Hydronic Radiant-Floor Heating

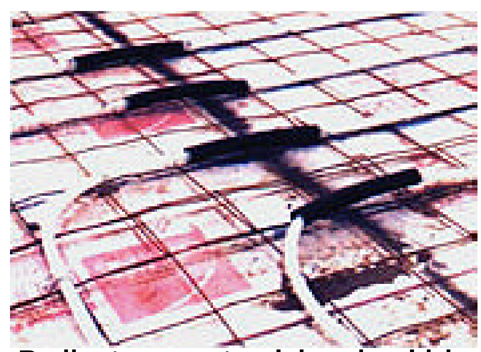
Concrete slabs, thin slabs and metal plates offer different ways of routing radiant heat underneath every floor in the home

Radiant floors can be installed almost anywhere. Radiant tubing is pneumatically stapled to a conventionally framed plywood subfloor before being covered with a thin concrete slab. Flooring choices include wood or carpet.

Living in a house with radiant-floor heating can almost make you forget that it's winter outside. I can't think of any other heating system that is as comfortable. Like a campfire on a cool night, heated floors deliver warmth to the skin and clothing without overheating and drying out the surrounding air.

Although usually associated with thick concrete slabs, hydronic radiant systems are now versatile enough to install underneath almost any type of finish flooring. New materials and installation techniques make hydronic heating adaptable to a great range of flooring choices. Although a complete hydronic under-floor heating system requires a boiler, manifolds and controls (to be covered in another article), this article focuses on tubing installation.

Basically, there are three methods of bringing radiant heat underneath the floor of a room: a slab-on-grade system, a thin-slab system and a plate-type system. Each type has advantages and disadvantages, but each system relies on tubing circuits laid underneath the floor. Rooms are heated by warm water circulating through these continuous circuits of tubing. The various circuits receive their heated water from a central supply manifold, a distribution point (like an electrical junction box) that receives water directly from a boiler. After circulating through the tubing, cooled water returns via the return manifold to the boiler to be reheated.



Radiant concrete slabs should be well insulated. Tubing is tied to reinforcing wire mesh and Is protected by PVC sleeves where it passes beneath walls and control joints.

Special considerations for radiant-floor systems—There are some general rules that apply to all types of hydronic radiant systems that can make the difference between success and failure. First, always have an accurate heating-load estimate for the spaces to he heated. Reputable dealers of floor-heating equipment are a good source of assistance, and most can provide complete designs, including load estimates, layout drawings and help with the sizing and the selection of system components.

Try to include a radiant-floor heating system as early as possible in the house-design process. Accommodations for insulation, load-bearing, floor thickness and other details are more easily and inexpensively resolved early in the process rather than later.

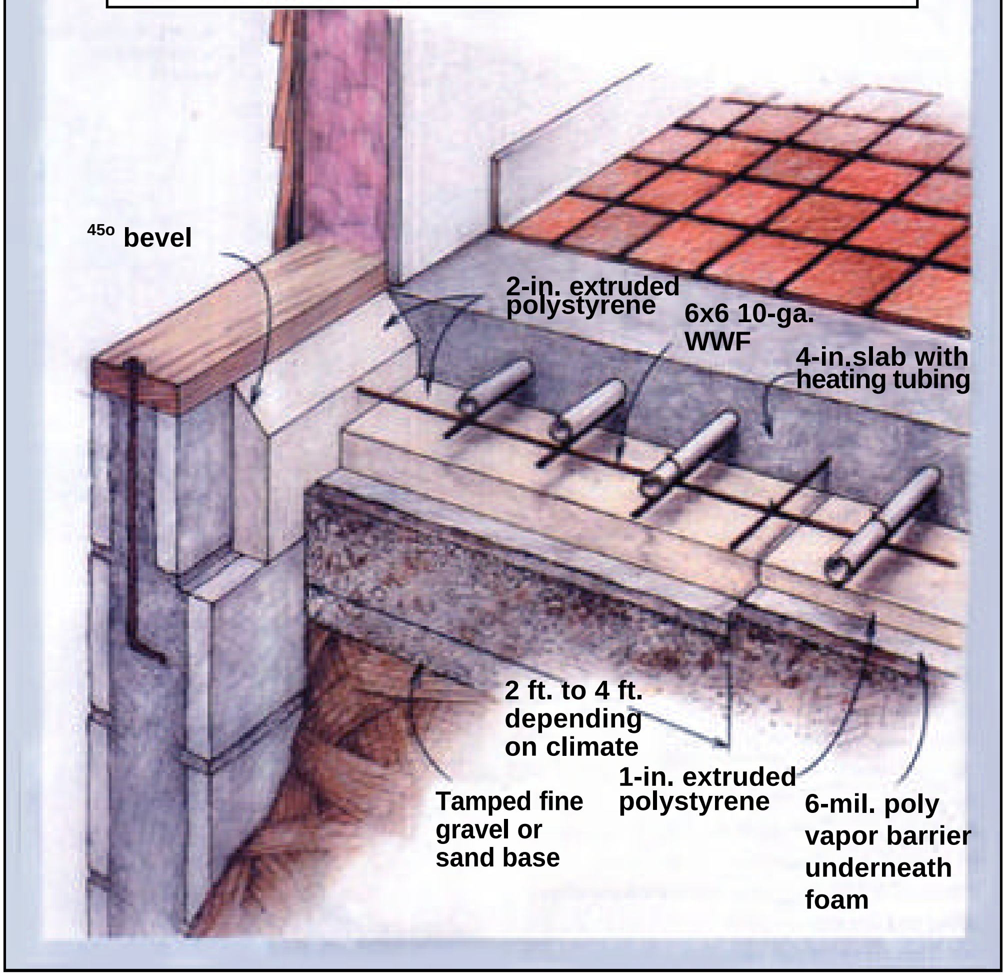
You must be aware that due to their thermal mass, slab-type floor-heating systems are slow to respond to thermostat changes. It can lake several hours to bring rooms to comfortable temperatures after prolonged setbacks at lower temperatures, so floor-heating systems are more suitable for locations where stable indoor temperatures are desired.

Don't use floor coverings with high thermal resistance over heated floors. Like wool blankets, high-resistance floor coverings such as plush carpets and pads or multiple layers of plywood under thick hardwood floors effectively insulate the radiant floor from the room that it's supposed to heat. If these floor coverings will be used, make provisions for a supplemental heating device such as a panel radiator or fin-tube baseboard to supplement or even to replace the floor-heating system in that portion of the house.

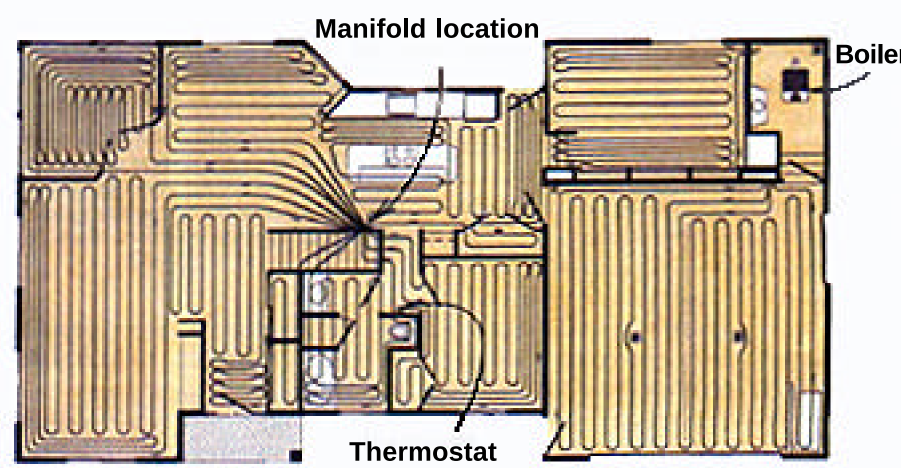
Tubing circuits should be carefully planned—Because the proper placement of tubing circuits has an impact on the overall performance of a radiant-heating system, I'm a firm believer in drawing a scaled layout of all the tubing circuits in place on the floor plan before beginning installation. This drawing can save hours of trial and error during tubing placement, especially for new installers. Although these drawings can be done by hand, I use a CAD program, ClarisCAD for Macintosh, which saves me considerable time and in some cases even automates the process of determining circuit lengths, floor areas and other repetitive tasks (bottom drawing). And with this diagram in hand, I can draw or spray-paint key portions of the tubing routes right on the insulating foam or floor deck.

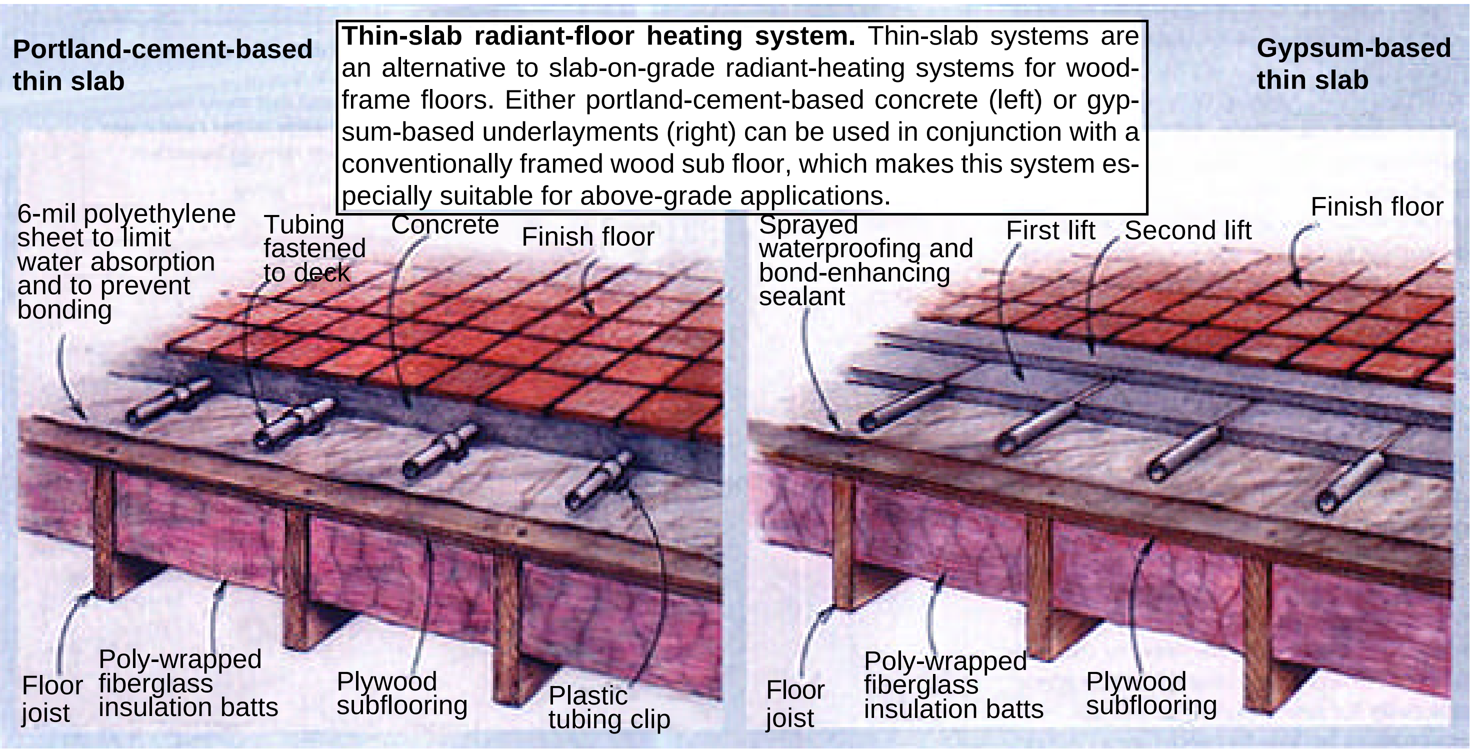
I prefer to plan tubing circuits on a room-by-room basis, taking into account at the same time such factors as the design heating load of each room, the necessity tube spacing, the location of the manifold stations and the necessity and location of control joints. Room-by-room planning allows for individual room-temperature control, either when the system is first installed or as an upgrade.

Slab-on-grade radiant-floor heating system. If a concrete slab is already planned, then adding radiant heating is an economical option. The slab must be well-insulated from below and thermally isolated from the foundation wall. Note how beveling the top edge of the rigid foam allows the slab to run to the edge of the foundation yet remain insulated. Tubing spacing is usually closer near colder outside walls.



CAD-generated tubing-layout diagram. Although it looks like a circuit board, this drawing is actually a floor plan showing the layout for the radiant tubing in each room. Note how tube spacing is closer near exterior walls, which increases heat output in these cooler areas.





Thin-slab radiant-floor heating system. Thin-slab systems are an alternative to slab-on-grade radiant-heating systems for wood-frame floors. Either portland-cement-based concrete (left) or gypsum-based underlayments (right) can be used in conjunction with a conventionally framed wood sub floor, which makes this system especially suitable for above-grade applications.

The manifold stations where each tubing circuit begins and ends are usually in interior partitions that allow for an access panel on one side. The inside wall of a closet is a good choice. The manifold station should be located so that tubing circuits to individual rooms go away from it like spokes from the hub of a wheel. This placement minimizes tubing runs down hallways or through other rooms on the way to the intended room.

As a rule of thumb, circuits using 1/4-in. ID tubing should not be longer than 300 ft. Circuits using 5/8-in. or 3/4-in. ID tubing shouldn't be longer than 450 ft. (For more on tubing, see sidebar p. 61.) These values help to limit the pressure drop the system's circulator must operate against as well as the temperature drop that occurs over the course of a circuit. To avoid punctures, it s best to minimize the locations where tubing passes under partitions that will be mechanically fastened to the slab. If this can't be avoided, mark the locations of buried tubing and make sure to use short fasteners. If the framer is agreeable to fastening the partitions with construction adhesive, a method that works well but that requires a warm, dry slab when the adhesive is applied, the tubing can be run under partitions without restriction.

Also, it's best to minimize the locations where tubing crosses under sawn control joints in the slab. This reduces the number of control-joint sleeves as well as the possibility of nicking a tube that might have been improperly lifted under a control joint. Leaks are repairable with special fittings, but the process is both time-consuming and costly.

Gypsum-based thin slabs are generally Installed by factory-trained crews. These underlayments are self-leveling and strong, hut they are susceptible to moisture and abrasion without an appropriate finish floor.

Slab-on-grade systems are cost-effective—A hydronic floor-heating system installed as part of a slab-on-grade floor is the most economical type of radiant system, and the most common. Because the installed concrete slab is already factored into construction costs, the extra cost for floor heating is essentially that of installing the tubing and subslab insulation.

Adequate insulation is an essential component of any slab-on-grade system (top drawing, p. 59). Extruded-polystyrene insulation both under the slab and near its exposed edges reduces downward and edgewise heat loss, which would otherwise waste a large portion of the energy supplied to the slab. Prior to installing this insulation, all under-slab piping and wiring should be in place. The entire area should then be leveled, thoroughly tamped and covered with a 6-mil poly vapor barrier generously lapped at any seams. Two-in, extruded polystyrene sheets placed vertically between the edge of the slab and the foundation wall thermally isolate the slab and can be held in place temporarily with foam-compatible construction adhesive. Ripping a 45^{o} bevel along the top edge of the foam before installing it allows the concrete slab to cover the exposed edge of the insulation and to provide a smooth base for the finish flooring yet still remain thermally isolated from the exterior wall.

A 2-ft. to 4-ft. width (depending on climate) of 2-in, thick extruded polystyrene should also be placed underneath the slab around the perimeter. The remaining interior portions of the slab should have a minimum of I in. of subslab insulation except where structural bearing pads (footings inside the perimeter walls) are located. And experience has taught me that it's a good idea to place welded-wire mesh reinforcement and spare planks or blocks over the foam as it is being placed. Otherwise, a good breeze can lift everything up and blow it away.

Of course, different foundation-wall designs, varying climate conditions and local-code requirements may necessitate other insulation details. The idea is to provide adequate insulation for the climate and a continuous thermal break between the heated slab and the colder surrounding materials.

Tubing is anchored to wire-mesh reinforcement—I establish the eventual location of the manifold station before actually laying down any tubing. A predrilled template block with two rows of holes spaced 2 in. o. c. can be used to anchor tubing in the correct location and orientation during the pour. This template should be exactly in line with the partition where the manifold station will be located, so carefully measure its exact location relative to the foundation walls.

Begin each circuit by pushing 2 ft. to 3 ft. of tubing up through one hole in the block; then unroll the tubing from its coil and progressively fasten it down along the length of the circuit. End the circuit by pushing another 2 ft. to 3 ft. of tubing up through the hole in front of or behind the starting hole.

The tubing is secured to the welded-wire reinforcing mesh using either soft wire ties, plastic pull ties or plastic clips. Plastic ties and clips are endorsed by more tubing manufacturers than are metal ties, and in some cases tubing warranties are contingent on the use of approved fastening methods. Ties are located about every 24 in. to 30 in. on straight runs with three ties at each return bend. Ties hold tubing in place and prevent it from floating up during the pour, so they don't need to be overly tight. Care should be taken that the loose ends of the ties aren't left pointing up where they could interfere with concrete finishing.

Tube spacing depends on several factors, including the rate that heat must be released from the floor, average water temperature of the heating system and the type of floor covering installed over the slab. Typical spacings for slab-on-grade jobs are 6 in., 12 in. and 18 in. o. c., which correspond nicely with the 6-in, grid pattern of welded-wire reinforcing mesh. Closer 6-in, spacing is common near the edges of the slab where heat losses are greater, or in areas with higher-thermal-resistance floor coverings, such as carpeting. Twelve-in, spacing is common for many residential applications in buildings with average heating loads and average areas of glass. However, 12-in, spacing should be limited to rooms where the upward-heat-flow rate does not need to exceed 20 Btu per sq. ft. per hr. Interior rooms with relatively low heating loads can sometimes get by with 18-in, spacing.

Other spacings, though possible, can complicate fastening the tubing to standard reinforcing wire. Combinations of spacing can sometimes be used within the same room. For example, the beginning of the circuit may use 6 in. o. c. spacing near an exterior wall with a large area of windows, and then make a transition to 12 in. o. c. spacing after it has progressed 3 ft. to 4 ft. in from the wall.

After all the circuits are in place, they must be pressure-tested to at least 60 psi for 24 hours to verify that no leaks are present. Compressed air or water can be used for this test, although water shouldn't be used *in* freezing temperatures. The tubing should remain under pressure during the pour. If necessary, wheelbarrows full of concrete can be rolled over the tubing without damaging it. Take special care not to pinch tubing under the metal nose bar as the wheelbarrow is dumped, though.

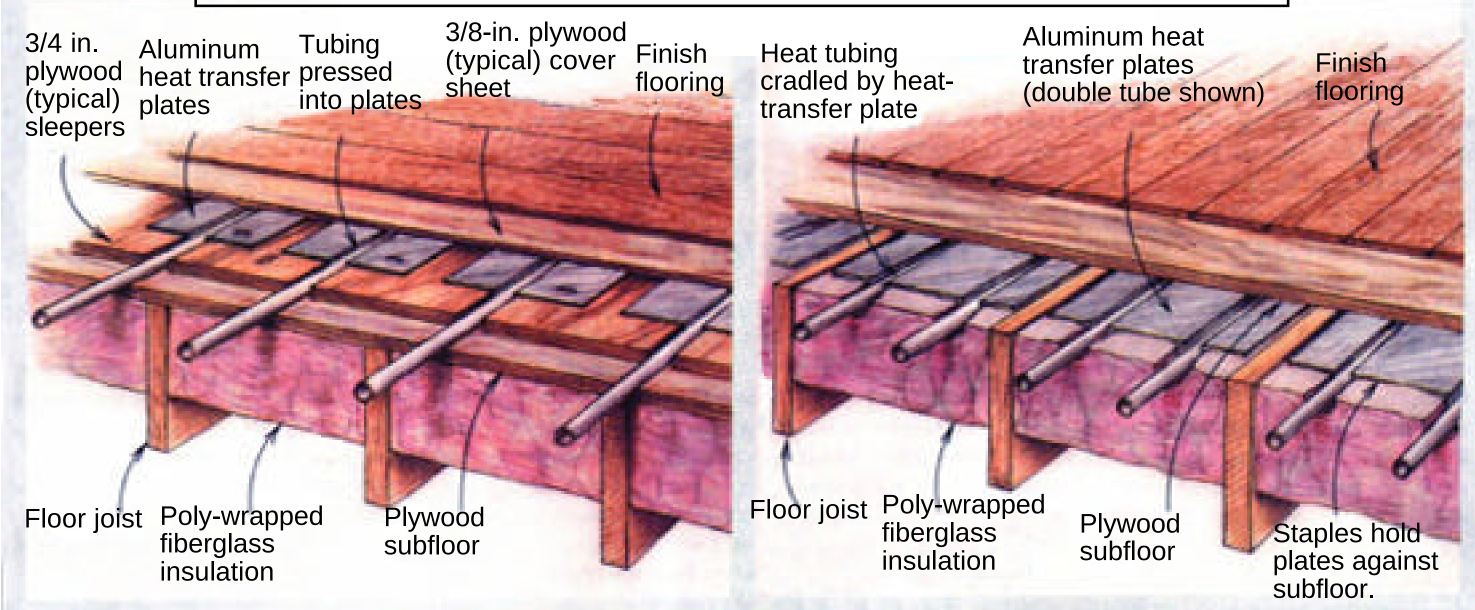


Plate-type radiant-floor heating system. Plate systems are a good alternative for retrofit situations where raising the level of the floor isn't feasible or when framing strength isn't sufficient for the added weight of a thin slab. They can be installed either above the sub floor (left) or below the sub floor (right) with staples.

The wire reinforcing with the attached tubing should be supported during the pour with wire or plastic high chairs, or lifted while the concrete is being placed, so that the tubing is about halfway through the slab's thickness, except where sawn control joints will be made. At these locations tubing and reinforcing wire should remain near the bottom of the slab, and the tubing should be protected with a sleeve made of polyethylene or PVC tubing (bottom photo, p. 58).

Installed costs for slab-on-grade systems in my area (upstate New York) run about $1.75 to $2 per sq. ft. of heated floor. This includes 5/8in. PEX tubing 12 in. o. c., 1-in. extruded-polystyrene insulation under interior slab areas (2 in. near slab edges), installation labor for the tubing and an allowance for manifolds.

Thin-slab systems can offer more installation versatility—Hydronic floor heating can also be used in combination with wood-frame floors. A common approach is to fasten tubing to subflooring, and then to cover it with a thin 1 1/4in. to 1 1/2in. layer of poured underlayrnent (drawing p. 60).

One material that's become popular for thin-slab systems is poured gypsum-based underlayment, such as Maxxon Corporation's Thermafloor (920 Hamel Road, Hamel, Minn. *55340-9610;* 800-356-7887). This product, a blendof gypsum cement, additives, masonry sand and water, is sold only as an installed product, meaning you can't buy it and install it yourself.

Factory-authorized crews proportion and mix the ingredients in a portable rig set up outside the house, pumping the resulting slurry into the house through a hose. With the consistency of a milk shake, it is essentially self-leveling as it flows onto the floor (photo p. 60).

Because gypsum-based underlayments shrink as they dry, they should be poured in two separate layers, or lifts, when used in floor-heating applications. The first lift is poured even with the top of the tubing and is usually firm enough to walk on after about two hours. Shrinkage will leave the top of the tubing protruding above the first lift, so the second lift easily covers this slight irregularity and produces a smooth surface.

Although the final compressive strength of gypsum-based underlayments ranges from 1,500 psi to 2,500 psi, they are too susceptible to moisture and abrasion to act as a finished wearing surface. Finish flooring such as sheet vinyl, ceramic tile, carpeting or laminated strip wood flooring are all suitable for gypsum-based underlayments, but it is crucial that the slab be thoroughly dry, which typically takes at least a week. before any of them is applied. In some cases the slab must also be coated with a specific waterproofing and bond-enhancing sealant. Always verify that the finish-flooring material will be warranted over a heated gypsum-based underlayment, and carefully follow the written installation specifications.

Concrete thin slabs need control joints— An alternative to poured gypsum-based underlayments is portland-cement-based concrete made with fine (#lA) pea-stone aggregate. Ad-mixtures such as water reducing agents, superplasticizers and Fibermesh are often added to the mix to increase slump, improve strength and reduce shrinkage.

Installing concrete thin slabs is easiest when it's done before any partition walls are in place. The wall locations and the tubing-circuit locations can be laid out on the deck, and then the deck is covered with 6-mil clear-polyethylene film. The poly acts as a slip sheet and prevents the concrete from bonding to the deck, allowing for differential movement between the slab and the framing. Otherwise, stresses can develop that could randomly crack the slab.

Two-by plates are then fastened over the poly to the layout lines. This creates a 1½ in, deep pan for the concrete on the deck. Toilet flanges and any other mechanicals should also be blocked up 1½ in. Coating the edges of all of the plates with mineral oil or another form-release agent will prevent the concrete from bonding to the plates.

The slab should be segmented into small sections that more easily absorb seasonal movement of the floor framing without random cracking. This is done with control joints, created by stapling the I-in. PVC angles that are typically used for drywall-corner protection (Trim-Tex. 3700 W. Pratt Ave., Lincolnwood, III. 60645: 800-874-2333) to the subfloor before the pour. These strips create fault lines in the slab and control the inevitable cracking. I typically place these control joints at doorways and inside corners, and I segment large rooms into smaller sections with them.

Concrete can be placed either from a wheelbarrow or directly from a concrete-truck chute. The 2x plates are perfect for screeding, and the slab is then floated and troweled as required for the selected finish floor.

Both gypsum-based and portland-cement-based slabs have pros and cons. Although the gypsum-based products are arguably faster and easier to install (by a trained crew), a concrete thin slab has higher thermal conductivity, excellent resistance to moisture and often significantly lower cost. The final decision about which to use may rest in the cost and availability of each system in a region or at a job site.

Thin-slab systems using gypsum-based underlayments run between $4.25 and $4.50 per sq. ft. of heated floor in my area. Those using pea-stone concrete have run between $2.25 and $2.75 per sq. ft. Both costs include 5/8-in. PEX tubing 12 in. o. c., slab materials, underside insulation, allowance for manifolds and labor.

Accommodating a thin-slab system—Regardless of which material is used, several factors must be considered in preparing for a thin-slab installation. For example, the floor framing must be able to support an additional 15 lb. to 18 lb. per sq. ft. of dead-loading due to the added weight of the slab. Although this additional framing strength can easily be planned for in new construction, the added cost of beefing up deficient framing in an existing building usually rules out this option.

Also, the heights of window and door rough openings, base cabinets, stair risers and toilet flanges must be raised to accommodate the added thickness of the slab. Again, this accommodation is easier to accomplish in new construction than in retrofits.

In any kind of thin-slab radiant installation, the underside of the floor must be insulated to limit downward heat loss. I use R-1 1 insulation for floors above heated space, R-19 for floors above semiheated basements and at least R-30 for floors over vented crawlspaces. I like to use polywrapped fiberglass batts for this, though other options include rigid foil-faced foam cut to fit or flexible foil-faced batts.

Plate-type systems are good for retrofits— Plate-type systems rely on. aluminum heat-transfer plates that wrap partially around tubing and conduct heat away and into the floor system (photo above). The tubing and plates can be installed either above (on sleepers) or below plywood subflooring, the latter being more common because of its lower cost and faster installation. Plate-type systems are especially well-suited for retrofit applications because they don't disturb existing flooring and add little weight to the floor (drawing facing page).

Because there is less contact area between the plates and the tubing as compared with tubing that is fully embedded in a slab, tube spacing is typically no more than 8 in. o. c. In the majority of cases, the supply-water temperature must also be higher for plate-type systems than it is for slab-type systems.

Tubing is routed down the space between the joists, makes a U-turn at the end and comes back up the same cavity. The tubing required for each joist cavity must be pulled through holes drilled near one end of the joists, which should be at least 1/2in. in. or so larger than the outside diameter of the tubing. This makes it easier to pull the tubing through. Keep in mind that holes drilled in solid-wood floor joists need to be placed a minimum of 2 in. from either the top or the bottom of the joist or to another hole in the joist, and that the maximum size of these holes cannot be more than one-third of the joists' depth.

Heat-transfer plates, which cradle the tubing, are then stapled to the underside of the subflooring. Plates that allow the tubing to be snapped in place after the plate has been fastened to the subflooring are also available.

Both tubing and plates expand when heated and contract as they cool, and sloppy installation is certain to cause expansion/contraction noises as the system operates. To avoid these noises, make sure that the tubing enters and exits the plates in alignment with the plates' centerline. Bends in the tubing should be as gentle as possible, and holes where the tubing passes through the joists should be oversize at least 1/2 in. to prevent any binding. A minimum 1/4-in. expansion gap should be included between adjacent plates.

Plate-type systems can't be seen from the top of the floor deck, so be sure all trades on the job are aware of their presence beneath the floor before a nail, a sawblade or a drill bit makes the discovery for them.

In assessing retrofit jobs for the possibility of a plate-type system, be sure to examine the underside of the floor decking. Interference from flooring nails, plumbing, wiring, bridging and any other types of obstacles can significantly slow installation or even eliminate the system from consideration.

Plate-type systems tend to be more expensive than thin-slab systems because of the closer tube spacing and the extra cost of plates. I currently use an installed cost of $5.50 per sq. ft. of heated space for estimating purposes. This includes 3/4-in. PEX tubing 8 in. o. c., plates, underside insulation, manifold allowance and labor.

Understanding Hydronic-tubing options

Tubing choices. Left to right; Vanguard polybutylene tubing; IPEX's Kitec PEX-AL-PEX tubing; Heatway's Entran synthetic rubber tubing with oxygen-diffusion barrier, Wirsbo PEX tubing with oxygen-diffusion barrier and Maxxon's Infloor VEX tubing (without oxygen-diffusion barrier).

Although copper tubing was once extensively used for radiant floors, its current cost, short coil length and tendency to expand and contract at different rates than the slab it's embedded in make it a poor choice compared with other tubing now available. Nowadays, nearly all floor-heating systems installed in North America use either polymer (plastic) or synthetic-rubber tubing. The three types of polymer tubing most often used are cross-linked polyethylene, or PEX; an aluminum/PEX composite tube often called PEX-AL PEX and polybutylene (photo above).

PEX tubing has a proven track record— Of the three, VEX holds the greatest share of the floor-heating market worldwide, and It's my first choice when I specify tubing. Wirsbo (800-3214739) estimates that it has over 2 billion ft. of PEX in service.

PEX tubing has a “shape memory characteristic that allows accidental kinks to be repaired on the job. Heating the kinked area with a heat gun to approximately 2750F will make the kink disappear without permanent damage to the tubing.

IPEX (800-473-9808) manufactures a composite tubing called Kitec, which consists of a thin-wall aluminum core with layers of PEX bonded both inside and outside. Because it's comparable in cost to PEX and has been used successfully in Europe and Canada, look for this type of tubing to gain a major market share in the United States In the near future.

Unlike PEX tubing, PEX-AL-PEX's aluminum core enables it to retain Its shape when bent. Return bends in floor circuits can be easily hand-bent to a minimum radius equal to five pipe diameters. The aluminum core also provides a nearly perfect oxygen-diffusion barrier (more on this later). Polybutylene tubing is also used for floor heating.

Polybutylene tubing is not cross-linked, and kinks can’t be field-repaired, except by cuffing out the section and splicing In a coupling. The current cost of Vanguard’s *(316-241-6369)* polybutylene tubing (with an oxygen barrier) is comparable to that of PEX tubing. Unfortunately (and for reasons unrelated to its performance in floor-heating applications), polybutylene tubing will no longer be available In the United States by early 1997. Look for polybutylene suppliers to begin distributing PEX tubing to be used as a replacement for radiant floors.

Synthetic-rubber tubing, such as Heatway’s Entran (800-255-1996), is also manufactured in the United States specifically for hydronic floor-heating applications. Consisting of several layers of synthetic-rubber compounds and a reinforcing mesh, it Is flexible and highly resistant to kinking damage. The cost of synthetic-rubber tubing is comparable to that of PEX and polybutylene tubing.

Oxygen-diffusion barriers are important—A characteristic of both polymer and synthetic-rubber tubings is their inability to stop oxygen molecules from diffusing through their walls. This steady flow of oxygen into the system can severely corrode iron or steel components, such as boilers and circulators, and will almost certainly lead to premature failure. Fortunately, this deficiency can be corrected with the addition of an oxygen-diffusion barrier to the tubing. Nearly all manufacturers of polymer floor-heating tubing, be it PEX, PEX-AL-PEX, polybutylene or synthetic rubber, currently offer tubing with such a barrier to reduce oxygen diffusion to an insignificant level. Tubing that is equipped with an oxygen-diffusion barrier is a must for systems with cast-iron components or steel components.

Most tubing Intended for floor-heating application is available with nominal Inside diameters from % in. to ‘A In. For short residential circuits or for places where close tube spacing is needed, 3/8-in. or 1/2-in tubing is suitable. To limit pumping pressure, circuits with ¾-in, tubing should not be more than 200 ft. long. Those with ‘A-In, tubing should not exceed 300 ft. For both residential and commercial systems, 3/8-in. and ¾-in, tubing *can be used,* Circuit with 3/8-in*.* tubing-should no be more than 450 ft. long. if properly designed, circuits using 3/4-in. tubing can be upward of 500 ft. long.