Below the Surface (Part 1)

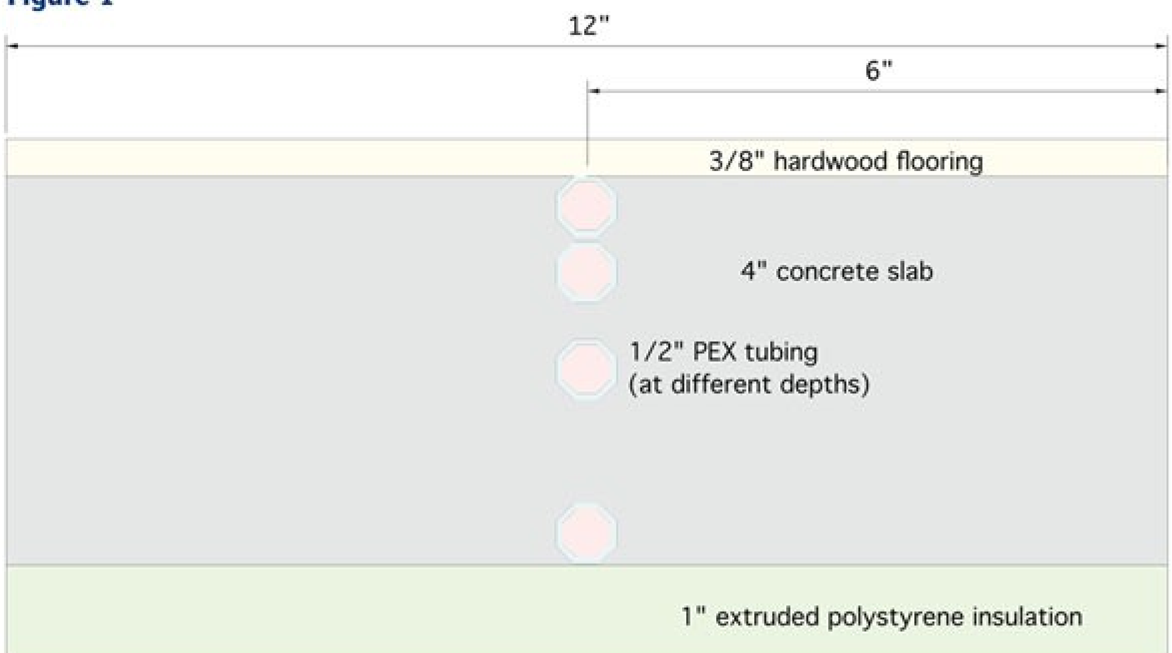
by John Siegenthaler , P.E.
August 1, 2007

Tubing depth DOES affect the performance of heated slabs.

Anyone who has installed hydronic floor heating has surely had their neatly placed tubing circuits get buried in concrete. Sometimes the tubing and reinforcing mesh gets lifted into the thickness of the slab as the concrete is placed. Other times, the masons trample over the tubing and mesh as if it's not even there. Any instructions given them by the radiant installer seemingly vanish when the concrete begins flowing down the chute.

Deep Questions

Figure 1



Unlike relocating a sensor or unthreading a pipe fitting, there's no way to change tubing depth once the concrete is placed. The thermal performance of the slab with its embedded tubing is now fixed for the life of the building. The irreversibility of the situation should make us question if we're installing the tubing in the best manner possible.

If the depth of the tubing doesn't have much of an effect on performance, why worry about it? On the other hand, if depth does have a substantial effect on performance, why be ignorant of it? Why sacrifice performance to a detail that adds very little, if any, to the cost of the system?

There are several ways tubing depth would theoretically affect the performance of a heated slab.

- The deeper the tubing, the greater the thermal resistance between it and the slab surface. The higher the thermal resistance, the higher the water temperature required to maintain a given rate of heat transfer.
- The closer the tubing is to the bottom of the slab, the greater the underside heat losses should be. This is true with or without underslab insulation. Thermal losses are obviously greater in the

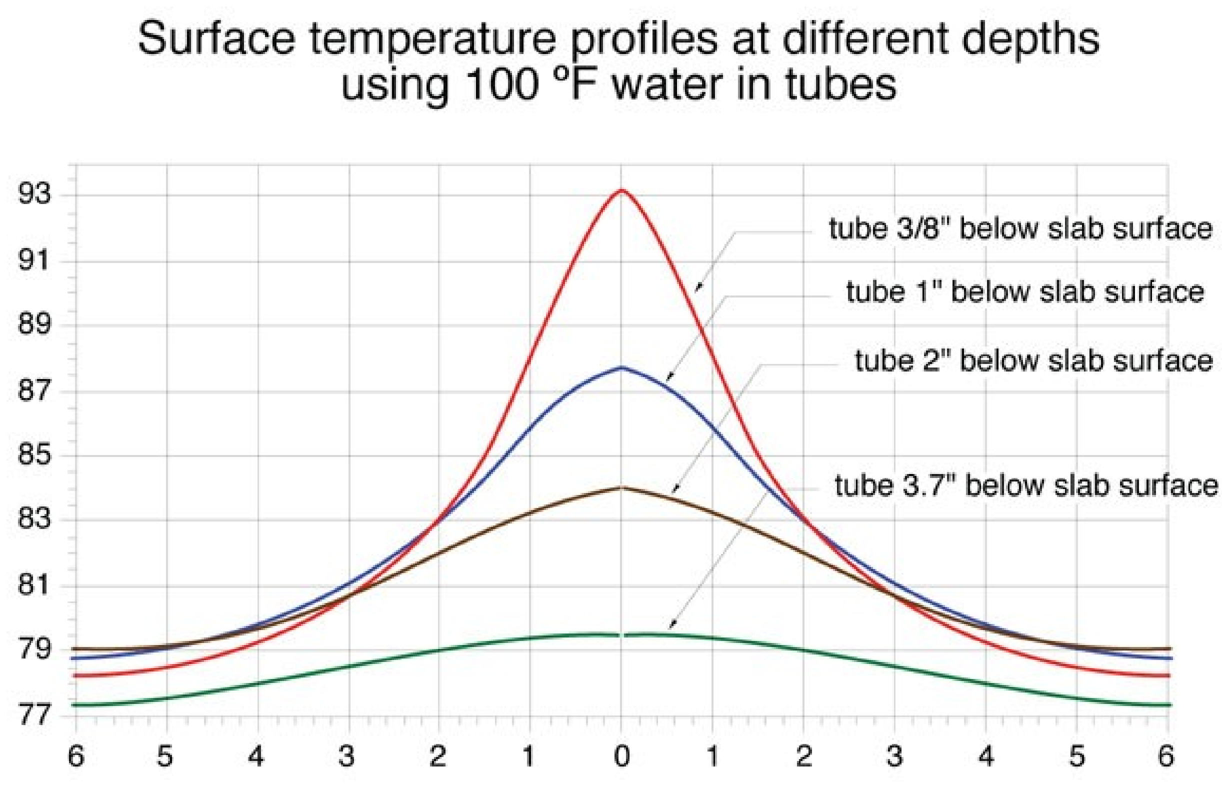
latter case.

- When the tubing ends up near the bottom of the slab, more of the slab's thermal mass is above the level where heat is being added. This lengthens the time it takes to warm the floor surface to normal temperatures following a call for heat. Its also lengthens the cool-down time after heat input is interrupted by system controls. A fully charged slab can hold several hours worth of heat that will continue to flow into the space as long as the air temperature and/or interior surface temperatures are cooler than the floor surface. This can be a real problem in buildings with significant internal heat gains from sunlight or other sources, especially when those gains follow a cold night in which significant heat was added to the slab.

  In light of these issues, it seems obvious that placing tubing higher in the slab will improve its performance. The harder questions are: 1. How much is performance affected by tubing depth? 2. Is the change in performance worth a few well-chosen words with a disinterested mason?

Slab Simulations

Figure 2



Like most engineers, my comfort zone with a design issue is usually bordered by numbers. To get a handle on the tube-depth issue, I turned to a specialized technique called finite element analysis (or FEA for short). FEA software allows one to build a model of the situation you want to test, run it and then see what the temperature would be at any point you're interested in. The calculations this software does in a couple of seconds would take weeks to complete by hand.

One of the models I constructed is shown in **Figure 1**. It consists of a 4" concrete slab sitting on 1-inch (R-5) polystyrene insulation and covered by 3/8" oak flooring. Several versions of the model were used to simulate tubing at different depths in the slab. Each time the model is run, it determines the temperature at hundreds of points within a small region of the slab, including points spaced 1/2-inch apart along the floor surface.

The curves in **Figure 2** show the predicted surface temperature profiles for the model of **Figure 1**. They indicate the following things happening as the tubing is placed deeper in the slab:

1. The floor surface temperature directly above the tube decreases due to the greater R-value between the tube and the surface.

2. The difference between the floor surface temperature directly over the tube and that halfway between adjacent tubes decreases. This is actually a desirable effect that makes it harder to feel where the tubing is located under the floor.

3. The area under each surface temperature profile is different. This area is proportional to upward heat output.

Using the temperature data from several runs of the FEA software, I estimated the heat output from the system for water temperatures of 100°F and 130°F. For both water temperatures, heat output increases as the tubing is lowered through the upper portion of the slab, then drops off as the tubing gets deeper. This means there's an optimal tube depth where the slab delivers maximum heat output. The simulations I ran suggest it's about one-fourth of the slab thickness down from the slab surface. This depth could vary depending on flooring resistance and other factors.

Figure 3 Upward heat flux from floor	Average circuit water temperature with tubing centered 2" below top of slab	Average circuit water temperature with tubing at bottom of slab
15 Btu/hr/ft^2	95°F	102°F
30 Btu/hr/ft^2	120°F	134°F

I also used the FEA results to determine the average water temperatures required to deliver heat outputs of 15 and 30 Btu/hr/ft2. The results are shown in **Figure 3**.

Notice that the average circuit water temperature required to deliver 30 Btu/hr/ft2 is 14°F higher when the tubing is at the bottom of the slab vs. centered in the slab thickness.

Can the system's boiler provide the higher water temperatures required by the deeper tubing? Sure it can. If it happens to be a conventional boiler, the effect on efficiency for operating the circuit 14°F higher is probably quite small.

But what if the heat source is a condensing boiler or geothermal heat pump? The increased water temperature required to deliver the same rate of heat output lowers the condensing potential of the first, and deceases the COP (efficiency) of the latter. Higher water temperatures also mean reduced capacity through mixing devices, higher heat loss from distribution piping and higher downward heat loss from the slab. These are all undesirable.

So much for a typical residential floor slab scenario. Next month, we'll continue the discussion with a look at bare slab performance as a function of tubing depth. We'll also look at downward heat loss and discuss locations where tubing should not be lifted in the slab. In the meantime, be sure you're specifying that tubing should be lifted to mid-slab thickness. It DOES make a difference.

Below the Surface (Part 2)

by John Siegenthaler , P.E.
September 7, 2007

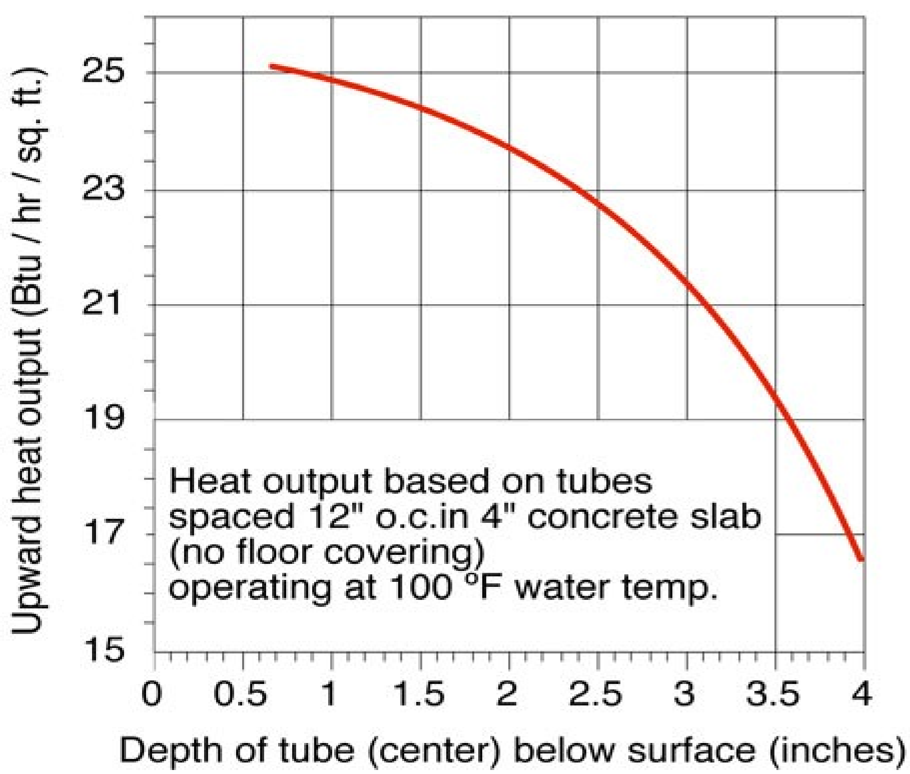
Tubing depth DOES affect the performance of heated slabs.

Last month, we began a discussion of how tubing depth affects the thermal performance of heated slabs. Based on computer simulations, we found the effect is significant. This month we'll continue the discussion with a look at bare slabs. We'll also look at some details for protecting tubing where it passes beneath sawn control joints.

Unlike relocating a sensor or unthreading a pipe fitting, there's no way to change tubing depth once the concrete is placed. The thermal performance of the slab with its embedded tubing is now fixed for the life of the building. The irreversibility of the situation should make us question if we're installing the tubing in the best manner possible.

If the depth of the tubing doesn't have much of an effect on performance, why worry about it? On the other hand, if depth does have a substantial effect on performance, why be ignorant of it? Why sacrifice performance to a detail that adds very little, if any, to the cost of the system?

Slab Simulations



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Using the temperature data from several runs of the FEA software, I estimated the heat output from the system for water temperatures of 100˚F and 130˚F. For both water temperatures, heat output increases as the tubing is lowered through the upper portion of the slab, then drops off as the tubing gets deeper. This means there's an optimal tube depth where the slab delivers maximum heat output. The simulations I ran suggest it's about one quarter of the slab thickness down from the slab surface. This depth could vary depending on flooring resistance and other factors. I also used the FEA results to determine the average water temperatures required to deliver heat outputs of 15 and 30 Btu/hr/sq. ft.

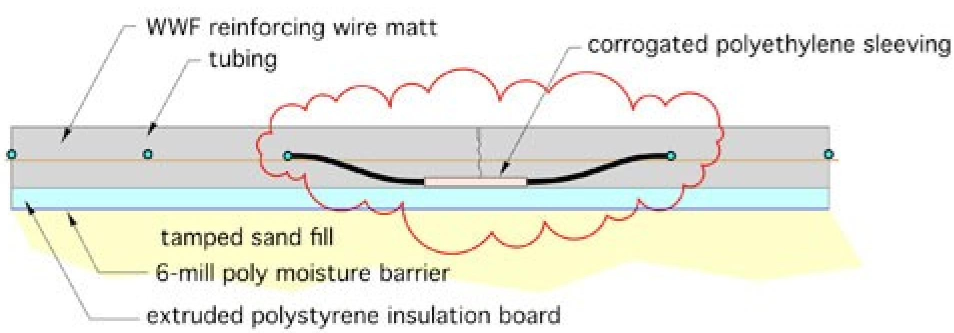
Running Bare

In addition, I used the FEA software to simulate how tubing depth affects heat output for slabs without any finish flooring. A graph showing upward heat output vs. tubing depth for a 4-inch-thick bare concrete slab is shown in **Figure 1.**

The results again show that heat output drops off as tubing depth increases. The highest output for the cases I ran occurs when the tube is centered about 3/4" below the slab surface (about 25 Btu/hr/sq. ft. at 100˚F water temperature). Lowering the tube another inch into the slab reduces output to 24 Btu/hr/sq. ft. Taking it down yet another inch lowers output to 22.3 Btu/hr/sq. ft.

These changes are relatively small. However, look what the model predicts when the tube is located at the bottom of the slab. Here the output is only 16.6 Btu/hr/sq. ft.—about 31% lower than when the tube is centered 2" below the surface. The slab with the bottomed-out tubing needs 115˚F water to yield an output of 25 Btu/hr/sq. ft., compared to only 101˚F water temperature if the tubing were centered 2" below the surface.

Lift Here…Not There



DETAIL AT CONTROL JOINT CROSSINGS

Of course, there are factors other than thermal performance that have a bearing on tubing depth. One of them is protecting the tubing near sawn control joints. The depth of such saw cuts is typically 20% of the slab thickness. I prefer to keep the tubing near the bottom of the slab at such locations to give the blade a wide berth as it passes over. A typical detail is shown in Figure 2.

Another consideration is penetrations by fasteners used to secure equipment to the slab. In most cases, it doesn't make sense to leave all the tubing at the bottom of the slab just to accommodate what might be a future bench or lift post. Find out where such equipment will be placed and keep the tubing a couple of feet away from where the fasteners are likely to go. Block out and note these areas on your tubing layout drawing. Be sure to leave a copy of the plan with the owner, since nobody will remember where the tubing is a few years after it's installed.

Summary

Although FEA simulation is a theoretical approach, the results obtained agreed fairly well with other published models for upward heat output.

The predicted increase in water temperature required for tubing at the bottom (rather than the center) of the slab is both believable and significant.

A nominal 10% increase in downward heat loss caused by higher water temperatures in bottomed-out tubing also was predicted.

Also keep in mind that these results are based on steady-state simulation. They don't predict the consequences of the longer response times associated with deeper tubing. Mix strong internal heat gains into such a situation and you've got the potential for significant overheating.

Considering the degraded performance of tubing at the bottom of slabs, I feel it's imperative to ensure that tubing is placed at the proper depth. For starters, be sure this is clearly shown on your plans and written into your specifications. Follow up by discussing the importance of the tube depth detail with those responsible for concrete placement.

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