DOE/GO-102001-1165
NREL/BK-710-29267
May 2001

5.3.1 Heat-Recovery Water Heating

Heat recovery is the capture of energy contained in fluids or gases that would otherwise be lost from a facility. Heat sources may include heat pumps, chillers, steam condensate lines, hot air associated with kitchen and laundry facilities, power-generation equipment (such as microturbines or fuel cells), and wastewater drain lines.

Opportunities

There are two basic requirements for heat-recovery water heating: (1) hot water demand must be great enough to justify equipment and maintenance costs, and (2) the waste heat temperature must be high enough to serve as a useful heat source. Large facilities such as hospitals and military bases often have the perfect mix of waste heat and demand for hot water to effectively use waste-heat-recovery systems for water heating. Consider heat-recovery water heating whenever adding or replacing large heating or air-conditioning equipment. For example, double-bundle chillers can easily provide for the recovery of heat normally lost to a cooling tower. The simplest heat-recovery water preheaters can even work with small commercial kitchens and housing units.

Technical Information

How waste heat is captured and utilized depend upon the temperature of the waste heat source. Where water temperature of 140–180°F (60–82°C) is required, waste heat sources with higher temperatures should be used. Lower-temperature sources, such as hot kitchen air or drainline water, may require mechanical systems to concentrate the heat or supplemental heating using another fuel (i.e., the waste heat serving to *preheat* the water).

Hot gas heat exchangers. The refrigeration cycle of an air conditioner or heat pump provides an opportunity to recover heat for water heating. HVAC compressors concentrate heat by compressing a gaseous refrigerant. The resultant superheated gas is normally pumped to a condenser for heat rejection. However, a hot-gas-to-water heat exchanger may be placed into the refrigerant line between the compressor and condenser coils to capture a portion of the rejected heat. In this system, water is looped between the water storage tank and the heat exchanger when the HVAC system is on. Heat pumps operating in the heating mode do not have waste heat because the hot gas is used for space heating. However, the heat pump system can still heat water more efficiently than electric resistance heating.

Double-bundle condensers. Some chillers have condensers that make it possible to heat water with waste heat recovery. Double-bundle condensers contain two sets of water tubes bundled within the condenser shell. Heat is rejected from the system by releasing superheated gas into the shell and removing heat as the refrigerant condenses by one of two methods. During the heating season, water pumped through the "winter bundle" absorbs heat that can be used for water heating or heating the perimeter of the building. During the cooling season, water pumped through the "summer bundle" rejects heat to the cooling tower after hot water needs are met.

Heat from engines. Heat exchangers can be placed on exhausts of reciprocating engines and gas turbines to capture heat for water heating or steam generation. Water jackets may also be placed on engines in order to capture heat from the engine and exhaust in series. Some of this equipment also acts as a silencer to replace or supplement noise-reduction equipment needed to meet noise-control requirements. Systems for domestic heating are unpressurized, but temperatures above 210°F (99°C) are possible with pressurized systems. Designers must be careful that the pressure drop is less than the back pressure allowed by the engine manufacturer.

Waste heat from electrical power generation can also be used for water heating. With fuel cells and microturbines beginning to be used for distributed power generation in buildings, for example, there are opportunities to recover the waste heat. See *Section 5.8.8 – Combined Heat and Power*.

Heat from boiler flues. Hot flue gases from boilers can provide a source of waste heat for a variety of uses. The most common use is for preheating boiler feed water. Heat exchangers used in flues must be constructed to withstand the highly corrosive nature of cooled flue gases.

Source: WaterFilm Energy, Inc.

The gravity film exchange (GFX) drainline heat exchangers —technology developed under a DOE grant—make sense in facilities with significant water heating loads, such as kitchens, laundromats, prisons, and military barracks. The system shown above is being installed in a hotel.

Steam condensate heat exchangers. Buildings with steam systems for space heating or kitchen facilities may recover some of the heat contained in hot condensate. Condensate is continuously formed in steam systems when steam loses heat in the distribution lines or when it performs work. A condensate receiver reduces steam to atmospheric pressure to allow reintroduction into the boiler. Condensate heat for heating water can be captured by a heat exchanger located in the condensate return before the receiver.

Heat pump water heaters. Rooms containing laundries and food preparation facilities are often extremely hot and uncomfortable for staff. Heat from the air can be captured for heating water by using a dedicated heat pump that mechanically concentrates the diffuse heat contained in the air. These systems are discussed in *Section 5.3 – Water Heating.*

Refrigeration equipment. Commercial refrigerators and freezers may be installed with condensing units at one location. This will enhance the economic feasibility of capturing heat from hot refrigerant gases for water heating.

Drainline heat recovery. Energy required to heat domestic water may be reduced by preheating with waste heat from drainlines. Kitchens and laundries offer the greatest opportunities for this type of heat recovery since water temperatures are fairly high and schedules are predictable. Drainline-heat-recovery systems can also work in group shower facilities (dormitories, barracks, prisons, etc.) and in residential housing units. The simplest such system has a coil of copper pipe wrapped tightly around a section of copper drainline. Cold water flowing to the water heater flows through this coil and is preheated whenever hot water is going down the drain. More complex systems with heat exchangers within the drainline must be designed to filter out waste materials or provide back-flushing to remove sediment that could cause clogging. It is also necessary to ensure that potable water is not fouled by the wastewater.

References

"Heat Exchangers in Aggressive Environments," Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), Analysis Series #16, 1995.

Vasile, C. F., "Residential Waste Water Heat Recovery System: GFX," Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), No. 4, December 1997.

Heat Recovery from Wastewater using a Gravity-Film Heat Exchanger
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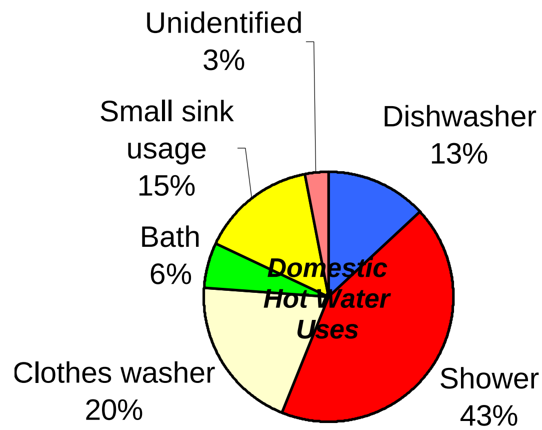
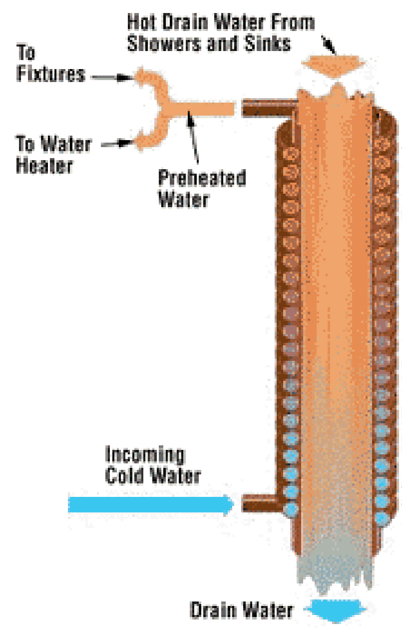
Introduction—



There are a number of uses of hot water in buildings including showers, tubs, sinks, dishwashers and clothes washers. In virtually all of these cleaning applications, the wastewater retains a significant portion of its initial energy – energy that could be recovered and used. Estimates by the U.S. Department of Energy (DOE) indicate that the equivalent of 235 billion kWh worth of hot water is discarded annually through drains, and a large portion of this energy is in fact recoverable. To capture heat from wastewater produced by all sources in a dwelling and to put it to use would require a regenerator-type, double-walled heat exchanger – one that can capture heat from wastewater generated by one fixture or appliance (e.g. a clothes washer) and apply this heat to assist another hot water demand that may occur at a later time. In cases where wastewater generation is in sync with the need for hot water (e.g. a shower), a non-regenerative, straightforward heat exchanger can be used. Heat exchanger systems of each type are available for use in buildings.

The Gravity-Film Heat Exchanger (GFX)—

The GFX is a simple heat exchanger design for heat recovery that arose from a grant under the DOE Inventions Program. This straightforward design is a vertical, counterflow heat exchanger that extracts heat out of drainwater (usually warm) and applies this heat for preheating the cold water entering the building. The GFX is installed into a section of available, vertical drain line in a dwelling. The design (see right) consists of a 3- or 4-inch central copper pipe (carries the warm wastewater) with ¼in copper coils wound around the central pipe. Heat is transferred from the wastewater passing through the large, central pipe to cold water simultaneously moving upward through the coils on the outside of the pipe. The coils are flattened a little where they touch the pipe and solder-bonded to the pipe to reduce thermal contact resistance and improve heat transfer. The key to this patented device was the observation by the inventor that wastewater clings in a flim-like fashion to the inside wall of the pipe as it undergoes gravity flow in the open drain, and this greatly improves the effectiveness of heat transfer from the falling drainwater to the copper coils that wind around the pipe.



The GFX has a number of advantages for wastewater heat recovery:

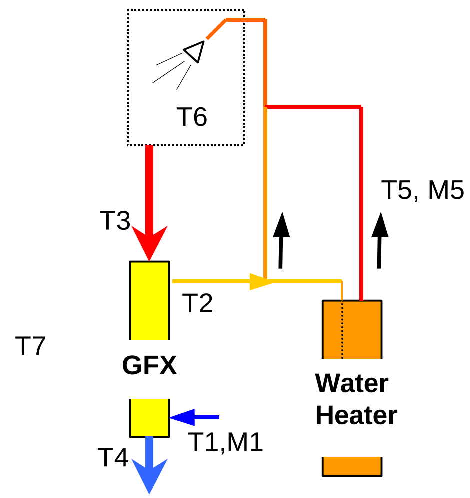
Rugged, no moving parts;
All copper construction;
Compact: Replaces about five feet of vertical drain line; can be installed where drains are piped including inside stud walls;
Sweat connections used at each end of the coil where line pressure exists; rubber connectors used to attach each end of the copper pipe to the drain ;

Models are available with multiple, parallel coils outside the central pipe to reduce pressure drop.

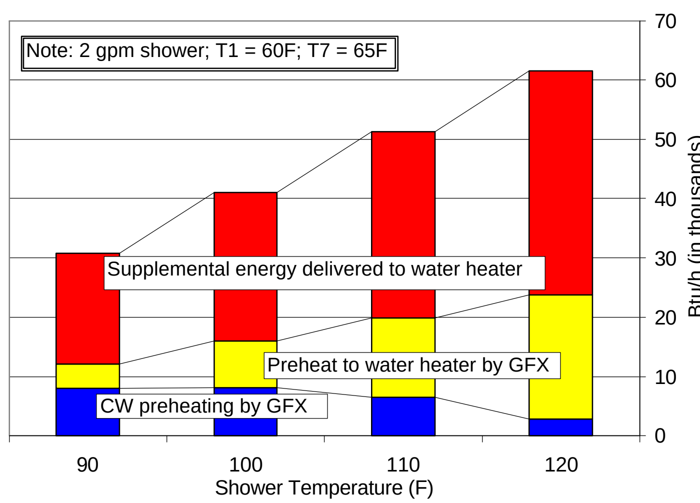
Since the GFX has relatively little thermal mass, it is unable to store much heat energy for a later use. Consequently, the GFX is designed to work best then there is coincidence between the production of warm wastewater and the need for hot or warm water. For example, a GFX would not be particularly beneficial for preheating water to a bath whereas it would be ideal for use with showers where the use of hot or warm water for the shower and the production of wastewater from the shower happen at the same time. Small sinks could also benefit from a GFX if water flows to and from the sink at the same time.

GFX Performance—

To evaluate the performance of the GFX in a typical residential application, we installed a GFX system in the basement of a single family home in Knoxville, Tennessee, instrumented the system and performed experiments to measure its performance. The basement layout of the water heater, entering water piping and distribution piping to the home were such that the hot and cold water to the shower (as well as all other fixtures) first passed through the GFX as shown in the figure at the right. For the evaluation, we ran the shower for several settings ranging from the warmest shower temperature available (no cold water to the shower) to the coolest reasonable shower temperature (90°F). During this time, we measured water flowrates (M's) and water temperatures (T's) including the shower temperature, T6, and the ambient air temperature, T7. We maintained each setting for several minutes to allow temperatures to reach constant values before measurements were recorded.



We found that the GFX could raise temperature of the inlet temperature from 60°F to 85°F by maintaining shower conditions at 2.0 GPM and 120°F (water heater setpoint). We noticed that under these conditions, the temperature of the wastewater inlet to the GFX unit (T3) was 12 F° lower than the shower temperature (T6) due to heat losses between the shower drain and the GFX. From measured temperatures and water flows through the GFX during this experiment, we calculated the total amount of heat transferred by the GFX and the supplemental heat delivered by the water heater. The GFX preheats the cold water to the shower as well as the inlet water to the water heater, and the distribution of preheating depends on the end-use (shower) temperature as shown at the right. In this figure, the total preheating by the GFX is shown by the two lower segments of each bar, and the upper segments indicate heat provided by the water heater. With cooler shower temperatures, more of the GFX contribution goes to preheating the cold water, whereas for warmer showers (e.g. 120°F), most of the energy from the GFX is used for preheating hot water. Over the range of shower temperatures studied, the GFX saved about 40% of the total energy needed for the shower in this experiment.



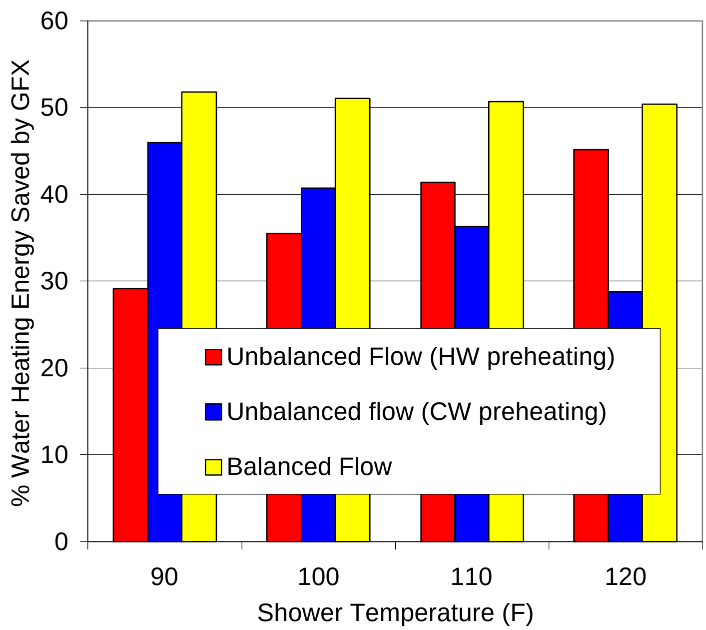
Installation Hints—

We used data from the experiment to develop a system model of the GFX. Based on the system model, we determined how several installed piping configurations to and from the GFX as well as other factors affect the performance of the GFX.

Balanced vs. Unbalanced Flow. There are three basic ways that piping to a GFX system can be installed: balanced flow, unbalanced flow for preheating cold water, and unbalanced flow for preheating water to the water heater. In balanced flow, all of the water that passes into the building also passes through the GFX before the split to the water heater occurs. The GFX in the experimental study was installed for balanced flow; accordingly, the GFX preheats all of the shower water including flow to the cold water side of the shower faucet as well as flow through the water heater to the hot water side of the faucet. Since the flows on both sides of the GFX heat exchanger are equal (balanced), the heat exchanger performance is higher than for any other flow arrangement. In balanced flow, the temperature drop of the drain water always matches the temperature increase of the incoming water.

The impact of unbalanced flow on GFX performance is less obvious. In unbalanced flow configurations, the GFX preheats either the water to the cold side of the faucet or water through the water heater, but not both. In this case, the wastewater flowrate through center of the GFX is higher than the water flow through the tubing on the outside of the GFX. This means that the rise in temperature of the freshwater through the GFX is greater than the change in temperature of the wastewater as it flows through the GFX. This apparent advantage is lost however, since the fresh water flow through the GFX is smaller for unbalanced flow than for balanced flow at a given wastewater flowrate.

To understand how balanced or unbalanced flow affects the performance of the GFX, we modeled three cases for a single shower: (1) balanced flow piping to the GFX, (2) unbalanced flow with the GFX used for preheating only cold water to the shower, and (3) unbalanced flow where the GFX is used for preheating water to the water heater. In accord with the DOE Water Heater Test Procedure, we assumed a water heater setpoint of 135°F and 58°F to be the incoming water temperature to the building. The results of this analysis shown at the right indicate that the GFX saves more energy under balanced flow conditions for all shower temperatures – approximately a 50% savings in water heating energy. In the cases of unbalanced flow, we found that the energy saved by the GFX depended on the end-use (shower) temperature as shown. Savings ranged from 30% to about 45% over all reasonable shower temperatures for the unbalanced flow case. Where it is impractical to install the GFX for balanced flow, using the GFX to preheat water to the water heater (HW preheating) is a reasonable option. Further, there would be no tempering of the cold water delivered to the fixtures in the dwelling.



Wastewater Temperature. Based on the experiment, we determined that the temperature of the wastewater stream into the GFX has a large effect on GFX performance. The temperature of wastewater entering the GFX from a 120°F shower was appreciably cooler than the shower temperature due to heat losses from the drain line. Had it been possible to insulate the drain line between the shower and the GFX, its performance would have been higher. In the systems modelled, we assumed that the shower temperature was 12 F° higher than the wastewater stream entering the GFX unit. Had we assumed that there was no heat lost by the shower drain water before it reached the inlet to the GFX, the water heating energy savings would have increased by 10% over what is shown in the chart above.

Economics—

A recent field evaluation of the GFX conducted by Pennsylvania Power and Light found the simple payback of a residential GFX system to range from 2 to 5 years. This was based on an installed GFX cost of $500 and electricity savings ranging from 800 kWh/y to 2300 kWh/y depending on the daily average number of showers in each home. The economics of the GFX improved with the number of daily showers in the residence as expected. In general, buildings that require large amounts of hot water for showers (e.g. homes of families with several children, multifamily apartments or barracks with showers on a common drain line) would be ideal candidates for the GFX and would lead to shorter paybacks.

In addition to operating cost reductions based on energy savings alone, the GFX provides additional benefits. By recovering heat from drainwater and simultaneously using this heat for preheating water to the water heater, the GFX effectively shortens the time needed for the water heater to recover. This is important if the existing water heater is undersized, or if there are more showers than usual taken back-to-back. Since heat is extracted from drainwater by the GFX, the capacity of the water heating system is increased. This means that it is possible to lower the thermostat setting on the water heater without directly affecting the capacity of the water heating system. These benefits, however, depend on hot water consumption patterns and the fraction overall hot water consumption that is amenable to heat recovery by the GFX.

Summary—

The GFX is a simple and effective method for significantly reducing the energy needed to produce hot water. The savings in water heating energy depends on the specific installation and hot water consumption patterns; however, based on our measurements, a 50% savings in the energy needed to heat shower water seems reasonable. The delivered performance of a GFX system can be improved by using balanced flow and, if possible, insulating the drain line to the GFX. The impact on overall hot water energy consumption depends on the fraction of total hot water consumption that simultaneously produces warm drainwater. Good candidates for GFX application in the Federal sector would be dormitories and barracks, health facilities, as well as commercial and industrial applications that produce waste heat that could otherwise be used for preheating.

Where to go for further Information—

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