John Siegenthaler, P.E.

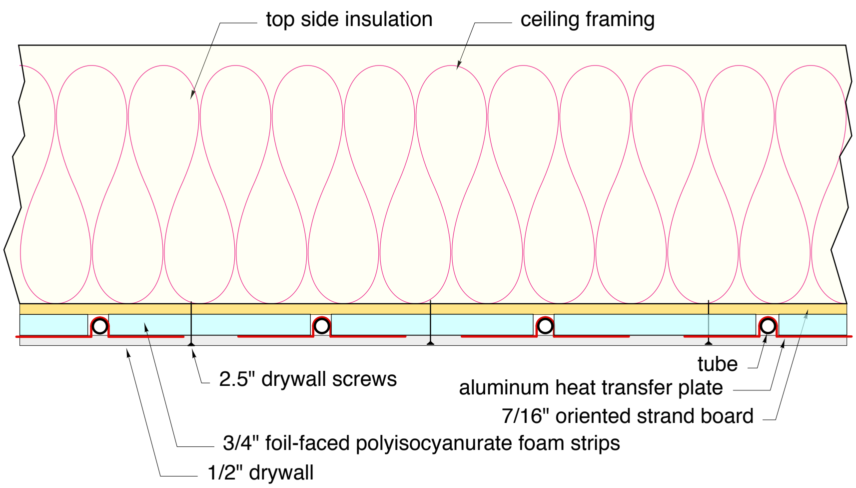
Removing limitations

Hydronic radiant ceiling cooling for smaller buildings.

Well-designed and properly installed hydronic radiant heating systems have earned a deserved reputation for superior comfort. Even so, many people hesitate on using these systems because they can't just push a button on their thermostat to change the system from heating to cooling. The combined cost of hydronic radiant panel heating, along with a separate central cooling system, often strains the construction budget to a point where something has to go and that something is usually the radiant heating option. It gets trumped by a lower-cost forced-air system that delivers both heating and cooling, albeit at often reduced comfort.

This doesn't have to be the case. There are methods for providing hydronic radiant panel cooling emerging in the U.S. market. They are well-suited for use with geothermal water-to-water heating pumps, which can provide chilled water in summer, as well as warm water in winter. They also can be used with the growing number of air-to-water heat pumps now available in the United States.

Figure 1



Sensible switchover

The traditional approach to hydronic cooling circulates chilled water through one or more air handlers. This approach has been used in many commercial and institutional buildings for decades. The expanding heat pump market is now leading to increased use of chilled water cooling in higher-end homes and light commercial buildings. It's also a lot easier to route flexible tubing through such buildings compared to air ducts, especially when the cooling system has several zones spread out over a large floor plan.

In these applications, water moves the cooling effect from the mechanical room to the air handlers, but forced air takes over for the final delivery. It takes a lot more electrical energy to make this final delivery of cooling comfort using air and blowers, compared to what's possible using water and high-efficiency circulators. Water is vastly superior to air when it comes to absorbing heat. A cubic foot of water can absorb 3,457 times more heat than a cubic foot of air for the same temperature increase. This is the physics underlying a rapidly developing global market for radiant cooling.

By switching as much of the sensible cooling load as possible to water-based delivery, rather than air-based delivery, the electrical energy used by the cooling delivery system can be drastically reduced. One reference indicates potential savings in overall cooling energy use of more than 40% by using hydronic radiant cooling rather than an air-based cooling system.

Currently, radiant cooling is used mostly in larger buildings. However, the basic principles are applicable to smaller systems.

Although there are several ways radiant cooling can be embodied within a building, I want to focus on one approach that allows the same radiant panel that provides heating in cold weather to also provide cooling in warm weather. That panel is located in the *ceiling*. Figure 1 (page 12) shows one way to construct it.

I've shown this panel construction in several previous Plumbing & Mechanical columns. It's a system that I developed along with my friend, **Harvey Youker**, for use in our office back in 1999. It's been performing well ever since. Over the last 15 years I've designed this radiant ceiling into several other projects. Its thermal output in heating is very respectable — with downward heat output of 0.71 Btu/hr./ft^2 for each °F that the average water temperature exceeds the room temperature. Thus, when operating at an average water temperature of 110° F, it can deliver about 28 Btu/hr./ft^2 into a room at 70°. This panel has very low thermal mass, allowing it to respond quickly to changing load conditions.

Give and take

This radiant ceiling panel also can serve as an excellent heat absorber. The rate of heat absorption can be calculated using Formula 1.

Formula 1

$$q = 1.48(T_R - T_C)^{1.1}$$

Where:

Q = rate of heat absorption (Btu/hr./ft^2)

T_R = average of room air and room mean radiant temperature (°F)

T_C = average lower surface temperature of ceiling (°F)

1.1 = an exponent (not a multiplier)

For example, suppose the room's operative temperature (e.g., the average of its air temperature and mean radiant temperature) was 75° and the average temperature of the ceiling surface was 70°. According to Formula 1, the ceiling could absorb about:

$$q = 1.48(T_R - T_C)^{1.1} = 1.48(75-70)^{1.1} = 8.7\frac{Btu}{hr \cdot ft^2}$$

Under this condition, the ΔT between the average water in the tubing circuit and ceiling surface temperature would be about 4°.

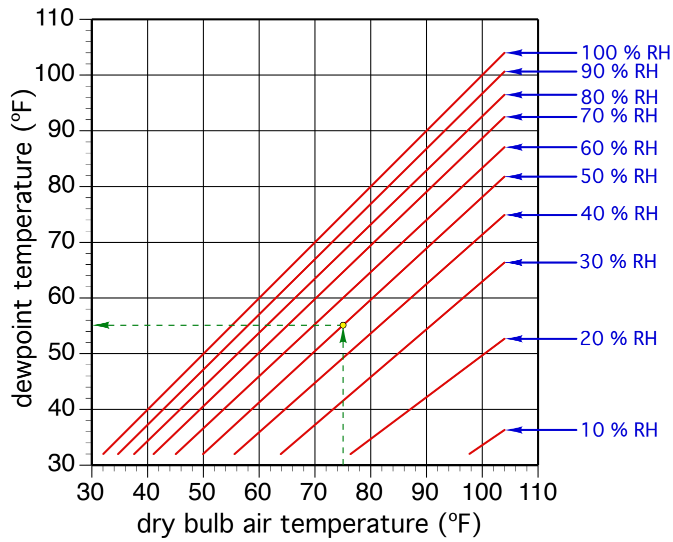
Lowering the ceiling's average surface temperature to 65° would increase heat absorption to about 18.6 Btu/hr./ft^2. The ΔT between average water temperature and panel surface temperature would now be about 8.6°.

There are definite limits to how cool the components within the radiant panel can get before a major problem arises. That problem is condensation and it occurs on any surface that cools down to the *dewpoint* of the surrounding air.

The dewpoint of air is determined by its dry bulb temperature and relative humidity. The graph in Figure 2 is one way to find the dewpoint based on these conditions.

For example, if the dry bulb air temperature is 75° and the relative humidity is 50%, the air in the room has a dewpoint of about 55°. If the temperature of any object in this room is at or below 55°, condensation will immediately form on it. If that object happens to be the ceiling, you can imagine what follows, and it's not pretty.

Figure 2



To avoid condensation problems, all radiant cooling panels must operate at a temperature that's a few degrees above the current dewpoint temperature of the interior air. Various references suggest chilled water supply temperature to such a panel be 3° to 4° above the current dewpoint. This provides a small safety margin that's compatible with current sensor and controller accuracy.

Dewpoint temperatures vary with time and location within the building. The dewpoint temperature within an entry vestibule, subject to frequent door openings on a humid summer day, could be several degrees Fahrenheit above the dewpoint temperature within an interior space. If the chilled water temperature supplied to radiant panels in both spaces is controlled by a single mixing device, but the dewpoint is only sensed within the interior space, then it's likely that condensation will form on the vestibule ceiling due to localized higher humidity.

To prevent such an issue, designers have to consider when and where localized sources of moisture may occur, and provide each of those areas with separate dewpoint sensors and chilled water mixing systems.

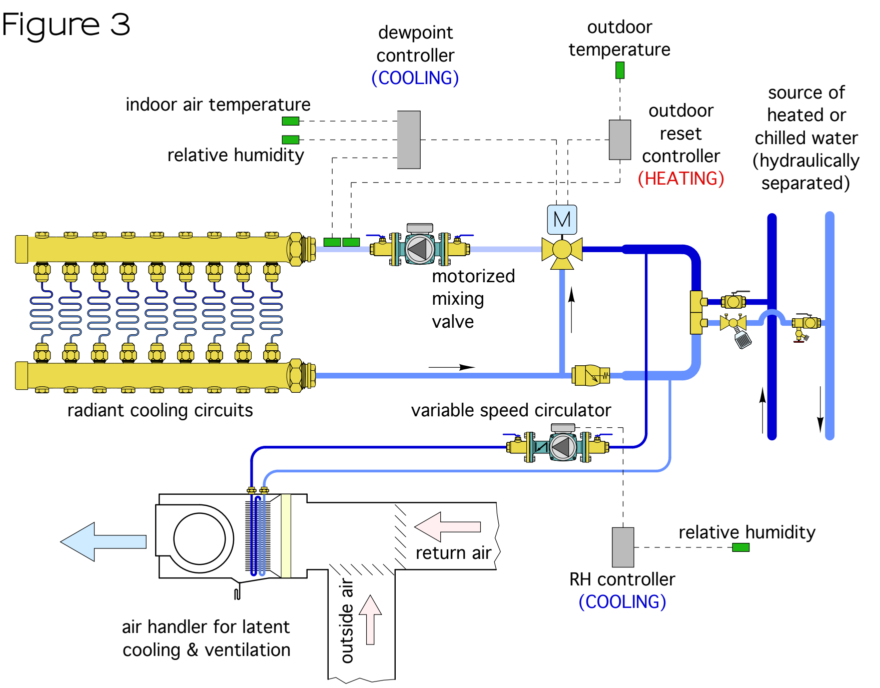
Figure 3 (page 16) shows an arrangement where a single three-way motorized mixing valve controls chilled water supply temperature, based on dewpoint temperature during cooling operation and outdoor reset control during heating operation.

Wringing out moisture

Radiant panel cooling only addresses the sensible portion of the total cooling load. The remaining latent load (e.g., moisture removal) must come from a device equipped to handle the resulting condensate. In most systems, this will be done using an air handler with a chilled water coil and drip pan.

The airflow rate and coil should be selected to provide the design latent cooling load using a supply water temperature no lower than 45°. Higher chilled water temperatures in the range of 50° to 55° may be possible depending on the latent cooling

Figure 3



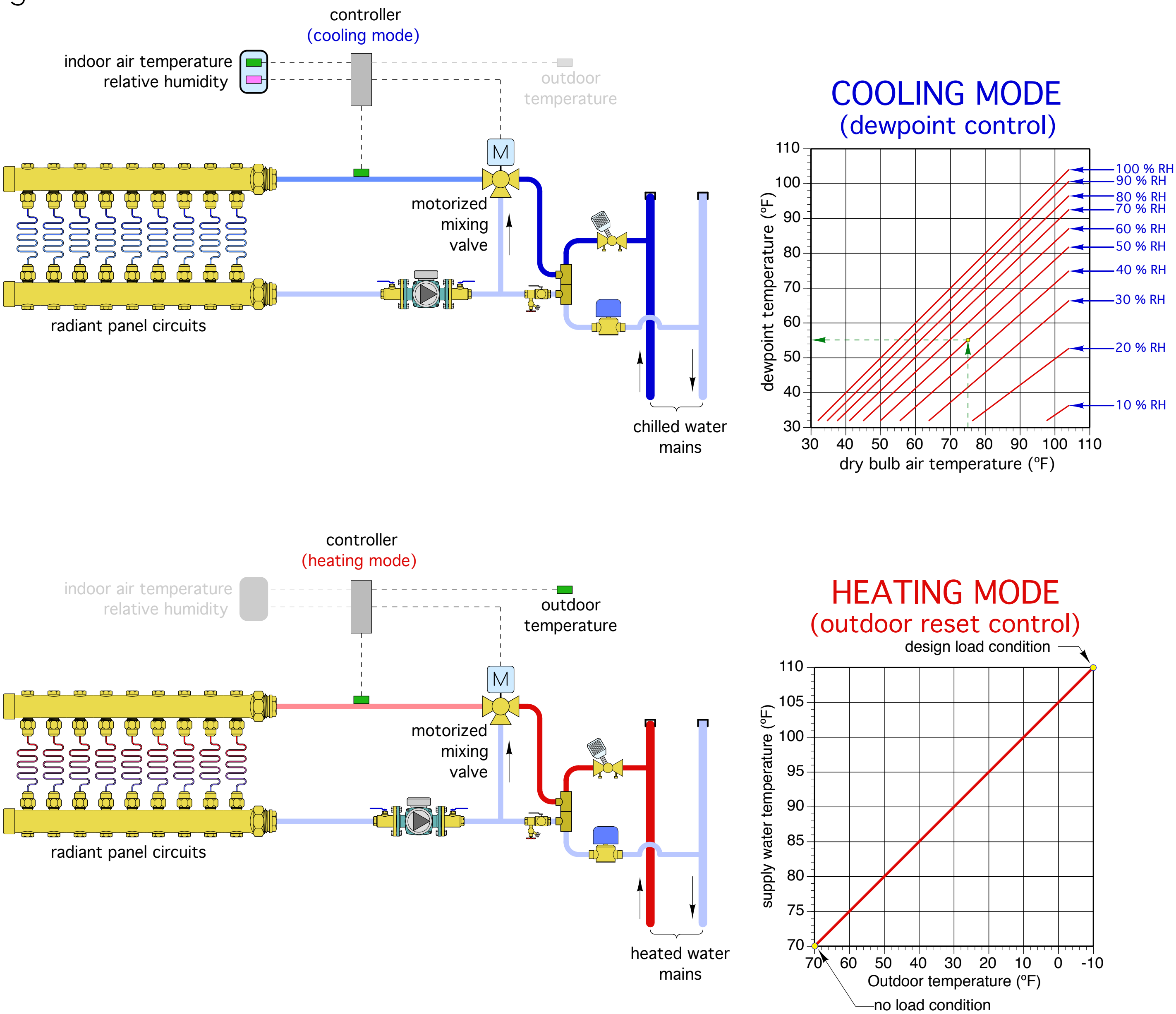
capacity of the coil and the location. Drier climates with lower latent loads favor higher chilled water temperatures.

These high temperatures increase the Energy Efficiency Ratios for both geothermal heat pumps and chillers using air-cooled condensers. The air handler that provides latent cooling also can be used to distribute ventilation air. The savings come from significantly reduced air flow rates, smaller air handlers and small ducting.

The cooling capacity (and rate of moisture removal) of the air handler shown in Figure 3 is controlled by the flow rate of chilled water through the coil. In this case, that flow is regulated by a variable-speed circulator, which responds to a controller that measures the relative humidity of the supply air stream and compares it to a setpoint value such as 50%.

The controller outputs a signal such as 2-10 VDC or 4-20 milliamp, which

Figure 4

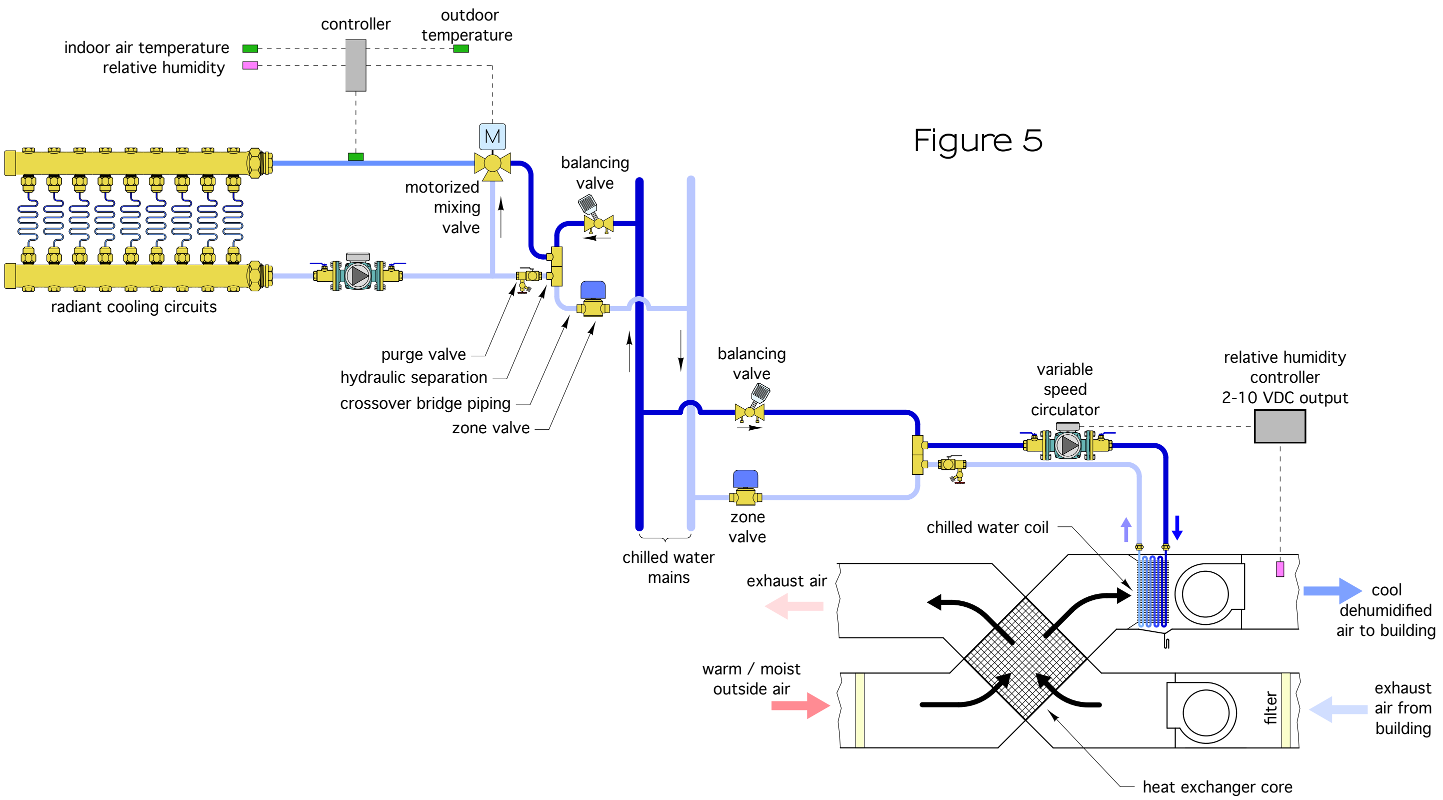


is compatible with the speed controller driving the circulator. When the relative humidity starts to rise above setpoint, the circulator speeds up to increase the capacity of the coil and vice versa.

The air-handler system also could be used for ventilation in winter. In cold climates, the circuit through the cooling coil, which could be used to warm incoming ventilation air in winter, should be protected by antifreeze.

Although separate controllers are currently available for dewpoint control and outdoor reset, I think our industry needs a controller that combines both functions into a simple, stand-alone device complete with sensors. This controller would regulate the three-way motorized mixing valve and manage chilled water flow through the coil of the air handler that provides latent cooling and ventilation. The concept for such a controller is shown in Figure 4. Figure 5 (page 20) shows an extension of the system of Figure 4. Specifically, it adds a heat recovery ventilator to the system. The HRV scavenges some of the cooling effect of the exhaust air stream and uses it to precondition the incoming ventilation air. This assembly also includes a multiple tube row chilled water coil that would be very effective in dehumidifying the air passing through it.

Figure 5



The goal is to dry the air supplied to the space to a condition that allows it to absorb sufficient moisture from the space to maintain a comfortable relative humidity. Time to get out those psychometric charts and ventilation manuals to see how this is done.

One long-standing criticism of residential hydronics has been its perceived inability to provide cooling. Radiant panel cooling provides an opportunity to help end that perception by offering not only the ability to provide cooling, but do it using state-of-the-art methods that improve comfort, leverage modern devices such as heat pumps and significantly reduce the "distribution energy" required to cool the building. It's also a great way to merge the best attributes of modern hydronics technology with air-side subsystems for ventilation and latent cooling.

John Siegenthaler, P.E., is principal of Appropriate Designs, a consulting engineering firm in Holland Patent, N.Y., and the hydronics editor for Plumbing & Mechanical. Email him at john@hydronicpros.com. He continues teaching his online course titled, "Mastering Hydronic System Design," in partnership with BNP Media and HeatSpring Learning Institute. Details are available at http://bnp.cammpus.com/courses/hydronic-system-design-training--online. **PM**