Don't Just Go With The Flow

Creating hydronic radiant equipment schedules is the key to successful radiant projects.

Successful radiant projects come in all shapes and sizes. For many projects in which the preliminary work is completed by a mechanical, electrical, plumbing (MEP) firm, a radiant equipment schedule is included. An effective radiant equipment schedule will ideally incorporate numerous golden nuggets of information about the proposed radiant system, both for other engineers supporting the design of a building's HVAC system, as well as for the contractor who is bidding the radiant system.

An effective equipment schedule provides: 1) the total flow rate required to each manifold, as well as the head loss it will induce, as reference for the engineer sizing the distribution system for the radiant manifolds 2) a fairly accurate idea of how many manifolds and how much PEX pipe will be needed to serve zones as reference for the contractor, and 3) the total radiant system capacity under design conditions, allowing the engineers specifying the air side of the HVAC system to appropriately size components to complement radiant capacity for an optimized hybrid radiant-forced air system design.

Radiant heating and cooling projects, such as the YWCA Toronto Elm Centre shown here, require an effective radiant equipment schedule.

Even if an MEP firm is not involved (as is the case with some residential construction projects), it is important that contractors have a basic understanding of when and how to apply hydronic equations that are commonly used to size a system. It is often the contractor – who is intimately involved in the installation – that is the first to raise red flags when errors have occurred in the sizing process. Although radiant design seems fairly straightforward, there are many steps in creating a radiant schedule that, when executed out of order or omitted completely, can leave the final radiant designer or contractor picking up the pieces during (or worse, after) the bid process.

RADIANT CAPACITY RULE OF THUMB

In the "good old days of radiant," in-slab systems only tackled the heating side of a building's conditioning. If more capacity was needed from a system, one could keep increasing the EWT[1] at least up until the surface temperature rose to 84.2F (29C)[2]. There is a wide range of supply temperatures with which a radiant floor heating system can operate (~90F < EWT < 140F) making this later "tweaking" fairly forgiving. Many specifying engineers could therefore leave it to ROT (rules of thumb) rather than diligently performing feasibility checks on the specific values for each project.

While ROT may suffice for heating projects, when one moves to the realm of operating the radiant system in cooling mode, greater precision is required. Operating ranges are much narrower (~55F < EWT < ~62F) and every bit of heat flux is important. Simply reducing the EWT is not an option, as the system approaches dew point and the risk of condensation increases.

In many cases, the design schedule is developed by taking the total heat loss of the space and dividing this by the total square footage of the space (often without considering hindrances that may not allow the installation of PEX such as toilets, floor drains and columns). The most common misstep then made by everyone from the installer to the engineer is assuming this value is the slab's actual capacity, and that a resulting flow rate can be calculated from this basic assumption given the following standard flow equation for water-based systems:

$$GPM = \frac{Btu/h}{500 \cdot \Delta T}$$

HOLD OFF ON THE HYDRONICS EQUATION

It is easy to see how one could believe that GPM and Btuh delivered by a radiant system are proportionally related. In fact, to some degree they are, but one needs to be cautious about when to apply this hydronics equation. When applied at this point, the designer tends to try to directly increase capacity by increasing GPM until the desired heat flux is achieved. The flaw in this approach is that, unfortunately, this equation only holds for the heat loss of the fluid within a pipe and does not account for the transfer required from the pipe itself to the surface that is being heated (in the case of a radiant heating source). As a side note, if one were sizing a fan coil or a heat exchanger, this approach would be reasonably valid, but in radiant projects, one must first account for the increased thermal resistance of the mass above the pipe.

Rather than jumping to the basic hydronics equation at this point, one must determine how the warmed or cooled PEX is transferring energy through the thermal resistance of the slab and floor coverings and then eventually heating or cooling the surface to a steady state design temperature. In other words, based on the systems parameters, a specifier must consider what heat flux is possible from the surface, not what is wanted, and apply this as the numerator to the hydronics equation[3].

CONSIDER THE BIG PICTURE

When designing a radiant system, it is always better to start with the big picture of the building, then zoom in on the slab itself, and finally hone to the actual pipe embedded within the concrete. Starting with a space's load, these are the recommended steps in beginning to define the system.

1. Determine what average surface temperature must be achieved to deliver the required heat flux (Btuh/ft²) using this equation (Note: HTC is approximately 1.2 in floor cooling and 1.9 in floor heating):

$$\dot{q} = HTC(T_{SURFACE} - T_{AIR})$$

2. Calculate the MWT[4], pipe sizing and pipe placement that will result in the desired surface temperature found in step 1. (Note: There is not a simple equation to calculate this and most methods [aside from FEA] require a number of lengthy equations and steps, making software the preferred route for this type of sizing. It is thus key to identify an experienced radiant systems specialist or a radiant manufacturer that offers design support to assist in this step.)
3. Verify the amount of flow needed to maintain the steady state operation of the system. Now is the appropriate time to use the following standard hydronic flow equation:

$$GPM = \frac{Btu/h}{500 \cdot \Delta T}$$

TAKE ADVANTAGE OF MWT

It is important to understand that under design conditions, a given pipe in a radiant heating system has only one GPM and corresponding temperature drop. The curve in *Figure 1* depicts the correlation between GPM and ΔT. A common misstep is to look for more capacity by increasing the GPM, but

Radiant equipment schedules developed with improved methodology will result in more optimized radiant systems.

not likewise reducing the ΔT. This will result in an artificial inflation of the expected capacity.

Figure 1: The effect of increasing the flow rate of a typical radiant cooling slab on its specific output capacity. Note that practical flow rates are limited to a fairly small range, shown in green, corresponding to a temperature rise between supply and return of approximately 4-10F (2.2-5.6C). This range is bounded by the limit of turbulent flow on the lower end and the maximum allowable flow per circuit through the manifold.

MWT has a much greater impact than GPM on the increase in capacity from a slab. *Figure 2* illustrates that a decrease in MWT achieves a much more pronounced increase in cooling capacity. In the case of radiant cooling, if a higher heat flux is needed (i.e., cooler surface temperature), MWT is the preferred variable to adjust.

Figure 2: The effect of decreasing the MWT on the specific output capacity of a typical radiant cooling slab. Adjusting the MWT is a much more effective means of increasing the capacity than adjusting the flow rate as illustrated in *Figure 1*.

BEYOND GOING WITH THE FLOW

Although rules of thumb had a significant impact on establishing radiant heating design principles for early applications throughout North America, successful engineers and contractors realize they aren't to be relied upon in the design of today's more sophisticated systems, including those with in-slab cooling. Based on this new wave of applications, the industry needs to fully grasp each step of successful design and work to better optimize radiant systems.

Figure 1 Flow Rate vs. Slab Capacity

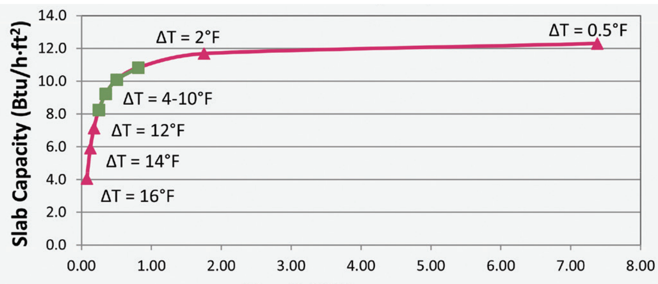
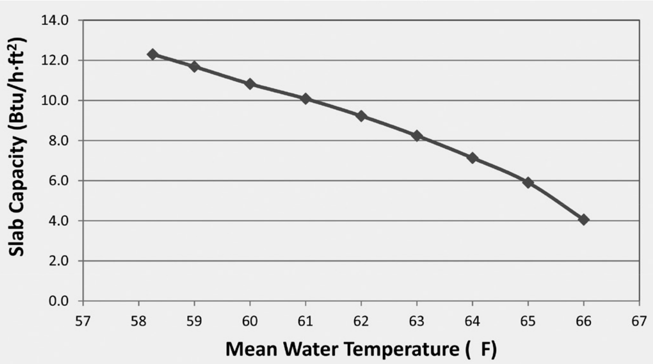


Figure 2 MWT vs. Slab Capacity



SUMMARY OF DESIGN STEPS

The following sequence of design steps will result in the most efficient radiant heating and cooling designs:

1. Using heating and cooling requirements for the space and understanding the useable area available for radiant, determine what heat flux is required from the slab.
2. Knowing the indoor setpoint temperatures in heating and cooling modes, confirm whether this capacity is reasonable given the average surface temperature limitations.
3. Based on slab structure, floor covering, pipe spacing, pipe diameter and indoor setpoints, determine the MWT required to achieve desired average surface temperature.
4. Assess the flow rates and temperature drops (ΔT between supply and return) required to maintain steady state design conditions.
5. Determine the incurred headloss from circuits and header pipes.
6. Add the effects of distribution piping (additional head loss) and size other hydronic components and piping accordingly.

To achieve accurate radiant heating/cooling designs, the commonly used practice of applying simple hydronics equations and beginning system design around flow rates needs to be replaced with a more comprehensive design methodology. Considering factors such as capacity based on surface temperature and the heat transfer between the PEX piping and the slab surface is an integral step toward this. Using improved methodology, the radiant equipment schedules developed by commercial specifying engineers will not only provide better direction to the HVAC system designers and radiant contractors and minimize their design iterations; it will also result in a more optimized radiant system. - **RYAN WESTLUND**

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[1] *EWT: Entering Water Temperature in this use refers to the temperature of the fluid entering the supply header pipe of the radiant manifold.*

[2] *ASHRAE Standard 55 upper limit of acceptable average surface temperature*

[3] *Note: This numerator contains all heat loss coming out of the pipe; therefore downward loss from steady state design conditions (often approximated, assuming adequate insulation, as between 10-20 per cent of upward heat flux) should be added to the useable upward capacity for flow calculations.*

[4] *MWT: Mean Water Temperature is the average fluid temperature in a pipe. In heating mode: MWT = EWT - (ΔT/2); in cooling mode: MWT = EWT + (ΔT/2).*