference is 20 F (70 F minus 50 F). To maintain the heat-transfer rate of a terminal unit at constant capacity with a decreased temperature difference, either the heat-transfer coefficient or surface area, or a combination of both, have to be increased. The heat-transfer coefficient in a terminal unit is a function of fluid velocity, and the surface area is a function of rows. The answer lies in increasing the flow rate through the heat exchanger or adding more rows, or a combination of both, to compensate for the decreased temperature difference. Figure 3 is an example of applying this

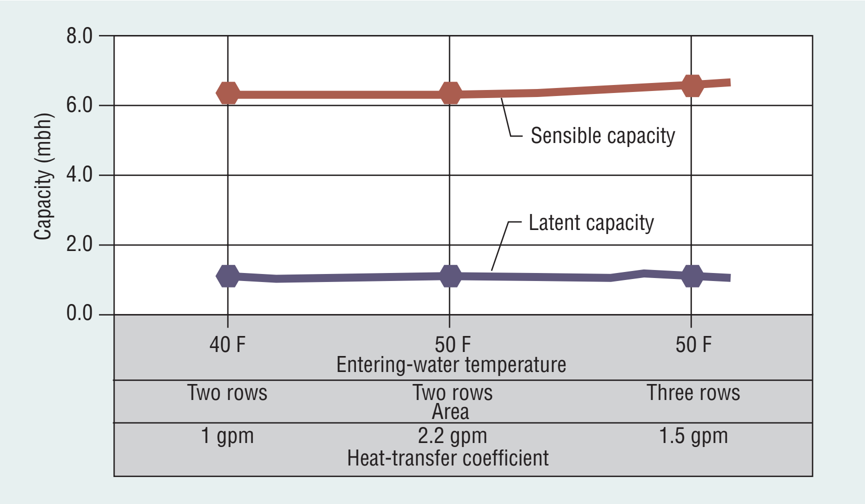

FIGURE 3. Fan-coil-unit cooling capacity.

simple concept to a typical fan-coil unit.

As Figure 3 shows, the sensible and latent capacity of the terminal unit can be achieved by increasing the heat-transfer coefficient (velocity) or area (number of fan-coil rows) in varying combinations. At the beginning of the primary loop—shown by the first set of points in Figure 3—40-F entering water, utilizing a two-row coil at 1 gpm, yields a given sensible and latent capacity in a standard system. At the end of the primary loop, the same sensible and latent capacity can be achieved with 50-F entering water—shown by the second set of points in Figure 3—by increasing the heat-transfer coefficient (50-F entering water utilizing a one-row coil at 2.2 gpm). The same capacity also can be achieved with 50-F entering water—shown by the last set of points in Figure 3—by increasing the area instead (50-F entering water utilizing a three-row coil at 1.5 gpm).

There may be concerns about the temperature cascade in regard to dehumidification. However, the use of basic principles of thermodynamics, as described previously, results in complete and comfortable cooling, including dehumidification in very humid climates.

Software that calculates the temperature cascade automatically and provides a flow diagram of entering-water temperature at every terminal unit in a system is available. Using flow-diagram information, an engineer can select a terminal unit for the cascading entering-water temperature.

Instead of selecting all terminal units at different entering-water temperatures, try selecting terminal units at the same entering-water temperature. A recommendation is to use a "worst-case" entering-water temperature, taking into account the diversity of the system. Diversity typically is defined as actual load divided by design load. For the 10-F design temperature difference, assuming a 70-percent diversity factor, one can select all the units at 47-F entering water (47 F equals 40 plus the quantity of 0.7 multiplied by 10). Therefore, using this method, the process to select terminal units for a single-pipe system is no different than the process to select terminal units for a two-pipe system.

There also is a common misconception that the use of multiple terminal units on a single-pipe primary loop adversely affects temperature cascade. Again, an examination of basic heat-transfer fundamentals provides the answer. Take the following steady-state mass-transfer equation:

$$\Delta Q = M \times Cp \times \Delta T$$

where:

delta Q = heat-transfer rate
M = mass flow rate
Cp = specific heat
delta T = temperature difference[2]

In any primary loop, mass flow rate is a function of the total load of all terminal units, divided by the specific heat and design temperature difference of the system. Because temperature differences are determined by designs and not the number of terminal units, flow always will increase to match load. Therefore, the last terminal unit on a primary loop never will experience more than the design temperature difference.

Interestingly, the more terminal units there are on a primary loop, the better the temperature cascade at the last terminal unit will be. This concept admittedly is counterintuitive, but it is the result of diversity in the system. With more terminal units, there will be more diversity and a better entering-water temperature at the last terminal unit.

Some might question the value of substituting pumps for valves. Their concern has to do with the perception that wet-rotor circulators require more maintenance than control valves. A wet-rotor circulator is one that uses system water, rather than oil, to lubricate bearings. An advantage of wet-rotor technology is that a circulator does not have any seals, couplings, or bearing assemblies. In fact, a wet-rotor circulator is entirely maintenance-free.

SECONDARY-CIRCUIT CONSIDERATIONS

In a single-pipe system, the secondary circuit is not fully shut off when circulators are used for temperature control. Without a control valve in place, the circuit is open to flow at all times. Therefore, it is important to prevent induced flows—sometimes referred to as "ghost flows"—because overheating or overcooling can take place. In a heating system, for example, if there is a difference in the height of the terminal unit above the main, gravity flow can occur in the secondary circuit. The use of a spring-type check valve, or flow check, eliminates gravity flows. Although the addition of a spring-loaded check valve adds pressure drop to a system, the elimination of control and balance valves reduces total pressure drop. A typical spring-loaded check valve has a pressure drop of approximately 0.5 ft. A typical control valve has a pressure drop of 10 to 15 ft, while a typical balance valve has a pressure drop of 2 to 5 ft. The net result is a decrease in system pressure drop of 10 to 20 ft.

Another factor that comes with induced flows is the pressure differential between two conventional tees and the primary pipe that connects to the secondary circuit (Figure 2). If the pressure differential between the two tees is not zero, then the path of least resistance for some of the water is through the terminal unit. This results in overheating or overcooling. This pressure-differential-induced flow can be prevented by using a twin tee (Photo A). In a twin tee, two takeoffs to the secondary circuit are perpendicular to the flow. In this arrangement, the pressure difference between the tees is zero. However, there are baffles installed in the tees to prevent short circuiting between return and supply takeoffs.

BALANCING CONSIDERATIONS AND VARIABLE-VOLUME FLOW

In two-pipe systems, a reverse-return system often is included so the differential pressure at every terminal unit is roughly the same, and, therefore, the system is self-balancing. Typically, reverse-return systems require extra piping, additional pressure drop, and increased cost. A single-pipe system, however, always is a direct-return self-balancing system, with lower head losses and less pipe. As a result, total installed horsepower to move heating and cooling energy around a system is reduced.

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PHOTO A. Twin tees.

Because a single-pipe system is self-balancing, the use of balance valves on all terminal units can be avoided. In the secondary circuits of a single-pipe system, the circulators operate to match the load, and the average flow is one of variable volume because the circulators cycle on/off. This achieves a variable-volume flow in the secondary circuits, even with constant-volume circulators. A variable-speed drive can be used to provide modulating control and increased comfort, if desired. This also achieves variable-volume flow in the secondary circuit.

The ability of a single-pipe system to maintain accurate temperature control with varying inlet-water conditions is another concern. As long as a terminal unit is sized for the correct entering-water temperature in a single-pipe system (Figure 3), a standard on/off or modulating analog control sequence functions the same as a two-pipe system and, therefore, maintains comfortable conditions in a space.

Using a variable-speed-drive circulator in a cascaded entering-water-temperature system achieves greater comfort control than a constant entering-water-temperature system using control valves. This is the result of a control sequence employed by a variable-speed circulator. A typical pneumatic or electric control valve on a terminal unit has a turndown in the range of 20- or 30-to-1. This means that below flows of 1⁄20 to 1⁄30 of a valve's maximum flow, a valve operates basically in an on/off, or two-position, control sequence. Therefore, at low loads, comfort is compromised.

However, a variable-speed drive on a circulator can employ a control sequence that utilizes pulse-width modulation at low speeds. This means that the pump can be pulsed at 100-percent voltage or torque, and the lengths and distances between pulses are varied to achieve turndowns far greater than a control valve can accomplish. This results in much higher turndowns and better comfort conditions at low loads.

Installing a variable-speed drive on primary pumps provides variable-volume flow in a primary circuit/loop. However, this option will not permit the use of diversity in sizing terminal units.

Control of a variable-speed drive on the pumps in a single-pipe system is accomplished with a single differential-temperature sensor across the generation equipment, whether it is a boiler or chiller. The control sequence is simpler because there is no requirement to put in multiple differential-pressure sensors as required by a two-pipe system. Multiple pressure sensors typically are used in two-pipe systems to determine the most hydraulically remote circuit because of the difference in pipe lengths of various circuits. This is because of the difference in the pressure drops of circuits with varying pipe lengths and terminal-unit pressure drops. Therefore, it is difficult to pick one circuit as the most hydraulically remote.

SINGLE-PIPE SYSTEMS AND GREEN BUILDINGS

While there are no standard certification criteria for building systems, single-pipe systems require less materials, operating energy, and maintenance than analogous air and hydronic systems. Compared with air systems, hydronic systems require about half of the horsepower of air systems to move heating and cooling energy around a building because the fluid is denser and has a higher specific heat. Additionally, a single-pipe system has a lower head loss than a conventional two-pipe system because of the elimination of the control-valve and balancing-valve pressure drops and less need for additional pipe if the conventional two-pipe system is a reverse-return system. As a result, the energy used to operate the pumps in a single-pipe system is less than that to operate the fans in an air system or the pumps in a two-pipe system.

CONCLUSION

Single-pipe systems have been installed in a variety of buildings across the United States and Canada over the past five years and have performed proficiently. Even in high-humidity areas, these systems have kept indoor moisture levels at design conditions, providing air-conditioned comfort.

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Design engineers, using a new software program that allows them to design single-pipe systems faster and with fewer chances to calculate errors, are recognizing the inherent simplicity and lifetime material and energy savings of the systems. Mechanical contractors like to work with the systems because of their ease of installation and maintenance. Building owners like single-pipe systems because of their simple operation, fewer maintenance needs, and lower life-cycle costs.

Hydronic systems possess a greater potential for realizing energy savings than either air or two-pipe systems. What results is an optimal single-pipe system that provides more comfort at a lower cost.

REFERENCES

1) Stethem, W.C. (1995). Single-pipe hydronic systems—historical development. *ASHRAE Transactions, 101,* 1251-1259.

2) ASHRAE. (2001). *ASHRAE handbook of fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

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