BY KEITH WHITWORTH

large Radiant systems

A BOILER'S WORST NIGHTMARE?

Large radiant heat systems place unique demands on a boiler or a series of boilers. These systems are typically characterized by cold starts with long boiler run-times, high water volume, high mass, cooler required supply water temperatures, and short boiler cycle-times when the mass is at temperature.

Of course, large radiant systems require a boiler or boilers with high output. A key advantage of radiant systems, however, is that when the thermal mass of a floor or heated surface has reached temperature, shorter and less frequent boiler cycle-times are required. Better yet, a boiler system with modulation permits the heating, and later heat-maintenance of the heated surface. Either a fully modulating burner, or the lead-lag staging of boilers, would allow a system to meet ever-changing load requirements for optimal system efficiency. Another option is to add mass to the piping system to increase boiler run times during periods of low demand. For this, water tanks can easily add mass to a piping system.

If you have a large boiler for a high-volume system, the boiler will short-cycle when the mass is at temperature. The short-cycling is the enemy. To get around the large boiler for high-thermal mass issue, but short cycle times when the mass is at temperature, mass must be added to the boiler system.

Snow melting systems pose a different challenge: high demand and high mass with extremely cold water/glycol temperatures. Here, the challenge is not short-cycling of the boiler. Typically, a boiler will not short cycle because the load is so high with snow melting (melting snow and atmospheric losses). The real enemy in snow melting, as far as a boiler is concerned, is thermal shock and flue-gas condensation.

Thermal shock happens when freezing return-water temperatures come crashing into the heat exchanger in a long, hard, cold start. The new generation of condensing boilers take this brutal jab in stride: See "Most Wanted Characteristics of Radiant System Boilers."

To prevent thermal shock, boiler bypass piping, the mixing primary and secondary returns, is one of the more popu-

PHOTOA. Installation of 29 miles of radiant tubing underneath the field at Gillette Stadium in Boston.

lar methods used to prevent cold system fluids from returning directly into the boiler, avoiding the key risk of condensing the boiler flue-gas, which can deliver a lethal blow to the sturdiest of non-condensing boilers. Thermal shock and flue gas condensation are two entirely different problems, but they both occur in a snowmelt system due to the cold return water temperature

Trying not to bring the outside in

The goal of any heating system is to keep us warm. However, a heating system does this not by heating us; we don't need the heat. A heating system keeps us warm by controlling the heat loss from our bodies.

High energy heat concentrations go to low energy cold concentrations—always hot to cold. Because of this, our bodies try to heat the objects around us. Comfort is determined by the amount of heat we lose from our bodies. If we lose too much heat, we feel uncomfortably cold. If we lose too little heat, the opposite happens. Naturally at object temperatures of above 85 F, objects will start to heat us.

Convective vs radiant

A heating system heats the objects around us to control the heat loss from our bodies. Heating systems do this in different ways and to different degrees of effectiveness. A forced air convective system heats air and then uses a fan to blow the air within interior spaces. However, air is a great insulator and a poor conductor of energy. We get insulation from still air spaces.So why use an insulator to conduct energy?

A baseboard system is another type of convective system. The air around the baseboard unit is heated. Hot air rises along outside walls to the ceiling, transfers its energy along the way, cools and falls back to the floor, setting up a convective loop within a space.

So, does a radiant floor provide radiate heat? Yes and no. Radiant floor heat transfers energy by conduction (items in contact with the floor radiation – hot going to cold) and some convection, with the air being heated near the floor, and rising. Using the equations in the

Most Wanted Characteristics for a Radiant-System Boiler

Sure, you can use a non-condensing boiler with boiler bypass piping and a heat exchanger to protect the heat source from thermal shock as cold, incoming fluids from the radian system rush into the unit at start-up. Or, you could specify a boiler designed to handle the rigors of large radiant system duty. There are some new products out there than can meet these challenges. Aside from ease of maintenance, high efficiency, and affordability, here are some ideal qualities for a boiler intended to feed large radiant or snowmelt systems:

- Condensing boiler with sealed combustion. The ultimate tool for low, and super-low liquid temperatures at start-up. Ideally, this boiler's secondary heat exchanger transfers exhaust heat to warm liquids before they reach the primary HEAT EXCHANGER. At peak efficiency, water vapor produced in the combustion process condenses back into liquid form to release latent heat. Also, its sealed combustion, positive-pressure design assures that the boiler can be installed in many environments, even outdoors. Without the need of room air for combustion, the boiler is not affected by limited air from within the building, or by negative pressures created by other equipment. However, not all condensing boilers have sealed combustion.
- Fully modulating.These units provide not just one or two stages of firing capacity, but a wide range of modulation between 100 and 25 percent of the input rate. Fully modulating tries to (and comes closest to) exactly matching the required output with the energy input.However, this feature is expensive may not justify the added expense.
- Durability. Units that have stainless steel secondary heat exchangers and accept water with up to 20 gpg hardness are good examples. Also, these systems should be built for direct contact with a 50-50 glycol mix, with no need for an external HEAT EXCHANGER. Keep in mind that inhibited glycol has corrosion inhibitors, whereas uninhibited glycol will "eat" cast iron boilers rather quickly.
- No risk of thermal shock. A radiant heating system's boiler should have heat exchangers that go with the flow, at any temperature. For example, while a boiler that requires a minimum of 70 F return water temperature on an ongoing basis, initial start-up temperatures should be far lower. Peak operating efficiency occurs when the return water temperature reaches 70 degrees, and a fully automatic internal mixing system protects the primary heat exchanger from condensation. An ideal system is one in which when temperatures begin to rise, the boiler's control system responds accordingly, maintaining the desired output temperatures and obtaining maximum efficiency from the boiler. Therefore, whether the radiant floor system includes placement of tubing in cold outside areas (snow melting), or traditional low temperature indoor systems, the boiler will not be damaged by short periods of cold return water, even as low as 30 degrees.

ASHRAE 1999 Handbook (HVAC Applications, Chapter 52, Radiant Heating and Cooling), for an 80 F panel temperature, 70 F room temperature, and 68 F average unheated surface temperature, total heat output is 17 Btu per square foot, of which 37 percent is convective. The remainder is radiative and conductive. When compared to a convective system, 37 percent is actually small.

What do you need all this pipe for?

On one memorable project, the owner of a general contracting firm summoned me to a site. As he stood among an impressive gridwork of rebar and thousands of linear feet of exposed tubing, neatly arranged for the next day's cement pour, he asked pessimistically: "Does this look right to you?" I scanned the plans and the tubing and saw no crossed circuits and everything was tied down properly. Pressure gauges showed a consistent 50-psi on all loops.

"Yes," I told him. "It looks fine."

"Well, then," he demanded, "What in the world do you need all this pipe for?"

He soon learned that all those pipes are there to perform an important function: heat transfer. The pipes carry warm water, or a mixture of water and glycol, to transfer heat to the material that surrounds them. Radiant floors are often concrete, but can be wood, gravel, sand, or even dirt. What are the implications of the type of flooring material for the radiant system design? The flooring material encompass items such as supply water temperature, tubing spacing, and the actual ability to deliver the required energy. The thicker and less conductive the floor covering, the less the ability to deliver energy into the space.The water transfers heat through the walls of the pipe into the floor. The floor warms, and then heats the rest of the space as hot moves to cold.

Low Mass vs. High Mass

With Radiant Floor heating, mass refers to the thermal mass of the heated space. The thermal mass is comprised of the objects in the space that the heating system must warm to control the heat loss from our bodies. The goal of any heating system is to warm the objects around us to control our heat loss.

High thermal mass systems consist of large, thick concrete slabs. There can also be a lot of mass in the space, like granite or more concrete. Another key consideration is insulation. Without insulation below the slab (but most importantly, always at the perimeter), the soil below the slab becomes part of the high mass.

Low thermal mass systems have less concrete or less mass in the space. And what may also be a key contributing factor will be the presence of insulation below and around the slab, helping to isolate and reduce the heated mass.

Of course, high mass systems take a long time to heat from initial system start-up. Consequently, they also take a long time to cool down, or loose their energy.

Low thermal mass systems don't take nearly as long to heat up. They respond to changes in heat demand much faster. However, low thermal mass systems cool down much more readily.

The amount of pipe is dependent upon the application—commercial, residential, or snow melting—and where the pipe is installed—slab, thin slab, under or over a wood subfloor—and lastly, the spacing. This issue could encompass an article all on its own.

The piping material can be any number of substances, but the two most popular are PEX (cross-linked polyethylene) or EPDM-ethylene propylene diene monomer, a synthetic rubber. Both of these materials are flexible, durable and have good high-temperature properties. Further, and maybe most importantly, both of these materials have a proven record for long life and durability. That's an important attribute when you consider that the material is inaccessible when buried in concrete.

Both materials work equally well. It depends upon the application as to which material will work best—EPDM has superior flexibility, but costs more. PEX is not as flexible, is less expensive, but works just fine for concrete slabs.

Because the tubes warm the thermal mass, another important difference between radiant floor heating and other forms of heat has to be mentioned. Radiant floor heating stores energy in the mass of the structure. Unlike forced-air systems, which store heat in the air, and try to use the air to transfer heat, radiant floor heating stores the heat in objects in the room. When a door is opened on a cold winter day, the warm air – and all the energy in it – escapes. Remember, the air does a very poor job of transferring the heat to the actual mass of the space

Similarly, with radiant floor heating, when the door is opened, the warm air escapes. But the objects still have stored energy, so the space returns to temperature quickly when the door is closed (See ASHRAE 1999 Applications Handbook, A52.6 Radiant Heating and Cooling, Design for Total Space Heating. "In addition, the peak load may be decreased due to heat (cool) stored in the structure (Kilkis, 1990, 1992)”For this reason, many large aircraft hangers, storage facilities and warehouses, and trucking distribution centers, to name a few, are heated with radiant floor heating. In a hanger, when large bay doors are closed, the space reaches the setpoint temperature in just 15 or 20 minutes, an impossibility with a forced-air system. Of course, the number of warehouses and storage facilities that are heated with radiant floors compared to the number heated with unit heaters or floor mounted furnaces is small, but that number is growing.

Pipes in the floor, however, require some special precautions. If heavy machinery is to be mounted to the floor, the setting of anchor points must be located long before people begin popping holes in the concrete. If there are trench-drains or floor drains, the piping must go around those. Basically, anything that goes through the floor, is bolted to the floor, or protrudes from the floor, the pipe should go around, or special provisions must be made.

But again, why all those pipes? One key reason is comfort. If piping in a concrete slab is spaced wider than 12-in. apart, or wider than 8-in. when installed under a wood subfloor, “thermal stripping” which is when the difference between heated and unheated areas is apparent to the touch of the foot. The difference reflects the actual conductivity of the material involved. 8-in. for wood, 12 in. for the more conductive concrete.

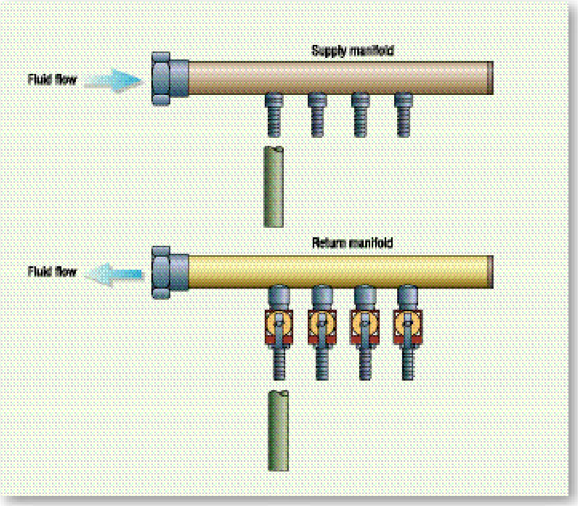

FIGURE 1.Standard manifold installation.

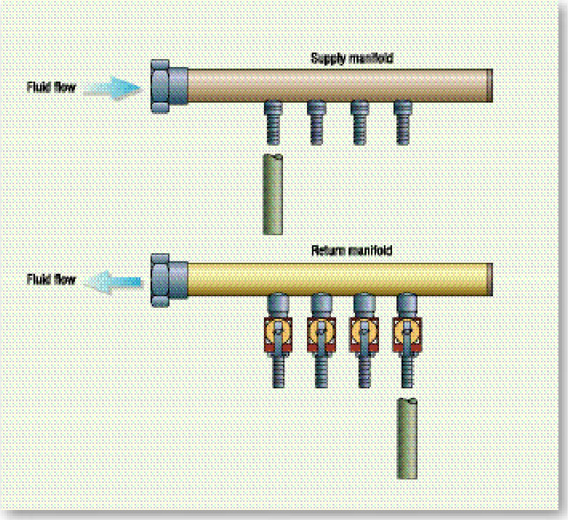

FIGURE 2. Reverse return manifold installation.

A volume of water moving through one relatively long pipe has a lot more friction loss than the same volume moving through 10 pipes of much shorter length. In a small system with, say, 5 gpm, friction loss isn’t a big deal. But increase the system by a factor of 10 or 20 or more, and piping losses start playing a much larger role. In large systems, there is a constant juggling act between the amount of pipe and the type of pump required.

Clearly, to heat large spaces, we must move enough water to accommodate the heat loss of a space. One gallon per minute of water equals 10,000 Btuh. For radiant floor heating, we almost always design for a 20 F delta T. One of the only systems that has a smaller delta T are perma-frost protection systems, which keep groundwater beneath large freezer floors from freezing. So if we had a heat loss of 50,000 Btuh, we would have to pump 5 gpm; and for 500,000 Btuh, we’ll need 50 gpm. For the larger of these, a 50 gpm volume doesn’t care if it’s traveling though one pipe or ten pipes—it still needs to be 50 gpm.

Pipes In, Pipes Out

Another part of the pipe puzzle is where manifolds can be located. The manifold is a piece of copper or stainless steel pipe, or extruded or cast brass or thermoplastic with barbs. The job of the manifold is to transition from all those pipes in the floor to a common supply and common return pipe to go back to the boiler and pump location. A single manifold location with a supply and a return manifold in a large area such as a warehouse would have a lot of pipes protruding from it. The amount of linear footage of piping is the same, but the amount protruding the slab at any given location changes .

However, if this same manifold pair is split into several manifold pairs in several locations, there would obviously be fewer pipes entering and leaving each location. You may say that you need the same number of pipes either way, so what difference does the number of manifolds make? The difference is the total cost of the project. For exam-

Case Study: Gillette Stadium

Among the more interesting applications of radiant heat systems are outdoor athletic fields. The goal is not to provide snowmelt, but to lengthen the growing season of the grass. During winter months, the grass wants to go dormant. By applying just the right amount of heat, we can keep the grass growing and the groundskeeper happy. This should also start the growing season earlier than would otherwise be possible.

In these applications, much depends upon the time of year. In early spring or late fall, more heat is required due to the ambient temperature and surrounding ground temperature. Water temperature can range from 110 F to 160 F depending upon depth of tube, tubing material. Ground temperature depends upon the type of grass used.

One such job is an installation done last year at the New England Patriots field at Gillette Stadium. The Patriots new radiant heating/turf warming system consists of 153,000 linear ft, (29 miles) of PEX tubing that feed warmth to the soil.

Even with new developments in irrigation and soil management, the ability to grow turf is directly related to the condition and temperature of the root zone. Constant root zone temperatures help to accelerate turf growth, allowing for faster repair of damaged areas, and also help to maintain a more pliable soil condition, the perfect environment for roots to grow.

Radiant turf warming systems are rapidly being integrated into the design of new and reconditioned professional field projects. There's more to a radiant turf system than just installing tubing under the soil. See the cross section above for details.

ple, if an area needed 20 circuits, each circuit with a supply side and a return side, that would be 20 supply ends and 20 return ends, or 40 ends of pipe coming to a single location. A manifold can typically have only 15 circuits, due to the flow issues and the ability to balance flow on a per circuit basis—even when using reverse return systems. Greater number of circuits equals a larger manifold.

But, if we took those same 20 circuits and split them into 4 groups of 5 circuits each, we could use four separate manifold locations. Each manifold location would then only have eight ends each. We would still have the same 20 circuits to heat the space, and we would perhaps need some more copper pipe for supply and return piping, but we would get a system that is easier to install and provides better heat distribution. This is important because when you have a huge mass of pipes going to one location in the floor, for one manifold location, you're going to get a hot-spot there. More manifold locations translate into more even floor temperatures, especially near the manifold .

But wouldn't those extra manifold locations require some sort of balancing to ensure equal flow to each manifold pair? Perhaps. Balancing valves can be employed. A simpler approach is " return" piping, using a first-in, last-out technique, as seen in photo B. In this way, the first manifold fed off the supply trunk has to be the last manifold feeding into the return trunk. This concept can even be extended down to the circuit level.The first circuit closest to the supply pipe on the supply manifold should be the last circuit farthest away from the return pipe on the return manifold. Reverse return always ensures a self-balancing system, because the water "sees" the same pressure drop through each circuit, or manifold.

Conclusion

At first, it may seem that radiant floor heating or snowmelting systems are detrimental to boilers--variable energy requirements with potentially cold return water crashing into a heat exhanger. However, with proper primary-secondary system piping employed with a mixing method to protect both the radiant floor heating system and the boiler, boilers can be ideally matched to radiant floor heating systems.

Radiant floor heating systems require large energy inputs at startup and greatly reduced energy input once the thermalo mass reached temperature. Ideally, the inpute energy of heated "mass" of the boiler system would be variable. In other words, multiple boilers could be staged to meet the ever-changing loads. Conversely, thermal mass could be added to the boiler system to act as a capacitator, or "shock absorber." The best way to add thermal mass to a boiler system is to add a hot-water storage tank. The boiler can feed the storage tank and the "loads" of the system can draw off the storage tank.

It may also seem that radiant floor heating uses a lot of piping. However, we learned some fundementals of radiant floor heating--the pipe is required to heat the thermal mass of the space, not just the air. The structure has a lot more thermal mass , thus requiring more heat-exhange surface and more pipe.

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