Novel, inexpensive, high efficiency dual water and space heating system

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The cost of upgrading to high-efficiency heating appliances is expensive, from 2500 to 4000 $ (uninstalled price in Canadian dollars) for a high efficiency furnace and from 1500 to 6000 $ for a high efficiency hot water tank or boiler. While the initial high cost does pay off over several years, there is an alternative high efficiency heating system at a fraction of the cost: *a high efficiency on-demand water heater to provide both domestic hot water and space heating*.

The operating principle of hot water tanks (HWTs) and furnaces is the same: heating water for domestic hot water or air for space heating. These heaters are usually powered by electricity or hydrocarbon-based fuel (natural gas, propane, heating oil). Electric units have the advantage of efficiencies approaching 100 % in site energy but the disadvantages of requiring large amounts of electricity during peak periods and the higher cost of electricity. Fuel costs are lower, but the appliance efficiency is also lower because hot exhaust gases must be vented and energy extraction from the exhaust is not 100 %.

Efficiency is a key consideration when chosing new appliances. The Annual Fuel Utilization Efficiency (AFUE) is the seasonal efficiency of a heating appliance. The Energy Factor (EF) is the fraction of useful energy output per unit energy input and is commonly used to report the efficiency of water heaters. Conventional appliances have efficiencies ranging from 50 to 80 %. Modern high efficiency appliances have efficiencies greater than 80 %. 'High efficiency' is herein defined as 80^+ percent AFUE or EF, whether condensing or not.

Appliances that function continuously, like HWTs and boilers, maintaining a ready state (in this case, a supply of hot water). This decreases the efficiency of the appliance, wastes energy, and wastes money. For example, while you are asleep, at work, on vacation, or comfortably reading this article, your HWT faithfully ensures a ready supply of hot water. The insulation on the HWT is not perfect (and never can be). Heat slowly and constantly bleeds from the HWT into the surroundings. HWTs often keep water hotter than required to increase their capacity, resulting in faster and greater heat loss. Unfortunately, the greater the temperature difference between the HWT and ambient air, the faster the heat loss. It is obviously better to have appliances that operate only when required.

Figure 1. A typical on-demand water heater: the Paloma Waiwela PH28CIFS.

Hot water can alternatively be generated only when required using an on-demand tankless water heater (ODWH). While not common in North America, ODWHs have been used in europe and asia for over 30 years. The technology is proven and robust. A typical ODWH is 35 cm × 60 cm × 30 cm (15” × 24” × 12”), wall-mounted, and operates on either natural gas or propane. Electric units are available, but have large electrical requirements and cannot supply enough hot water for more than one appliance or fixture.

The Okaloosa Gas District in Florida conducted a study in 2002 and found that a Rinnai Continuum ODWH uses 45 % less energy than a natural gas HWT (Rheem 21V40-38) and 35 % less energy than an electric HWT (Rheem 81V40D). The test procedures were derived from the “Test Procedures for Water Heaters” outlined by the Federal Register, Title 10 of the Code of Federal Regulations (CFR), Part 430. These procedures provide a standard for fair comparison between energy efficiency, energy use, and the annual operating cost of water heaters. (www.okaloosagas.com/appliances/waterHeaters/waterheatertest.cfm).

Table 1 provides information on common domestic water heating and space heating systems.

Table 1. Typical appliance price, without installation, and efficiencies of residential heating appliances. VSM refers to variable speed motors.

Unit	Price /CAN $	AFUE or EF /%	Life Expectancy /years
Mid efficience furnace	800 – 1500	50 – 80	20 – 30
High efficiency furnace	1500 – 3000	80^+	20 – 30
High efficiency furnace (w/ VSM)	2500 – 4000	80^+	20 – 30
Electric baseboard heating	1500 – 2000	95 – 100	20 – 30
Electric HWT	400 – 600	85 – 100	10 – 15
Standard fuel HWT	400 – 900	50 – 80	8 – 12
High efficiency fuel HWT	1500 – 2200	80^+	8 – 12
High efficiency boiler	4500 – 6000	80^+	20 – 30
ODHW	1200 – 2000	80^+	20 – 30

Dual water and space heating systems are not new, but have not been well received in North America, possibly due to their *historical* high cost, *historical* limited efficiency savings, *historical* large space requirements, and *current* consumer and dealer resistance to change. Previous dual systems often employed multiple HWTs or a boiler with multiple heat exchangers to supply both domestic hot water and space heating. These systems required substantial space and wasted energy maintaining reservoirs of hot water. This article introduces an advancement to existing heating technology by employing an ODWH, without a wasteful hot water reservoir, for both domestic hot water and space heating. Instead of separate heaters in the HWT and in the furnace — each with their own chimney and varying efficiencies — this system employs a single heater in the ODWH to supply hot water for domestic use and to heat air for space heating.

The primary focus of this article is towards the renovation market, where a furnace and ducting was previously used for space heating. The ODWH could equally be used in a home which previously employed hot water heating. In new home installations, the ODWH can be used with hydronic heating.

Components, features, and operation of a dual system

Figure 2 gives the schematic of the dual system described herein. Briefly, an ODWH heats water for domestic hot water and to supply a fan-coil heat exchanger for space heating. The fan-coil and ODWH exist in a closed loop configuration, with a pump circulating the fan-coil outflow into the intake of the ODWH. Domestic hot water is extracted from the loop and tempered as necessary to minimize the risk of thermal injuries at the taps. The valve assembly before the circulating pump is used in descaling the ODWH and fan-coil: the center, normally open, valve is closed; the circulating pump draws descaling fluid from the left valve and discharges it out the right valve.

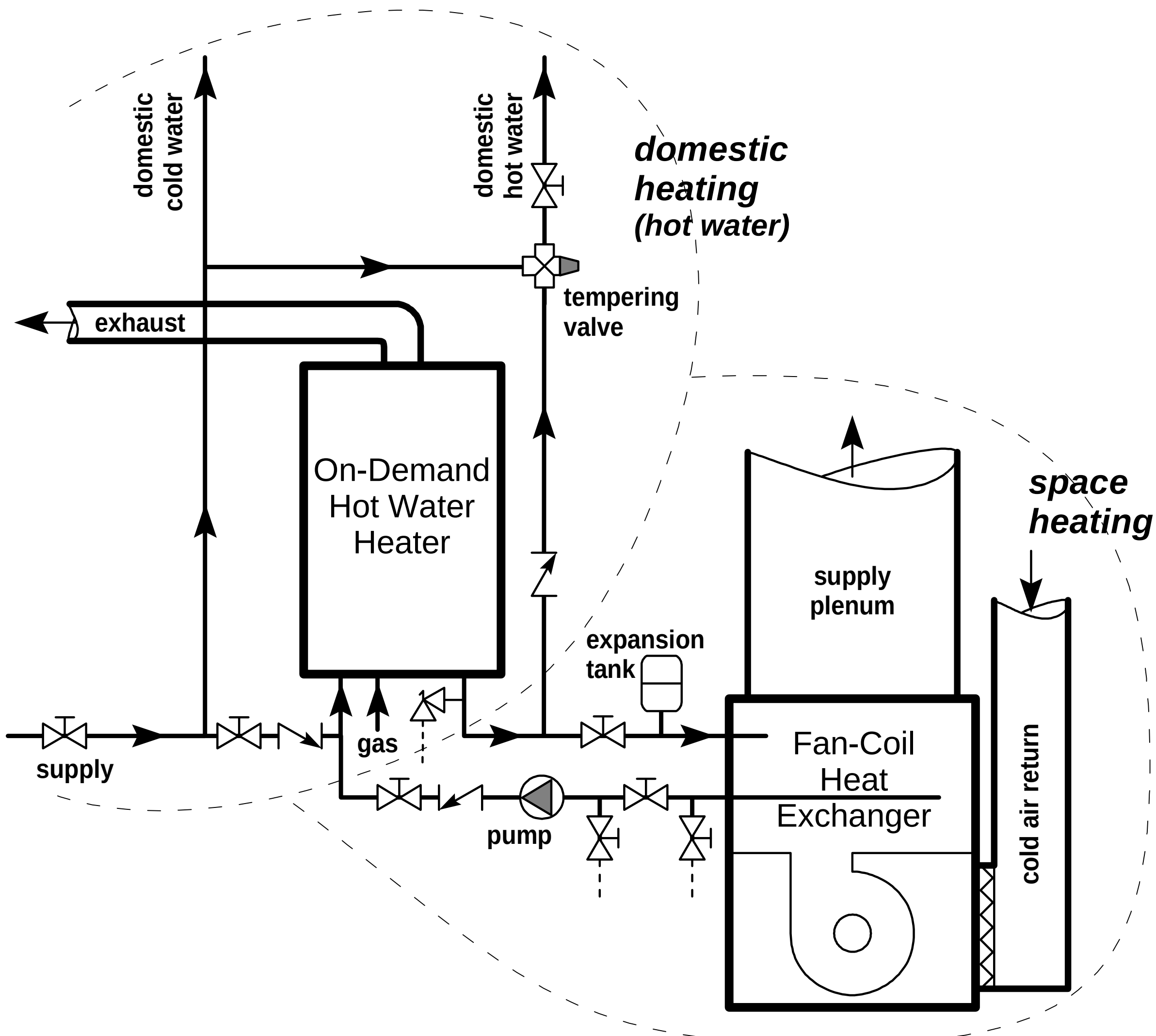

Figure 2. Schematic of the dual domestic hot water and space heating system. All water lines should be copper until beyond the tempering valve.

To simultaneously meet the domestic hot water and space heating requirements of a typical home, the ODWH should be able to heat water to 80 °C (175 °F) and have energy output greater than 180 000 BTU per hour (BTUh). Bosch, Noritz, Paloma, Rinnai, and Tagaki have one or more models that meet these requirements. A Paloma Waiwela (model PH28CIFS; 199 900 BTUh; 1400 $) ODWH was used in the test system. The Waiwela ODWH can be vented horizontally. A mixture of stainless steel elbows and linear segments totaling three meters cost approximately 500 $. Some ODWHs employ a dual vent system and can draw in outside air for combustion, which further increases efficiency. ODWHs have many benefits over conventional water heaters (HWTs and boilers). The benefits include

- efficiencies of 80^+ %;
- hot water only when needed (no wasteful hot water reservoir);
- water not over-heated to extend reservoir supply;
- an infinite supply of hot water at a limited flow rate;
- life expectancies of 20 to 30 years, compared with 8 to 12 years for HWTs (boilers and furnaces have a comparable life expectancy to ODWHs); and
- lower purchase cost and comparable installation costs.

Space heating can be accomplished using radiant floors, baseboards, or a fan-coil connected to existing ducting.

Specially designed subfloors can accommodate hydronic lines. A heated fluid pumped through baseboards or the hydronic tubing conducts heat to the room. Hydronic systems cannot be retrofitted without major costly renovations. They are, however, easy to install during the construction of new homes and provides clean, uniform, and quiet space heating. The ODWH, through a liquid-liquid heat exchanger, is an inexpensive high efficiency heat source for hydronic lines.

A fan-coil is a liquid-air heat exchanger, much like an automobile radiator (conventional furnaces are air-air heat exchangers). The high heat capacity of water means the fan coil can operate at lower temperatures than furnaces. Operating on natural gas, a furnace produces a maximum combustion temperature of 2150 °C in half of the heat exchanger, used to heat room air at approximately 15 °C is in the other half. This high temperature differentials in furnaces leads to static thermal stresses during operation and variable thermal stresses when turning on and off. While purportedly designed for these extreme temperature differentials, premature heat exchanger failure is a common occurrence due to design flaws and manufacturing defects. Fan-coils are commonly used with heat pumps, geothermal, and solar heating systems. They operate at a maximum temperature of the heating fluid boiling point (below 100 °C for water), resulting in significantly less thermal stress. A variable speed fan-coil (Energy Saving Products model LV-120; 1100 $) was used in the test system and

Input water temperature /°F	**Energy output /BTU**	
	LV-120	**LV-140**
130	48700	56600
140	56300	65600
150	64000	74600
160	71700	83600
170	79400	92600
180	87200	101600

Equivilant energy output of the fan coils, adjusted to a flow rate of 7.5 gallons per minute. <www.Hi-Velocity.com>

integrated into the existing ducting by replacing the furnace. Benefits of a fan-coil space heating system include

- up to 100 % efficient. (No energy is wasted since the out-flow water is recycled back into the ODWH.);
- no second chimney or exhaust; and
- the ability to function as a central cooling system if a cold supply is available.

The domestic heating component in figure 2 is typical for any domestic water heater. Because the ODWH has the capability to heat water to 82 °C (180 °F) and higher water temperatures are required for space heating in winter, a tempering valve (Honeywell model AM101; 100 $) was used in the system to ensure that the domestic hot water temperature stays reasonable (50 °C (122 °F)). Check valves ensure the correct water flow when the space-heating component is functioning.

The space heating component exists in a closed-loop and uses a circulating pump (Taco model 0011-BF4; 350 $) to circulate water through the ODWH and fan-coil. The pump is controlled by the fan-coil and wired to start when the thermostat requests heat. Check valves prevent the pump from circulating warm water into the domestic cold supply or from extracting water and possibly air from the domestic hot water lines. The pump is located downstream from the heat exchanger to minimize its thermal load and extend its life. Because the space heating system is closed loop and subject to thermal cycling, a thermal expansion tank (Diatrol model 537; 110 $) is incorporated to accept thermal expansion. The check valve on the domestic hot water line is situated a distance from the tee to provide a trap for gases potentially entrained in the water flow.

In operation, the ODWH should be set to give hot water at as low a temperature as possible to minimize thermal stress, minimize scaling, increase the efficiency, and increase the operational life of all components. During periods where space heating is minimal, the ODWH should be set to 50 °C, which is sufficient for domestic hot water and space heating. With outside temperatures below –10 °C, the ODWH should be set to maintain a comfortable interior temperature with a duty cycle of less than twenty percent. This duty cycle was chosen to reduce the chance of insufficient domestic hot water, but all appliances are rated to function with at least a 95 % duty cycle.

Maintenance

Seasonally adjusting the ODWH temperature to the lowest possible temperature minimizes the rate of scale build-up in the system. Scale (calcium and magnesium carbonate) is less soluble in hot water. If scaling is present, it may be removed by flushing the ODWH and fan-coil with a descaling agent. Depending on the hardness of the local water, this may have to be done between every few years and never.

On start-up, the stale water in the fan coil can be flushed by opening the drain line. During the heating season, water will not stagnate because it is drawn off by the domestic supply.

Average Outdoor Temperature	Approximate ODHW Setting
above 10 °C	50 °C (125 °F)
–10 to 10 °C	60 °C (140 °F)
–30 to –10 °C	65 °C (150 °F)
below –30 °C	70 °C (160 °F)

A homes ODHW setting may vary because of home size and insulation rating.

Test system

The test home is an 88 m^2 (950 ft^2) bungalow with a fully finished basement (176 m^2 total) in Edmonton, Alberta, Canada, built in 1959 with 10 cm (4 in.) walls. The novel dual heating system proposed herein was installed in fall 2005. It has performed flawlessly for a family of two adults and one youth. Set at the default temperature of 50 °C, the system functioned successfully when the outside temperature was above –10 °C. When the outside temperature ranged from –20 to –40 °C for a three week period, the system functioned successfully when the ODWH was set to supply water at 70 °C (160 °F). To date, there is no evidence of scale in the system.

Figure 3. A picture of the installed test system. The system follows the schematic in Figure 2. The fan coil is on the other side of the cold air return. All hot water lines are insulated.

Pre-installation energy usage is not known, but post-installation energy usage (since November 2005) for space heating and hot water is 5.9 BTU/ft^2/HDD (HDD = heating-degree day at a 65 °F base; 67 MJ/m^2/HDD), 39 % of the national average of 15 BTU/ft^2/HDD and in the top 15 % of all single-family homes in North America (www.homeenergy.org/consumerinfo/benchmarking-energy-usage.php).

Electrical usage does contribute to home heating. Considering both electricity and natural gas, the 1959 test home has an energy usage of 9.1 BTU/ft^2/HDD. In 2005, Michigan's Habitat for Humanity built several Energy Star homes. The Habitat homes averaged a total energy (natural gas and electricity) usage of 8.5 BTU/ft^2/HDD (www.warmtraining.org/pdf/energy-report-2006.pdf).

My thanks to Anna Jensen for the opportunity and trust to design and install this system.

Observations

By design, an ODWH can produce a constant amount of hot water indefinitely. The Paloma Waiwela is rated to supply 28 L/min (7.4 gal/min) with a temperature increase of 25 °C (45 °F). ODWHs are advertised to produce sufficient hot water to supply three appliances simultaneously (shower, washing machine, dishwasher, etc.). The fan-coil counts as approximately two appliances. Thus, there may be the occasional time where demand exceeds supply. This occurred twice since fall 2005, but was rectified in minutes (waiting for the dishwasher to fill with water before showering) rather than hours (waiting for a HWT to heat more water).

In circumstances where a single ODWH provides an insufficient supply (very large homes or commercial buildings), additional ODWHs can be added in parallel or separately for hot water and space heating. This multiple ODWH system will still be less expensive than conventional systems with multiple furnaces or larger boilers.

Appliances that may require water hotter than 50 °C, like dishwashers and sanitizing washing machines, will take longer to complete their cycle as they must heat the water to the required temperature.

Numerous contractors made negative and condescending comments when told about or observing this system during installation. I attribute their comments to be based in ignorance of technologies beyond what they normally work with and in a fear of the unknown. To address the most common comment, “This violates the building code.”, my response was always, “What section of the building code is violated?” In Alberta, Canada, the answer is *NONE*! Yes, this configuration is different, but ***different does not mean wrong***. Since building codes vary from region to region, it is important to verify compliance in your area.

Summary

A dual water and space heating system is shown to be capable of providing hot water for domestic hot water and space heating to a residential home in Edmonton, Alberta, Canada year round, including winter periods with temperatures of –40 °C (–40 °F). This novel system replaces both the conventional furnace and hot water tank with a single high efficiency appliance. With a total cost of 3600 $, this system is about half the price of separate high efficiency appliances and has numerous benefits over conventional appliances:

- without the high thermal stresses of furnaces,
- without the wasteful hot water reservoirs of hot water tanks and boilers,
- with the ability to provide an unlimited supply of hot water,
- with up to triple the life expectancy of hot water tanks, and
- requiring less space and less venting.

This system is ideal for residential and commercial applications.

Disclosure

Roy Jensen is a chemistry instructor in Edmonton, Alberta. No remuneration was received from any company to use or promote their products in the installed system or this article.

My thanks to the Paloma Corporation for the image of the Paloma Waiwela PH28CIFS and to the staff at Bartle & Gibson Co., Ltd. for reviewing this article and providing much of the information in table 1.

