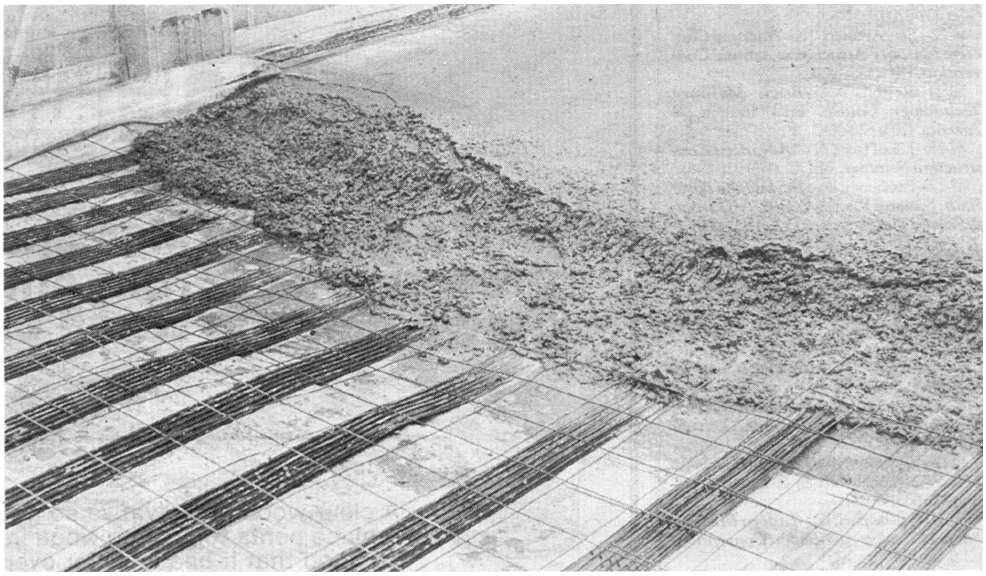
Radiant Heat



BESI's "Radiant Roll" EPDM tubing system disappearing under a pour for a new radiant, hydronic slab.

by Paul Hanke

Praised for its ability to provide draft-free, even heating that is economical and virtually noiseless, radiant heating has been used for centuries. The Romans used a *hypocaust* to channel warm air under the floors of their villas. A similar system, the *ondol*, was used in Korea to channel flue gases underfloor, thereby providing warmth on the way to the chimney.

More recently, large masonry stoves that radiated heat into living spaces for hours or days after fuel ceased burning were used in several eastern European countries. In the U.S., Frank Lloyd Wright championed radiant slabs and used them in many of his houses. And recent decades have seen the development of the Trombe wall, which stores solar heat while the sun shines, transfering it to the house when the skies darken.

This article will look at these and other examples of innovative radiant heating systems. In addition to discussing the applications of various systems on the market, we'll look at how careful planning and modern materials can be used to overcome such radiant-heat drawbacks as slow response time, short life spans and floor-covering constraints.

But first, let's look at how radiant heat works.

The best known source of radiant heat may be the sun, which beams all the energy we need for life from 93 million miles away. Whether we are dealing with the sun or the wood stove, the closer we are to the source, the more intense the heat.

Wood stoves also demonstrate the fact that radiation travels in straight lines; if we face the stove, our fronts will be warm, while our backs will be cool. This basic concept is an important consideration in the design of radiant heating systems.

Comfort and the MRT

Another important concept in radiant heating is the effect of the so-called *mean radiant temperature* (MRT). All warm bodies radiate heat in the form of long, or infrared, waves and thus have a "radiant temperature" of their own.

If we stand near a cold window, our bodies rapidly lose heat to the glass and we feel chilly even if the room air temperature is warm. When we stand close to an insulated exterior wall in the same room, however, we don't feel cool because the wall has a higher MRT—which means that we don't lose as much heat to the wall surface as we do to the glass. Warm up the wall (or floor or ceiling) by making it a radiant heater, and we will feel even more comfortable.

This is the basis for the claim that radiant heating provides comfort at lower air temperatures. As a result, we can lower the thermostat and cut our heating bills.

Point sources of radiant heat, such as heat lamps or small wall-mounted electric panels, provide the ultimate in energy conservation by heating *us* instead of our surroundings, but of course we have to stay beside the heater to feel its effect (and our backsides may still be cold).

Solar Systems

Perhaps the simplest radiant heating system is the *solar slab*—a masonry slab floor placed where it gets direct exposure to the sun through a south-facing window. Particularly if it is a dark color, the floor has a high heat capacity and soaks up the sunshine.

As the temperature of the slab increases, it radiates heat into the living space above; some heat also is transferred by convection. This process continues into the evening hours, until the floor finally reaches the same temperature as its surroundings. The next sunny day charges it up again.

According to *The Thermal Mass Pattern Book* published by Total Environmental Action (TEA), a typical four-inch-thick slab floor should be about four times the surface area of the south-facing windows to which it is exposed. For instance, south-facing windows in a 120-square-foot room with a slab floor should have a glass area of 30 square feet (120 divided by 4) and be located so that the slab is in direct sun for six hours a day.

In addition, the surface of the floor must be masonry and must be in good thermal contact with the slab below. It cannot be covered by large rugs or shaded by furniture placement—a potential problem for some homeowners, so it should be considered early in the design stage. Many decorative finishes can be used to beautify a solar slab, including the use of dyed or stained concrete, ceramic tiles and brick.

Perimeter insulation is always desirable, but the question of whether to insulate *under* a radiant slab (solar or otherwise) is a subject of much debate. Underfloor insulation is discussed in greater detail in the "Hydronic Radiant Slabs" section.

An excellent manual on solar slab design with ceramic tile is available from American Olean (Lansdale, PA 19446; ask for "Passive Solar Ceramic Tile Handbook No.1950").

Trombe Walls

Solar slabs are *direct-gain* solar heaters—the sun directly heats the living space. Trombe walls (named after their French developer, Felix Trombe) are *indirect* solar heaters—the sun heats the masonry storage wall, and then the wall itself heats the living space behind it.

Because there is a time lag as the heat travels through the wall (approximately 1.5 inches per hour in concrete), heat is delivered to the living space much later than the time of peak surface temperature on the outside of the wall.

As a result, masonry storage walls are best used in such areas as bedrooms, where heat is needed overnight and recharging can occur during the day. They are also suitable—and most popular—in solar subdivisions, where privacy can be obtained by the use of a full or partial Trombe wall when the south side of the house faces the street.

According to the TEA booklet noted earlier, a rule of thumb for full masonry storage walls is that they should be 8 to 12 inches thick and equal in exterior surface area to the glazing outside. They should extend the full length of the room they serve and reach from floor to ceiling. Windows are permissible; guidelines for their use along with more sophisticated design information can be found in Ed Mazria's excellent *Passive Solar Energy Book.*

According to solar architect William Langdon, in very cold climates like those of St. Paul, Minn., or northern New England, Trombe walls must have both a selective surface on the outside of the masonry *and* some form of nighttime insulation. A selective film is a special type of foil that readily absorbs solar (short-wave) radiation but does not re-emit long-wave radiation very well, thereby reducing heat loss to the glass.

In more moderate areas, Langdon recommends that either a selective surface or night insulation be used, but not both. (A partial wall not only allows for much easier operation of nighttime insulation and cleaning of the glazing, but it admits direct sun early in the day for a quick warm-up and provides good views and more daylight. According to the TEA, the mass/glass ratio should be 2:1 for partial walls.)

In all cases, the wall should be solid masonry—brick, concrete, or block with grouted cores. Exterior shading is required to prevent overheating in the summer. The interior surface of the wall may be any color, as emission of long-wave radiant heat does not depend on color.

Finally, experts agree that the high and low thru-the-wall thermosiphon vents shown in many Trombe wall illustrations are unnecessary and undesirable. While they do transfer some heat by convection more rapidly into the living space, they must be sealed against backsiphoning at night. They apparently do not improve performance or comfort significantly, while they do add expense and can constitute a fire code violation. Unvented full or partial walls are the way to go.

Hydronic Radiant Slabs

Having considered solar walls and floors, let's look at the more common realm of hydronic radiant floor applications. (Any surface of a room may be warmed and used as a heat source, but floors and ceilings are the most common.)

The basic hydronic slab system consists of a heat source (usually a boiler or even a domestic hot water heater), a manifold, a network of supply and return pipe loops, and controls. A grid of pipe loops (traditionally copper or iron) is installed within a poured-in-place concrete floor. Hot water (85 to 125 F) is circulated through the pipes, and heat is transferred by conduction through the pipe wall into the concrete. The concrete gradually warms the floor surface, which in turn radiates heat into the building.

This gradual warm-up, which is due to the thermal mass of concrete, is one potential drawback of radiant slab systems. For instance, the thermostat may call for heat when the house air temperature reaches 68 F, but it can take several hours before the slab finally delivers—and it may continue to pump out heat long after the room is warm.

Various control systems have been devised to counteract this problem by turning on the heat several hours in advance of need and shutting it off early. One computerized (and presumably expensive) controller even allows you to turn on the heat via phone from anywhere in the world (ideal for jetsetters who want to fly into their New England ski get-aways from financial capitals afar). Other effective controls exist that are simpler and less costly.

One such system uses two thermostats—one to sense the room air temperature and the other to monitor the outdoor temperature. Working together (sometimes through programmable controls) the units provide hot water flow before it's actually needed and restrict it before comfort levels are reached.

Some designers prefer a simple and less costly "on-off" method of control with a programmable setback with manual override. Others opt for the more costly "progressive propagation" method, which can vary boiler output, flow rate, supply/return mix ratio, and scheduling.

(In the March '84 issue of *NEB*, Henry Spies suggested that single-zone systems are best controlled by a thermostat that governs both pump and burner, with a high-limit control to prevent overheating the living space. For systems with two or more zones, he recommended that thermostats control the pump(s) (a single pump can supply up to 12 zones) or a motorized valve for each zone, and that the burner be controlled by its own manually set aquastat.)

The output temperature of a conventional boiler (typically 140 to 180 F) is too high for use in a radiant floor and must be stepped down by dilution with cold water to 80 to 100 F.

The hot water for hydronic slabs can be provided by oil- or gas-fired boilers or domestic water heaters. Designers report that hydronic systems also are compatible with wood-fired heaters—and that they are especially suited to active solar applications, where the low-temperature heat requirement increases collector efficiency. Electricity also can be used to heat the water for radiant slabs, of course.

It's probably worth noting that radiant slabs are not limited to hot water for their heat source. The job also may be done with forced hot air using an intriguing pillow-shaped, sheet-metal form called "Airfloor," an interesting descendant of the Roman hypocaust. It's available from Aircontrol Systems, 13310 Mapledale Street, Norwalk, Calif. 90650. The Northeast rep for Aircontrol is the Calvin Duke Corp., 203/869-0087.

Alternatives to Copper Pipe

Traditional hydronic radiant floors used copper (or iron) pipes. But copper is expensive and has a limited life span in concrete; the first leaks can occur in as little as 20 years due to pipe corrosion and the necessary presence of joints in the slab.

On the other hand, copper has the advantage of being impervious to oxygen diffusion (and therefore corrosion)—possibly an important consideration (we'll take a detailed look at this concern in next month's *NEB*).

In recent years, however, flexible plastic tubing and EPDM rubber extrusions have replaced copper as the preferred in-slab piping material.

Polybutylene (PB) plastic tubing is most common. It is widely available in rolls up to 1,000 feet long and either ½ inch or ¾ inch inside diameter. Extremely flexible, it can easily be bent on site to a radius of six inches. This means that a serpentine network of pipe loops can be laid out without the necessity of any connections (a common source of leaks) within the slab.

Connections to the supply and return manifolds are made with compression fittings and placed where they will be readily visible and accessible for repair.

PB tubing that meets Standard D-3309 of the American Society for Testing Materials (100 psi at 100 F) is approved for radiant slab applications by both the International Conference of Building Officials and the Southern Building Code Congress. The raw material itself is produced in the U.S. solely by the Shell Chemical Co.

Extruded EPDM rubber matt is extremely flexible (rated for use at -60 to 375 F) and therefore virtually freezeproof. It can also be installed later in the season than PB tubing because it retains its flexibility in cold weather.

> ***Insulation should always be provided around the perimeter of a heated slab, but in most cases I wouldn't go to the added expense of placing it under the rest of the slab.***

As with plastic tubing, connections are made to manifolds outside the slab. Continuous loops are formed by simply stripping away the support matt between individual tubes and bending it to change direction.

The matt can be located near the bottom, middle or top of the slab. Depth affects the rate of warm-up but not the ultimate surface temperature of the floor.

One EPDM product available in the U.S. is "Radiant Roll," manufactured by BioEnergy Systems (BESI) (Box 87, Ellenvllle, RY. 12428; phone 914/647-6700). It comes in two-tube extrusions connected by a matt webbing. BESI provides connectors for use with the tube matt; design advice for architects, engineers, and heating, ventilation and air-conditioning contractors; and excellent installation and design manuals (the latter written primarily for engineers).

Both EPDM and plastic pipe can be also used in thin slabs poured over wood floors. "Gyp-Crete" (Gyp-Crete Floors of New England, Box 10343, West Hartford, Conn. 06110; phone 203/289-3411) is the regional supplier of light-weight concrete for such applications and provides a useful booklet entitled "Radiant Floor Heat". (Gyp-Crete also has plans to begin marketing its own radiant system through a subsidiary, Hydradiant, Inc.)

While polybutylene is common in the U.S., the use of *polyethylene* tubing for radiant slabs has been more common in Europe. Cross-linked polyethylene (PEX) tubing is now imported from Sweden by the Wirsbo Co. (Box 2025, Rockford, Ill. 61111; phone 815/282-1141).

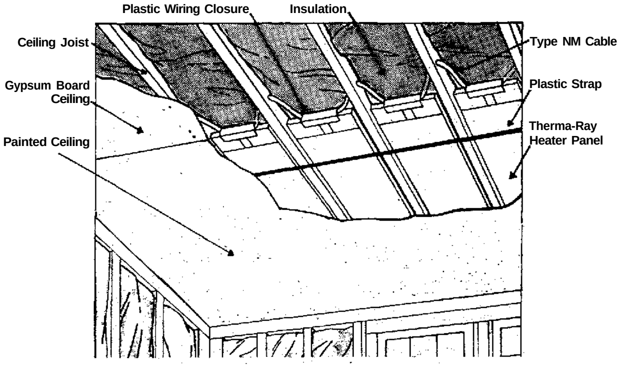
Wirsbo PEX comes in rolls of 400 and 800 feet (5/8 inch inside diameter) for installation without joints in the slab. It is rated for 100 psi at 180 F (ASTM Standard F876-877) and is flexible enough to allow loops to be installed with tight bends. According to company literature, accidental damage to the tubing can be repaired by applying gentle, hot air (*not* a torch) to the puncture—which could be quite an advantage on the job site.

Wirsbo provides engineering assistance, manifolds and other accessories, and an installation manual along with general literature on its product.

System Layout & Installation

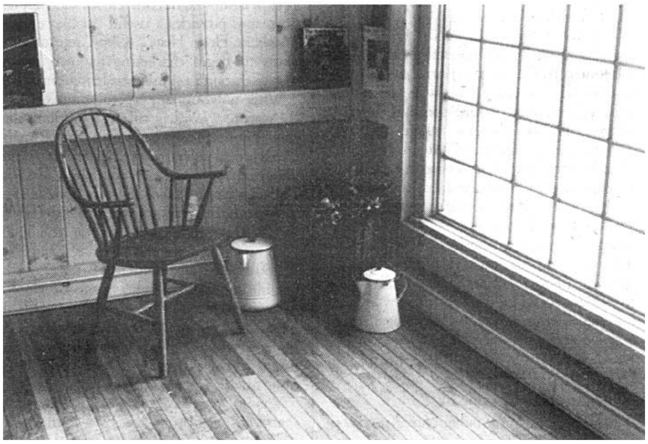
Radiant slabs with PB or PEX tubing are installed by tying the tubing to the reinforcing mesh in the slab with common twist ties every three to four feet. Pipe loops should be continuous and limited to about 200 to 300 feet in length. Individual loops should be kept at the same length to balance the system, as balancing with valves is more difficult and costly.

One of Aztech's three types of radiant ceilings being installed. The SunComfort panels shown here are made of 5/8" gypsum board in which radiant cables are embedded, producing a completely concealed heating system.



Therma-Ray's radiant ceiling is achieved by the installation of its panels above the gypsum ceiling as shown here.

The "Airfloor" system by Aircontrol Systems makes use of metal forms (shown here) over which a concrete slab is poured. The forms provide channels for forced hot air to heat the slab.



With Danex, Inc.'s "Elpan" radiant baseboard units, the conventional baseboard is replaced. The units are billed as being "slim, attractive and easy to install."

Typical layouts place supply loops closer (perhaps 6" o.c.) at the perimeter, where most heat loss occurs, and further apart (9" to 12" o.c) near the interior of the slab. Loops are sized to replace the heat lost from each room in the winter.

Other factors that should be considered in system layout are floor covering, probable furniture placement, and location of counters and appliances (for example, you *don't* want to supply heat directly under a refrigerator). Some installers also place loops closer together in bathrooms on the theory that more heat flux is needed in a room where people are often disrobed. (However, I would argue for fewer pipes—and therefore lower background temperatures—in rooms that are used infrequently; supplemental heat could be provided by heat lamps or radiant electric panels.)

During installation, the piping must be pressure-tested before pouring concrete, and it must be kept under pressure during the pour and while curing. Because care must be taken not to damage the tubing, pumping concrete may be the preferable technique.

Protection in the form of galvanized or stainless steel plates must also be provided wherever nails might puncture the tubing, such as under partition walls, and sleeves must be installed in any interior footings poured prior to the slab.

> ***A typical four-inch-thick slab floor should be about four times the surface area of the south-facing windows to which it is exposed.***

Insulation

Insulation always should always be provided around the perimeter of a heated slab, but in most cases I wouldn't go to the added expense of placing it under the rest of the slab. With earth temperatures between 45 and 60 F, heat loss to the earth below a slab-on-grade floor would be minimal, so it might be more cost-effective to put the money into insulation elsewhere in the house (such as in "Low-E" or triple-glazed windows).

At most, I would place an inch or so of beadboard under a radiant slab (that's right, *beadboard*). It's less expensive than the extruded stuff, almost as good in R-value, and can be expected to perform well for a long time if it's protected from ground moisture by a poly sheet.

A compromise that I used recently on an earth-sheltered house under construction in Woodstock, Vt., is a system of gradually tapered thicknesses of insulation based on an excellent article by Ken Labs in the March '85 issue of *Solar Age* magazine. I made this modification at the request of the heating designer, but I remain unconvinced of the need for more than a bare minimum of insulation in this location.

Electric Radiant Heat

Despite the high operating costs of electric heat, the concensus seems to be that electric heat is a legitimate primary-heating source for houses with *very low* heating demands because of its low initial cost. It also has definite application as a supplemental heat source.

Electrically heated slabs are best suited to houses with very low winter heat loads located in areas of off-peak rates. Radiant slabs are ideal for off-peak storage due to their high thermal mass and thermal lag characteristics.

A properly sized grid of electric cables can be buried either within the concrete slab or below it in an insulated bed of sand, which is the method employed in the "Deep Heat" system available from Smith-Gates Corp. (Farmington, Conn. 06032; 203/677-2657).

Electric radiant heat also can be provided by *radiant ceiling or wall panels.)*

Materials for ceiling applications come in several forms. Therma-Ray Manufacturing Co. (Box 516, Old Saybrook, Conn. 06475; phone 203/399-7933) makes a panel that contains nichrome wires within a piece of ½" gypsum board. The panel is installed between ceiling joists and *above* the normal gypsum-board ceiling.

Strips of plastic hold the Therma-Ray panels in place until the ceiling is installed. The ceiling then acts as a low-temperature (95 to 103 F) radiator. These panels have a relatively slow response time, but they a higher thermal mass than other types because of their gypsum-board construction.

Flexible electrical materials also designed for installation above a gypsum-board ceiling are manufactured by Flexwatt (611 Neponset St., Canton, Mass: 02021; phone 617/821-1111) and Aztech International (2417 Aztec Rd. NE, Albuquerque, N.M. 87107; phone 800/545-8306).

The Flexwatt product consists of a conductive ink printed on a substrate sandwiched between layers of plastic, while the Aztech product is a fiberglass cloth impregnated with a conducting graphite sandwiched between plastic that is 16" or 24" wide. These flexible materials operate at a somewhat higher temperature than the panels and therefore have a quicker response time (between 10 and 15 minutes).

> ***The output temperature of a conventional boiler (typically 140 to 180 F) is too high for use in a radiant floor and must be stepped down by dilution with cold water to 80 to 100 F.***

Both products are installed by stapling them to the bottom of ceiling joists; Aztech also makes radiant panels that can be either flush or surface mounted.

All radiant ceiling devices should be installed with a vapor barrier and covered by adequate insulation above. Room-by-room control is very easy; the coverage may vary from 10 to 50 percent of the ceiling area depending on the application and whether the system provides primary or supplemental heat. Installation costs are just over $1 per square foot.

New Entries in the Radiant Market

New entries in the radiant-heating field include the very attractive *Elpan and Wanpan Danish baseboard units,* which are imported to the U.S. by Danex Inc. (Rt. 23, Box 66, Acra, N.Y. 12405; phone 518/622-3160).

The "Elpan" unit is an electric model (UL approval expected very soon) that joins together very simply with snap-together connections. The panels provide for installing electrical receptacles, and special fittings allow installers to turn corners and to leave "blank" areas where heat is not supplied. Temperatures are controlled by a unique wall-mounted thermostat that senses radiant (not air) temperature and can be programmed for varying setbacks.

The "Wanpan" model is a hydronic unit consisting of two pipes welded to the back of a five-inch-high baseboard. Connections here are just as simple—made with high-temperature nylon tubing that is cut to length.

According to Erling Andersen, Danex president, both units deliver 80 percent of their heat by radiation, with the balance by convection. Installation costs are typically $3,000 or more for Elpan—roughly double the cost of conventional fin-tube radiators for Wanpan—targeting them to the upscale designer market for which these slim and beautiful units seem well suited.

Both types can be installed in the kickspace under slightly raised kitchen cabinets. In any application, the units are virtually invisible and replace standard baseboards throughout the house.

Andersen says that his firm has captured up to 20 percent of the new and retrofit market in Denmark, and that his current marketing efforts here are focused on heating, ventilation and air-conditioning contractors in the Northeast. There are no plans to introduce the product to the do-it-yourself market.

These are just some of the many radiant-heat options on the market today that overcome the drawbacks of years past. New techniques and materials are constantly emerging, enabling the modern builder and designer to flex their creative muscles as never before. The key, of course, is making sure that it works well—and with proper planning, there's no reason it shouldn't. •

Resources

Hydronic Slabs

Davis Energy Group Seminars
2655 Portage Bay Ave.
Davis, CA 95616
(916)753-1100

"Radiant Floor Heat" (booklet)
Gyp-Crete Floors of New England
Box 10343
West Hartford, CT 06110
(203)289-3411

"Warm Floors"
by Michael Luttrell
Fine Homebuilding
June/July '85, page 68.

"Radiant Floor Heating"
by Dennis Adelman
Fine Homebuilding
Aug./Sept. '85, page 69.

"Roll-on Solar Collector"
by V. Elaine Smay
Popular Science
June '79, page 120.

Passive Solar

Passive Solar Ceramic Tile Handbook (No. H1950)
American Olean Tile Co.
Lansdale, PA 19446
(215)855-1111

The Thermal Mass Pattern Book
Total Environmental Action
Harrisville, NH 03450

The Passive Solar Energy Book
by Ed Mazria
Rodale Press, 1979
Emmaus, PA 18049

"Climate Indexing for Indirect Gain"
by William Langdon
Passive Solar Journal
Vol. 2, No. 2, 1983
American Solar Energy Society
2030 17th St.
Boulder, CO 80302

Insulation

"How Much to Insulate Under the Slab"
by Ken Labs
Solar Age
March '85, page 28.