RESIDENTIAL WATER HEATING - ENERGY CONSERVATION ALTERNATIVES

Maier Perlman
Ontario Hydro Research Division

ABSTRACT

Water heating plays a vital role in many household activities. Therefore, a permanent ready supply of hot water is considered one of the most important attributes of a modern residence.

Over the last decade the structure and life-style of the family have gone through changes that have significantly altered the patterns of household hot water consumption. At present, domestic water heating represents the second largest use of energy, next to space heating, in North American residences.

For these reasons the utilities and the water heater manufacturers have become increasingly concerned with the suitability of available water heating devices in relation to the needs of consumers. As a result, standard residential water heaters became remarkably simple, reliable and affordable. They are efficient, safe and clean. However, emphasis has also been placed on the development of energy conserving techniques and novel technologies.

The paper outlines a number of potential energy conservation techniques designed to improve the overall operating efficiency of conventional domestic water heating installations. Recent developments such as heat pump based heat recovery devices (eg exhaust air heat recovery and waste water heat recycling) are also addressed. The attractiveness of these novel technologies results from the high efficiency of the systems developed and consequently, their potential for significantly lowering the energy consumption in both new and retrofit applications.

A comprehensive summary of present water heating trends and alternatives is given in the "potential energy savings" matrix. Available data showed that standard conservation techniques have relatively limited potential for energy savings. However, they are technically feasible not expensive and easily retrofitted by homeowners. They could also be attractive to utilities on large scale energy and load management programs.

New water heating technologies are very efficient. Laboratory and field experiments indicated that recovery and delivery capability of the systems developed are satisfactory. The initial capital cost is higher in comparison with available conventional water heating equipment. However, the benefits associated with energy savings, space cooling, humidity control and indoor air quality may justify the cost.

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INTRODUCTION

Water heating plays a vital role in many household activities. Therefore, a permanent ready supply of hot water is considered one of the most important attributes of a modern residence.

Over the last decade the structure and life-style of the family have gone through changes that have significantly altered the patterns of household hot water consumption. Due to variations in family size, age of family members, presence and age of children, hot water use volumes and temperatures and other "factors of influence", the demand patterns are continuously subject to wide fluctuations in both magnitude and time distribution.

At present, domestic water heating represents the second largest use of energy, next to space heating, in North American residences. For this reason the utilities and the water heater manufacturers have become increasingly concerned with the suitability of available water heating devices in relation to the needs of consumers.

Recent studies have shown that the annual electric energy consumption to supply a "typical" average residential hot water demand of 227 L (60 gallons)/day is approximately 5600 kWh. This energy is used to heat the water and to keep it hot while in storage.

During the past few years there have been increased efforts to maximize the efficiency of conventional water heating equipment. As a result standard residential water heaters became remarkably simple, reliable, and affordable. However, emphasis has also been placed on the development of energy conserving techniques and novel technologies such as heat traps, add-on insulation blankets, heat pump/heat recovery systems and others. This paper summarizes some of the presently available options to enhance the operating capabilities and economics of residential water heating installations.

CONVENTIONAL TECHNOLOGIES

Tank Insulation

Manufacturing. Most of the currently marketed electric water heaters are thermally insulated with 50-75 mm (2-3 inches) of fiberglass insulation. Because of the temperature difference between the hot water in the storage tank and the ambient air, heat is continuously lost to the surroundings through the tank walls (standby energy loss). On average, standby losses of standard electric storage-tank water heaters represent approximately 10-15 percent (600-900 KWh/yr) of the household water heating energy consumption.

Manufacturers have focused on the reduction of standby losses either by increasing the thickness of commonly used thermal insulation such as fiberglass or by using different kinds of more effective insulation materials such as double density fiberglass and polyurethane.

Laboratory evaluations showed that an increase in the thickness of standard fibreglass insulation from 50 to 75 mm (2 to 3 inches) lowers the standby losses by approximately 14-18 percent (130-200 KWh/yr) depending on the tank size, 182 or 272 L (48 or 72 gallons) respectively/1/. Further reductions of up to 40 percent were obtained using polyurethane foam. In addition to energy savings the rigidity and small bulk of the polyurethane insulation led to a structurally stronger and more compact water heater/2/.

Add-On Insulation Blankets. Add-on insulation blankets are the in-situ retrofit version of increasing the thickness of thermal insulation of storage-tank water heaters. Adding an extra layer of insulation to the exterior of the tank reduces the energy standby loss by approximately 25-30 percent/3,4/. Special blankets made of flexible polyurethane sheets save up to 45 percent. A "typical" kit consists of a 25-50 mm (1-2 inches) thick fiberglass blanket, that is wrapped around the heater and secured with tape. Some kits may have an insulating lid or top plate to cover the top of the heater. The kits can be easily installed by a homeowner.

Although the addition of exterior thermal insulation to electric water heaters is believed to be an effective conservation technique some controversy has surrounded the use of insulation blankets because of the possibility of overheating the electrical service conductor insulation. Recent tests indicated that temperatures measured on the internal wiring of the water heater were high enough to exceed the 60 to 75°C (140 to 167F) rating of wiring found in older homes/5/. Therefore, obtaining the advice of a qualified person from the local utility before installing an add-on insulation blanket is strongly recommended.

Heat Traps and Pipe Insulation

When hot water is not being used, electric water heaters stay in a warm, idle state. As a result, convective heat losses occur due to the continuous natural circulation of the hot water from the tank into the hot water distribution pipe where it cools before returning to the tank. Conductive losses are also inherent due to the thermal gradient along this line. Similar phenomena, but of a lower order of magnitude also occur in the cold water supply. Such circulation turns the first few meters of the water distribution pipes into a "radiator" giving off heat from the hot water stored in the tank (Figure 1). The installation of a heat trap would reduce the convective losses considerably (Figure 2) while the conductive losses could be lowered by using thermally insulating materials in the construction of the heat trap or in short lengths of pipe at the tank inlet and outlet. Figures 3 and 4 illustrate two of the most widely used heat traps.

"Ball" Heat Traps. The hot water line heat trap is provided with a heavier than water ball while the cold water line heat trap has a lighter than water ball. When flow stops the "hot water ball" sinks to its seat while the other one floats to its seat. When water is drawn both balls are forced to move from their seat allowing full water flow from and to the tank. Both heat traps are provided with a safety relief port.

"Square" Heat Traps. The "square" heat traps are easy to manufacture and install. They are simple and have no moving parts. The flow passages are free of any flow restrictions and they should not be affected by scale deposits.

Laboratory evaluations conducted at Ontario Hydro Research Division (OHRD) indicated that approximately 35 kWh/yr can be saved on the standby losses of a storage-tank water heater by installing ordinary "ball" or copper "square" heat traps, on both the hot and cold water distribution pipes. Short lengths of thermal insulation on these pipes will reduce the system standby losses by about 75 kWh/yr. Both heat traps and thermal insulation would lower the system standby losses as much as 105 kWh/yr on the average/6/.

Heat traps of plastic materials are claimed to have even better performance. Square type heat traps made of plastic may lower standby losses by about 100 kWh/yr on uninsulated distribution lines and perhaps as much as 160 kWh/yr when insulated. However further tests are needed to establish the behaviour of plastics when used in hot water distribution systems.

Another energy loss associated with the hot water plumbing results from the cool-down of hot water in the distribution lines between uses. This energy loss is difficult to estimate, since it depends on the physical components of the hot water system, its layout, the household hot water use patterns, and in particular, the time periods between uses. However, simplified calculations indicated that 5-10 percent of the water heating annual energy consumption (approximately 300-600 kWh/yr) could be lost through the distribution lines. Depending on the time between draws, pipe insulation may reduce this loss to about half. The heat loss of the hot water distribution line could be further reduced by placing the water heater as close as possible to the tap of most frequent use, by lowering the hot water temperature or by reducing the pipe diameter consistent with the restrictions of plumbing design.

One of the latest innovations in this area is the *"Energy-Saving Expansion Chamber"*. The system known as the *"Hot Water Saver"* works after a faucet is shut off, "pushing" hot water back into the water heater instead of leaving it in the pipe to turn cold. Because hot water is returned to the tank, less energy is required to maintain the desired temperature and the hot water pipe losses are reduced considerably. The device is still under development and preliminary test results appear to be promising/7/.

NEW WATER HEATING TECHNOLOGIES

Heat Pump Water Heaters (HPWH)

General public awareness of energy saving and conservation coupled with increasing energy costs has placed new emphasis on the development of energy conserving devices. One such development is the Heat Pump Water Heater (Figure 5).

A HPWH works primarily the same as a space heating heat pump using the mechanical work provided by an electric motor to transfer heat from one location to another. Low grade heat is extracted from the surroundings, upgraded by means of a vapour compression cycle, and transferred to the potable water.

The attractiveness of the HPWH results from its high efficiency. A conventional electric water heater (EWH) converting electrical energy directly into thermal energy has a system coefficient of performance (COP) of 1. A heat pump water heater transferring heat through the latent heat of a working fluid can achieve an effective COP in excess of 1, usually about 2. Consequently, a heat pump water heater uses less purchased energy than that required by the conventional water heating system to heat a given quantity of water and increasingly represents a cost-competitive alternative to electric resistance, oil and natural gas water heating.

Laboratory evaluations have shown that under "simulated-use" conditions HPWHs can reduce the water heating energy consumption up to 60 percent/8/. In practice, energy savings of 25 to 45 percent were achieved in four residential installations tested over one year in the Toronto area/9/. This study also suggested that in comparison with electric resistance water heaters, which have relatively low load factors and high demands, HPWHs have a higher load factor and a more "consistent" demand pattern that is attractive to utilities. Additional economic incentives could include: moderate dehumidification and air conditioning as well as heat recovery from indoor clothes dryer venting, attic venting and exhaust/ventilation air.

It is important to note that drawing heat from the air is an advantage when the weather is warm. In a northern climate, to operate efficiently, the heat pump water heater should be installed in a heated or at least semiconditioned space. This could increase the average residential space heating load by approximately 7 percent (1500 kWh/yr) and reduce the energy savings accordingly. Larger than average water draws will cause proportionately larger space heating penalties.

With the present trend towards better-sealed and well insulated homes the more energy-efficient a house is, the better a HPWH should look. This is because in practice the actual heating season of a superinsulated house is "shorter"! As an example, the OHRD study/8/ assumed that the heating season was 250 days long. For superinsulated houses the time when heat is needed is much shorter than that and there is often excess heat in the house during the winter months. At those times, the energy taken by the HPWH is waste heat which will greatly contribute to the heat recovery process and a better energy management/10/.

Exhaust Air Heat Recovery Systems

In a "tightly sealed" house without mechanical ventilation, the risk of indoor air contamination because of fewer natural air changes is a major concern. In addition, normal activities such as laundry, cooking and showers can produce excess humidity conditions. An innovative solution to these undesirable effects was the development of a new generation of heat pump based devices capable of providing mechanical ventilation, controlled humidity and improved indoor air quality while recovering a large part of the exhaust air energy for space and/or water heating (Figure 6).

The air is drawn into the unit through a duct system from commonly vented areas such as kitchens, bathrooms and laundry rooms. An air-to-water heat pump (A to W HP) transfers the heat recovered from the exhaust air stream to the water in a storage tank (EWH) provided with auxiliary electric heating element(s) for backup. Evaluation tests conducted at OHRD indicated that available heat recovery systems are efficient and reliable/11,12/. Energy savings of up to 40 percent were measured in comparison with conventional electric resistance water heating equipment. There are additional benefits such as humidity control (reduction of exfiltration, dehumidification), moderate air conditioning and improved air quality due to the installation of such systems in residences. In addition, heat recovery from indoor clothes dryers and attic venting are two particular ways of supplementing the amount of ambient energy available for the system operation.

Waste Water Heat Recovery Systems

The basic principle of a waste water heat recovery system is reuse of the heat contained in domestic hot water after the water has been put to its intended use. All domestic waste water except that from toilets is temporarily stored for heat retrieval. The system involves three basic parts: a 454 L (120 gallons) capacity waste water holding tank, a 1.2 kW water-to-water heat pump (W to W HP) and a 272 L (72 gallons) capacity domestic (fresh) hot water storage tank (EWH). The fresh water storage tank is provided with a 3 kW auxiliary heating element for backup (Figure 7).

System operation involves retaining waste water in the holding tank while its heat is extracted by the heat pump. The recovered heat and the compressor's own work are then transferred to the fresh potable water in the storage tank. The design of the system eliminates any possibility of cross-contamination. A waste water heat recovery unit was tested in the laboratory and the average energy savings under "simulated-use" conditions, compared to a standard 272 L (72 gallons) capacity electric water heater were approximately 60 percent /13/.

Desuperheaters

Sometimes called *"heat reclaimers"* , desuperheaters are heat recovery devices that reclaim "waste" heat from the hot gas discharged by the compressor of an air conditioner or heat pump. The recovered energy is then used to heat domestic water. Most of desuperheaters are installed in retrofit applications for which energy savings of up to 60 percent are claimed. Some manufacturers are offering desuperheater water heaters as options for their central air conditioners and heat pumps.

Since the desuperheater only collects heat when the air conditioner or heat pump is running, the effectiveness of the system depends somewhat on how much the space cooling or heating system runs. The more energy-efficient a house is, the less those systems run. In hot climates, the effect of the house energy efficiency is probably negligible because the air conditioner will still run more than enough to generate all the hot water needed. In moderate and cold climates, the effect might be substantial and the desuperheater may not supply enough hot water to justify its installation/10,14/.

OTHER TECHNOLOGIES

There are several water heating technologies that merit brief mention in this paper. *Solar assisted water heating* is one of those which was extensively studied. Because of the intermittent nature of solar energy, solar systems still require backup heating. Average annual energy savings of up to 45 percent are easily achievable/15,16/. The initial capital cost is very high so that the installation of such systems in northern climate residences, at todays energy prices, is rarely justified.

"Tankless" water heaters also called *"demand"* , *"point-of-use"*, or *"instantaneous"* water heaters, produce hot water on demand. Having no storage at all tankless water heaters save energy because they eliminate the standby energy losses associated with conventional storage tanks. They also can reduce heat losses from piping when the demand heater is located at the point-of-use. The savings would depend on the length of the hot water distribution pipes and the pattern of hot water use in the household. However, to heat water from cold to hot at the rate at which it flows through the heater requires very high power (approximately 10 to 30 kW). A more practical use is as a capacity *"booster"* to increase the hot water temperature for various household appliances (eg. dishwashers).

The *"Chemical Heat Pump"* is the product of another developing technology which has lately elicited a somewhat special interest for several water heating applications. The operating principle of this device is based on a discontinuously working absorption heat pump, incorporating a storage function. Any source of low-temperature heat can be used to charge the system, including solar thermal collectors, waste heat from industrial processes, exhaust heat from turbogenerators and the like. Further work is needed to assess the system capabilities, reliability and economics before it becomes commercially available.

CONCLUSIONS

The potential for energy savings by standard conservation techniques is relatively limited. However, these techniques are not expensive and easily retrofitted by homeowners. New water heating technologies are very efficient. The initial capital cost is higher, however the benefits in terms of energy savings, space cooling, humidity control and improved air quality may justify the cost.

SUMMARY

ELECTRIC WATER HEATING ALTERNATIVES POTENTIAL ENERGY SAVINGS BY CONSERVATION TECHNIQUES AND NEW TECHNOLOGIES

Technique/Technology	Potential Average Annual Energy Savings (%)*	Additional Features/Remarks
Tank Insulation** (manufacturing) increased thickness of fibreglass or use of polyurethane	3 - 6	• fibreglass: minimum thickness 75 mm • polyurethane: rigid, tank structurally stronger and more compact
Add-on Insulation Blankets**	4 - 8	• easily retrofitted by homeowner • advice of local utility recommended
Heat Traps	0.5 - 3	• easily retrofitted • qualified person needed for installation
Distribution Lines Insulation	2.5 - 5	• easily retrofitted by homeowner
Heat Pump Water Heaters	25 - 45	• moderate air cooling/dehumidification • heat recovery from clothes dryers
Exhaust Air Heat Recovery***	up to 40	• air conditioning/dehumidification • air quality improvement • heat recovery from clothes dryers, attic venting and exhaust/ventilation air
Waste Water Heat Recovery***	up to 60	• residential waste heat recovery • better suited for new installations
Desuperheaters	up to 60	• prepackaged units • easily retrofitted • qualified person needed for installation
Solar Water Heaters	up to 45	• suitable for retrofit • special installation criteria apply
"Tankless" Water Heaters	up to 25	• suitable for retrofit; special wiring required • electric units mostly used as "boosters" for various household appliances.

* Expressed as percentage of total annual household water heating energy consumption of ~5600 kWh/yr.
** As reported versus EWHs with 50 mm (2 inches) of fibreglass insulation used as baseline.
*** Economics to be assessed.

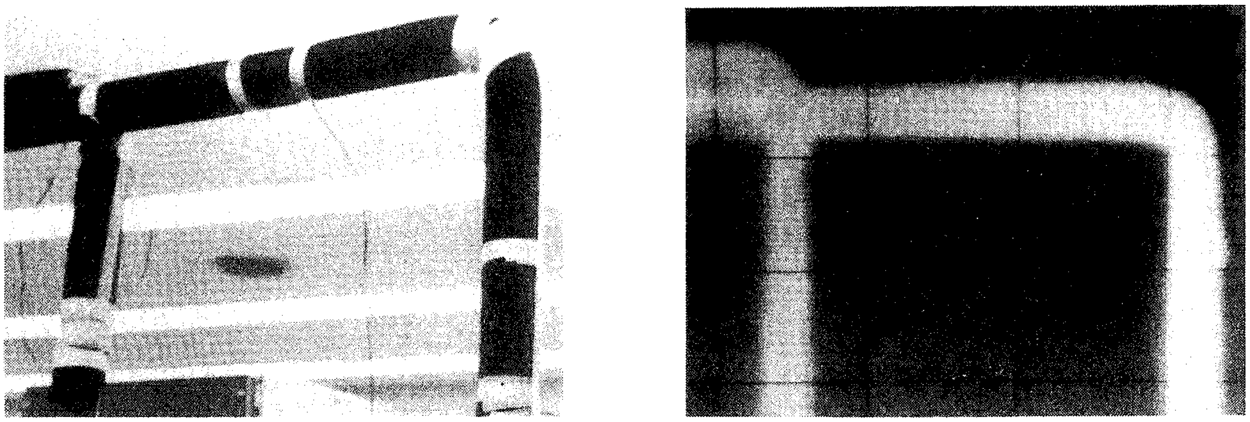


Figure 1. Water distribution lines - temperature distribution.

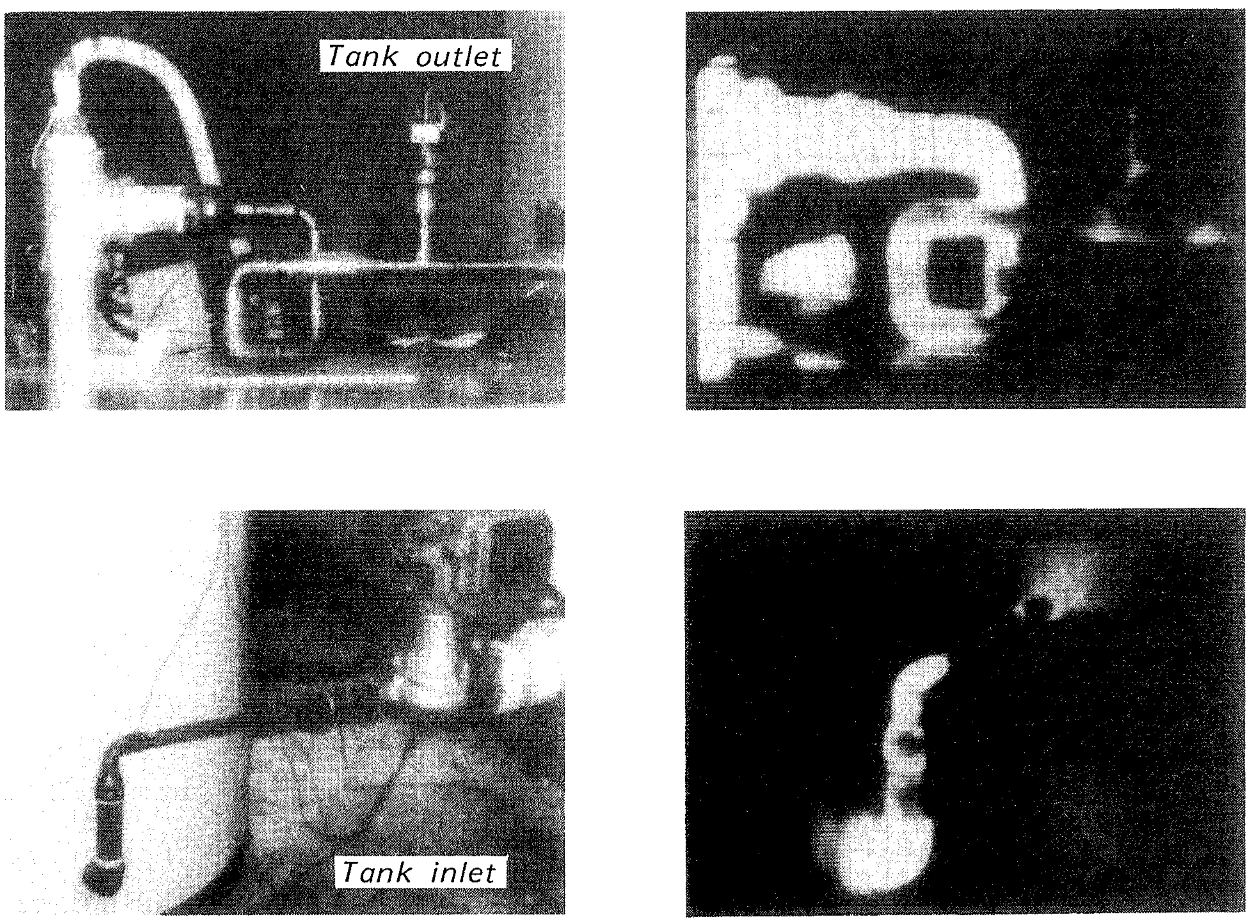


Figure 2. Heat traps on water distribution lines.

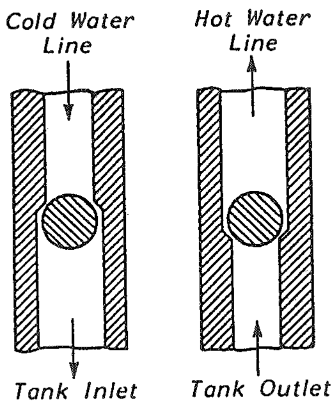


Figure 3. "Ball" heat trap.

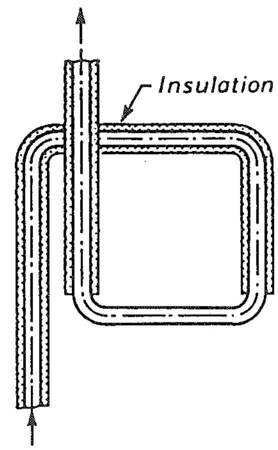


Figure 4. "Square" heat trap.

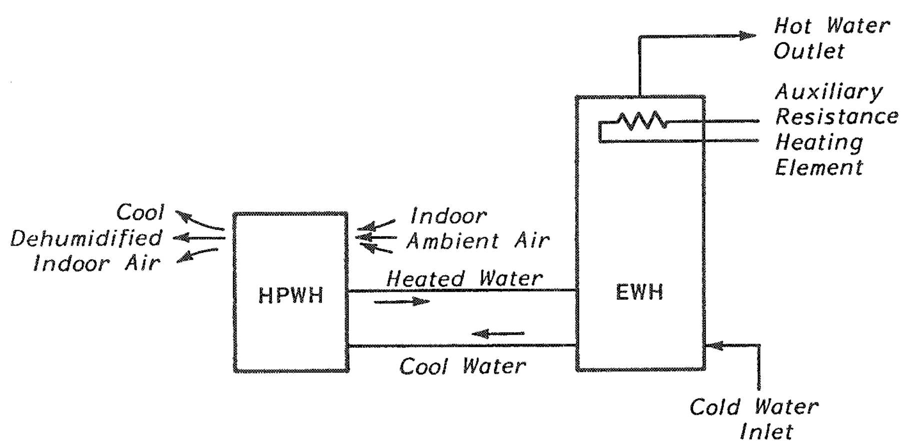


Figure 5. Heat pump water heater - schematic diagram.

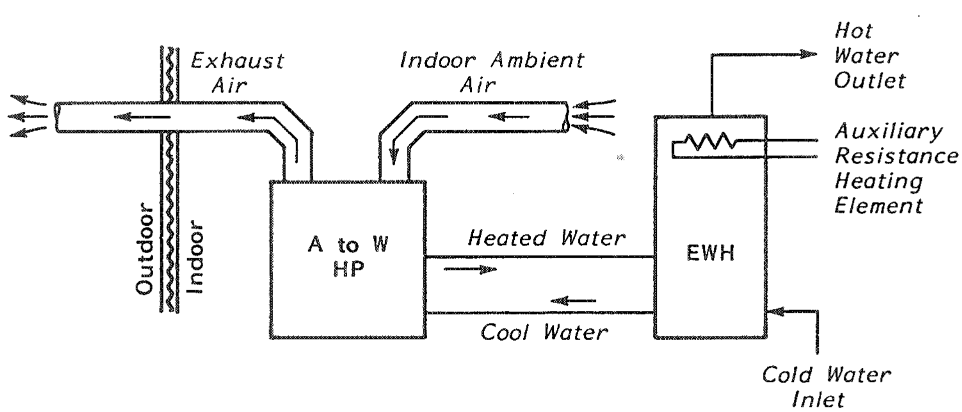
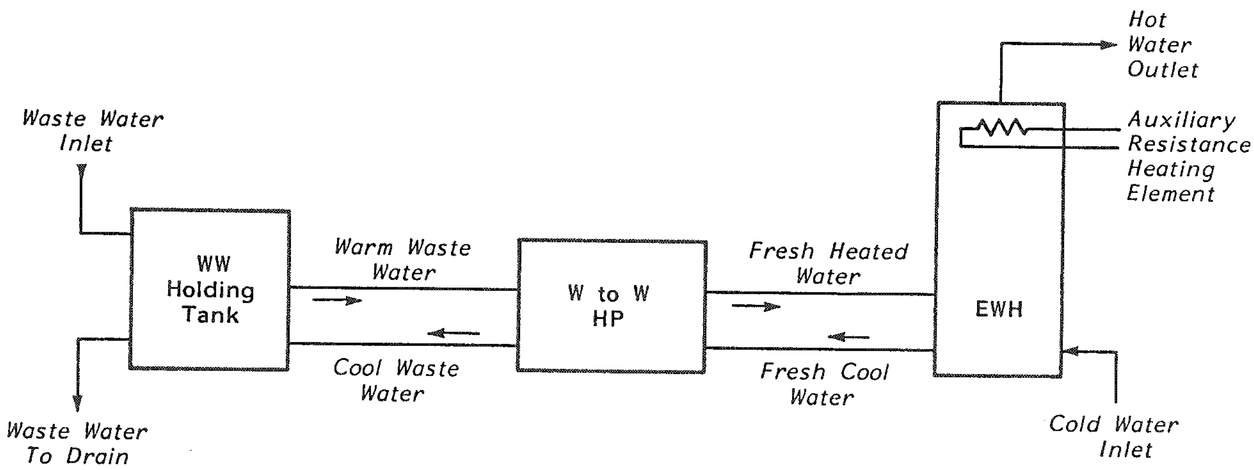


Figure 6. Exhaust air heat recovery system - schematic diagram.



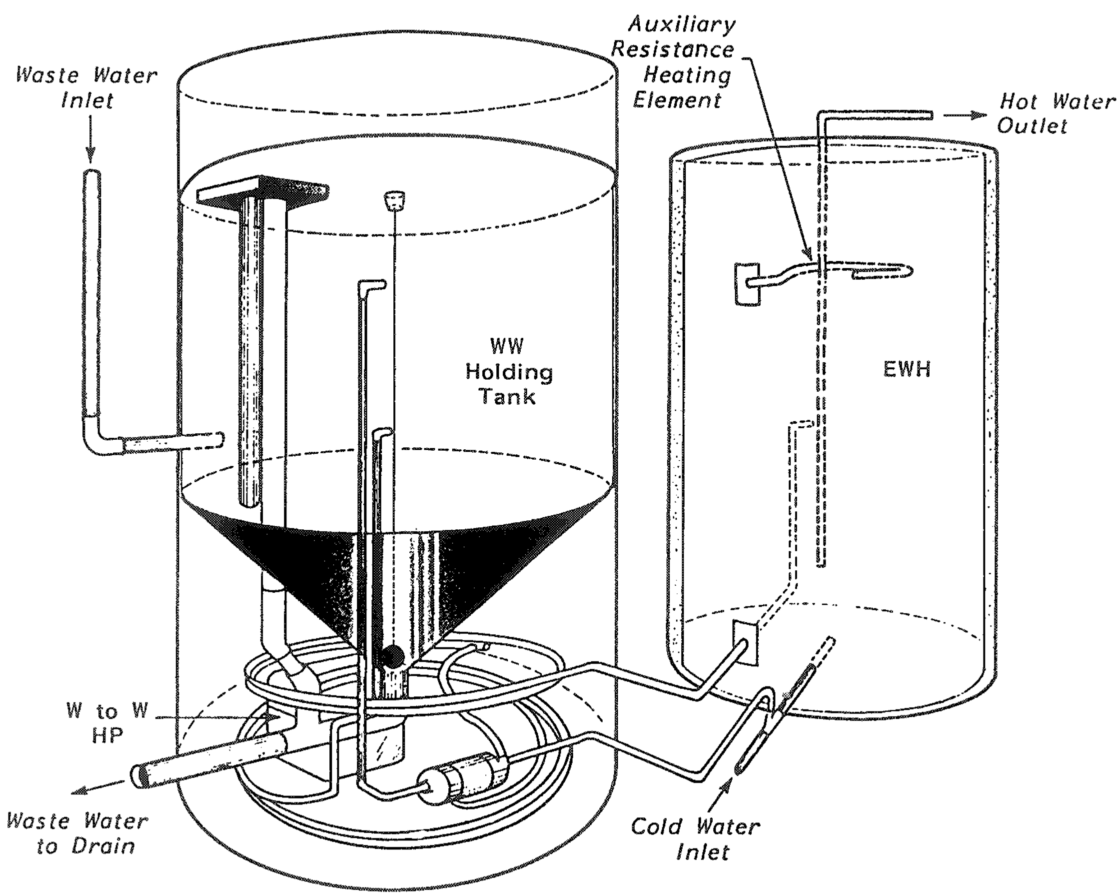


Figure 7. Waste water heat recovery system - schematic diagrams

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