GEO-TO-RADIANT RETROFIT

by John Vastyan
photos by Holly Noel

Three 300-foot-deep boreholes provide the thermal-coupling to the earth's stored energy. Geothermal heat pumps convert that thermal energy for use in space heating of the home, garage, and bunkhouse.

Some outdoor enthusiasts go to great extremes to set up the perfect camp. An example of just how far the Wengers will go is the "regreening" of their rural lakeside log home in west-central Pennsylvania.

Travis and Rachel Wenger spent most of the autumn months of 2007 shopping for a family retreat and hunting lodge. During a second visit to one of the properties—a 2,400-square-foot, three-bedroom log home built in 1994—their decision was made much easier by the arrival of a 400-pound harbinger. While they were admiring views from the home's deck, a black bear, ignoring them, had climbed up the other side of the deck to assault the gas grill.

Convinced it was "the sign we were looking for, we immediately agreed to buy the place," says Travis.

From Idyllic to Ideal

Nestled on a mountainside, the 16-acre home site borders thousands of acres of state game lands where deer, turkey, and bear roam freely. Nearby are several state parks, the Juniata River, and miles of wildlife trails.

While the property was just what they'd looked for, the home itself was less than ideal. "Before the remodel, the place left a Sasquatch-sized carbon footprint," says Dave Yates, the contractor hired to update the home's mechanical systems. "The log home leaked like a sieve. Winters are brutal up there, so they were burning LP gas furiously and getting dizzy watching the electric meter spin."

Yates visited the Wengers' retreat that fall to calculate the home's heating load and to take notes about the upcoming job, which included a geothermal-to-radiant space-heating system.

"For the homeowners, improving energy efficiency was just as important as having year-round comfort," adds Yates.

"The home had electric air-conditioning and a 140,000 Btu per hour propane furnace with supplemental heat from a fireplace and three old potbelly wood heaters," says Yates. "They also used several portable electric heaters and an old electric water heater."

The Wengers gave Yates a lot of flexibility in designing a "green" system, adding that if it made sense to keep some of the old equipment, fine; but where it made better sense to toss out the old to make room for the new…even better.

To prepare for the heating system overhaul, Travis and his father Merv, no strangers to remodeling jobs, added "truckloads of insulation," upgrading many of the walls to R-16 or better and the ceiling to approximately R-48, with plans to add a radiant barrier to interior trusses this winter.

By the time the contractor's crew began work at the home, 100 miles from their shop, the Wengers had already resealed all the logs in the home, began the basement remodel—including rigid-foam insulation—and set the foundation for the log garage, with a 150-foot, 4-foot deep trench from the house for an insulated loop to carry geo-to-radiant system heat between the two buildings.

The old 10-SEER (seasonal energy efficiency ratio) central air-conditioning system was disconnected and replaced with a 4-ton (48,000 Btu per hour) ClimateMaster Tranquility water-to-air system. Rated at 27-SEER—2.7 times the efficiency of the old air-conditioning system—this unit can also provide backup heat if needed.

For space heating, the Wengers settled on a unique mechanical system designed by Yates. For the heating season, the heart of this system is a high-temp, water-to-water ClimateMaster thermal hot water (THW) heat pump, two twin-coil Bradford White indirect water heaters that source heat from the heat pump system, and several preassembled HydroNex control panels by WattsRadiant—one of which is designed to accept solar heat for domestic water, then to share additional heat with the radiant system.

The heat pump system has a rated maximum output of 145°F with a peak coefficient of performance (COP) of

(continued on page 69)

Fred Umble of Creative Energy (left) hot-fuses geothermal pipe connections at one of the three well-heads.

Scott Barnett works on the new ClimateMaster water-to-air heat pump, rated at 27-SEER. This unit provides all cooling and supplemental heat.

Dave Yates does final soldering on the buffer tank that connects to the hydronic control panels in the background.

Travis's father, Merv Wenger, installs the Sea Tech "home-run" domestic water lines into the central manifold.

Geothermal Heating Basics

A few years ago, when "green" hadn't quite entered the mainstream vocabulary, and natural gas prices were continuing to climb, Tom and Cindy Shepherd saw the writing on the wall. They took out a home equity loan to pay for the installation of a geothermal heating and cooling system for the family's Indianapolis, Indiana, area home on the assumption that energy rates would quickly outpace interest on the loan. They were right.

Tom and Cindy spent several months researching the type of system best suited to their needs, interviewing installers and asking a lot of questions. An admitted "techno-junkie," Tom's job as a systems control technician for Honeywell became his trump card while he probed for answers.

With the help of Kris Kyler at Indiana Geothermal, a geo-loop contractor and geothermal equipment distributor, Tom and Cindy settled on a 4-ton (48,000 Btu per hour) water-to-air geothermal system to heat and cool their 3,600-square-foot, five-bedroom home. Their intent was for the new system to replace the 93% AFUE (annual fuel utilization efficiency) gas furnace and standard electric air-conditioning system.

The "geo" loops tap the earth's abundant energy through four 150-foot boreholes. "For the most part, it was a standard geothermal install," says Kyler. "And the benefit to the Shepherds' utility budget was immediate."

While many of their neighbors helplessly watch their utility bills soar higher, the Shepherds are enjoying record savings. In 2006, the Shepherds paid $3,620 for natural gas and electricity—energy used for space and water heating, air-conditioning, and pool heating. During the 12-month period following the installation, they paid $2,400 to accomplish the same thing—a 34% savings. The pool is also mostly heated geothermally, thus eliminating most gas heater operation, resulting in a further monthly savings of $100 to $400.

"Indianapolis Power and Light added to the savings by dropping our electricity rate from 4.4 cents per kWh to 3.8 cents because we installed the geothermal system," says Tom. "IPL also added a $50 rebate, and we picked up another $300 federal tax break."

"That played nicely into our overall savings on the loan," says Cindy. "With the rebate, the reduction in the electricity rate, and the energy savings, a substantial part of the loan payment is covered."

"The traditional heating and air-conditioning system that we had—considered to be high efficiency—was terribly inefficient when compared to geothermal, and rather uncomfortable," adds Tom. "Today, we have terrific comfort year-round and an expected seven-year payback on our investment."

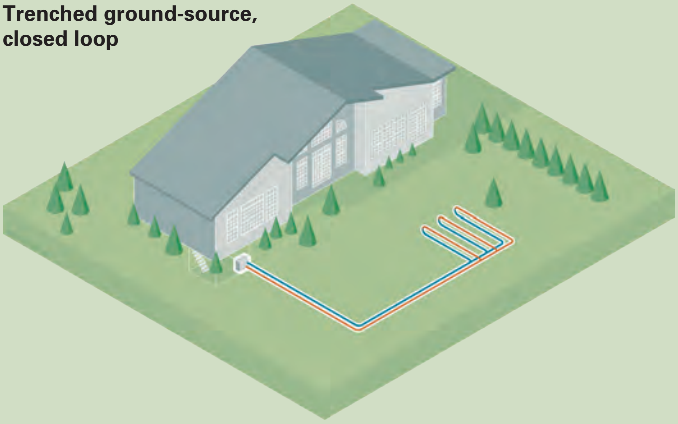
Takes Little Area

The earliest geothermal systems tapped heat in the earth through pits or fissures that pushed hot water to the surface to heat homes and domestic hot water. Many of these systems used a very small pump to distribute the heat. These systems are site-specific and rare, but technology has vastly improved, permitting efficient geo-exchange from almost any plot of land. Modern systems use heat pumps to transfer heat for home space and water heating, and these systems will work in most climates. The difference in the systems is the cost of electricity to run the heat pump compressor and pumps—a good deal more electricity than used by natural geothermal systems.

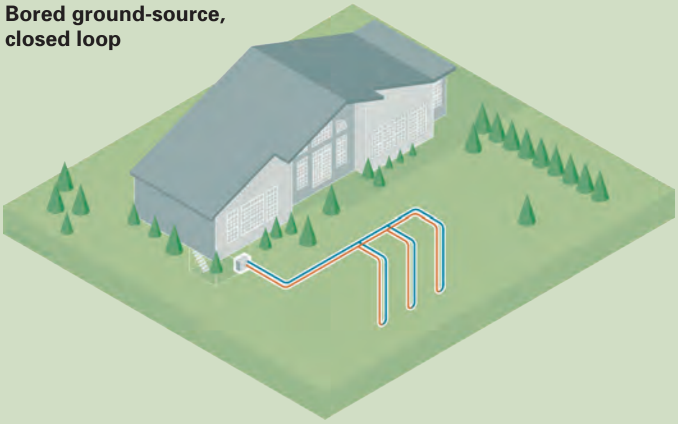
A basement mechanical area is ideal for geothermal system components—equipment is protected and secure.

System Configurations

Trenched ground-source, closed loop



Bored ground-source, closed loop



Even if you have just a small patch of land, you might be able to use a geothermal system as a hedge against an energy crisis. Modern technology extracts thermal energy with greater ease, with little disruption to the surrounding landscape, and at high enough operating efficiencies to make payback shorter than ever.

Even though the installation price of a geothermal heat pump (GHP) system can be several times that of a similarly sized air-source system, the U.S. Department of Energy states additional costs are returned in energy savings in five to 10 years. System life is estimated at 25 years for the indoor equipment and 50 or more years for the ground loop.

A ground-source unit works like a conventional heat pump to cool a home in the summer, and heat it in the winter. The key difference between an air source heat pump and ground-source is that the ground-source unit harvests the stable and renewable heat from beneath the earth's surface, whereas air-source relies on widely varying air temperatures to do the same job. As with any heat pump, geothermal and water-source heat pumps provide space heating and cooling, and can also supply the house with hot water.

Depending on latitude, ground temperatures range from 45 to 75°F. Like a cave, this ground temperature is warmer than the air above it during the winter and cooler than the air in the summer. The GHP takes advantage of this by exchanging heat with the earth through a ground heat exchanger using a liquid transfer medium such as water or an antifreeze solution.

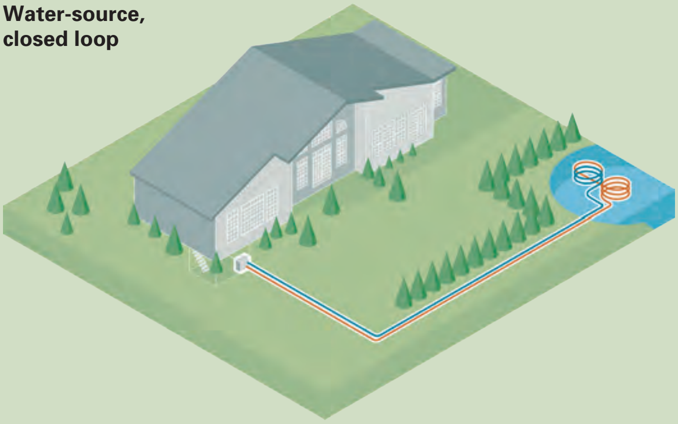
On larger lots where there is ample property to excavate, the geo-exchange field can be trenched instead of drilled—a less expensive method than drilling holes.

If a pond is present, a water-to-water geothermal system may be able to tap this thermal sink by running "slinky lines" from a trench into deep water.

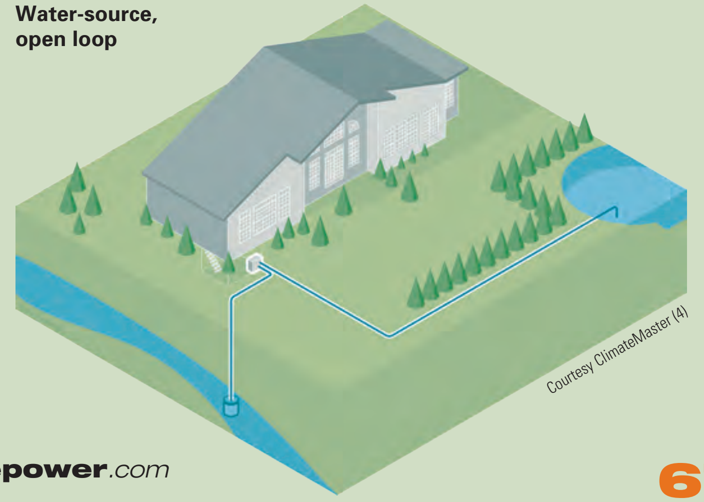
Because a GHP harvests energy from the earth, less fossil-fuel-based energy is used, which reduces greenhouse gas emissions and can cut utility bills by up to 70%, says Tony Landers of ClimateMaster. And very little maintenance is required because the stable heat source avoids thermal stresses to the compressor and the enclosed unit is inside, protected from the weather.

The Shepherds' geothermal system taps the earth's constant temperature of about 51°F in Indianapolis. From the variety of loop configurations available for a geothermal system, the Shepherds and Kyler—like the Wengers—chose the closed-loop borehole method, which disturbs the least amount of earth. For homes where ground space is limited, or for homes with

Water-source, closed loop



Water-source, open loop



Courtesy ClimateMaster (4)

mature landscaping, this configuration is ideal because all evidence of the drilling can be removed, and lines are buried.

"Most geothermal systems supply three or four units of heat or cooling for every unit of electrical energy input," says Kyler, who has installed geothermal systems for more than 20 years.

Open- & Closed-Loop Systems

Electricity is used only to power the equipment says Tony Landers, marketing director for ClimateMaster, a manufacturer of geothermal systems. "The rest of the process uses the free, clean, and renewable energy that's tapped just below the earth's surface."

There are two basic types of water-source geo systems: open-loop and closed-loop. An open-loop system typically pumps water out of a deep well, extracts heat from it, and injects it back into another well, a pond, or a river. An open-loop system tends to be more efficient because it pulls the heat out of a steady stream of water from deep in the ground. But open-loop systems are prohibited in many parts of the country because of water quality and water conservation concerns.

A closed-loop system uses a continuous loop of plastic tubing as a heat exchanger. The tubing is connected to the indoor heat pump to form a sealed, underground loop through which a glycol or alcohol antifreeze solution is circulated. Unlike an open-loop system that consumes water from a well, a closed-loop system recirculates its heat-transferring solution in the pipe. Closed-loop systems can be trenched, "bedded" (in an excavated, flat, deep bed) or drilled.

Doing the Work of Three

A geothermal heat pump system typically replaces two systems: heating and air conditioning. A geo system uses ground water or the earth as a source of heat in the winter by pulling heat from the water or ground, and using water or ground as a place to "sink" heat in the summer. The final process of thermal exchange takes place in mechanical equipment that serves both heating and cooling needs for a building. Typically, a system distributes the heat through a conventional forced-air ducted system, or through hydronic tubing in the floor like the Wengers' system.

Many systems can also heat a home's domestic water by either integrated water preheating or through "desuperheating." A desuperheater reclaims heat from the air-conditioning cycle to heat water by transferring the compressor's waste heat to a hot water storage tank, and can reduce water-heating costs in the summer by 40 to 60%, according to Landers.

Geothermal systems are not without their disadvantages, which mainly center on installation time and up-front costs. With many pieces and components to set up and integrate, the installation is more complicated and involved and, therefore, more time-consuming.

And, compared to other space-heating methods, geothermal systems are also more expensive. However, Yates points out that it's not the equipment that eats up the budget but the preparation—outside drilling and trenching, and fusing the pipes—and connecting the many systems that take heat from the heat pump.

—John Vastyan

Geothermal vs. Conventional HVAC & Water Heating System

Year	Projected Propane Cost ($/gal.)	Projected kWh Cost	91% Efficiency HVAC System[a]	Geothermal Heat Pump[a]	Yearly Savings	Annual ROI[d]
1	$2.99	$0.110	$4,966[b, c]	$1,725[c]	$3,241	28.1%
2	3.14	0.116	5,214	1,811	3,403	29.5%
3	3.30	0.121	5,475	1,902	3,573	31.0%
4	3.46	0.127	5,749	1,997	3,752	32.6%
5	3.63	0.134	6,036	2,097	3,940	34.2%
6	3.82	0.140	6,338	2,201	4,136	35.9%
7	4.01	0.147	6,655	2,311	4,343	37.7%
8	4.21	0.155	6,987	2,427	4,560	39.6%
9	4.42	0.163	7,337	2,548	4,788	41.5%
10	4.64	0.171	7,704	2,676	5,028	43.6%
11	4.87	0.179	8,089	2,810	5,279	45.8%
12	5.11	0.188	8,493	2,950	5,543	48.1%
13	5.37	0.198	8,918	3,097	5,820	50.5%
14	5.64	0.207	9,364	3,252	6,111	53.0%
15	5.92	0.218	9,832	3,415	6,417	55.7%
16	6.22	0.229	10,324	3,586	6,738	58.5%
17	6.53	0.240	10,840	3,765	7,075	61.4%
		Total	$128,319	$44,569	$83,750	

Table Parameters:

The table compares a 4-ton ClimateMaster Tranquility geothermal heat pump to a 91% efficiency, propane-fueled condensing system, electric air-conditioner unit, and electric water heater.

[a] Yearly costs include space and water heating, cooling, a blower, and domestic water heating. Assumptions were a heat loss of 59,602 Btu/hr. and a heat gain of 25,940 Btu/hr.

[b] Assumes a propane cost of $2.99 per gallon for the first year, with a 5% annual increase.

[c] Based on an initial electricity rate of 11 cents per kWh, with a 5% annual increase.

[d] Calculated using the added cost of the GSHP compared to a conventional heating system. Installation costs were $29,503.60, with 30% tax credit subtracted. A conventional HVAC system price was estimated at $17,977; the added cost of GSHP was $11,526.60, which includes loop, piping, etc.)

Left: Dave Yates installs hydronic radiant tubes to the underside of the garage subfloor.

Above: Insulation directs radiant heat upward to the room above.

Right: Homeowner Rachel Wenger ties radiant tubing into place before the garage workshop's concrete floor is poured.

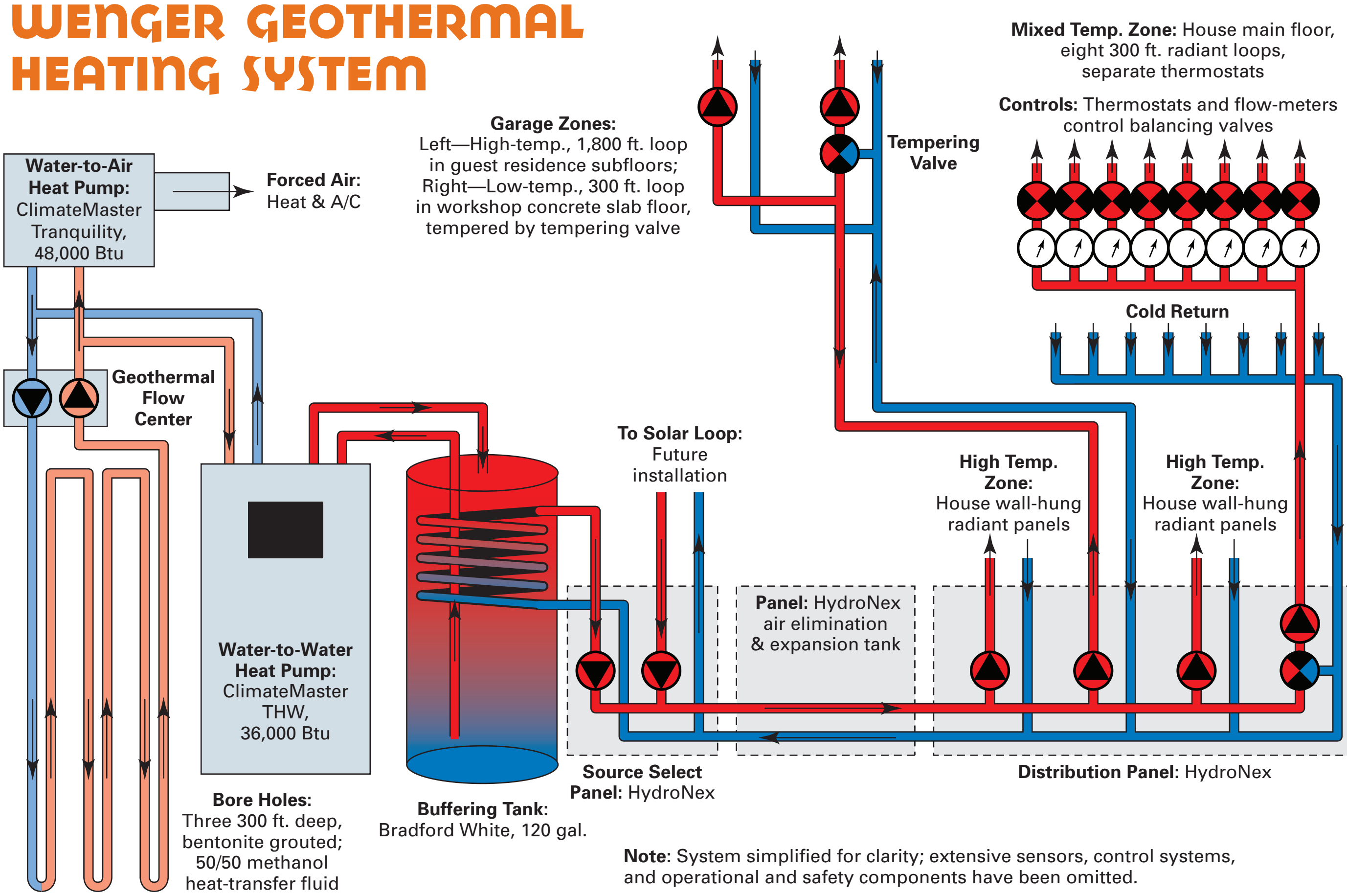
4.5, assuming sufficient geo-exchange, which required three 260-foot boreholes. The COP means that for every unit of (electrical) energy used to operate the system, 4.5 units of heating/cooling are available.

But the Wengers asked geothermal driller Dave Eriksen to drill down farther, lengthening each run by another 40 feet. "I knew from a friend's geothermal system that their heating needs would occasionally max out the field's capability," says Travis, "so by adding 15% or so to the field size, I figured we'd have an underground insurance policy."

Eriksen drilled three holes into which geothermal pipe was inserted. The holes were also thermally grouted, a process that injects a bentonite slurry to enhance temperature exchange between the pipe and earth.

"We believe this was the reason for one of the big surprises we had with the system's startup in December 2008," says Yates. "Though outside temperatures hovered between 10 and 12°F, the THW unit delivered system heat of 157°F—substantially higher than what it was rated for."

WENGER GEOTHERMAL HEATING SYSTEM



Dave Yates installs backup Fujitsu minisplit heat pumps, which also provide air-conditioning for interior garage spaces.

Radiant Details

All of the home's PVC plumbing—which, according to Yates, was a "snake pit of code violations"—was replaced with WaterPEX lines that connect to a central Sea Tech manifold in the new mechanical room.

While the basement remodeling was underway and the joists were accessible, the Wengers' crew stapled 2,400 lineal feet of Onix radiant-heat tubing to the subfloor to heat the home's main floor. The eight 300-foot loops were attached to manifolds with balancing valves and flow meters for precise control of heat distribution. "The Onix tubing flexes like rope, can be doubled-up and pushed through joist bay holes, and flattens slightly during staple-up, greatly improving heat transfer," says Yates.

While the subfloor tubing was being attached, the crew mounted the control panels, which temper system water based on outdoor temperatures. "We designed the system so that the 36,000 Btu water-to-water geothermal unit sends heat directly into a 120-gallon, two-coil indirect water heater next to it," says Yates. "This was the heat pump's 'thermal target,' which efficiently exchanges heat that then moves to the control panels."

Heat exchangers separate the geothermal system's 50/50 methanol solution—a special antifreeze chosen for stability and heat exchange properties—from the water systems within the home. "We run the system all winter long," says Travis, "so we didn't need to circulate an antifreeze solution within the radiant tubing."

The home's hydronic heating requires two water temperatures: a lower temperature for the floor loops (in three zones, each with a separate thermostat) and a higher temperature for several wall-hung radiant panels and the underground loop to the garage.

"The hydronic control panels—in the house and garage—came preassembled, with all the controls and components needed for low- and high-temp heat distribution," says Yates, "saving weeks of labor."

Rigging the Radiant System

"We could meet a lot of needs with the THW heating the 120 gallons of water in the main source tank between 145 and 155°F, but it couldn't exceed 36,000 Btu," says Yates. "So we had to choose carefully what and how to heat, and had to insulate real well in all directions. With house needs met, we still had plenty of Btu to heat the injection loop to the garage."

Heated water is sent to the garage loop via R-flex, a polyethylene-insulated, tandem underground PEX pipe. The subterranean tubing thermally connects the house buffer tank's 120-gallon volume with the garage's slightly smaller, two-temperature radiant heat system.

In heating mode, high-temp water (145 to 155°F) from the buffer tank enters the garage's control panel and then supplies two radiant zones. Water at about 125°F is sent through the 1,800 lineal feet of tubing that heats the guest quarters, and 90 to 110°F water is sent through the single, 300-foot loop of tubing embedded in the tool room's 10-by-30 foot concrete slab.

The stapled-up tubing's heat is directed upward by R-19 batting insulation below the tubing. By applying many layers of R-19 fiberglass batts, and 2-inch rigid insulation, the Wengers achieved R-90 in the ceiling and upper kneewalls of the garage.

"The massive dose of insulation started when we needed to thermally protect the long radiant supply and return tubing runs in one of the kneewalls," says Merv. "We made a cocoon for the tubing that was as long as the garage and just kept adding layers. We had a good source for the material, so we decided to buy a good bit more than we'd need, knowing that it could only help to keep heat in the building."

The only thing they didn't ask of the geothermally heated water was to heat domestic water for the guest quarters' sinks and shower, so an electric, 30-gallon tank-type water heater was placed in the radiantly heated tool room, directly below the shower.

Phase I Performance

Just before their first full heating season, the Wengers added more insulation in the ceiling of the home's main floor and replaced the potbellied stoves with a more efficient, small, centrally located Vermont Castings wood heater.

"Last winter was amazing," says Rachel. "Even though all the systems weren't operational, we had plenty of heat for the house with the geo water-to-air heat pump, the new wood heater, and a little electric radiant heat that we used. This winter will be the first for the home's main radiant system and the garage radiant, but we've prefired all parts of the system and everything went well. The thermostats are set, so all we need now is for the outdoor temperatures to drop."

"Based on our preliminary calculations and the performance we've seen so far, the Wengers will probably see a 60 to 80% drop in their energy expenses," says Yates. "The carbon footprint got a lot smaller, while they've added tremendously to the size of their comfort zone!"

Access

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