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VIABILITY OF GREYWATER HEAT RECOVERY

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Exam Preview:

1. According to the reference material, the Oak Ridge National Laboratory study (Tomlinson 2008) estimated 40 gal/day/person.
   a. True
   b. False
2. Using Table 1. Summary of daily water usage by study (gal/person), which of the following entities had the lowest estimated water consumption estimate?
   a. Berkely
   b. Navy
   c. Oak Ridge
   d. ERDC/CERL
3. Using Table 3. Typical savings for a high efficiency flight-type dishwasher., what is the expected annual water savings for a Large-Sized Food Service Dishwasher that experiences low usage?
   a. 65,000 gal/yr
   b. 120,000 gal/yr
   c. 500,000 gal/yr
   d. 1,000,000 gal/yr
4. Using Table 9. Results of calculations used to perform savings payback period for commercial dishwashers, what is the payback period, in years, if the gas price is $27.49/MMBtu?
   a. 2.40 yrs
   b. 1.89 yrs
   c. 1 yrs
   d. 3.26 yrs

5. According to the reference material, many GWHR are purported to last 80 years. Therefore, 40 years is reasonable to use for SIR calculations.
    a. True
    b. False
6. According to the reference material, the cost to purchase and install a GWHR system is between $___ and $____.
    a. 400, 800
    b. 500, 1000
    c. 600, 1200
    d. 800, 1600
7. According to the reference material, the SIR value for greywater systems increase as the payback years decreases
    a. True
    b. False
8. Using Table 9. Results of calculations used to perform savings payback period for commercial dishwashers, what is the payback period, in years, if the electric price is $0.1195/kWh?
    a. 8.82 yrs
    b. 2.74 yrs
    c. 1.71 yrs
    d. 1.15 yrs
9. According to the reference material, the water temperature during dishwasher operations typically peaks 200 °F.
    a. True
    b. False
10. For warfighting units, Soldiers are assumed to occupy the (1 + 1 style) barracks __ wks/yr. This value assumes several field exercises and holidays scheduled throughout the year.
    a. 46
    b. 36
    c. 50
    d. 48

Abstract

This quantitative study examined the economic viability of using greywater heat recovery (GWHR) systems. This study discusses the technology theory, installation, and expected costs and savings. Theoretical analysis is done using a variety of thermal effectiveness and savings data from independent studies, assumed water usage levels for barracks and dining facilities, and actual fuel cost data. The analytical study determined that it was economically viable, in most cases, to install GWHR systems in training barracks and in dining facilities. In almost every case, both facility types would have short payback periods and have correspondingly high savings to investment ratios. Results for a "1 + 1" barracks configuration show GWHR viability only with high energy costs and a high number of floors. Finally, this study will provide a decision tool regarding the installation of GWHR systems based on various energy costs and size of facility.

Executive Summary

This quantitative study determined that it is economically viable to install greywater heat recovery (GWHR) systems in training barracks and in dining facilities. In almost every case, both facility types would have short payback periods and correspondingly high savings-to-investment ratios. Results show that GWHR systems are most viable for barracks with a “1 + 1” configuration with a higher number of floors (and higher initial energy costs).

In 2006, the “Canadian Centre for Housing Technology” conducted a performance evaluation (Zaloum, Gusdorf, and Parekh 2006) of several GWHR technologies to determine effectiveness values and energy savings for five GWHR systems. These performance and savings values were used to determine theoretical energy savings for this study.

To determine applicability to Army facilities, energy consumption in barracks was estimated based on facility size, estimated showering water use, and yearly occupation. For dining facilities, water usage was estimated based on facility capacity, estimated number of daily customers, and expected annual operating days. Geographic location was not considered.

Results showed that, based on simple payback and savings to investment ratio (SIR) values, it is viable to install GWHR systems in almost all cases.

Tables ES1 and ES2 summarize simple payback periods using GWHR systems in training and “1 + 1” barracks.

Table ES3 summarizes simple payback periods using GWHR systems for average-sized dining facilities.

Table ES4 lists energy costs and water usage applied for payback calculations.

Savings to investment ratios (SIRs) were also calculated for training and “1 + 1” barracks, and dining facilities.

Table ES1. Simple payback (yrs) for training barracks GWHR systems.

Energy Costs (Table 5)	Stories	High	Average High	Average	Average Low	Low
Gas	3	1.18	2.24	2.84	3.85	7.38
	4	0.89	1.68	2.13	2.89	5.54
	5	0.71	1.34	1.70	2.31	4.43
Electric	3	1.03	1.36	2.02	3.24	8.06
	4	0.77	1.02	1.52	2.43	6.05
	5	0.62	0.82	1.21	1.94	4.84

Table ES2. Simple payback (yrs) for "1 + 1" barracks GWHR systems.

Energy Costs (Table 5)	Stories	High	Average High	Average	Average Low	Low
Gas	3	4.83	9.13	11.56	15.70	30.09
	4	3.62	6.84	8.67	11.78	22.56
	5	2.90	5.48	6.93	8.42	18.05
Electric	3	4.20	5.56	8.25	13.19	32.85
	4	3.15	4.17	6.19	9.89	24.64
	5	2.52	3.34	4.95	7.91	19.71

Table ES3. Simple payback (yrs) for dining facilities.

Energy Costs (Table 5)	High	Average High	Average	Average Low	Low
Gas	1.00	1.89	2.40	3.26	6.24
Electric	0.87	1.15	1.71	2.74	6.82

Table ES4. Energy costs and water usage applied for payback calculations.

	High	Average High	Average	Average Low	Low
Gas ($/MMBtu)	$27.49	$14.54	$11.48	$8.45	$4.41
Electric ($/kWh)	$0.1584	$0.1195	$0.0806	$0.0505	$0.0202
Water (gal/yr/person)	10,950	9,695	7,655	5,615	5,537

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Preface

This study was conducted for the Office of the Assistant Chief of Staff for Installation Management (OACSIM) under the FY08 Installation Technology Transition Program (ITTP).

The work was managed and executed by the Energy Branch (CFE), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL principal investigator was John L. Vavrin. Franklin H. Holcomb is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Martin J. Savoie, CEERD-CVT. The Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the US Army Engineer Research and Development Center (ERDC), US Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Kevin J. Wilson, and the Director of ERDC is Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
Gallons water	8.34	Pounds water
Gallons water	3,79	Liter
British thermal units (BTU, International Table)	0.00293	Kilowatt-hours
Btu	1,000,000	MMBtu
BTU/s	1,06	Kilowatts
Cubic Meter Natural gas	35.315	Cubic foot natural gas
Cubic foot natural gas	1030	Btu
Cubic foot	0.03	Cubic meter
pints (US liquid)	0.473176	Liters
cubic feet	0.02831685	cubic meters

1 Introduction

1.1 Background

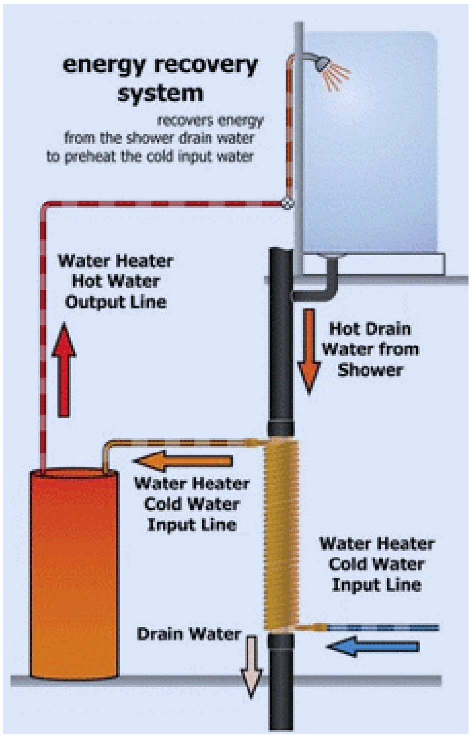
Domestic hot water (DHW) is one of the major energy users in Army barracks and dining facilities. DHW can consume more than 60 percent of the total annual heating energy supplied to barracks buildings (Underwood et al. 2008) and the dominant hot water consumer during the non-heating season. Dining facilities use large amounts of water for dishwashing operations and require high hot water temperatures (~180 °F) for sanitation purposes. Recovering the residual heat from the drain water from these facilities is both economical and viable over the long-term. Adding the recovery system is easily adaptable to both new construction and renovations.

1.2 Theory of greywater heat recovery

Greywater heat recovery systems are non-mechanical counter-flow heat exchangers that extract heat from drain water "greywater." The device is used to heat incoming domestic water either directly for use or for storage in a hot water tank. The system replaces normal vertical drain water piping with a metal (normally copper) pipe; wrapped on the circumference is smaller metal tubing (normally copper) that carries the incoming cold domestic water. For hygiene reasons, the two fluids are completely separated; only the heat is extracted. Pressure for the incoming water is maintained by normal domestic water pressure; no additional pumping is required. As the drain (grey) water flows down the metal pipe, it creates a water film along the pipe periphery. The high thermal conductivity of the metal extracts heat from the water as it drains. Vertical systems are much more efficient than horizontal systems. (Horizontal systems extract only about 20 percent of the heat that a vertical position can extract.) Figures 1 to 3 show several examples of the GWHR system. Figure 1 shows a single shower GWHR system and Figure 2 shows a single dishwasher GWHR system. Figure 3 shows multiple hot water discharges that use multiple GWHR systems.

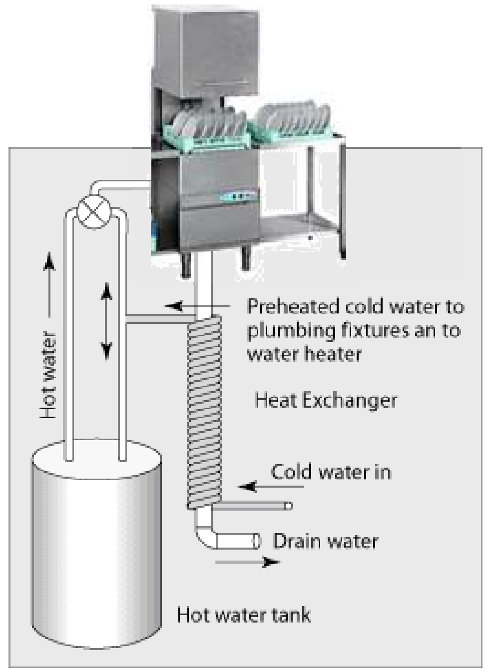
1.3 Objective

The objective of this study was to determine the economic viability of using greywater heat recovery systems both for barracks and dining facilities in military facilities.



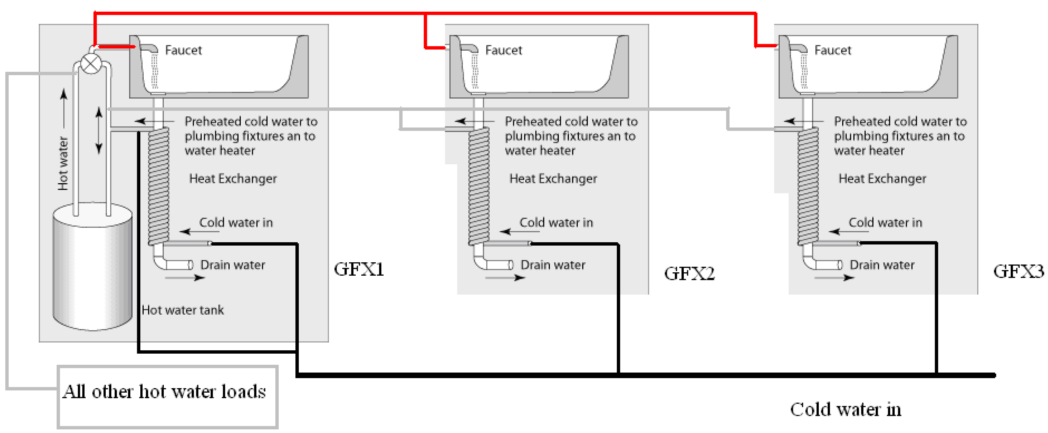
Source: http://www.watercycles.ca/

Figure 1. Simple shower GWHR system.



Source: www.eer.energy.gov/consumer/your home/water_heating/index.cfm/mytopic=13040

Figure 2. Simple dishwasher GWHR system.



Source: www.eer.energy.gov/consumer/your home/water_heating/index.cfm/mytopic=13040

Figure 3. Multi-loop GFX system with other hot water loads.

1.4 Approach

This assessment used experimental data from independent demonstrations (USDOE 2005) and applied this information to determine the energy savings in barracks and dining facilities. This experimental data was then used in conjunction with actual Army energy cost data to determine annual savings, simple payback periods, and savings to investment ratios (SIRs).

1.5 Scope

This work determined the economic viability of using GWHR by using experimental data and applying it to Army facilities, either in a barracks and dining facility.

1.6 Mode of technology transfer

This report will be made accessible through the World Wide Web (www) at URL: http://www.cecer.army.mil

2 Estimated Annual Water Usage in Barracks Showers

2.1 Examples/studies

To determine the estimated individual annual water usage in barracks showers, several studies and one facility guide were used.

2.1.1 Example 1. ERDC/CERL study at West Point

The author estimated that cadets at the US Military Academy at West Point shower (Underwood et al. 2008, p 65), on average, 1.5 times/day, 7 days/wk, 46 wks/yr. (Note that the following calculation assumes 46 wks/yr for warfighting units.) It was assumed each shower lasts approximately 5 minutes with a flow rate of 1.5 gal/minute. Assuming that daily usage equals 11.25 gal, estimated annual water usage is 3623 gal/cadet.

2.1.2 Example 2. Oak Ridge National Laboratory Study

The Oak Ridge National Laboratory study (Tomlinson 2008) estimated 30 gal/day/person.

2.1.3 Example 3. The Canadian Centre for Housing Technology Study

The Canadian study (Zaloum, Gusdorf, and Parekh 2006) shows that a family of four uses 15.6 gal/day/person for showers.

2.1.4 Example 4. Berkeley National Laboratory Study

The Berkeley National Laboratory study (Biermayer 2005) estimated 15.15 gal/person/day. This value was calculated as follows. The average number of showers per person per day is 0.70. The study shows the average shower time is approximately 8.2 minutes. However, this study did not provide an average shower head flow rate. Therefore, the national average for shower head flow rates of 2.64 gal/minute was used (Heat Exchanger NF, Inc. 2000). This gives a total of 2.64 gal/minute, 0.70 showers/day, and 8.2 minutes/shower for a total of 15.15 gal/day for each person's showers.

2.1.5 Example 5. Unified Facilities Criteria (UFC) estimate

Unified Facilities Criteria (UFC) 3-401-05N (DOD 2004) is intended to be used as a tool for estimating current and future energy consumption attributable to buildings, ships, and other energy uses at Navy installations.

Total water usage (from all sources) is estimated at 150 gal/day in the summer and 125 gal/day in the winter, which yields an average:

(150+137.5+137.5+125)/ = 137.5 gal/day

This average value includes all domestic hot water (DHW) usage. Oak Ridge National Laboratory determined that showers use 43 percent of total daily usage of DHW (Zaloum, Gusdorf, and Parekh 2006). Therefore, water usage for showers would be:

137.5 gal * (0.43) = 59.1 gal

2.1.6 Example 6. Princeton University Study

A Princeton University study of dormitory water usage (PERC 1998) showed that the average shower took 12.5 minutes. Using the national shower head flow value (2.64 gal/minute) gives a shower total of 33.0 gal. Assuming 0.7 showers/person/day (from the Berkeley example), equates to 23.1 gal/day/student.

Using the study from Berkeley National Laboratory, the average number of showers per person per day is 0.70. The study shows the average shower time to be 8.2 minutes. (Average shower head flow rate was not given so the national average for shower head flow rates of 2.6426 gal/minute was used.) This gives a total of 2.64 gal/minute, 0.70 showers/day, and 8.2 minutes/shower for a total of 15.15 gal/day for each shower.

2.2 Daily water usage summary

After eliminating the “Navy study” usage rate (its value is out of range from the others), it was determined that the average individual daily value of water used for showers is 17.4 gal. Table 1 summarizes the results of studies done to determine daily shower water usage

Table 1. Summary of daily water usage by study (gal/person)

ERDC/CERL	Oak Ridge	Canadian	Princeton	Navy	Berkeley
11.25	30.00	15.60	15.15	59.10	15.15

2.3 Individual annual water usage estimation

Estimated annual shower usage will vary depending on the type of unit assigned to the barracks.

For training units, Soldiers are expected to occupy the barracks 50 wks/yr.

For warfighting units, Soldiers are assumed to occupy the (1 + 1 style) barracks 46 wks/yr. This value assumes several field exercises and holidays scheduled throughout the year.

Calculations also assume 100 percent occupancy.

2.4 Shower drain connections in barracks

The drain pipe in the Army standard barracks (1 + 1) design is a vertical pipe that is typically connected not only to the individual shower drain, but also the room sink toilet and sink. This drain pipe is also connected to other drains from rooms directly under it. Connections to the main drain typically do not occur until after all the vertical piping is below grade. Therefore, the amount of drain water from showers is limited to just a few rooms; it is a function of the number of barracks floors. Additionally, there is a possibility that colder water from the toilet and sink could mix with the shower water drain water, lowering the temperature of the incoming drain water to the GWHR system.

For training barracks, large shower rooms are provided, typically with 6–12 shower heads/room/floor. This shower drain is normally connected to the toilet drain using a horizontal pipe and then is sent vertically. It is also connected to shower rooms directly underneath. It is then sent to the drain main below grade. It is estimated that 30 soldiers use each shower room.

Table 2 lists estimated water usage based on the above conditions.

Table 2. Summary of annual water usage by study (gal/yr/drain).

Type of Unit	Training			"1 + 1" Configuration		
Floors	3	4	5	3	4	5
gal/yr/system	548,100	730,800	913,500	33,620	44,820	56,030

2.5 Water temperatures

Most references determined that the temperature increase of the incoming cold water across the GWHR system was approximately 25 °F. This increase varies based on the initial water temperature. To support this temperature increase, four GWHR units will be installed in parallel for training barracks configurations. A single GWHR unit is adequate on “1 + 1” shower configurations.

3 Estimated Annual Water Usage of Commercial Dishwashers in Dining Facilities

3.1 Dishwasher water usage

This study used an average-sized dining facility designed to feed approximately 400–600 soldiers/meal. For this facility size, calculations were based on the use of an Insinger DA3 11 pot and pan washer. The capacity for this dishwasher is 2 racks/cycle with 25 cycles/hr at a rate of 5.6 gal/cycle. The water usage is 140 gal/hr. The capacity and water usage of the Insinger CA3 is half of the DA3 (1 rack/cycle with 25 cycles/hr at a rate of 2.8 gal/cycle totaling 70 gal/hr).

For the average-sized Army garrison dining facility, the total number of dishwashers per facility is two. Normal operations are typically from 5 a.m. until 7 p.m. Throughout the day, each meal (B, L, D) lasts approximately 1½ hrs during which time the dishwashers will operate almost continuously. It is also assumed that the dishwashers will operate at 100 percent capacity for ½ hr prior to and after each meal; this is to take into consideration the cleaning of food preparation equipment and post meal cleanup. This would total 7½ hrs of operation at 100 percent capacity. Additionally, there are other times when the dishwashers are needed for additional cleaning; it is estimated this would total 3 hrs daily. Therefore, total daily dishwasher usage equates to 10.5 hrs at 140 gal/hr. This would equate to a daily usage of 1470 gal/day or 426,300 gal/yr. It is also assumed these facilities operate approximately 290 days/yr. If a smaller than average dining facility is modeled, an Insinger CA3 dishwasher uses half of the above amount (213,150 gal/yr). For larger dining facilities, multiple DA3 dishwashers could be used.

An Alliance for Water Safety study (2008) investigated water usage of several sizes of food service facilities using high efficient dishwasher systems. Table 3 lists the actual savings using high efficient dishwasher systems and Table 4 lists an extrapolation of those savings to actual usage rates without using the efficient systems. Those results and support this study's assumptions and calculations of annual water usage at medium-sized Army dining facilities. The estimated annual usage of 426,300 gal falls within the range of low and high usage rates for a medium-sized food service facility.

Table 3. Typical savings for a high efficiency flight-type dishwasher.

Typical Savings for a High Efficiency Flight-Type Dishwasher	Medium-Sized Food Service		Large-Sized Food Service	
	Low Usage	High Usage	Low Usage	High Usage
Annual water savings (gal/yr)	65,000	500,000	120,000	1,000,000
Average savings (%)	25%		25%	

Table 4. Extrapolated annual water usage at medium and large-sized food service facilities.

Medium-Sized Food Service (gal/yr)		Large-Sized Food Service (gal/yr)	
Low Usage	High Usage	Low Usage	High Usage
260,000	2,000,000	480,000	4,000,000

The data in Table 4 represent an extrapolation of these savings to an estimated yearly usage, and are based on the 25 percent savings of water usage as listed in Table 3.

3.2 Dishwater water temperatures

Three examples in two separate case studies were used for savings calculations for heat transfer rates. The first case study involved a commercial wash system supplying hot water to a “flight-type” conveyor dishwasher. Included in the case study were calculated heat transfer rates (GFX Case Study). The second case study was of a commercial restaurant (Bell et al. 2007). The water temperature during dishwasher operations typically peaks 180 °F. The temperature from the dishwasher to the GWHR system varies depending on the temperature set point in the dishwasher, the flow rate, cycle setting, and distance of piping from the dishwasher to the GWHR system. However, most references researched found that the temperature increase of the incoming cold water across the GFX was approximately 38 °F. To support this temperature increase, studies showed that four GFXs were used in parallel. Chapter 5 contains the calculations used to perform savings and payback periods results for commercial dishwashers.


Figure 4. Sixteen GFX systems used in parallel.

4 Fiscal Year 2007 Army Energy Data

The following information was compiled From 2007 Army Energy Data (HQUSACE 2007).

Table 5 lists the breakdown of electric rates from 100 Army facilities; Table 6 lists the breakdown of gas rates from 81 Army facilities.

Table 5. Breakdown of electric rates from 100 Army facilities.

Rate	Measure
High rate	$0.1584/Kwh
Average rate	$0.08055/Kwh
Low rate	$0.02023/Kwh
Average high rate (from 150)	$0.10748/Kwh
Average low rate (from 51100)	$0.05363/Kwh

Table 6. Breakdown of gas rates from 81 Army facilities.

Rate	Measure
High rate	$27.49/MMBtu
Average rate	$11.48/MMBtu
Low rate	$4.41/MMBtu
Average high rate (from 140)	$14.54/MMBtu
Average low rate (from 4181)	$8.45/MMBtu

5 Savings, Simple Payback Period, and SIR Calculations

5.1 Calculations for savings payback periods for shower applications

For energy savings, we will use energy transfer of:

$$q = \dot{m}\ cp\ (t_e - t_i) / \eta$$

where:

q	=	Heat transferred (Btu/[unit time])
$\dot{m}$	=	mass across heat exchanger (unit lbs/unit time)
cp	=	specific heat of water (Btu/lb – °F)
te	=	temperature exiting heat exchanger
ti	=	temperature entering heat exchanger
η	=	water heater efficiency (Btu into water heater/Btu of water heat gain).

Most references (Oikos® Green Building Source, Home Energy Magazine Online, Minnesota Department of Commerce Home Energy Guide) cited a heat gain of 20 to 30 °F. Oak Ridge National Laboratory used 25 °F as the heat gained. Therefore, the calculations here used (te – ti) of 25 °F for shower heat recovery:

Q = gal/yr * 8.34 lb/gal * 1.0 Btu/lb – °F * 25 °F / water heater efficiency = Btu/yr

5.2 "1 + 1" Barracks Electric and Gas Calculation

Using the mean average water usage rate of 17.4 gal/day/person, in a "1 + 1" shower application with five stories, and the mean average electric rate with one GFX, cost savings for electric would be:

17.4 gal /day/person/room * 2 personnel/room * 5 floors * 7 days/wk * 46 wks/yr * 8.34 lb/gal * 1.0 Btu/lb – °F * 25 °F / 0.91 = 12,837,185 Btu/yr

Assuming 3,413 Btu/kW:
12,837,185 Btu/yr / 3,413 Btu/kW = 3761 kW/yr * $.08055/kW = $302.97 savings/yr.

Using the mean average water usage rate and the mean average gas rate for barracks with a “1 + 1” shower application using one GFXs, cost savings for gas would be:

17.4 gal /day/person/room * 2 personnel/room * 5 floors * 7 days/wk * 46 wks/yr * 8.34 lb/gal * 1.0 Btu/lb – °F * 25 °F / 0.62 = 18,841,674 Btu/yr

18,841,674 Btu/yr * $11.48/MMBtu = $216.30 savings/yr.

5.3 Training Barracks Electric and Gas Calculation

Using the mean average water usage rate of 17.4 gal/day/person, in a five-story training facility application with five stories, and the mean average electric rate with four GFX, cost savings for electric would be:

30 occupants/shower * 17.4 gal/day/person * 5 floors * 7 days/wk * 50 wks/yr * 8.34 lbs/gal * 1.0 Btu/lb – °F * 25 °F / 0.62 = 209,301,923 Btu/yr

Assuming 3,413 Btu/kW:
209,301,923 Btu/yr / 3,413 Btu/kW = 61324.91 kW/yr * $.08055/kW = $4939.72 savings/yr.

Using the mean average water usage rate and the mean average gas rate for a five-story training facility using four GFXs, cost savings for gas would be:

30 occupants/shower * 17.4 gal/day/person * 5 floors * 7 days/wk * 50 wks/yr * 8.34 lbs/gal * 1.0 Btu/lb – °F * 25 °F / 0.62 = 307,201,200 Btu/yr

307,201,200 Btu/yr * $11.48 MM/Btu = $3,526.67 savings/yr.

Payback Period = $1,500/savings/yr

The following calculation correlates the Canadian Study with this work:

9,656 gal/yr * 8.34 lbs/gal * 1.0 Btu/lb – °F * 25 °F / 0.62 = 3,247,200 Btu/yr* $11.48/MMBtu = $37.28/yr savings

Canadian study savings/yr: $24.62 to $49.48. Midpoint of study = $37.05/yr savings Therefore a good correlation exists.

Tables 7 and 8 list the results of these calculations.

* This assumes one GFX for each shower.

Table 7. Results of calculations used to perform savings payback periods for barracks with “1 + 1“ shower applications.

Gas ($)	Floors (1+1)	$/MMBtu	Savings/yr	Payback (yrs)	SIR
High number	3	$27.49	$310.79	4.83	1.8
	4		$414.38	3.62	3.5
	5		$517.98	2.90	5.2
Average high	3	$14.54	$164.38	9.13	−0.6
	4		$219.17	6.84	0.3
	5		$273.97	5.48	1.2
Average number	3	$11.48	$129.79	11.56	−1.2
	4		$173.05	8.67	−0.5
	5		$216.31	6.93	0.2
Average low	3	$8.45	$95.53	15.70	−1.8
	4		$127.37	11.78	−1.3
	5		$159.22	9.42	−0.7
Low number	3	$4.41	$49.86	30.09	−2.6
	4		$66.48	22.56	−2.3
	5		$83.09	18.05	−2.0
Electric ($)	**Floors (1+1)**	**$/kWh**	**Savings/yr**	**payback (yrs)**	**SIR**
High number	3	$0.1584	$357.48	4.20	2.6
	4		$476.64	3.15	4.6
	5		$595.80	2.52	6.5
Average high	3	$0.1195	$269.63	5.56	1
	4		$359.51	4.17	1.1
	5		$449.39	3.34	2.6
Average number	3	$0.0806	$181.79	8.25	4.1
	4		$242.38	6.19	−0.4
	5		$302.98	4.95	1.7
Average low	3	$0.0504	$113.72	13.19	−1.5
	4		$151.63	9.89	−0.9
	5		$189.54	7.91	−0.2
Low number	3	$0.0202	$45.66	32.85	−2.6
	4		$60.87	24.64	−2.4
	5		$76.09	19.71	−2.1

Table 8. Results of calculations used to perform savings payback periods for training barracks shower applications

Gas ($)	Floors (Training)	$ / MMBtu	Savings/yr	Payback (yrs)	SIR
High number	3	$27.49	$5066.97	1.18	17.7
	4		$6755.96	0.89	24.8
	5		$8444.95	0.71	31.8
Average high	3	$14.54	$2680.02	2.24	7.8
	4		$3573.36	1.68	11.5
	5		$4466.70	1.34	15.2
Average number	3	$11.48	$2116.00	2.84	5.4
	4		$2821.33	2.13	8.4
	5		$3526.67	1.70	11.3
Average low	3	$8.45	$1557.51	3.85	3.1
	4		$2076.68	2.89	5.3
	5		$2595.85	2.31	7.4
Low number	3	$4.41	$812.85	7.38	0.0
	4		$1083.80	5.54	1.1
	5		$1354.76	4.43	2.3
Electric ($)	**Floors (Training)**	**$/Kwh**	**Savings/yr**	**Payback (yrs)**	**SIR**
High number	3	$0.1584	$5828.30	1.03	20.9
	4		$7771.06	0.77	29.0
	5		$9713.83	0.62	37.1
Average high	3	$0.1195	$4396.06	1.36	14.9
	4		$5861.41	1.02	21.0
	5		$7326.77	0.82	27.1
Average number	3	$0.0806	$2963.82	2.02	9.0
	4		$3951.76	1.52	13.1
	5		$4939.70	1.21	17.2
Average low	3	$0.0504	$1854.09	3.24	4.3
	4		$2472.12	2.43	6.9
	5		$3090.15	1.94	9.5
Low number	3	$0.0202	$744.36	8.06	0.3
	4		$992.48	6.05	0.7
	5		$1240.60	4.84	1.8

5.4 Calculations used to perform savings payback periods for commercial dishwasher

For commercial dishwashers, an average temperature increase of 38 °F was used based on the three studies cited earlier. A relatively high cold water input value of 67 °F was used. For lower cold water input values, the temperature increase was greater, about 51 °F. For commercial dishwashers, two ways for calculating savings can be used. The first method is using the low-usage medium-sized food service facility, assuming that there would only be one commercial dishwasher in the facility. This could then be extrapolated for larger facilities. (If the total yearly gallons is known this value is then used to determine the number of dishwashers needed, e.g., 426,300 gal, one dishwasher, 852,600 gal, two dishwashers, etc.) The savings for one dishwasher at 260,000 gal/yr and one GWHR is calculated below using an average energy cost would be:

426,300 gal/yr * 8.34 lbs/gal * 1.0 Btu/lb – °F * 38 °F / 0.62 = 217,908,000 Btu/yr

132,902,000 Btu/yr * $11.48 /MMBtu = $2,502/yr savings.

Payback Period = $6,000/$2,502 = 2.40 yrs.

Table 9 lists the results of these calculations.

Table 9. Results of calculations used to perform savings payback period for commercial dishwashers.

Gas ($)	gal/yr	$/MMBtu	Savings/yr	Payback (yrs)	SIR
High	426,300	$27.49	$5990	1.00	21.6
Average High	426,300	$14.54	$3168	1.89	9.8
Average	426,300	$11.48	$2502	2.40	7.0
Average Low	426,300	$8.45	$1841	3.26	4.3
Low	426,300	$4.41	$961	6.24	0.6
Electric ($)		**$/kWh**			
High	426,300	$0.1584	$6890	0.87	25.3
Average High	426,300	$0.1195	$5197	1.15	18.3
Average	426,300	$0.0806	$3503	1.71	11.2
Average Low	426,300	$0.0504	$2192	2.74	5.7
Low	426,300	$0.0202	$880	8.82	0.3
If a smaller dining facility using a CA3 is modeled, savings and SIR would be half that listed and payback would be doubled.					

5.5 Calculation methodology used to obtain the results of the SIRs shown in Tables 7, 8, and 9

Payback periods and SIRs were calculated using a number of scenarios, taking into consideration high and low values of both water usage and energy costs.

According to 10 CFR 436, SIR is computed over a period no longer than 25 yrs with the composite yields of all outstanding US Treasury bonds. The calculations use the rates listed in Table 10 (effective for Fiscal Year 2008). Many GWHR are purported to last 50 yrs. Therefore, 25 yrs is reasonable to use for SIR calculations. The initial investment of $1500 includes purchase and installation.

SIR and Present value saving (PVS) are calculated:

SIR = Present value saving (PVS) / Present value costs

PVS = Annual saving * Years – Present value of initial investment

For present value of $6000 in 25 yrs, using a inflation rate of 5 percent, would be:

(1.05)25 * $6,000 = $20,320

Using the most recent example of $2502/yr savings for a dishwasher, the SIR would be:

SIR = [($2,502*25) $20320] / $6,000 = $42,230 / $6,000 = 7.04

Table 10. Average market yields on Treasury securities for the month of September 2007 at various intervals (US Department of the Treasury 2007).

From and Including	Up To But Not Including	Rate
0 yrs – 3 months	0 yrs 5 months	41/8%
0 yrs – 5 months	1 yr 2 months	41/4%
1 yr 2 months	4 yrs 5 months	41/8%
4 yrs – 5 months	6 yrs 6 months	41/4%
6 yrs – 6 months	8 yrs 8 months	43/8%
8 yrs – 8 months	10 yrs 8 months	41/2%
10 yrs 8 months	12 yrs 5 months	45/8%
12 yrs 5 months	14 yrs 5 months	43/4%
14 yrs 5 months	29 yrs 1 month	47/8%
29 yrs 1 month	30 yrs – 1 day	43/4%

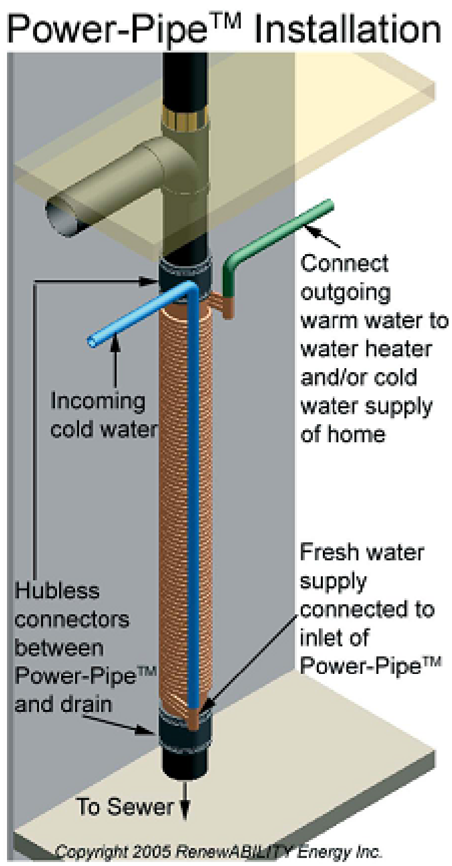
5.6 Water heater efficiencies

Federal Energy Management Program minimum requirement for a gas water heater (50 gal or less) is 62 percent. The percentage for larger units is 59 percent (EPACT2005).

The Federal Energy Management Program minimum requirement for electric water heater (60 gal and larger) is 91 percent.

6 Cost and Installation of the GWHR System

The cost to purchase and install a GWHR system is between $600 and $1200 (RenewABILITY Energy 2008). Adding a 25 percent contingency allowance (Parsons 1999) to this would increase this cost to $750–$1500. This cost includes contracting overhead, contingency, additional piping/fittings, and other unforeseen expenses. Therefore, this study used an installed price of $1500/GFX. Figure 5 shows a GWHR system installation.



Temperature sensors would need to be added to the incoming cold water and outgoing warm water from the Power-Pipe itself. In addition, a flow meter would need to be added to the incoming cold water.

Figure 5. PowerPipe® installation.

7 Conclusions and Recommendations

7.1 Conclusions

This quantitative study determined that installing greywater heat recovery (GWHR) systems both in Army training barracks and dining facilities is economically viable across the spectrum of energy costs and water usage. These systems would have short payback periods and have high savings to investment ratios in almost every case. It is feasible in barracks with a "1 + 1" configuration with high energy costs and with a high number of floors (> 3).

Another benefit and design consideration of GWHR systems is the ability to design a smaller hot water heater than previously considered without the system. If water usage for showers or washing dishes make up a large portion of the hot water demand, smaller water heaters could potentially be installed and used, offsetting some of the costs of the GWHR system.

7.2 Recommendations

For new construction, it is economically beneficial to install GWHR systems for training barracks and dining facilities, and limited instances for barracks with a "1 + 1" configuration.

For retrofit applications, GWHR systems would be viable and economically beneficial only after actual installation costs are provided and then measured against expected savings.

For barracks with "1 + 1" shower applications, there are few scenarios where GWHR systems would be recommended except at installations with high fuel costs and high number of floors (cf. Table 7, p 14). This is due to the fact that there are two personnel/floor/system. Only if more than one room/floor would have drain connections to the same system would SIR numbers be viable for lower (average) fuel costs. Therefore, for most cases, GWHR systems for barracks with "1 + 1" shower configurations are not recommended except in those instances where the above caveats are met and fuel costs were high.

Depending on their size and usage rates, installations should consider also adding them to fitness centers.

Additionally, to improve GWHR systems, adding pipe insulation is recommend. Depending on the type of insulation, additional savings are possible. Insulation reduces heat loss caused by emission and is easy to install. Several studies have shown, energy saving rates of over 20%, compared to systems without pipe insulation. Investment costs are also very low, which indicates a short payback period.

7.3 Operations and Maintenance Considerations

Beside the positive economic benefits of a GWHR system, maintenance is absolutely required. Each greywater pipe system contains impurities, caused by micro-organisms. This bacteria is present in every greywater system and found on clear surfaces inside the piping. The micro-organisms will reduce the efficiency of GWHR system by 60 percent. Maintenance costs will increase the overall Life Cycle Costs (LCC) and would have a slight negative impact on payback time periods. These maintenance costs are not included in this quantitative analysis, although they would be minimal.

Acronyms and Abbreviations

Term	Spellout
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CCHT	Canadian Centre for Housing Technology
CERL	Construction Engineering Research Laboratory
CFR	Code of the Federal Regulations
DHW	domestic hot water
DOD	Department of Defense
DOE	US Department of Energy
ECM	Energy Conservation Measure
ERDC	Engineer Research and Development Center
FAQS	Frequently Asked Questions
FAR	Federal Acquisition Regulation
FSTC	Food Service Technology Center
GWHR	Greywater Heat Recovery
ITTP	Information Technology Training Program
LBNL	Lawrence Berkeley National Laboratory
LCC	Life Cycle Costs
OACSIM	Office of the Assistant Chief of Staff for Installation Management
PERC	Princeton Environmental Reform Committee
PVS	Present value saving
SIR	savings to investment ratio
TR	Technical Report
UFC	Unified Facilities Criteria
USDOE	US Department of Energy
VWP	Vitalized Water Products

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Appendix A: GWHR System Effectiveness Calculations using the Canadian Study1 and ASHRAE Handbook20

The Canadian study defines effectiveness (ε) as:

$$\varepsilon = (t_{co} - t_{ci})/(t_{hi} - t_{ci}) \text{ when } C_c = C_{min}$$

where:

Ch	=	(mcp)h = hot fluid capacity (Btu/(lb °F)
Cc	=	(mcp)c = cold fluid capacity (Btu/(lb °F)
C_{min}	=	smaller of capacity rates Ch and Cc
th	=	terminal temperature of hot fluid, °F (subscripts i and o indicate entering and leaving conditions, respectively)
ti	=	terminal temperature of hot fluid, °F (subscripts i and o indicate entering and leaving conditions, respectively)
Cc	=	Cmin is used because only the hot water to the shower runs through the cold side of the GWHR unit on its way to the water heater, while both the hot and cold water from the shower runs down the drain.

In accordance with the ASHRAE Handbook, page 3.28, equation (49):

$$q = \varepsilon C_{min} (t_{hi} - t_{ci}) = [\ (t_{co} - t_{ci})/(t_{hi} - t_{ci})\ ]\ C_{min} (t_{hi} - t_{ci}) = C_{min} (t_{co} - t_{ci})$$

As can be seen from above, given $C_c = C_{min}$, ε is reduced out from the equation.

From above, $C_{min} = C_c$

From the ASHRAE Handbook, page 3.28, $C_c = (\dot{m}\ cp)_c$

From the ASHRAE Handbook, page 3.28, equation (51):

$$q = \dot{m}\ cp\ (t_e - t_i)$$

where:

t_e = temperature entering GWHR heat exchanger
t_i = temperature exiting GWHR heat exchanger.

According to the Canadian study, there is a savings of 0.162 to 0.325 m^3 (5.72 to 11.48 sq ft) of natural gas savings per 100 L (26.4 gal) of shower water used per day:

(100 L/day * 365 days)/3.78 L/ gal
= 9,656 gal /yr; 5.72 cu ft to 11.48 cu ft natural gas/day * 365 days
= 2,088 cu ft to 4,189 cu ft natural gas/yr.

Savings are calculated as:

2,088 cu ft to 4,189 cu ft natural gas/yr * 1030 Btu/cu ft natural gas
= 2.15 MBtu to 4.31 MMBtu/yr

At an average price of natural gas given in Table 6 (p 11) of $11.48/MMBtu, savings = $24.62/yr to $49.48/yr.

Appendix B: Results of a 2011 European Market Analysis of GWHR

Introduction

This Appendix contains additional information concerning greywater heat recovery based on a European market analysis conducted in June 2011.

Usage

Rising energy costs have made it necessary to find alternative and efficient ways to reduce energy losses and to recover energy. The use of GWHR is one such alterative that has become more widespread during the last few years in Europe, especially in Switzerland and Germany.

After several years of testing, greywater heat recovery technology has emerged as an efficient and reliable technology. Different ways have been found to use the recovered energy—not limited to heating. For example, in addition to the use of recovered heat energy to preheat domestic hot water, it is also possible to use the recovered energy (or alternatively, the technology) for space heating or cooling.

The major users of greywater heat recovery energy are:

- preheat domestic water
- space heating
- space cooling.

Due to the fact that greywater normally has a constant temperature level of 10–20 °C, it can be used for both heating and cooling. During the winter season, it is possible to use the high temperature level of greywater for space heating and preheating domestic hot water. Through the summer season, the greywater temperature level is lower relative to environment temperatures, which makes it possible to use it for cooling as well as for preheating domestic hot water.

Note that "domestic hot water" is not simply water used for showers; it refers to entire hot water loop, and includes dishwashers, laundry washing machines, and all hot water using devices.

Two devices are used to recover energy from greywater:

1. A conventional heat exchanger. (See p 1 in the body of this report.)
2. A heat pump system.

The following sections describe these devices.

Technologies

7.3.1 Heat exchanger

A heat exchanger has two characteristics. The device separates greywater from domestic water and extracts energy from greywater. Over the past years, different devices have been tested to recover heat or energy from greywater.

The first way is to install a heat exchanger in an existing building sanitation system. One method to install a heat exchanger as described in the body of this report. Another approach is to install a storage tank and amass the greywater before it flows into the sewer system. This storage tank includes a heat exchanger that recovers energy from the greywater. Figure B1 shows a heat exchanger in a storage tank, and Table B1 shows the major pros and cons of this type.

Alternative 2 includes the possibility to add heat exchangers to the sewer network. Several heat exchangers devices are integrated into the sewer line segments over a length of 600 ft (183 m). It is possible to implement the segments into an existing sewer network or to install them when a new network is going to be built. Figures B2 and B3 show two types of integrated heat exchangers and Table 2 shows the major pros and cons of this alternative.

A third option is a central solution. To recover energy from greywater, a heat exchanger is installed into a filter plant. This system recovers energy from cleaned greywater and transfers the energy back to the user. Compared to alternative 2, this way of energy recovery is easy to install and to operate. Like every other device, this system has advantages and disadvantages. Table 3 shows the major pros and cons of this type.

1. Sensor -water level minimum
2. Sensor -water level maximum
3. Waste pump
4. Stand pipe, insulated
5. Overflow pipe
6. Sensor temperature
7. Sewer line
8. Ventilation
9. Heat exchanger
10. Domestic water pipe
11. Grey water feed
12. Grey water drain

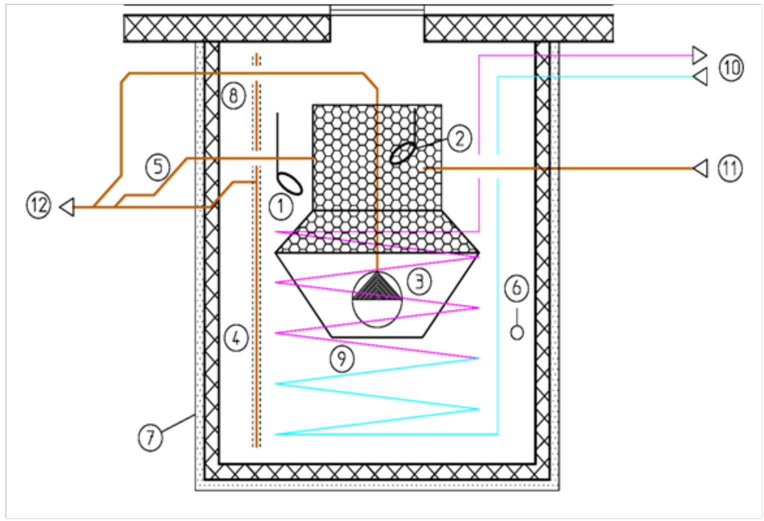

Figure B1. Storage tank with heat exchanger; (reference 4).

Table B1. Pros and cons of inside building heat exchangers.

Advantages	Disadvantages
Usage of high greywater temperature	Heat exchanger cleaning
No long water pipe installations	
Low investment costs	

Figure B2. Integrated heat exchanger segment; (reference 2).

Figure B3. Fluting heat exchanger; (reference 2).

Table B2. Pros and cons of integrated heat exchangers.

Advantages	Disadvantages
Constant water flow	Lower temperature level
Easy to clean	Higher investment costs

Table B3. Pros and cons of filter plant heat exchangers.

Advantages	Disadvantages
Hugh amount of water	Low temperature level
Easy to install	Long distance to user
No cleaning necessary	
Lower investment costs for heat exchanger	

Important for all different solutions is the water flow rate. For technical reasons, a use of pipes with a minimum water flow rate of 3 gal/s (11.36L/s) is necessary. Running the system with a lower flow rate would cause technical problems and be economically inefficient.

The described heat exchanger technology can be used to recover heat energy from greywater. This recovered energy has a low temperature level and can only be used to preheat domestic hot water.

7.3.2 Heat pump

A heat pump is another option. Heat pump technology allows the use of recovered heat for both space heating and cooling. Space heating requires a water temperature of 122–158 °F (50–70 °C) at the boiler. In combination with a heat pump and a boiler, high temperature levels are feasible. A positive aspect of this technology is that the higher supply guarantees a higher efficiency. Figure B4 shows a heat pump system that raises water from a temperature of 54–158 °F (12–70 °C).

Furthermore it is possible to use a heat pump in combination with a block heat and power plant. Figure B5 shows the efficiency of a system that incorporated heat pump technology compared to that of a conventional heating system.

Figure B4. Heat pump unit; (reference 2).

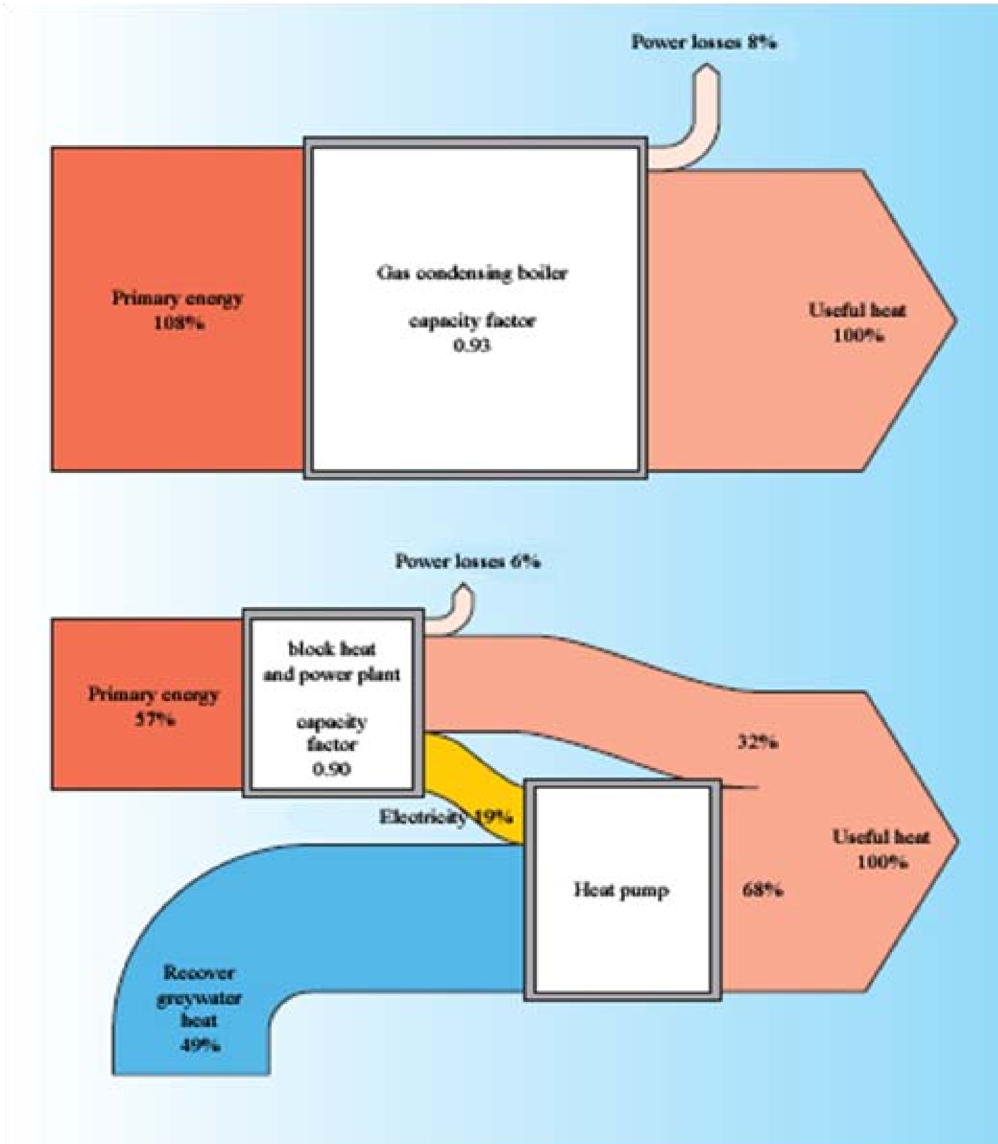

Figure B5. Comparison energy efficiency of conventional and heat pump heating system; (reference 2).

Heat pumps allow the recovered heat to be used for cooling as well as for heating. The heat pump, intermediate circuit, and heat exchanger, can all be used without any changes; no additional equipment or investments are required to run the cooling process. Three different running modes are available. Table B4 lists the greywater heat recovery cooling modes and the technological background or usage.