Hydronic Baseboard Basics

New controls, fittings, and installation techniques have refined this economical, reliable heating method

by John Siegenthaler, P.E.

Despite the rapid growth of radiant floor heating in the last few years, fin-tube baseboard is still the staple of American hydronic heating. Hydronic baseboard was first introduced in the late 1940s as a lightweight and easily installed alternative to cast-iron radiators, and its current U.S. sales now exceed 11 million linear feet annually. With a proven service record of several decades, it will undoubtedly retain a large portion of both new and retrofit markets for hydronic heating.

This article discusses the procedures necessary to ensure a top-quality hydronic baseboard installation — one that puts the right amount of baseboard in the right locations, and eliminates the noise problems that can plague carelessly installed systems.

Convective vs. Radiant Heat

Most of the heat released from a typical radiant slab is, of course, by radiation: The hot water in the embedded tubing warms the concrete, which at its surface radiates heat to nearby people and furniture. By contrast, most of the heat produced by fin-tube baseboard is convective: Hot water passing through the element quickly heats air between the fins, setting the convection process in motion. Warm air rises through a slot at the top of the enclosure while cool air flows in at floor level to replace it (see Figure 1, next page).

Although produced by several manufacturers, most brands of fin-tube are similar in construction. The element consists of a 1/2-inch, 3/4-inch, or 1-inch copper tube with mechanically attached aluminum fins. It rests on support cradles within a painted steel enclosure. Most baseboard enclosures have an adjustable damper at the top that can be used to reduce heat output.

Heat output from baseboard depends largely on water temperature. The chart in Figure 2 shows how pronounced this effect is for a typical residential system. As water flows through a series piping circuit containing several baseboards, its temperature is constantly decreasing. To select the proper length of baseboard for a room, it's necessary to estimate the water temperature at the location of the particular baseboard within the circuit. (For a technical explanation of how to size baseboard, see the sidebar).

Baseboard heat output is tested under an impartial standard called the IBR Testing and Rating Code for Baseboard Radiation. The results appear in manufacturers literature as heat output per linear foot of finned element (which is typically 3 to 6 inches less than the length of the enclosure). Ratings are usually given for several water temperatures and two water flow rates, as shown in Figure 2.

A footnote to the ratings indicates that 15% has been added to the tested thermal performance values to account for something called the "heating effect factor." The origins of this go back several decades, to when baseboard was being compared with the freestanding cast-iron radiators found in older homes. The assumption was that the baseboard would be immersed in a pool of cool air near the floor and would thus give off more heat than a standing radiator. (The greater the temperature difference between the air and the hot water, the greater the heat transfer.) The tested ratings were increased 15% to account for this.

Although this may have been an accurate assumption in 1950s housing, it's not the norm today, because houses are tighter and more evenly heated, with fewer drafts and less air stratification. I prefer to size the baseboards based on their true tested performance. To do this when using a published chart, just divide the heat output value by 1.15. Otherwise you risk putting too little baseboard in a given space.

How Finned-Tube Works

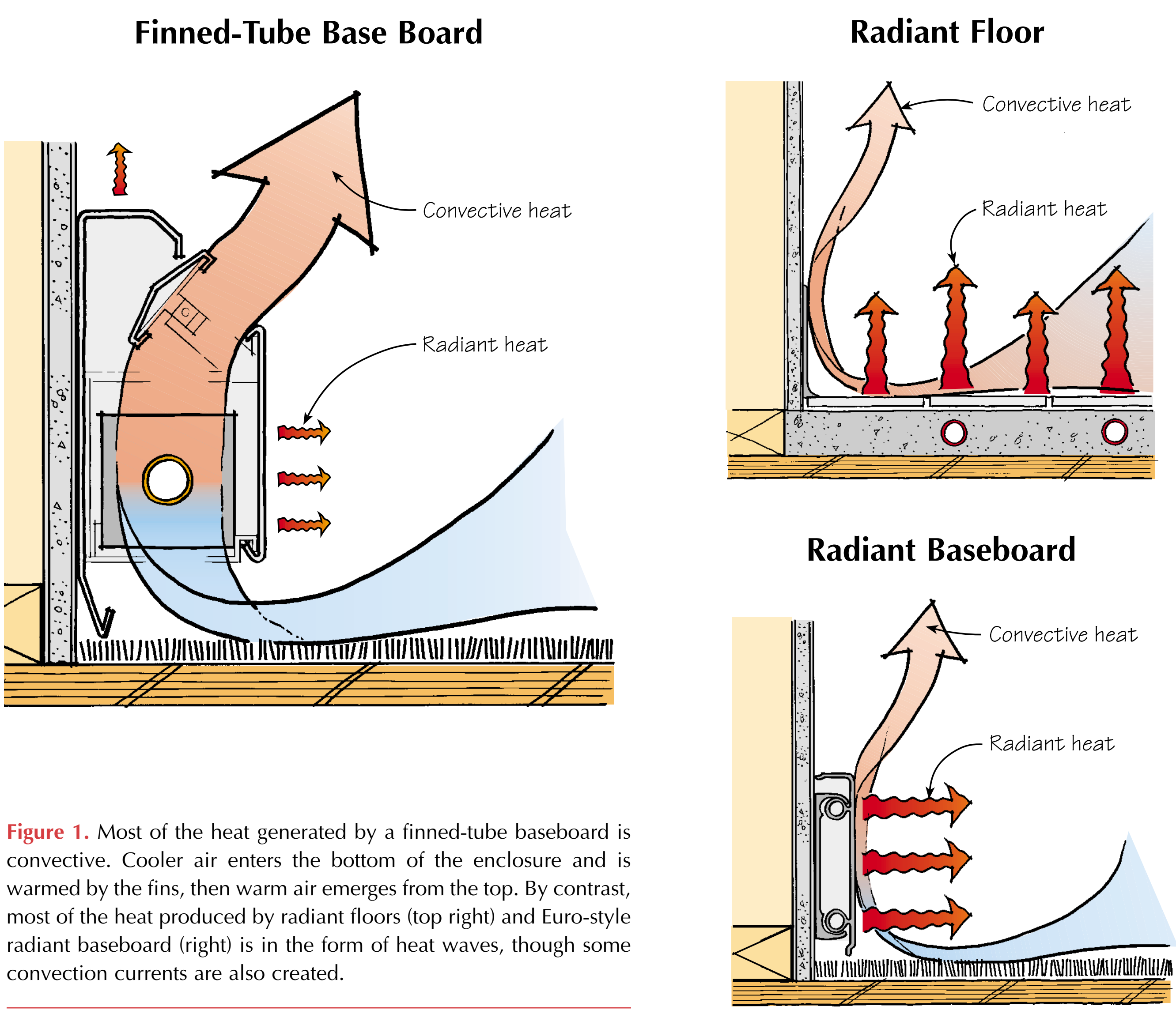


Figure 1. Most of the heat generated by a finned-tube baseboard is convective. Cooler air enters the bottom of the enclosure and is warmed by the fins, then warm air emerges from the top. By contrast, most of the heat produced by radiant floors (top right) and Euro-style radiant baseboard (right) is in the form of heat waves, though some convection currents are also created.

Zoning for Comfort

The ability to accurately control heat delivery among several independent zones is a major advantage of hydronic heating. The more zones there are, the greater the ability to adjust the system to individual preferences.

Most clients instinctively like the idea of having lots of zones until they realize the extra cost involved. Sometimes, too, people will spend the money for elaborate zoning, then seldom use it. Here are some guidelines for matching zoning needs to the budget.

Zone controls are not always necessary. Remember that in many cases baseboard systems can be designed to keep different parts of a building at different temperatures without adding zone controls. Simply closing the damper on a baseboard can reduce heat output to a room by about 50%.

Zone selectively. Areas that aren't used much are obvious candidates for zoning. Examples include workshops, guest rooms, and basements. Energy savings will easily repay the extra cost of putting such areas on a separate zone.

Bathrooms are good candidates for separate zoning. With the bath zoned separately from the bedroom, the homeowner can sleep in a cool room, then step into a toasty-warm bathroom for a morning shower.

Consider other heat sources. Heat delivery to sunny rooms and areas with fireplaces or woodstoves should be able to be interrupted without affecting other areas of the house.

Zoning Strategies

The most common way to build a zoned system is to use a separate piping circuit to and from each zoned area, equipped with either a circulator or a zone valve. Heat input is controlled by individual thermostats in each zone. Hot water flows through the zone circuit only when its thermostat is calling for heat.

Although both circulators and zone valves have been used in thousands of systems, I prefer circulators. The cost is slightly higher, but so is the long-term reliability. If you install a multi-circulator system, be absolutely sure a "flow check," or spring-loaded check valve, is installed in each zone circuit to prevent off-cycle heat migration and reverse flow.

Monoflo piping. One piping alternative is called a "monoflo" system. With this approach, the baseboard in each room has its own thermostatic valve and can be separately controlled. The piping is arranged so that hot water is always flowing through the piping loop from which all the baseboards are "tapped." This creates a constantly circulating loop of heated water from which any of the individual baseboards can extract heat when needed.

A thermostatic radiator valve (TRV) piped into each supply riser regulates flow through its baseboard as necessary to maintain the desired level of comfort in the room (Figure 3, next page). When a room is warm enough, the TRV closes, and flow through the distribution circuit bypasses that baseboard altogether. As the room begins to cool, the TRV slowly opens.

Home run piping. Another zoning technique, relatively new in the U.S. but common in Europe, is the "home run" manifold system. Each baseboard gets its own supply and return line, usually of PEX or PEX-AL-PEX tubing. All supply lines begin at a supply manifold like that used in radiant floor systems, and all return lines go back to a return manifold. Zone control is provided in one of two ways: with low-voltage valve actuators mounted on the manifold valves

Typical Ratings for Finned-Tube Baseboard

Slant/Fin Fine/Line 15 Series
(Hot water ratings, Btu/hr per linear ft. with 65˚F (18.3˚C) entering air)

Element	Water Flow	Pressure Drop*	140˚F†	150˚F	160˚F	170˚F	180˚F	190˚F	200˚F	210˚F	215˚F	220˚F
No. 15-75E	1 gpm	47	290	350	420	480	550	620	680	750	780	820
Baseboard with 3/4" element	4 gpm	525	310	370	440	510	580	660	720	790	820	870
No. 15-50	1 gpm	260	310	370	430	490	550	610	680	740	770	800
Baseboard with 1/2" element	4 gpm	2880	330	390	450	520	580	640	720	780	810	850

* Milli-inches per foot.

† Ratings at 140˚F determined by multiplying 150˚F rating by the IBR conversion multiplier of .84.

NOTE: Ratings are for element installed with damper open, with expansion cradles. Ratings are based on active finned length (5" to 6" less than overall length) and include 15% heating effect factor. Use 4 gpm ratings only when flow is known to be equal to or greater than 4 gpm; otherwise, 1 gpm ratings must be used.

Figure 2. This chart gives the tested heat output for Slant/Fin's Fine/Line 15 baseboard elements. When sizing baseboard for modern construction, the author recommends dividing these numbers by 1.15 to remove the "heating effect factor."

Figure 3. Thermostatic radiator valves (TRVs) allow adjustment of individual baseboards in a series loop. The plastic wrap is to protect against splatters from drywall mud.

and wired to thermostats or with non-electric TRVs on each baseboard.

Layout at the Boiler

The arrangement of components near the boiler has undergone some changes in the last few years. Figure 4 depicts a typical arrangement for a system with three heating zones and a separate zone for domestic water heating. One important change is the placement of circulators on the supply side of the boiler and downstream of the system's expansion tank. This makes air purging simple, often eliminating the need to "bleed" air from the baseboards. The traditional air scoop used in older systems is being replaced by a newer device called an air separator, or deaerator, which can capture even microscopic air bubbles and eject them from the system.

Notice, too, that all the wiring for the system's circulators and thermostats has been consolidated into a single control panel called a multi-zone relay center. Several manufacturers now offer a relay center (see Sources, at end of article), which greatly simplifies installation and reduces cost compared with systems that use a number of single zone controls with a separate 24-volt thermostat for each zone.

Also disappearing is the traditional tankless coil for domestic water heating. Taking its place is the indirectly-fired storage water heater, of which dozens of models are now available. In this type of system, the boiler fires only when

Components of a Hydronic Baseboard System

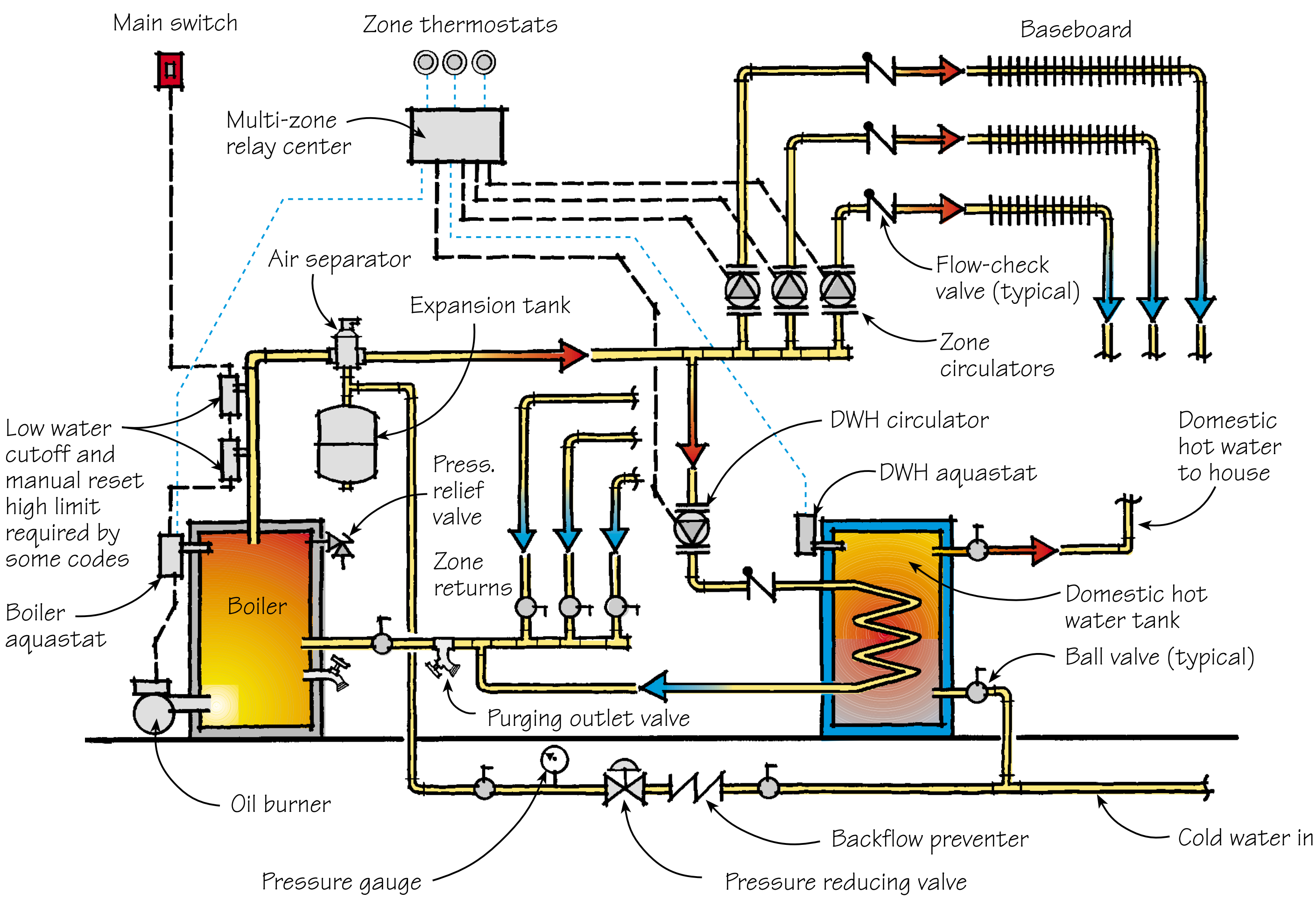


Figure 4. In contemporary hydronic installation, the circulators are placed on the supply side of the boiler downstream from the expansion tank, making it easier to purge air from the system. The air separator is also an improvement over traditional in-line air purgers.

there's a demand for space heating or water heating rather than inefficiently maintaining a minimum water temperature year-round. Most multi-zone controls have a switch that can be set to provide "priority" domestic water heating. In this mode, all space heating is temporarily suspended during DHW heating, allowing full boiler output to quickly heat the tank.

Distribution Piping Options

Although type-M copper tubing has long been the standard for hydronic distribution circuits, it now has some serious competition, in particular from crosslinked polyethylene (PEX) tubing manufactured with an oxygen-diffusion barrier (ASTM F876). A number of companies now market PEX tubing along with brass fittings for making either soldered or threaded connections. The tubing can easily be snaked through joist cavities where installing rigid piping is all but impossible — a tremendous advantage in retrofit jobs.

A variation is PEX-AL-PEX composite tubing, which has an inner and outer layer of PEX bonded to a welded aluminum core. PEX-AL-PEX manufactured to the ASTM F1281 standard is rated for service conditions up to 210°F at 115 psi. After being uncoiled, PEX-AL-PEX tends to retain its shape better than standard PEX. Its thermal expansion is only about one-seventh that of PEX, because it's controlled by the aluminum core rather than the plastic.

Installing Baseboard

Although it's possible to install baseboard almost anywhere wall space is available, placement can affect room comfort. The preferred location is always along exterior walls, specifically under windows. The rising current of warm air from the baseboard counteracts the draft effect of the cool window and wall surfaces, and also helps prevent interior condensation on the glass during very cold weather.

A careful baseboard layout should also consider furniture arrangements, door swings, and obstacles such as wall columns (Figure 5). Whenever possible, talk over baseboard placement with the homeowner before doing a final layout, remembering that compromises are inevitable. Here are some other points to consider.

Avoid moist locations. Baseboard is not well-suited to the moisture levels of heavily used bathrooms, especially when placed next to or behind a toilet. The enclosures will start to rust within a couple of years. Since available wall space in most bathrooms is minimal, a panel radiator is often a better choice, though it will cost two to three times more for the same heat output. Another option would be to use underfloor heating, which is also more expensive.

Leave an air space. When baseboard is installed before finish flooring, remember to leave at least a 1-inch space beneath the enclosure. This ensures that the finish floor will not block air coming into the enclosure.

Locate floor framing. Before mounting the baseboard enclosure to the wall, be sure to locate the floor framing so you don't have to butcher a joist to make room for the riser pipe from below. Try to keep riser pipes at least 2 inches away from any framing to make soldering easier.

In most cases you can get a measurement for the riser pipe holes by sliding an elbow onto each end of the element and measuring between the centers of the elbow sockets. If the design requires a flow balancing valve or thermostatic radiator valve on one end of the element, dry-assemble the components before measuring.

Drill oversized holes. After marking this center-to-center distance on the floor, use a bit that's at least 3/8 inch larger than the outside diameter of the riser piping to drill the holes. This provides space for the element to expand without jamming the riser against the side of the hole. For single-piece ele-

Good & Bad Baseboard Layout

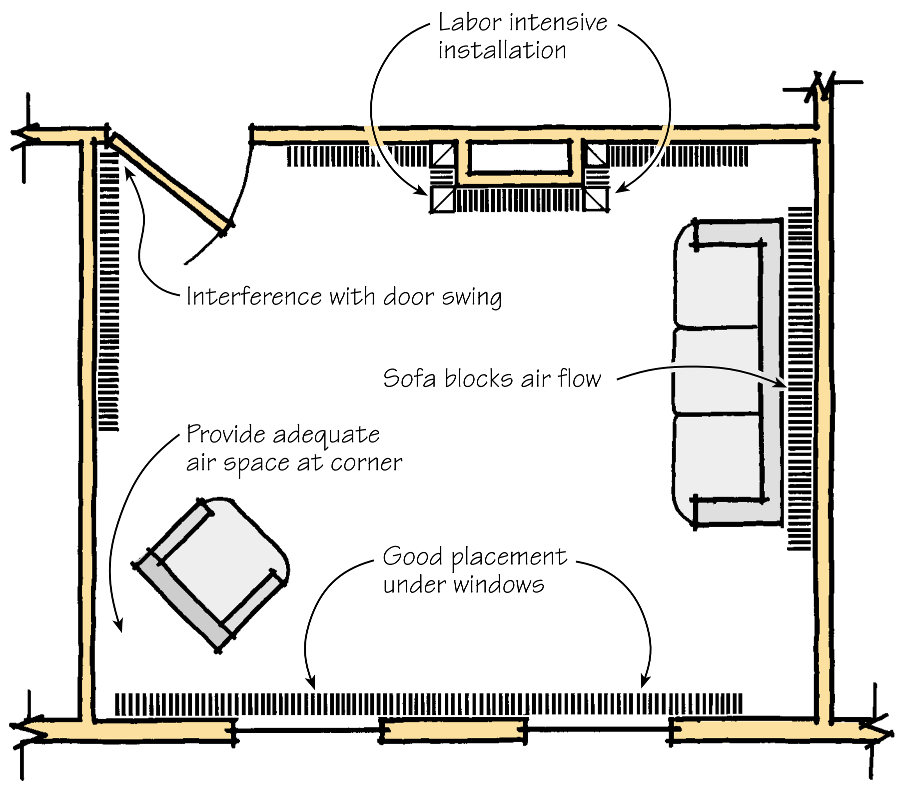
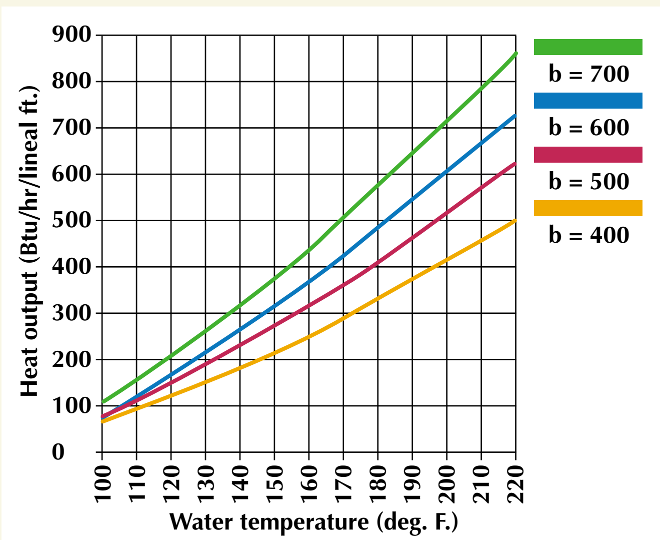


Figure 5. Baseboard layout should be carefully planned to avoid labor-intensive installations and to ensure even, effective heating.

Sizing Baseboard

Using the procedure outlined here, you can accurately calculate the length of finned-tube baseboard required in each room served by a series piping circuit. First, you have to determine the design heating load for each room (for more on heat load calculations, see "Trouble-Free Forced-Air Heat," 12/98). The formulas presented here are based on using water as the system fluid.

Graph A shows how the heat output of baseboard varies with the water temperature in the element. The four curves represent finned-tube elements with different rated outputs. Each curve has a *b* value, which is the baseboard's heat output (in Btu/hr/ft. of finned element) at a standard water temperature of 200˚F and a flow rate of 1 gpm. You can get this value from the ratings table in the manufacturer's literature. For the most accurate results, divide the table value by 1.15 to remove the heating effect factor before finding the nearest *b* value on the graph.



Graph A. This graph shows the heat output (in Btu/hr/ft of finned element) of four different models of finned-tube baseboard. The graph assumes the air entering the baseboard at floor level is at 65˚F. The *b* value, which can be found in the manufacturer's literature, is the baseboard's heat output with 200˚F water and a flow rate of 1 gpm.

Heat output also depends on the flow rate through the element. The higher the flow rate, the higher the heat output. Graph B gives the flow rate in a series piping circuit powered by a typical 1/25 horsepower wet-rotor circulator.

Step 1: Select a boiler outlet temperature; 180˚F is typical. The inlet temperature to the first baseboard is assumed equal to the boiler outlet temperature.

Step 2: Estimate the flow rate through the baseboard using Graph B.

Step 3: Calculate the average water temperature in the first baseboard as follows:

$$T_{avg} = T_{inlet} - \frac{\text{room load}}{980 \text{ x flow rate}}$$

Step 4: Use Graph A to estimate the heat output of one foot of baseboard at T_{avg}. This value is designated as *q*.

Step 5: Calculate the required baseboard length as follows:

$$L = \frac{\text{room load}}{q}$$

Round off to the next higher whole foot length, referred to as $L_{rounded}$.

Step 6: Calculate the outlet temperature of the baseboard using:

$$T_{outlet} = T_{inlet} - \frac{L_{rounded} \text{ x } q}{490 \text{ x flow rate}}$$

Use the outlet temperature of this baseboard as the inlet temperature to the next baseboard, and repeat the procedure starting at Step 3. Repeat for each baseboard in the series circuit, each time treating the outlet temperature from one baseboard as the inlet temperature for the next.

Example

Size the first baseboard in a series piping circuit for a room heating load of 4,000 Btu/hr. Assume the overall piping circuit is 150 feet long, and built with 3/4-inch tubing. Also assume the boiler outlet temperature is 180˚F, and the baseboard used has a rated output of 600 Btu/hr/ft. with 200˚F water.

Step 1: T_{inlet} = 180˚F

Step 2: From Graph B, the circuit flow rate is estimated to be 5.5 gpm.

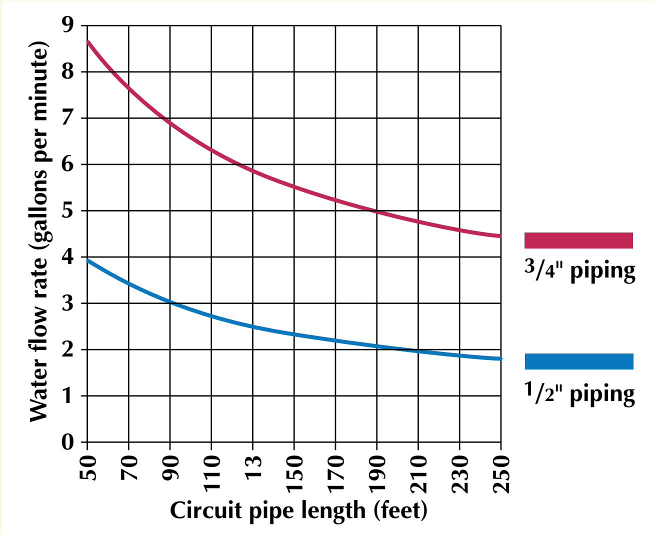
Step 3: Calculate the average water temperature in the first baseboard:

$$T_{avg} = T_{inlet} - \frac{\text{room load}}{980 \text{ x flow rate}} = 180 - \frac{4{,}000}{980 \text{ x } 5.5} = 179.3˚F$$

Step 4: From Graph A (blue line), the output of the baseboard at 179.3˚F is about 480 Btu/hr/ft.

Step 5: The required length of the first baseboard element is:

$$L = \frac{\text{room load}}{q} = \frac{4{,}000}{480} = 8.3 \text{ feet (round to 9)}$$



Graph B. This graph gives the estimated water flow rate in piping circuits of different lengths. An allowance has been made for a typical assortment of fittings and valves.

Step 6: The outlet temperature from this baseboard is:

$$T_{outlet} = T_{inlet} - \frac{L_{rounded}\ x\ q}{490\ x\ flow\ rate} = 180 - \frac{9\ x\ 480}{490\ x\ 5.5} = 178.4°F$$

This would be the assumed inlet temperature to the next baseboard.

Computer Assistance

This procedure cries out for spreadsheet programming. Once programmed, you can compare the effects of varying design factors like flow rate, boiler outlet temperature, and so forth, in seconds. The *Hydronics Design Toolkit* software (written to accompany my book, *Modern Hydronic Heating for Residential and Light Commercial Buildings*) has both a heat load estimating program and a complete baseboard sizing program that does all these calculations, as well as allowing you design options such as speccing antifreeze instead of water or plugging in different air temperatures for each baseboard. The program costs $70 and is available from Iris Communications (541/767-0355) or the Radiant Panel Association (800/660-7187).

—J.S.

ments, you can solder the element and any fittings and valves together, then lower the whole assembly into the enclosure. Be sure to support all fittings so the assembly is not twisted when soldered. When set into the enclosure, be sure the element rests on the support cradles provided. Some manufacturers supply plastic expansion cradles that prevent metal-to-metal contact, and minimize expansion noise.

For situations where a baseboard must be supplied and returned from the same end, install a vented 180-degree "return" fitting at the far end, and route the return pipe back through the enclosure above the element.

Preventing Noise

Preventing noise from thermal expansion is an important part of piping installation. Where copper tubing is suspended beneath floor joists, use the plastic-coated wire hangers with pointed ends that drive into the joists. These hangers flex as the pipe expands, preventing the noise you would get if the pipe were expanding inside a rigid support.

With I-joists, use a filler block in the web space before using this type of hanger. *Don't* drive the points into the I-joist flanges, or you'll damage this key structural component.

Support 1/2-inch and 3/4-inch tubing at intervals not exceeding 4 feet. Supports for 1-inch and 1 1/4-inch tubing should be not more than 6 feet apart. PEX tubing should be supported about every 30 inches.

Make sure all holes in the joists are aligned. Again, drill holes at least 3/8 inch larger than the outside diameter of the piping. Never rigidly fasten the copper tubing to any framing, and don't wedge a length of pipe tightly between any rigid surfaces. Be sure hangers are rated to operate at temperatures at least 20°F above the design water temperature of the system — typically 180°F in residential systems.

Pressure Testing

When the piping system is completed, it's time to test for leaks. This is best done with compressed air rather than water (unless you like running through buildings desperately searching for shutoff valves). Don't get smug and "blow off" this step. I know guys who could probably solder pipe in their sleep, but still religiously test every system before the piping gets covered up.

Before you pressure test, make sure all air vents are tightly sealed, and all inline valves are open. Add air to the system with a Schrader valve (like the valve on a tire). Pump the system up to 20 to 25 psi — any higher and air starts leaking from the 30 psi relieve valve. If all's well, the pressure should remain stable for at least 12 hours. If the pressure slowly decreases over a few hours, check all joints by brushing on a solution of dish detergent or a commercially available leak detection fluid, and look for bubbles. Threaded joints tend to be more prone to leaks. Track down any leak and fix it before covering the piping or adding water.

Charging the System

If pressurized domestic water is available on site, the system can be filled by closing the isolation flanges on all but one of the zone circulators, opening the purging outlet valve, and lifting the fast-fill lever on the pressure reducing valve. Water flows into the boiler and up through the system piping. As the boiler fills, air exits through the air separator. The water continues up through the open zone circuit, pushing most of the entrapped air ahead of it. Eventually the water-air mixture makes it back to the open outlet valve. After a minute or so the exiting stream will be relatively free of air bubbles.

Open the next zone circuit and close the first. Repeat the procedure, one zone circuit at a time, until all the zones are purged. Reset the fast-fill lever and close the purging outlet valve. Most of the air, other than that dissolved in system water, has now been expelled from the system. The air separator will get the rest during the first few days of operation.

When a system like the one in Figure 4 is first turned on, what happens depends on the control settings. If they're set for DHW priority, the DHW zone will be the only one operating. Assuming the DHW tank has water in it, set the tank thermostat to 100˚F and wait a few minutes for this load to be satisfied.

To check space heating, turn each zone thermostat all the way up, one at a time. The boiler should fire up as each zone is turned on. Don't be surprised if you still hear slight gurgling sounds in the piping. Expect to hear occasional air hissing from the air separator as the water gets hotter. Make sure the boiler stops firing when it gets up to the aquastat setting (170˚F to 180˚F for a typical baseboard system).

***John Siegenthaler** owns Appropriate Designs, a building systems engineering firm in Holland Patent, N.Y. He is author of* Modern Hydronic Heating for Residential and Light Commercial Buildings *(Delmar Publishers, 800/347-7707).*

Sources of Supply

Argo
P.O. Box 8098
Berlin, CT 06037
860/828-6513
www.argoindustries.com
Baseboard convectors, relay panels, electric boilers

Bell&Gossett
8200 N. Austin Ave.
Morton Grove, IL 60053
847/966-3700
http://fhs.ittind.com/bellgoss.htm
Controls, relay panels, circulators, air separators

Buderus Hydronic Systems
P.O. Box 647
Salem, NH 03079
603/898-0505
Boilers, indirect water heaters

Burnham Radiant Heating Co.
P.O. Box 3079
Lancaster, PA 17604
717/397-4704
www.burnham.com
PEX tubing & fittings, cast-iron boilers, controls, cast-iron baseboard

Embassy Industries Inc.
300 Smith St.
Farmingdale, NY 11735
516/694-1800
PEX tubing & fittings, controls, baseboard convectors

Erie Manufacturing
4000 S. 13th St.
Milwaukee, WI 53221
800/558-3916
Hydronic controls, relay panels

Honeywell, Inc.
P.O. Box 524
Minneapolis, MN 55440
800/345-6770
www.honeywell.com
Hydronic controls, relay panels

IPEX Inc.
7025 S. Fulton St., Suite 100
Englewood, CO 80112
800/473-9808
www.kitec.com
PEX-AL-PEX tubing & fittings

Rehau
P.O. Box 1706
Leesburg , VA 20177
800/247-9445
PEX tubing & fittings

Slant/Fin Corp.
100 Forest Drive
Greenvale, NY 11548
516/484-2600
www.slantfin.com
Boilers, pex tubing & fittings, convectors

Sparco Inc.
65 Access Rd.
Warwick, RI 02886
401/738-4290
Air separators, valves, controls

Spirotherm Inc.
25 N. Brandon Dr.
Glendale Heights, IL 60139
630/307-2662
www.spirotherm.com
Air separators

Stadler Corporation
3 Alfred Circle
Bedford, MA 01730
781/275-3122
PEX tubing & fittings

Utica Boilers
P.O. Box 4729
Utica, NY 13504
315/797-1310
Boilers, indirect water heaters

Weil-McLain Corp.
500 Blaine St.
Michigan City, IN 46360
800/368-2492
www.weil-mclain.com
PEX-AL-PEX tubing & fittings, cast-iron boilers, indirect water heaters, baseboard convectors

Wirsbo
5925 148th Street West
Apple Valley , MN 55124
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www.wirsbo.com
PEX tubing & fittings