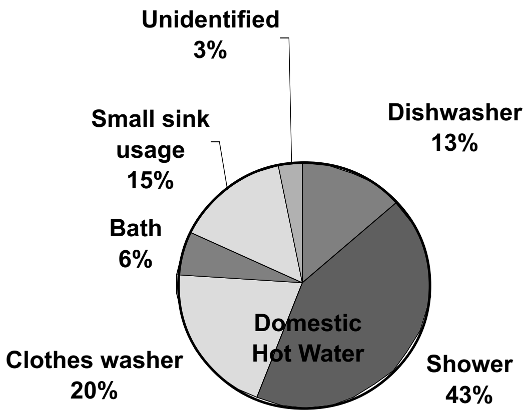
DOE/EE-0247

Heat Recovery from Wastewater Using a Gravity-Film Heat Exchanger

Technology to capture heat from wastewater

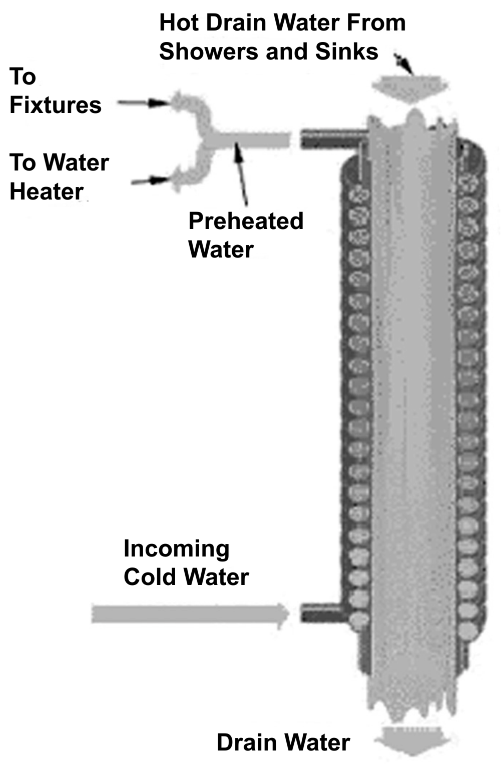


Introduction

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 based on the U.S. Department of Energy (DOE) test procedure for water heaters indicate that the equivalent of 350 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 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. If wastewater generation is concurrent with the need for hot water (e.g., a shower), a nonregenerative, 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 was developed under a grant from the DOE Inventions Program. This straightforward design is a vertical, counterflow heat exchanger that extracts heat out of drainwater (usually warm) and applies it to preheat the cold water entering the building. The GFX is installed into a section of available, vertical drain line in a dwelling. The design consists of a 3- or 4-inch central copper pipe (that carries the warm wastewater) with 1/2-in. 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 to increase the contact area and improve heat transfer. The key to this patented device was the inventor's observation that wastewater clings in a film-like fashion to the inside wall of the pipe as it undergoes gravity flow in the open drain, and this warm, falling film transfers heat through the pipe



Technology Focus

An update on technologies for energy and resource management

Prepared by the New Technology Demonstration Program

wall to the incoming cold water that passes through the copper coil wound 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 at each end of the coil where line pressure exists; rubber connectors to attach each end of the copper pipe to the drain
- Available with multiple parallel coils outside the central pipe to reduce pressure drop.

Because the GFX has relatively little thermal mass, it is unable to store much heat energy for later use. Consequently, the GFX is designed to work best when the production of warm wastewater and the need for hot or warm water coincide. For example, a GFX would not be particularly beneficial for preheating water for a bath, but it is ideal for use with showers where the use of hot or warm water for the shower and the production of wastewater from the shower occur 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 60-inch GFX system in the basement of a single family home in Knoxville, Tennessee. We 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 Figure 1. For the evaluation, we ran the shower at several settings, ranging from the warmest shower temperature available (no cold water to the shower) to the coolest reasonable shower temperature (90ºF) by adjusting the hot and cold water valves. During this time, we measured water flowrates (M) and water temperatures (T) 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 the inlet temperature from 60ºF to 85ºF by maintaining shower conditions at 2.0 GPM and 120ºF (water heater setpoint; see Figure 2). We noticed that, under these conditions, the temperature of the wastewater inlet to the GFX unit (T3) was 12 Fº 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 heat provided 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 in Figure 2.

In Figure 2, 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., 120ºF), 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

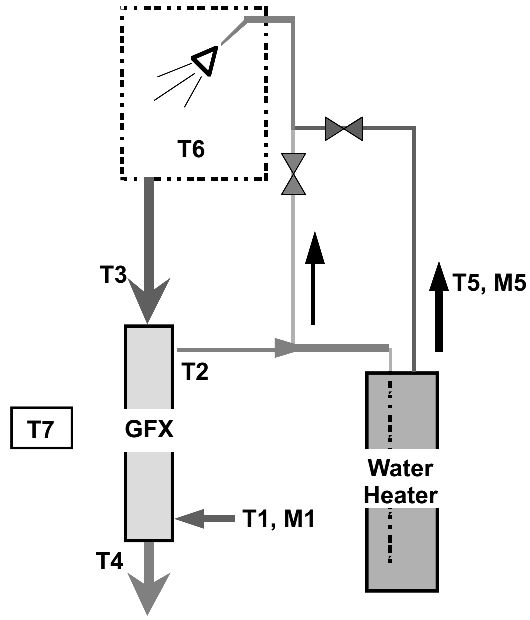


Figure 1. Layout of GFX system in residential application.

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. This arrangement ensures that the incoming water is balanced by an equal flow of drainwater. 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. Where 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.

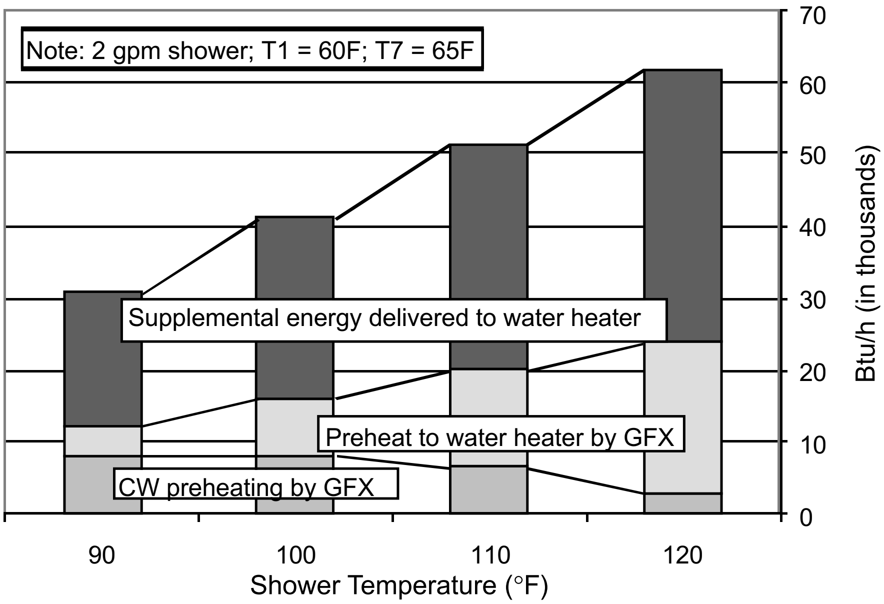


Figure 2. Heat exchange from GFX.

The impact of unbalanced flow on GFX performance is less obvious. In unbalanced flow configurations, the GFX preheats the water to the cold side of the faucet or the water through the water heater but not both. In this scenario, the wastewater flowrate through center drain pipe of the GFX is higher than the water flow through the tubing on the outside of the GFX because the wastewater includes cold water that bypasses the GFX. Thus for equal shower drain temperatures and flowrates, 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, because 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 where the GFX preheats only cold water to the shower, and (3) unbalanced flow where the GFX preheats water to the water heater (see Figure 3). In accord with the DOE Water Heater Test Procedure, we assumed a water heater setpoint of 135ºC and an incoming water temperature of 58ºF. The results of this analysis, shown in Figure 3, indicate that the GFX saves more energy under balanced flow conditions for all shower temperatures—approximately 50% savings in water heating energy required for a shower.

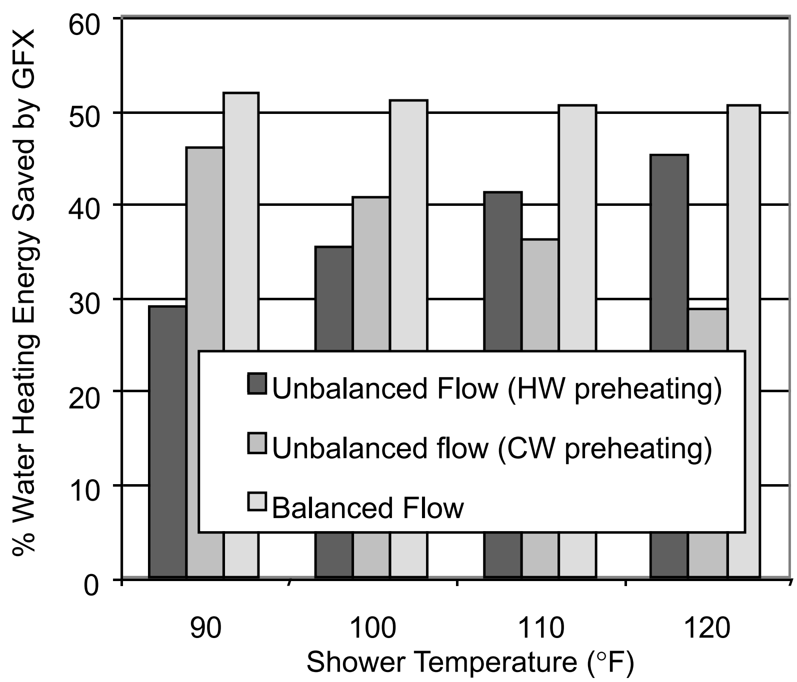


Figure 3. Energy saved by using GFX according to flow.

In the unbalanced flow cases, 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 in the figure) 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 120ºF 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 modeled, we assumed that the shower temperature was 12ºF higher than the wastewater stream entering the GFX unit.

Had we assumed that there was no heat lost by the shower drainwater before it reached the inlet to the GFX, the water heating energy savings would be ten times greater than that shown.

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 average number of daily 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. Because 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 of 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, hot water consumption patterns, and whether the GFX is piped as balanced or unbalanced flow; however, based on our measurements, a 30 to 50% savings in the energy needed to heat shower water seems reasonable. Balanced flow and, if possible, an insulated drain line to the GFX improve its delivered performance. 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, and commercial and industrial facilities that produce waste heat that could otherwise be used for preheating water.

Where to go for further Information

Doucette Industries, Inc.
P.O. Box 2337, York, Pennsylvania 17405
Tel: 1-800-445-7511; Fax 717-845-2864
www.endlessshower.com

Attention: John Lebo,
e-mail johnl@doucetteindustries.com:
WaterFilm Energy Inc.
Box 128, Medford, NY 11763
Tel: 631-758-6271; www.oikos.com/gfx/
Attention: Carmine Vasile,
e-mail: gfx-ch@msn.com

For More Information

FEMP Help Desk
(800) 363-3732
International callers please use
(703) 287-8391
Web site: www.eren.doe.gov/femp

General Contacts

Ted Collins
Program Manager
New Technology Demonstration
Federal Energy Management
Program
U.S. Department of Energy
1000 Independence Ave., SW, EE-92
Washington, D.C. 20585
Phone: (202) 586-8017
Fax: (202) 586-3000
theodore.collins@ee.doe.gov

Steven A. Parker
Pacific Northwest National
Laboratory
P.O. Box 999, MSIN: K5-08
Richland, WA 99352
Phone: (509) 375-6366
Fax: (509) 375-3614
steven.parker@pnl.gov

Technical Contacts

John Tomlinson
Oak Ridge National Laboratory
P.O. Box 2008, MS 6070
Oak Ridge, TN 37831-6070
Phone: (865) 574-0291
tomlinsonjj@ornl.gov

Randall Linkous
Oak Ridge National Laboratory
P.O. Box 2008, Bldg. 3144
Oak Ridge, TN 37831-6070
Phone: (865) 574-2043
linkousrl@ornl.gov

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