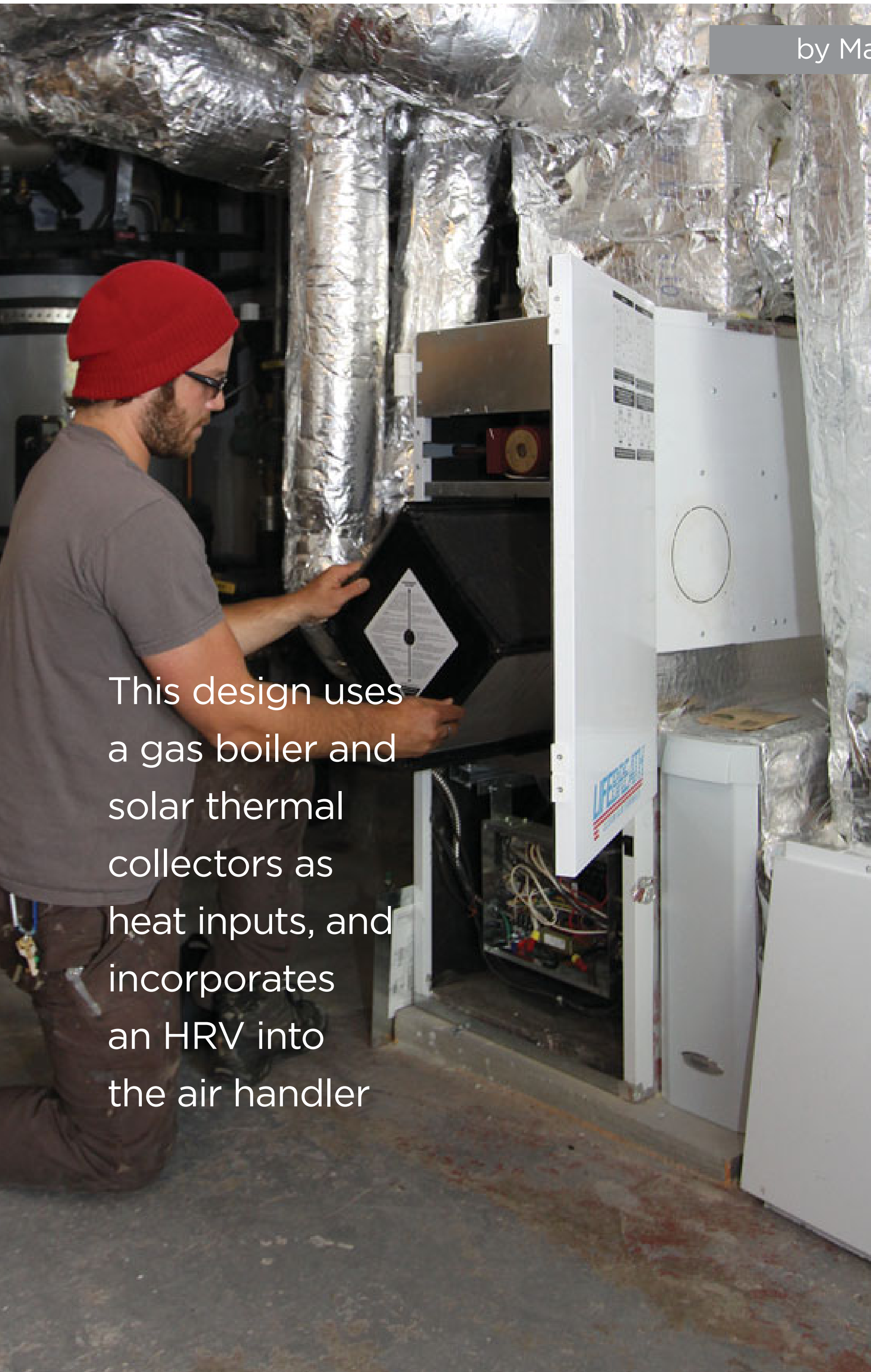
Retrofitting a High-Tech Heating System



This design uses a gas boiler and solar thermal collectors as heat inputs, and incorporates an HRV into the air handler

by Matt Golden and Adam Winter

As home performance contractors, we provide energy audits and a range of such services as air sealing, insulation, hvac work, and the like. When we inspect existing homes, we usually find heating appliances that vary in age and efficiency and were never designed to work as a system. Last summer we replaced the equipment in just such a home in San Francisco; we installed a new energy-efficient system that provides heat, hot water, and air exchange.

The 1,600-square-foot main floor of the house had been remodeled several years before, and at that time the furnace and ductwork were replaced. Despite the new equipment, the owners still had high utility bills, uneven heat distribution, and poor indoor air quality. When they decided to convert an unused ground-level basement into 800 square feet of additional living space, they contacted us to address the shortcomings of the heating system.

Our inspection uncovered a number of problems. For starters, the 100,000-Btu forced-air gas furnace was greatly oversized, even for the newly enlarged living area. The ductwork was also improperly sized and poorly sealed against air leakage. Domestic hot water came from an old, inefficient gas water heater.

Design Goals

After explaining the shortcomings of the existing equipment to the clients, we talked with them about their goals. They hoped to reduce the energy they consumed while increasing the home's comfort. With three young children, they were particularly concerned about indoor air quality.

We recommended replacing the existing equipment with a combined hydronic system, in which the same heat source — usually a boiler — provides both domestic hot water and space heating. The home would continue to have forced-air heating, but instead of the one zone there would be three; this would allow the family to selectively heat different areas. To improve indoor air quality, we would install mechanical ventilation and a whole-house air cleaner. The equipment would go in the garage, on the other side of the wall from the new living space.

The homeowners planned to install a photovoltaic system as well, so they asked about solar water heating. We explained that solar thermal collectors could supply a portion of their needs but the home would need a boiler as a backup heat source.

The system we designed relies on roof-mounted solar collectors and a small gas-fired boiler to heat the water in an insulated storage tank (**see Figure 1**). Domestic hot water is drawn directly from the tank; space heating is provided by circulating hot water from the tank through a liquid-to-air heat exchanger inside a hydronic air handler.

Figure 1. The solar thermal collectors (above) are expected to produce 40 percent of the yearly demand for heat and hot water. The Munchkin boiler (right) will fire whenever the collectors are unable to keep the water in the storage tank at or above 120 degrees.

Why Combined Hydronic?

We recommend combined hydronic systems for a couple of reasons: Replacing two combustion appliances with a single efficient boiler usually results in fuel savings, and hydronic systems work well with zoned forced-air heat. Because the stored hot water serves as a buffer against peak demand, the boiler can be smaller than it might otherwise be.

The boiler fires only when the water in the tank falls below a certain low-end set point, and it continues to run until a higher set point is reached. This increases the system's efficiency by allowing the boiler to fire infrequently and for longer periods of time. By contrast, a forced-air furnace must fire every time a zone calls for heat. Using a traditional forced-air furnace to heat a single zone in a multi-zone system causes it to operate below optimal efficiency and reduces airflow over the heat exchanger — sometimes to the point where the heat exchanger overheats and is damaged.

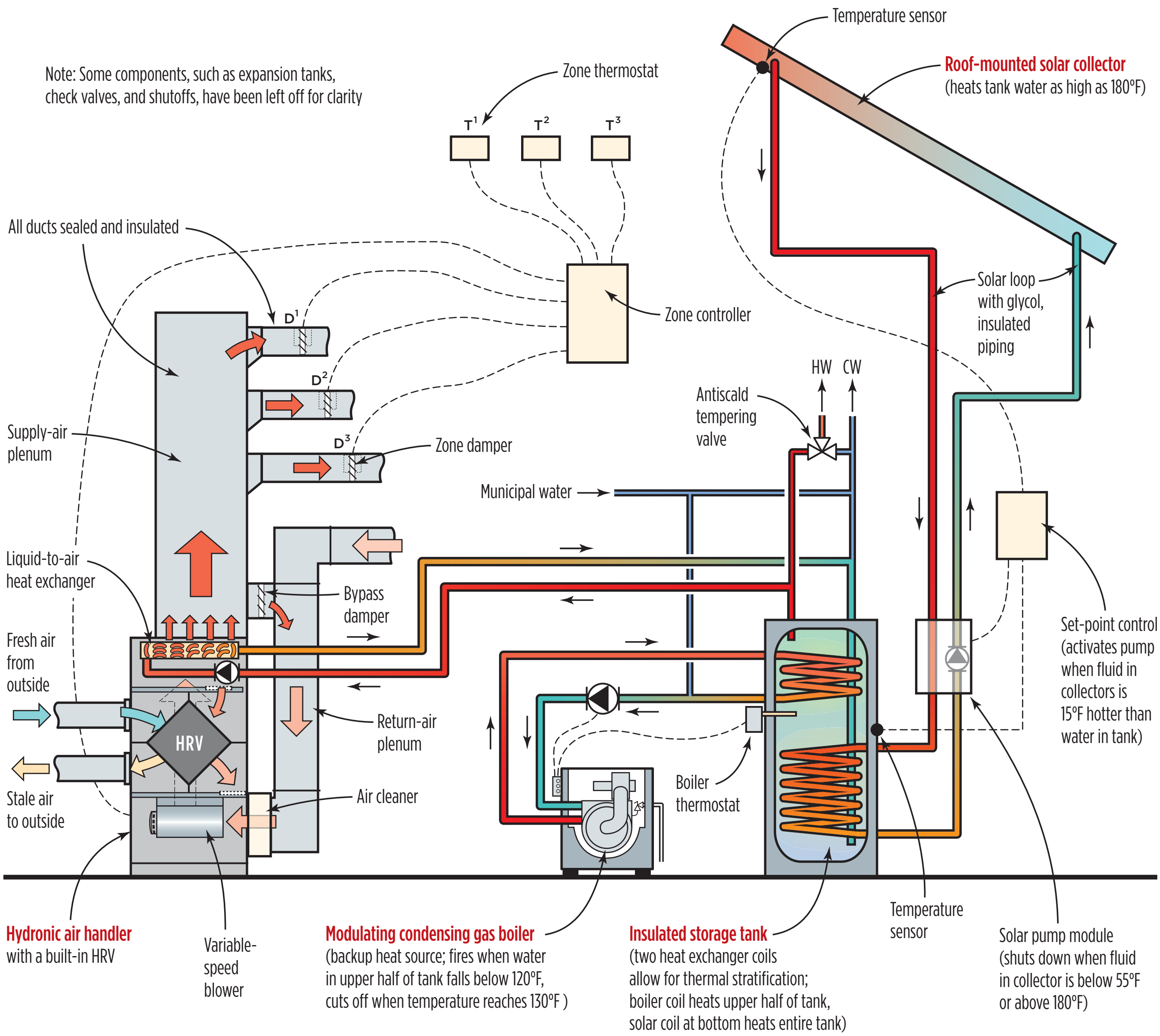
Distribution System

To ensure proper airflow, our designer used Air Conditioning Contractors of America (ACCA) *Manual D* to size the ducts and *Manual T* to size the diffusers. Heat is supplied through a pair of 6x12 trunk lines, a rectangular profile that fits neatly inside a small soffit. The trunk lines run through conditioned space between the first and second floors, feeding branch ducts to individual floor and ceiling registers. To prevent leakage and heat loss, we sealed all the ducts with water-based duct mastic and wrapped the ductwork in the garage with foil-faced insulation.

Modulating Boiler

Our designer used ACCA *Manual J* to calculate the size of the boiler. We selected an 80,000-Btu Munchkin boiler (Heat Transfer Products, 800/323-9651, htproducts.com) with a rated efficiency of 95 percent. The Munchkin is a modulating condensing gas boiler. A condensing boiler is designed so that the water vapor in the combustion gas condenses and releases its latent heat before it reaches the flue. A modulating boiler varies its firing rate based on the temperature of the return water, a highly efficient mode of operation well-suited to zoned systems. When there is only a small demand for heat — if, say, only one zone is calling — the boiler fires at a lower rate. The model we selected can operate at full efficiency between 19,000 and 80,000 Btu.

Like other condensing gas appliances, the Munchkin has sealed combustion and uses PVC plumbing pipe for the air intake



Solar thermal collectors and a backup gas boiler heat the water in the storage tank, which provides both domestic hot water and — by heat exchange in a fan-coil unit — forced-air space heating. An HRV built into the air handler brings fresh air into the house while extracting heat from the exhaust air.

and flue (**Figure 2, next page**). Combustion produces an acidic condensate that must be neutralized before discharge, which is done by running it through a cartridge filled with chips of marble.

Solar Thermal System

The solar thermal portion of the system is expected to produce 40 percent of the combined heat and hot water demand over the year — approximately 70 percent in the summer and 15 percent in the winter. When the collectors are not producing the required heat — when the sun isn't out or there's a high demand for hot water — then the condensing boiler becomes the backup heat source.

The system heats water indirectly by circulating a freeze-resistant fluid, food-grade propylene glycol, through a pair of roof-mounted solar collectors and a heat exchanger coil in the bottom of the storage tank. A set-point control (Tekmar Control Systems, 250/545-7749, tekmarcontrols.com) monitors sensors in both locations. When the collectors are 15°F hotter than the tank, a circulator is activated, circulating the glycol until the temperatures in the collector and tank equalize (**Figure 3, next page**).

The solar thermal array can heat the water to as high as 180°F in the summer and to almost as high on sunny winter

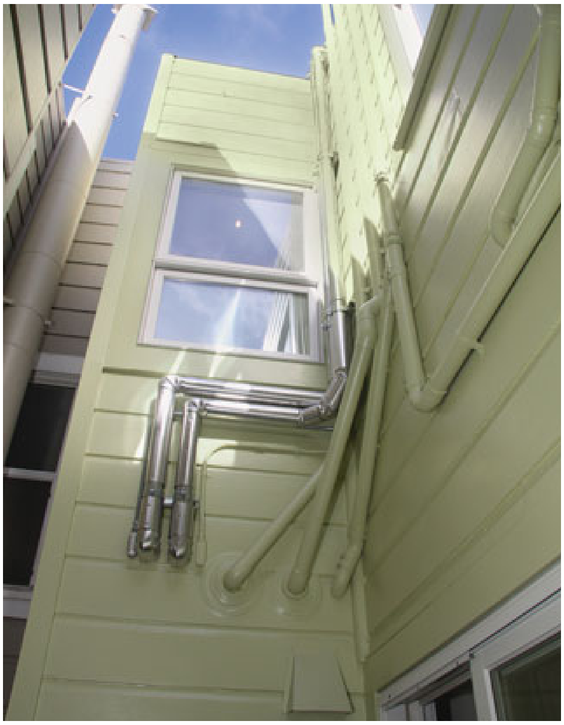


Figure 2. Aluminum cladding protects the insulation on the two pipes that carry fluid to the solar collectors (left). Slightly lower and to the right are the PVC flue and air intake for the condensing boiler. The hood by the door is the HRV's air intake. Further down the wall (above) are the HRV exhaust hood and, to the left of the exhaust, a small pipe that serves as the outflow for the boiler condensate.

Figure 3. A circulator pumps heat transfer fluid between the storage tank (left) and the solar collectors in response to a set-point control (the white box with the screen, right). The control is programmed to activate the pump when the fluid in the collectors is 15°F hotter than the water in the tank. The gray box beneath the set-point control houses the zone controller, which activates the zone dampers and air handler when a thermostat calls for heat.

days. To protect sensitive components like valves, gaskets, and air vents, the pump shuts down when the fluid in the collectors is below 55°F or above 180°F.

Stored Heat

The storage tank holds 119 gallons of water and contains two heat exchanger coils, which are located to allow for thermal stratification. The coil for the boiler is placed so that it heats the upper half of the tank, or about 60 gallons — enough to supply the combined demand of domestic hot water and space heating. The coil from the solar thermal collectors is at the bottom, so that it can heat the entire tank, giving the solar collectors priority over the boiler. Since solar heat is more or less free, it makes sense to collect and store as much of it as possible when the sun is out.

The boiler fires when the water in the upper half of the tank falls below 120°F and cuts off when the temperature reaches

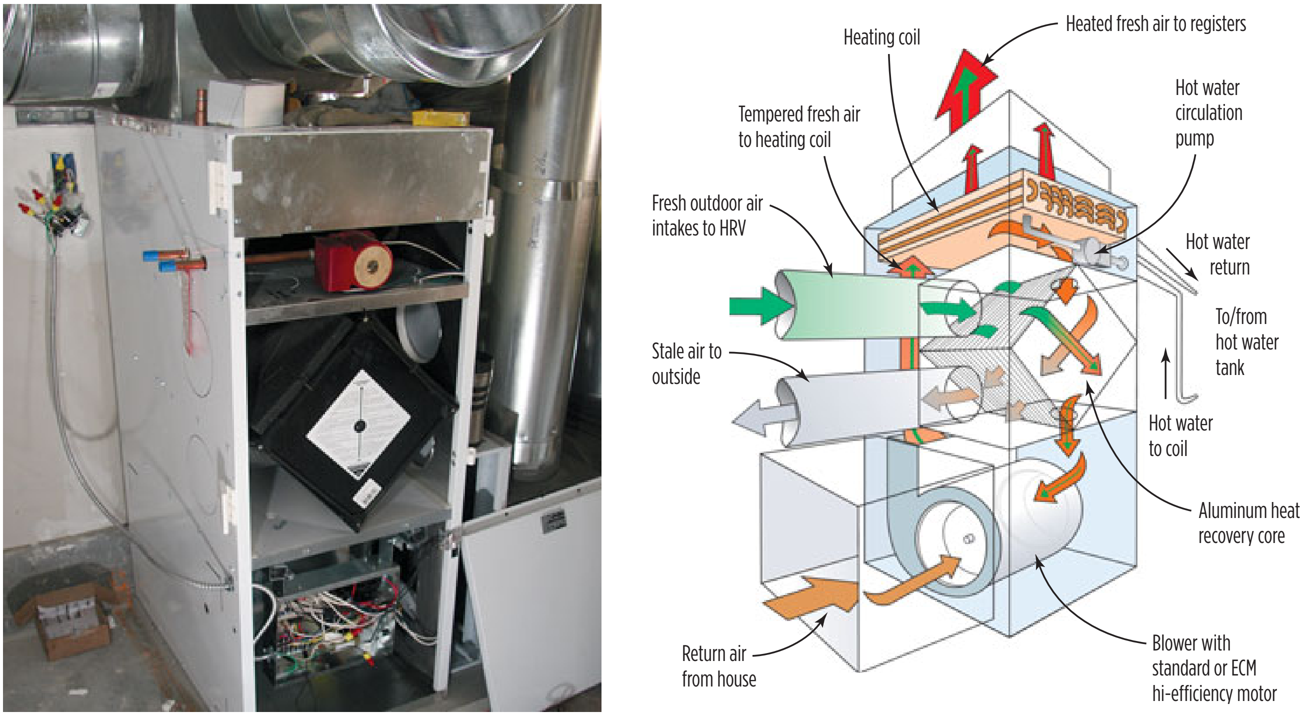


Figure 4. The air handler — a Lifebreath Clean Air Furnace — has a blower below, an HRV in the middle, and a pump and water-to-air heat exchanger coil above. Whenever a thermostat calls for heat, the blower is activated and the pump circulates hot water between the storage tank and the heat exchanger coil. The blower is powered by a high-efficiency motor that modulates between higher speeds in heating mode and low speed when only the HRV is operating.

130°F. To prevent scalding, the domestic hot-water supply passes through a tempering valve that reduces the temperature to 120°F.

Air Handler

To avoid having to integrate separate ventilation and air handler components — and to save space — we used a Lifebreath Clean Air Furnace (Aria Brands, 937/439-6676, lifebreath.com), a hydronic air handler with a built-in heat recovery ventilator, or HRV (**Figure 4**). To further improve indoor air quality, we installed an Aprilaire whole-house media cleaner (800/334-6011, aprilaire.com) between the return air plenum and air handler.

The air handler is an updraft model; it has a pump and heat exchanger at the top, an HRV in the middle, and a blower and control wiring below. When a thermostat calls for heat, it sends a signal to a zone controller, which opens the appropriate zone dampers and activates the pump and blower. The blower is powered by an efficient electronically commutated motor (ECM) that operates at high speed when the heat is on and at low speed when only the HRV is running. At low speed, the ECM uses 80 watts.

The HRV draws in fresh outside air while exhausting stale interior air. The two streams pass through opposite sides of an aluminum heat-exchanger core, which captures about 70 percent of the heat contained in the exhaust and transfers it to the incoming air. In heating mode, the HRV runs in tandem with the air handler and continuously adds outdoor air to the supply mix. Fresh air can also be introduced when the heat is off; when set to ventilation-only mode, the HRV runs for 20 minutes each hour. Ventilation can be controlled separately by a programmed seasonal setting or manually by the homeowner.

Bypass damper. The air handler is designed to produce a constant flow of air in heating mode. Closing off one or two of the zones increases the static pressure in the ductwork and causes the ECM blower motor to work less efficiently. To solve this problem, we installed an automatic bypass damper, which relieves excess pressure by allowing some of the air in the supply plenum to bleed back into the return.

The Results

The homeowners have reported that they are far more comfortable with the new heating system in place. It has been running only since the end of the summer, so we haven't yet got data on energy consumption. Based on our experience with similar systems, though, we expect their energy use will be significantly lower than before, even with the newly enlarged living space.

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