Heat Loss to Head Loss

Radiant Design - 12 Step Program

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For those in the radiant design business no conversation invokes more frustration than the one where "design" is taken for granted. The leap to tube spacing and fluid temperatures without a heat loss calculation or consideration for floor coverings, the selection of pipe diameters without crunching the numbers on flow rates or the installation of a circulator without considering velocity and head losses – all oh so common. Arbitrarily installing equipment without consideration for the human factors and science behind the design is the root of all evils.

For radiant system the systematic process can be described as a 12 step program beginning with the heat loss and ending with the head loss.

Step 1 - Heat Loss (Btu/hr)

Heat loss influences everything in the design process. One can't begin to think about materials or assembly until this key calculation is done. Heat loss is Btu's lost. For my non technical accountant friends I describe a Btu as the amount of heat a match puts out. How many matches must burn in an hour is what we're talking about. Is it 10, 100 or 100,000? In any other profession whether it's a doctor, a cab driver or the teenager selling burgers – no one wants to hear guessing as to how much when it comes to paying for anything. You shouldn't be guessing in hydronics either. You have to do the math. How many burning matches is it going to take to keep the place warm? How many gallons are going to have to circulate through the floor carrying those matches? The heat loss calculation provides answers to these questions and you can't go to step two unless you do step one.

Step 2 – Flux (Btu/hr/sf)

We're not talking about soldering here we're looking at how many matches must burn per hour per square foot. If your heat loss calculation shows you need 10,000 matches in an hour and your available floor area is 1000 sq. ft. then your flux = 10,000/1000 = 10 Btu/hr/sf. Imagine the equivalent heat of 10 matches burning per hour every square foot. You want to try guessing 100 or 1? Not a good idea. Do the math.

Step 3 - Surface Temperature (ºF)

One of the critical but simplest calculations to perform is the floor surface temperature. The floor can't be too hot (max 84 ºF, ANSI/ASHRAE Standard 55-2004) or it will be uncomfortable and if it isn't warm enough it may not be able to transfer the Btu's. To calculate the surface temperature simply divides the flux by 2 and add the result to the desired operative temperature. The value of 2 is a 'heat transfer coefficient' or HTC and before continuing let's be very clear the value of 2 is for radiant floors and is a nominal number which means it's not exactly 2. It's a different number for walls and ceilings and it also changes for cooling. For our heated floor example we take our flux of 10 Btu/hr/sf divide it by 2 (units = Btu/hr/sf/ ºF) which

= 5 ºF plus our operative temp of 70 ºF = 75 ºF surface temperature. At 75 ºF we will be able to transfer 10 Btu/hr/sf to keep the room at 70 ºF.

Step 4 - Floor Coverings *($ft^2 \cdot h \cdot °F/Btu$)*

Contrary to popular misunderstanding, the heat flux is not affected by floor coverings as long as the floor is not a highly polished mirror like surface. Carpet or concrete have for practical purpose identical abilities to emit radiant energy the only difference floor coverings have on the design is in the tube spacing and fluid temperature. The greater the sum of R values of the floor assembly above the tubes, the closer the tubes and or the hotter the fluid temperature must be. The hotter the fluid temperature the greater the back loss and thus the higher the insulation required below the tubes. (Still think we should be guessing?)

Step 5 – Spacing (inches)

Up to this point the building specifications have influenced the radiant design. In step 5 and step 6, the radiant designer begins to influences the systems in terms of capital cost for equipment and operating costs for fuel and power. Spacing and average fluid temperatures are joined at the hipped. The greater the tube density (closer the spacing) the lower the average fluid temperature. The less tube density the hotter the fluid temperature. There is no right or wrong spacing other than what impact it may have on surface temperature consistencies and ultimately in flow rates and fluid temperatures. For the moment we're going to ignore tube pattern layouts, tube depth and upward resistances and advise that generally the closer the tube spacing the less variance one will have in surface temperatures. Conversely the wider the spacing the greater the surface temperatures inconsistencies.

Step 6 – Average Fluid Temperature (ºF)

For a given flux and R-value the closer the spacing the lower the average fluid temperature. Fluid temps drive heat transfer. You could have a 100 US gpm running through the 1000 sf floor and if the temperature in the pipes is the same as the floor or room temperature there will be zero heat transfer – none – zero - zip. Flow is the container but temperature drives heat transfer and temperature comes from burning matches…the more flames the hotter the fluid. The hotter the fluid the wider the spacing…the wider the spacing the greater the inconsistencies in surface temperature. The closer the tubes spacing the lower the fluid temperature the greater the efficiencies from your boiler. As mentioned above Step 5 and Step 6 are linked.

Step 7 – Flow (USgpm)

All you have to is take a look at the units and see that flow is a container per unit of time. That's it. In the U.S. the standard units are US gallons per minute. Imagine a one gallon milk jug. When we calculate the flow all we're doing is figuring out how many one US gallon containers carry heated fluid have to travel through the floor in one minute. What influences the flow is the amount of Btu we have to move into the space every hour (see step 1) plus the characteristics of the fluid (lbs/USgal & Btu/lb ^{o}F) and temperature difference(Δt ^{o}F) between the fluid going into and coming out of the floor. This is how the formula looks:

q_w, flow USgpm = (Q_w, Btu/hr) divided by (60 min/hr * p_w lbs/USgal * c_p Btu/lb ^{o}F * delta t ^{o}F)

A few last words on this step 7…the intent of this article is to give a general overview of the steps to designing radiant systems. Our courses at www.healthyheating.com provide detailed explanations as to fluid characteristics, heat loss calculations and selecting Δ t's.

Step 8 - Flow per Loop (USgpm per loop)

Once you figure out how many one gallon buckets have to rotate through the zone in one minute the next is figure out if all that water should travels through one loop or several loops. This where hydronic design turns into hydraulic design.

This is also where we introduce one of those fancy dinner party words called "iterative". This means repetition, recurrence, or reiteration. Step 7, 8, 9, 11, and 12 is about repeatedly playing with the sequence and with the values to optimize the design for easiest installation with the lowest pressure drop for the least operating and capital equipment cost. We could decide to rotate the fluid through one loop but that one loop might have to be really long which drives up the head loss. We could increase the pipe diameter to reduce the head loss but then the cost of the pipe goes up as does the installation difficulty. We could split the flow into a number of loops to reduce the flow per loop and thus the head loss but then the cost of the manifold would go up. This is where experience and software reduce the design optimization to the least amount of engineering time.

Step 9 - Pipe Diameters (inches)

Once you have decided on the number of loops (and by deduction the flow per loop) then you can pick a diameter of pipe which regulates the flow velocity between a nominal 1.5 to 5 feet per second and head losses between 1 ft. to 4 ft. per 100 ft of pipe. The bigger the pipe the less differential pressure required which may mean a smaller pump which then equals less cost but it also means more money for pipe and associated items like fittings.

Step 10 - Total Tube (ft)

This step is easy since all you have to do is convert your selected spacing from step 5, into total tube by using a tube density multiplier. If the tube spacing is 12" o.c then every square foot you need one foot of pipe so the multiplier is 1. If you have 6 " o.c. spacing you'll have twice as much as 12" o.c. so your multiplier is 2. Take your area in sq. ft. times the multiplier and you have the total footage. (See our design manuals for tube density multipliers.)

Step 11 - Loop Length (ft)

At this stage you divide the total footage by the number of loops and you have loop length. The experienced guys when playing with spacing and fluid temperatures can work the iterations so the calculated loop lengths reduce waste from a roll and really talented designers can fine tune the system head loss so circulators operate at their highest efficiency. Conversely some designers will work backwards from standardized loop lengths. Either way is fine.

Step 12 - Head Loss (ft of head)

Once you have determined the flow per loop and know the loop length you can calculate how much differential pressure is required to move the quantity of fluid at the prescribed velocity.

So there you have it - heat loss to head loss. Without crunching the numbers you end up with inefficient systems which are over priced (meaning you left money on the table) and under perform - contributing to customer dissatisfaction…and that my friends is a reputation best owned by the competitors.

You can post your questions to the online forum at http://www.healthyheating.com/bb2

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