Final Report

Performance Evaluation of Drain Water Heat Recovery Technology at the Canadian Centre for Housing Technology

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1.0 Background

Drain water heat recovery is a relatively simple technology that has proven its capacity to reduce hot water heating demand. The technologies tested in this project consist of a 3-inch nominal (76.2 mm) copper drain wrapped with either a half-inch (12.7 mm) nominal or 3/8-inch (9.5 mm) nominal soft copper tube in which the cold water circulates to recover the heat from the drain water, as shown in Figure 1. The devices work on the concept of thin films in liquid piping on vertical runs. Since drains are typically very much oversized relative to typical water flows, when a vertical run is encountered, the small volume of water relative to the pipe size spreads out in a thin film and effectively coats the interior of the drain pipe. The effect is due to surface tension. This gives the drain water a very high surface contact to volume ratio on the vertical run in the drain system.

Five different drain water heat recovery (DWHR) units from three manufactures were tested during this project. The units from each manufacturer had a different pattern for winding the tube pipe around the drain pipe, and used tubes formed into slightly different shapes. For two of the manufacturers, we tested units of different lengths. Each unit was tested in two configurations: one in which warmed water from the unit went to the hot water tank only, and one in which warmed water went to both the hot water tank and the cold water supply to the shower. Two types of tests were performed. In the first type, each unit and configuration was tested during three or four days with scheduled daily draws of hot and cold water. There were four different schedules, so each unit was tested in eight combinations of configurations and schedules. The second type of test consisted of a “long shower” during which the effectiveness, the pressure drop, and the ability to maintain the shower temperature over time of each unit in each configuration were tested. The objectives are to quantify the energy savings in using a DWHR unit in a typical home with 2, 3 and 4 occupants, and to determine the effectiveness of each of the units.

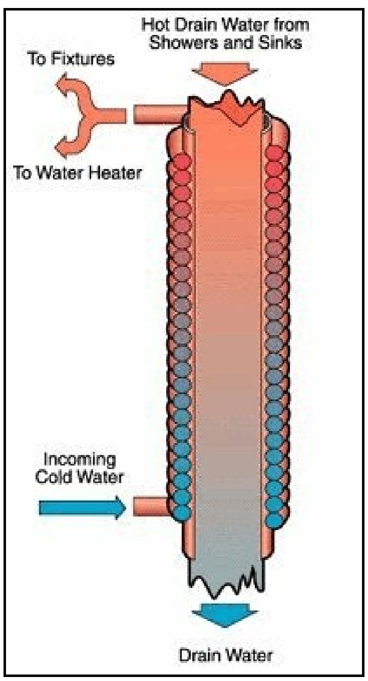

Figure 1. Schematic cross-section of a typical DHWH unit.

All units tested are double-wall-vented heat exchangers. This design prevents drain water from contaminating the fresh water, and makes leaks visible. The devices tested were those received from the manufactures.

2.0 Project Objectives and Scope

The objectives of this project were to:

- Measure the daily natural gas savings from three drain water heat recovery units in two plumbing configurations and four daily schedules of hot and cold water draws;

- determine the effectiveness of five DWHR units, including the three tested for daily savings; and

- determine whether non-simultaneous water draws have an impact on energy savings and whether they should be considered in future modelling efforts.

The scope of this project was to determine the heat recovery benefits using standard operating conditions on a daily basis.

3.0 Methodology

3.1 Installation

Each DWHR unit was installed as shown in Figure 2. The five valves allow for three modes of operation:

1. Benchmark. The DWHR unit is isolated so that no cold water passes through it. This allows the consumption of natural gas by the domestic hot water tank (HWT) with no drain water heat recovery to be measured for each daily water draw schedule.

2. Configuration A. All water entering the HWT passes through the DWHR device and all fresh water passing through the device goes to the HWT. Thus, the device preheats water going to the HWT.

3. Configuration B. All water entering the HWT and all water flowing through the cold water valve to the shower passes through the DWHR device. Thus, the device preheats both the water going to the HWT and the cold water going to the shower.

A mixing valve (labelled "mix" in Figure 2) keeps the shower temperature close to a constant, pre-set value. The 100-litre reservoir simulates the storage of water in baths, clothes washers and dishwashers. The use of natural gas by the HWT is measured by a pulse-generating natural gas meter connected directly to it. The flows of cold, hot and warmed water are measured by the three pulse-generating water meters labelled "W" in Figure 2. The eight thermocouples (labelled "T1, T2, . . ., T8") allow the performance of the system, and the effectiveness of the DWHR device to be evaluated. All sensors are connected to a data logger that records all data a ten-minute intervals during the testing of daily water draws, and a one-minute intervals during the long-shower tests of effectiveness. The data logger also controls the five solenoid valves that control the flows of water to individual uses during the tests of daily water draws. P1 and P2 are manually read pressure gauges that measure the cold water pressure into and out of the DHWR. The gas meter is a Canadian Meter Company, Inc. AC250 that generates one pulse for each cubic foot (0.02832 m^3) of gas used. The HWT is a power-vented GSW Superflue with a capacity of 150 L (39.6 US gal) and an input of 33,000 Btu/hour (9.67 kW).

Figure 3 shows part of the installation in the basement of the building. The fact that each fixture or appliance in the house has separate hot and cold water lines from the basement made it relatively easy to install the solenoids to control them. Figure 4 shows one of the DWHR devices installed for testing. When tested the devices were insulated with half-inch (12.2 mm) thick closed-cell foam pipe insulation. Figure 5 shows the 100-litre tank used to simulate a bathtub, clothes washing machine and dishwasher, and Figure 6 show the motorized damper used to flush the toilet.

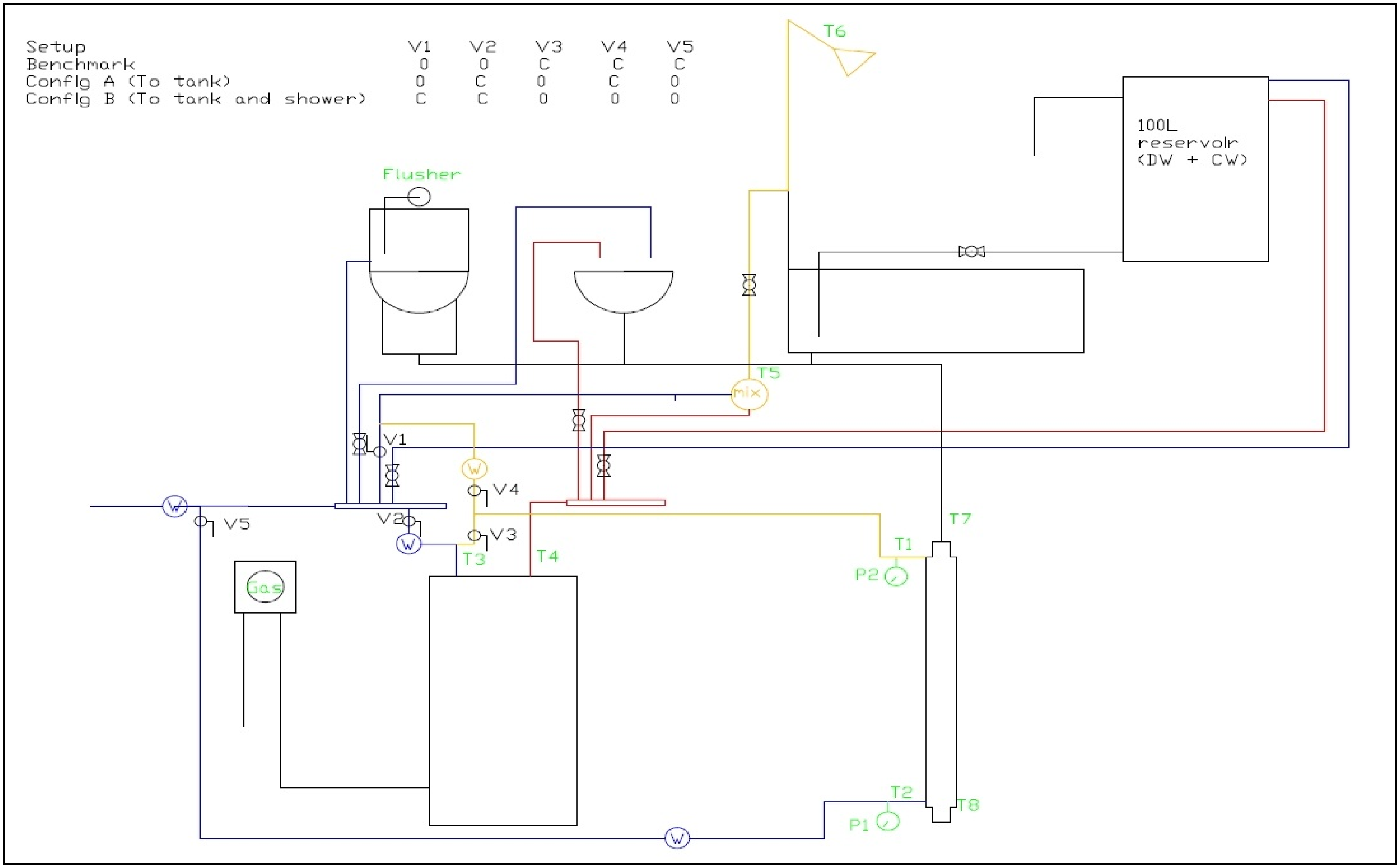

Figure 2. Schematic layout of the DWHR device testing configuration.

Figure 3. Part of the installation in the basement.

Figure 4. A DWHR Device installed for testing.

Figure 5. Tank for simulating baths, clothes washing and dishwashing.

Figure 6. The motorized damper used to flush the toilet.

3.2 The Daily Water Draw Schedules

The daily water draw schedules represent typical hot water draws for a family of two (163 L), three (244 L) and four (325 L) people, and for a family of four that takes four showers a day instead of three showers and a bath. The schedules are based on a Marbek[1] study that determined that the average hot water use for an average family (2.9 people) was 236 Litres. The water draws taken from the study are similar to those used to evaluate water heaters at the CCHT, and are broadly accepted. Appendix II compares these draws with those from a recent study in Seattle. The schedules include events which use cold water only (toilet flushes), both hot and cold water (sinks, clothes washing and showers), and hot water only (dishwashing). Some events involve hot water draws and flows of warm waste water that occur simultaneously (sinks and especially showers), and some that involve delays between that hot water draws and the flows of warm waste water (clothes washers, dishwashers and baths).

The distinction between simultaneous and non-simultaneous flows is important because the type of DWHR device tested in this project has very little storage and works best with long simultaneous flows, i.e., showers. When a flow of warm drain water occurs after its hot water draw, then only the cold water in the outer tube(s) of the DWHR is warmed, and if there is a long delay before the next hot water draw, then it will cool during the interval. If a flow of cold waste

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[1] Marbek, 1994. *Technology Profile Report: Electrical Storage Tank Water Heaters*, Marbek Resources Consultants, Ottawa.

water occurs during the interval, then it will cool the water in the outer tube(s). The details of each daily schedule are shown in Appendix 1.

3.3 Testing with Daily Water Draw Schedules

The objective of this testing was to determine the savings in daily natural gas use due to each DWHR device in each combination of configurations and schedules. The first step was to determine how much natural gas the HWT used for each schedule with no heat recovery. Thus, three or four days of testing were done for each schedule with the DWHR isolated to establish a benchmark. Three or four days were required in order to average out variations in natural gas use by the hot water tank. Because the tests were carried out from September 2005 through early February 2006, the cold water temperature varied significantly, making it necessary to repeat the benchmarks a few times for each schedule. Three or four days of testing were done with three DWHR units in each of the two configurations, and for each of the four daily water draw schedules. For each combination of device, configuration and schedule, the average natural gas consumption was compared with the benchmark consumption for the same schedule. Daily totals of hot, cold and preheated water were also compared to ensure that the schedules were correctly implemented in each case.

3.4 Testing for Effectiveness and Shower Length

A DWHR device is a water-to-water heat exchanger, and therefore can be evaluated in terms of its effectiveness. Effectiveness is best measured during near steady-state conditions. This was done by running the shower until its temperature dropped below body temperature while recording data every minute. In order to make the starting conditions for each test as similar as possible, we ran a shower with the benchmark configuration until the temperature dropped below body temperature (37.0 C), and then allowed the HWT to completely heat up. As soon as the HWT stopped burning gas, we started the effectiveness test in configuration B. When that test was over, we waited until the HWT had heated up and stopped burning gas before starting the test in configuration A. Then a third test was done in benchmark configuration to compare the shower length above body temperature with those in configurations A and B. Figure 7 shows a complete cycle of such testing. The resulting values of effectiveness can be called "*in-situ* effectiveness" because they are measured under conditions not as effectively controlled as in a laboratory.

Effectiveness ε is calculated according to the equation in *2005 ASHRAE Handbook - Fundamentals 2005*, page 3.28:

$$\varepsilon = \frac{t_{co} - t_{ci}}{t_{hi} - t_{ci}} \quad \text{when } C_c = C_{min}$$

where

C_h	=	$(mc_p)_h$ = hot fluid capacity rate, W/K
C_c	=	$(mc_p)_c$ = cold fluid capacity rate, W/K
C_{min}	=	smaller of capacity rates C_h and C_c
t_h	=	terminal temperature of hot fluid, °C (subscripts i and o indicate entering and leaving conditions, respectively)
t_c	=	terminal temperature of cold fluid, °C (subscripts i and o indicate entering and leaving conditions, respectively)

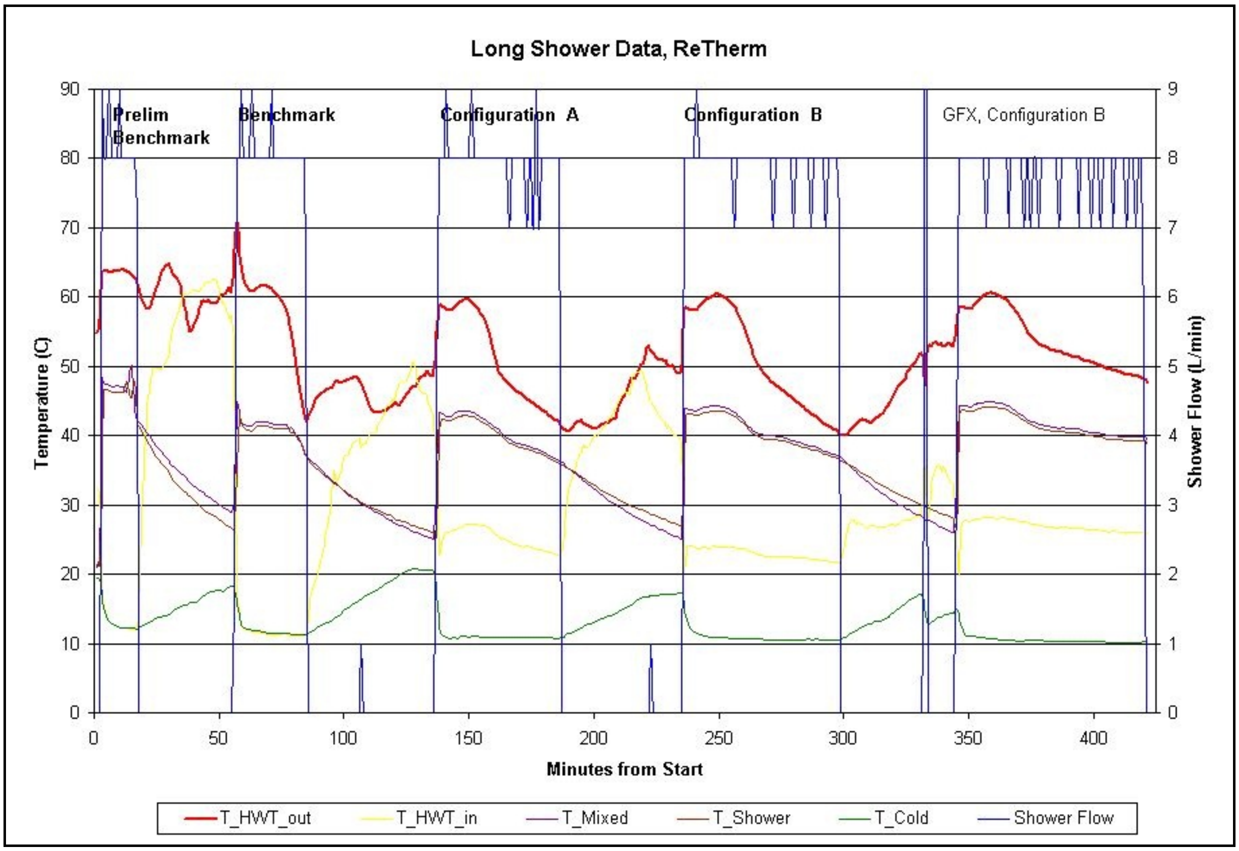

Figure 7. The Testing Sequence for Effectiveness and Shower Length.

$C_c = C_{min}$ is used because in configuration A only the hot water to the shower runs through the cold side of the DWHR device (on its way to the HWT), while both the hot and cold water run down the drain (warm side of the DWHR device). In configuration B, both the hot and cold water run through both sides of the DWHR device, so the flows are equal, and either the equations for $C_c = C_{min}$ or $C_h = C_{min}$ could be used.

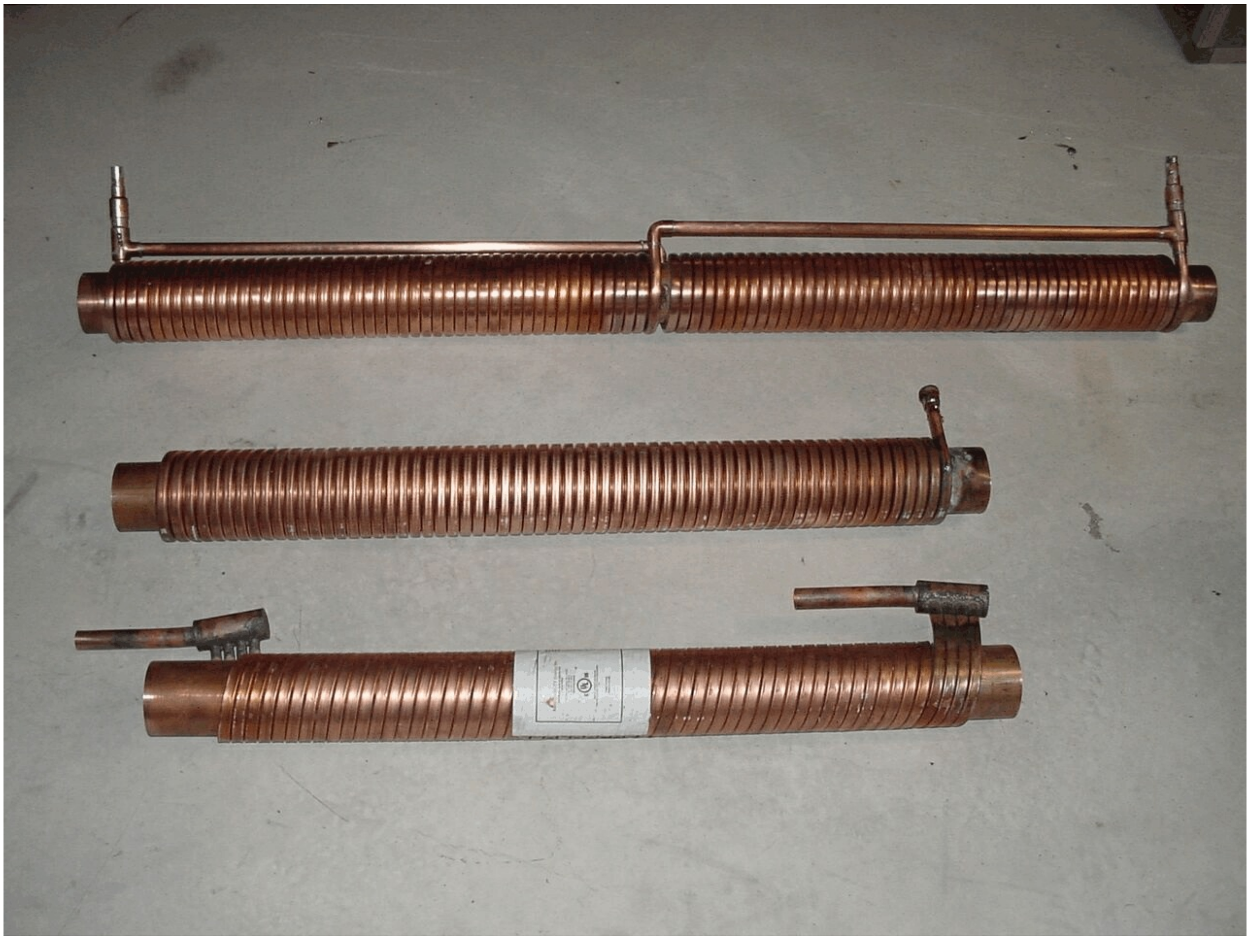

Figure 8. Three of the DWHR units. See text for descriptions.

3.5 Models Tested

DWHR units from three manufactures were tested in this project. The units from the three manufacturers had three different arrangements for winding the outer copper tube around the three-inch drain, as shown in Figure 8. (The manufacturers make units with more than one arrangement). The units shown in Figure 8 are, from top to bottom:

- The Retherm S3-60. A 60-inch (1,525 mm) long unit in which the one half-inch tube is wound in two equal length sections so that approximately half the cold water flows through each section.
- The GFX G3-40. A-40 inch (1,016 mm) long unit in which the half-inch copper tube is wound in one length.
- The Power-Pipe R3-36. A 36-inch (914 mm) long unit in which four tubes, each three-eights of an inch are wound around the length of the unit.

All three manufacturers make the cross section of the soft copper tube squarer in order to increase the contact area between the drain pipe and the tube. The Power-Pipe has the most nearly square tubes, and the Retherm and GFX have similar cross sections.

In addition to the units shown in Figure 8, a 60-inch (1,525 mm) Power-Pipe (Model R3-60 with the same configuration as the Power-Pipe in the figure), and a 60-inch GFX (G3-60 with the same configuration as the GFX in the figure) were also tested. The three 60-inch models were tested for both daily water draws and effectiveness, while the two shorter models were tested for effectiveness only, as summarized in Table 1.

Unit	Length (in, mm)	Tests	
		Daily water draws	Effectiveness
Power-Pipe, R3-60	60 in, 1,525 mm	✓	✓
Power-Pipe, R3-36	36 in, 914 mm		✓
GFX, G3-60	60 in, 1,525 mm	✓	✓
GFX, G3-40	40 in, 1,016 mm		✓
Retherm, S3-60	60 in, 1,525 mm	✓	✓

Table 1. DWHR units tested.

4.0 Results

4.1 Daily Water Draws

Testing occurred from 1 September 2005 through 5 February 2006. There were 33 days of benchmarking, and 72 days of testing the three DWHR units in the two configurations and four daily water draw schedules. Theoretically, only twelve days of benchmarking should have been required (three for each of the four schedules), but as mentioned in Section 3.3, significant changes in cold water temperatures required the benchmarks to be done several times. Cold water temperatures varied from 19.4°C on 1 September 2005 to 9.5°C on 5 February 2006. (These cold water temperatures are the minimums recorded each day, which occur during the second morning shower. This eliminates most of the warming that can occur as the cold water passes through the foundation and the plumbing inside the house.) Results of this testing are summarized in Table 2.

These results represent the natural gas savings under specific conditions: the cold water temperature which changes over time, and the water draws as described in Appendix I. Consequently, these results cannot be used to project annual savings through simple multiplication.

Table 2 includes the average cold water temperatures for the benchmarking and testing days for each DWHR device and set of conditions. In most cases, the difference between the benchmark and test temperatures are less than 0.5°C; the largest difference is 2.3°C, which is for GFX, configuration A, two occupants. Table 3 shows the average savings for each of the DWHR devices.

During the benchmarking for the Retherm with 4+ occupants, the average temperature out of the mixing value to the shower was approximately 3.6°C cooler than it was during the tests. This was due to the inaccuracy of the mixing valve, and fortunately did not occur during other sets of benchmarks and tests. For the 236 L of shower hot water in the 4+ occupancy schedule, a difference of 3.6°C would cause a reduction of 0.119 m^3 of natural gas.[2] Therefore this amount is added to the measured differences of 0.397 m^3 for configuration A, and 0.460 m^3 for configuration B to get the values shown in Table 2. Without these adjustments the Retherm savings for 4+ occupants would be lower than those for 4 occupants, which is inconsistent with the results for the other DWHR units, and contrary to expectations.

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[2] 3.6 K * 236 L * 4179 J/L-K = 3.55 MJ.
3.55 MJ / 0.80 (eff) = 4.44 MJ of gas.
4.44 MJ / 37.3 MJ/m^3 = 0.119 m^3.

Device	Configuration	Occupants	Cold Water Temp (C)		Natural Gas Savings	
			Bench	Test	m^3/day	%
PowerPipe	A	2	19.2	18.7	0.161	11%
	A	3	18.9	18.5	0.171	9%
	A	4	19.3	18.6	0.379	15%
	A	4+	10.3	10.1	0.637	21%
	B	2	19.3	19.1	0.198	14%
	B	3	18.9	19.4	0.223	12%
	B	4	19.3	19.7	0.531	21%
	B	4+	10.3	10.6	0.635	21%
GFX	A	2	19.2	16.9	0.209	14%
	A	3	18.9	18.0	0.180	9%
	A	4	19.3	18.2	0.456	18%
	A	4+	16.3	16.1	0.664	24%
	B	2	19.2	17.2	0.162	11%
	B	3	18.9	17.7	0.227	12%
	B	4	19.3	18.5	0.482	19%
	B	4+	16.3	16.2	0.768	27%
Retherm	A	2	15.3	15.4	0.179	12%
	A	3	14.2	14.3	0.317	15%
	A	4	13.3	13.4	0.457	16%
	A	4+	12.6	12.8	0.516	18%
	B	2	15.3	15.9	0.209	14%
	B	3	14.2	14.6	0.326	15%
	B	4	13.3	13.8	0.493	18%
	B	4+	12.6	13.0	0.579	20%

Table 2. Summary of Daily Water Draw Testing.

In configuration A, warmed water from the DHWR units goes to the hot water tank only.
In configuration B the warmed water goes to the hot water tank and the shower's cold water.
The temperature of the shower was set to 46°C (see page 16).

Device	Average natural gas savings (m^3/day)	Percent
Power-Pipe	0.37	15.5%
GFX	0.39	16.8%
Retherm	0.38	16.0%

Table 3. Average Gas Savings for each Device in Daily Water Draw Testing.

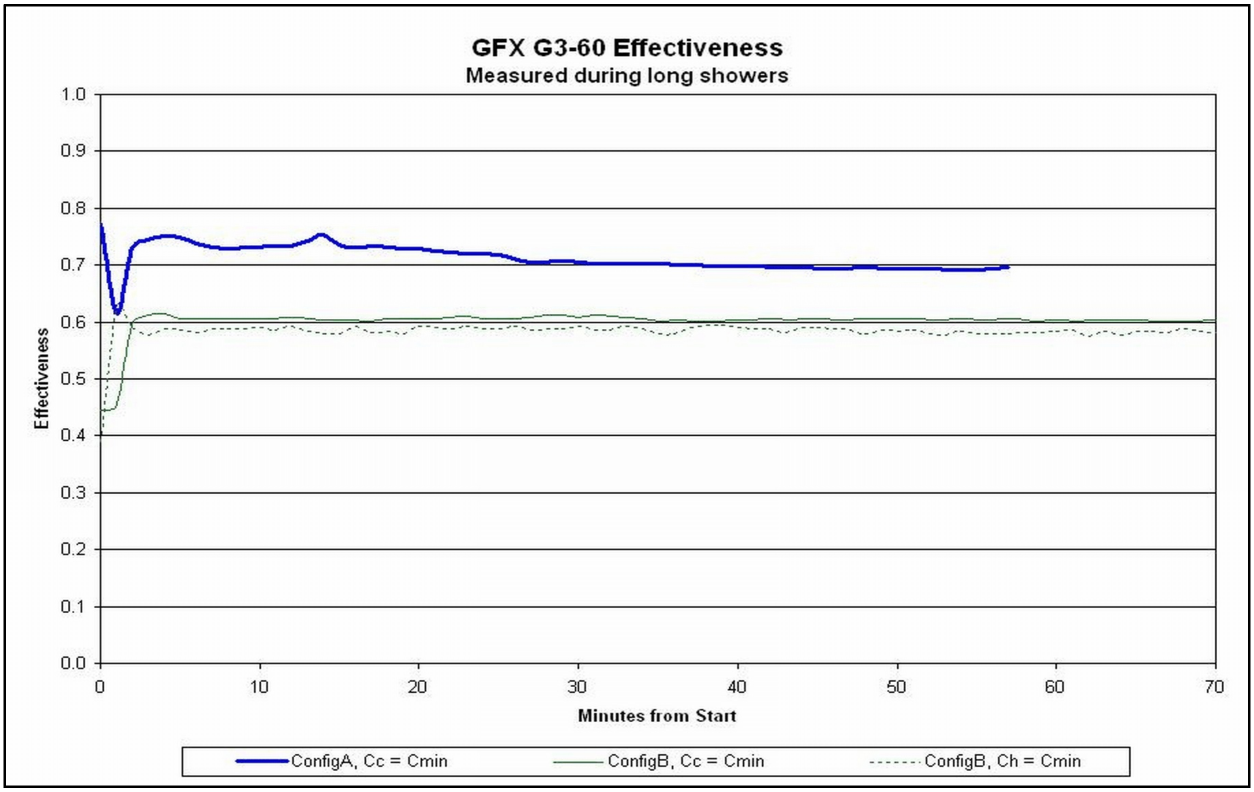

Figure 9. Results of a Test for Effectiveness.

4.2 Effectiveness

Figure 9 shows the results of a typical long shower test of *in situ* effectiveness. The average value is calculated from the point where the values stabilize three minutes into the test until the end. For configuration B, the values calculated for $C_c = C_{min}$ are virtually the same as those calculated for $C_h = C_{min}$, which follows theoretically from the fact that the flows through both sides of the DWHR device are the same (see Section 3.4). Table 4 summarizes the results of effectiveness tests for all five DWHR devices. The effectiveness tests took place in a two-day period (12 & 13 December 2005), and the cold water temperature during the tests varied from 10.2°C to 11.1°C. Thus, variation in cold water temperature was not a significant factor in the effectiveness tests. As shown in Table 5, average shower flow rates varied from 7.9 to 8.1 L/s – a difference of 2.5%, so that is not a significant factor either. The *Ontario Building Code*[3] specifies maximum shower head flow rates of 9.5 L/min, so the flows used here may be closer to those with low-flow shower heads. The table in Appendix III compares the steady-state effectiveness values with shorter-term ones. Generally, the shorter-term values are lower.

Unit	Length (mm)	Mass (kg)	Configuration	Effectiveness (ε)	ε/m	ε/kg
Power-Pipe, R3,60	1,524	12.84	A	0.67	0.44	0.052
			B	0.56	0.37	0.044
Power-Pipe, R3-36	914	7.84	A	0.49	0.54	0.063
			B	0.40	0.44	0.051
GFX, G3-60	1,626	16.14	A	0.70	0.43	0.043
			B	0.61	0.38	0.038
GFX, G3-40	1,016	9.66	A	0.60	0.59	0.062
			B	0.50	0.49	0.052
Retherm, S3-60	1,524	17.27	A	0.55	0.36	0.032
			B	0.46	0.30	0.027

Table 4. Measured Effectiveness of the DWHR units.

The GFX G3-60 has the highest effectiveness in both configurations. Table 4 also shows the effectiveness per metre of length and per kilogram of mass. Length is important because longer units will not fit in all locations, and because longer units will be more expensive. The GFX G3-40 has the highest effectiveness per metre. Mass is important because the devices are made (almost) entirely of copper which is expensive, so heavier devices will tend to be more expensive. The Power-Pipe R3-36 and the GFX G3-40 have the highest effectiveness per kilogram. (The 0.001 differences between them are insignificant, and each is that much better in one configuration).

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[3] Ontario, 2003. *Ontario Building Code 1997, September 1, 2003 update.* Ontario Ministry of Municipal Affairs and Housing, Toronto. Section 7.6.4.1.

4.3 Maximum Shower Lengths

As mentioned, effectiveness tests were generally run until the shower temperature dropped below body temperature (37.0°C). This allows the results to be analysed for the length of time a shower can be run before the water temperature goes below that temperature, and is another way of comparing the DWHR devices, as shown in Table 5.

In some cases, time constraints required that a particular test be stopped before the shower temperature dropped below body temperature. In those cases, the shower length in Table 5 includes a greater than (>) or much greater than (>>) sign before the number of minutes, based on the final temperature and the slope of the temperature graph. As expected, all DWHR devices allow for significantly longer shower times than the benchmark, and all devices allow longer showers in configuration B than in configuration A. Of all the 60-inch devices, the Retherm provides the shortest showers, which is consistent with its lower effectiveness ratings. The actual maximum length of a shower will depend on several factors in addition to the characteristics of a DWHR device. Such factors include the water temperature and flow rate of the shower, the characteristics of the hot water tank (capacity, first hour rating, input and recovery efficiency), and the ground water temperature. For this reason, the results of these tests have only relative or comparative meanings.

Unit	Config	Unit Length (in)	Shower Length (min)	Final Temp (C)	Average Flow (L/min)
None	Benchmark	N/A	28	36.9	8.1
Power-Pipe, R3-60	A	60	58	37.0	8.0
	B	60	>74	38.3	8.0
Power-Pipe, R3-36	A	36	39	37.0	8.1
	B	36	53	36.9	8.1
GFX, G3-60	A	64	62	37.0	8.0
	B	64	>>75	39.3	7.9
GFX, G3-40	A	40	46	37.0	8.0
	B	40	>72	37.6	8.0
Retherm, S3-60	A	60	43	36.9	8.1
	B	60	59	36.9	8.1

Table 5. Maximum Shower Lengths.

4.4 Pressure Drops

During the effectiveness tests, the pressure drop through each of the DWHR devices was measured. The results were read from simple liquid filled pressure gauges with an accuracy of ± 2 psi. Given the accuracy of the gauge and the relatively small differences between the pipe, further measurement with more sophisticated gauges would be required for proper comparison. Results are not published in this report to avoid misinterpretation.

5.0 Analysis & Discussion

For the testing with daily water draw schedules, all DWHR devices and configurations showed significant gas saving potentials of 9 to 27%, as shown in Table 2. As expected, for a given DHWR device the savings generally increase with the number of showers, and are higher in configuration B than in configuration A. Thus for the Retherm, within each configuration the gas savings (both in m^3 and in percent) increase with the number of occupants (showers), and for each number of occupants, the savings are higher in configuration B than in configuration A. For the GFX, the m^3 savings for configuration A, 2 occupants seems to be high, but all others are in the expected order. For the Power-Pipe, the m^3 savings for 4+ occupants are reversed (A slightly higher than B). Thus, for savings expressed as m^3 of gas, there is one large deviation from the expected order (GFX, A, 2 to 3 occupants), and one smaller one (Power-Pipe, 4+ occupants, A to B). All other savings are as expected.

The savings expressed as a percentage seem less consistent, but can be explained by the percentage of total hot water draws going to the showers. For the Power-Pipe, the percentage savings for 3 occupants are lower than those for 2 occupants in both configurations, even though the m^3 savings are higher. For the GFX and the Retherm in configuration B, the percent savings go up by only 1%, but the m^3 savings are substantial. In configuration A the Retherm does show a significant percentage increase, but the m^3 increase is much larger. These differences between savings in m^3 and percentages may be explained by the fact that the percentage of hot water used in the showers is smaller for 3 occupants than for 2. That is, for 2 occupants 57% of the total daily hot water draws are shower draws, while for 3 occupants 43% of the total goes to the showers. A smaller percentage of hot water to the showers means that a smaller percentage is available for recovery by the DWHR devices.

Thus, the only deviations from the expected order that are not explained are the two m^3 savings mentioned above. These deviations are not surprising since these tests were done with a commercial hot water tank and mixing valve, neither of which are precision instruments. The HWT's aquastat may not turn on and off at exactly the same temperatures each time, and the mixing valve allows some fluctuations in the shower temperature. Thus, while not 100% accurate, the results are probably indicative of the sort of savings that would be obtained in actual residences.

When daily gas savings are compared with the measured effectiveness of the devices, the results are not as expected. For any combination of configuration and occupancy, one would expect the DWHR device with the highest effectiveness to have the greatest savings. Thus the GFX (ε=0.71 for configuration A, 0.61 for B) should have the greatest savings, and the Retherm (0.55 & 0.46) should have the lowest. The Power-Pipe (0.67 & 0.56) should be in between, but closer to the GFX. In fact, the Retherm has the highest savings for configuration A, 3 occupants, and for configuration B, 2 and 3 occupants. The Retherm also has higher savings than the Power-Pipe for two other combinations.

The most likely explanation for the higher Retherm performance is that it was tested with lower cold water temperatures. We attempted to remove the bias caused by variations in cold water temperature by ensuring that the benchmark and testing cold water temperatures for each combination of device, configuration and occupancy are close. Nevertheless, a given DWHR device will save more gas when water temperatures are lower, even when compared with benchmarks at the same temperature as the tests. As shown in Table 7, the variation in cold water temperatures definitely favours the Retherm, which was tested at almost three and four degrees colder than the other two. It also slightly favours the Power-Pipe over the GFX, but this one degree difference is not significant. When the daily results for the Power-Pipe and GFX are compared, the GFX shows larger m^3 savings in 75% of the combinations, and greater or equal percentage savings in 75%, so these results are consistent with the higher effectiveness of the GFX.

Device	Average Cold Water Temperature (°C)		
	Benchmark	Testing	Average
Power-Pipe	16.9	16.8	16.9
GFX	18.4	17.4	17.9
Retherm	13.9	14.2	14.0

Table 7. Average cold water temperatures during daily water draw tests.

The daily natural gas savings apply specifically to the water draw schedules outlined in Appendix I, which include warm water clothes washing and baths that may or may not apply to all situations. As these non-simultaneous water draws are removed or replaced, the percentage savings should increase.

5.1 Non-Shower Savings

Although the types of DWHR devices tested in this study work best with simultaneous flows (showers), they should theoretically provide some savings in non-simultaneous flows due to the storage of heat in the water contained in the outer tube and in the mass of copper. For example, when a dishwasher cycle drains its hot water, it should heat up the water and copper in the DWHR device. When the next cycle fills, this heat should be transferred to the hot water tank, saving some energy. On the other hand, if there is a drain of cold water, e.g., a toilet flush, or a long delay between a drain and the next hot water draw, then the heat stored in the DWHR device will be lost.

To estimate the importance of non-shower savings, we compared the benchmark and testing data from 8:30 am on (after the hot water tank has had time to recover from the last shower at 6:50 or 7:15) for two, three and four occupants. The data for 4+ occupants was not used due to the shower in the evening. The results were averaged for each of the 60-inch devices, and the resulting non-shower gas savings were negative for all three, as shown in Table 8.[4] Negative savings are unexpected. One would expect some savings from the second and third dishwasher filling, and some warming of the water in the DWHR devices from the surrounding air. This is discussed in Appendix IV. The conclusion is that there are no significant savings from non-shower draws.

Device	m^3/day	%
Power-Pipe	-0.051	-5.4%
GFX	-0.033	-3.3%
Retherm	-0.035	-3.5%
Average	-0.040	-4.1%

Table 8. Non-shower Gas Savings.

5.2 Performance simulation

Due to the variability in cold water supply, the daily gas savings cannot be directly compared or used to extrapolate annual savings. This raises the issue of standardized performance testing for all DWHR systems being promoted in DSM (Demand-Side Management) and other Energy Efficiency programs. Since only flows through showers are relevant to DWHR performance, the simple models developed by the manufacturers should be suitable for this purpose.

5.3 Total Resource Cost

Utilities considering a program to promote DWHR devices will be interested in their Total Resource Cost (TRC). TRCs are discussed in the Ontario Energy Board's *Total Resource Cost Guide,*[5] which defines the net present value of TRC as:

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4 Note that the percent savings in Table 8 are the savings divided by the benchmark gas use for the same period, i.e., from 8:30 am on. Compared with benchmark gas use for the entire day, they are -2.3%, -1.5% and -1.3%, respectively. The non-shower savings in App. IV are calculated in the same way, and would also be much smaller if compared with entire days.

5 Available from: http://www.oeb.gov.on.ca/documents/cdm_trcguide_141005.pdf

$NPV_{TRC} = B_{TRC} - C_{TRC}$

where:

$$B_{TRC} = \sum_{t=1}^{N} \frac{AC_t}{(1+d)^{t-1}}$$

$$C_{TRC} = \sum_{t=1}^{N} \frac{UC_t + PC_t}{(1+d)^{t-1}}$$

and,

B_{TRC} = the benefits of the program
C_{TRC} = the costs of the program
AC_t = avoided costs in year t
UC_t = DSM program costs in year t
PC_t = Participant cost in year t
N = Number of years (equipment life)
d = Discount rate

In order to get an indication of whether DWHR devices would have a positive TRC value, we performed a simplified calculation that considers only the installed cost of a DWHR device, and the fuel savings that it will provide. This analysis leaves out the DSM program cost, and also any benefits from reduced utility capacity costs, for the simple reason that we have no way of estimating these costs. Table 2 shows that there are four combinations of device, configuration, and occupancy that could produce natural gas savings of 0.6 m^3/day or more. (The largest saving is 0.768 m^3/day). The first table in Appendix V shows the TRC present value calculations with this rate of savings (which is 219 m^3 per year), an installed cost of $750, the current marginal cost of natural gas in Ontario (0.4767 $/$m^3$)[6], a discount rate of 6.5%, and a fuel inflation rate of 5%. The DWHR device show a positive net present value from year nine on, and assuming a lifetime of 30 years, the lifetime net present value is $1,408.

The second table in Appendix show the TRC calculation for an electric hot water tank. In this case the corresponding savings are 5 kWh/day, or 1,825 kWh/yr, and the marginal cost of electricity is 0.1091 $/kWh.[7] The DWHR device shows a positive net present value from year five, and a 30-year TRC net present value of $2,679. These simplified TRC calculations are only an indication of the actual TRCs of DWHR devices, but they do show that they have a strong potential for positive values to utilities and homeowners.

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[6] http://www.cgc.enbridge.com/A/A15-03-01_r-rates.asp

[7] https://www.hydroottawa.com/residential/index.cfm?lang=e&template_id=118

6.0 Summary & Conclusions

Using the test facility at the Canadian Centre for Housing Technology (CCHT), the project team developed standard test procedures for evaluating the performance of drain water heat recovery (DWHR) devices. The test protocol included: 1) full-day water use schedules to determine the energy impacts of the DWHR devices, and 2) "long showers" lasting about 60 minutes each for determining the *in situ* thermal effectiveness of each DWHR device.

The purpose of testing at the CCHT is to combine aspects of laboratory testing and testing in occupied houses. Water draws can be repeated exactly each day as in a lab, while draws of hot, cold and mixed water can be made through a variety of devices as in a house. The test results are not completely satisfactory because we did not foresee that cold water temperatures would vary as much or as quickly as they did. We also found that the mixing valve used to control shower temperatures was not as reliable as we thought. If we perform this sort of testing again, we will control cold water temperature to ±1 °C, and use a more precise proportional, integral and differential (PID) controlled mixing valve.

Nevertheless, we believe that the tests with daily water draw schedules do show the range of savings that can be expected from such DWHR devices, although they should not be used to compare one device with another. We found that all the units tested at CCHT could save an appreciable amount of energy in the range of 0.162 to 0.325 m^3 of gas per 100 L of hot water used in the showers. Based on simple projections (daily results x 365 days), annual savings would be in the range of 59 to 280 m^3 of natural gas, or 2.2 to 10.5 GJ. These predictions should be taken lightly due to cold water temperature variations, and further simulation work will be required to accurately determine the annual savings.

Unlike the daily water draw tests, the tests of effectiveness were all done under very similar conditions, and are valid. The *in situ* thermal effectiveness of all four units ranged from 0.46 to 0.67. All the units had higher effectiveness in configuration A (in which warmed water from the DWHR unit went to the hot water tank only) than in configuration B (in which the warmed water went to both the hot water tank and the cold water to the shower). This is due to the lower flow rate of cold water through the DWHR unit in configuration A. The lower flow allows the temperature of the warmed water exiting the unit to get closer to the temperature of the drain water entering the unit. During the full-day tests, more natural gas was saved in configuration B than in configuration A. This is because in configuration B the larger amounts of water flowing through the DWHR units more than compensated for the lower effectiveness.

This project found that the three DWHR devices that were tested with daily water draw schedules show no gas savings for non-simultaneous water draws. This finding reinforces the current assumptions on this issue. There is no reason to believe that simulation tools should consider non-simultaneous events. For this reason, it should be possible to predict annual savings using the models developed by the manufacturers.

Appendix I: Daily Water Draw Schedules

Note that for each schedule, the specified number of litres of hot and cold water had to be adjusted and rounded to allow for integral numbers of litres because the meters used had a resolution of one litre. These adjustment made the most difference when applied to each filling of the clothes washer and the dishwasher.

Schedule 1: 2 Persons, 163 litres per day of hot water per day

Draw	Start Time	Event	Specified Draws (L)		Adjusted Draws (L)	
			Hot	Cold	Hot	Cold
1	6:00	Toilet	0.00	6.50	0	7
2	6:05	Toilet	0.00	6.50	0	7
3	6:15	Kitchen	2.52	2.48	3	2
4	6:20	Shower	47.41	28.59	47	29
5	6:30	Lavatory sink	2.52	2.48	2	2
6	6:50	Shower	47.41	28.59	47	29
7	7:00	Lavatory sink	2.52	2.48	3	2
8	7:45	Kitchen	7.57	7.43	8	7
9	17:00	Toilet	0.00	6.50	0	7
10	17:05	Kitchen	7.57	7.43	8	7
11	17:25	Toilet	0.00	6.50	0	7
12	17:30	Lavatory sink	2.52	2.48	2	2
13	18:00	Dishwasher, fill	3.78	0.00	4	0
	18:11	Dishwasher, drain	0.00	0.00	0	0
	18:15	Dishwasher, fill	3.78	0.00	4	0
	18:26	Dishwasher, drain	0.00	0.00	0	0
	18:30	Dishwasher, fill	3.78	0.00	4	0
	18:41	Dishwasher, drain	0.00	0.00	0	0
14	19:30	Laundry, fill	12.63	12.38	13	12
	19:44	Laundry, drain	0.00	0.00	0	0
	19:50	Laundry, fill	12.63	12.38	13	12
	19:59	Laundry, drain	0.00	0.00	0	0
15	20:05	Toilet	0.00	6.50	0	7
16	21:30	Toilet	0.00	6.50	0	7
17	21:35	Lavatory sink	2.52	2.48	3	2
18	22:00	Toilet	0.00	6.50	0	7
19	22:05	Lavatory sink	2.52	2.48	3	2
Totals			**162**	**157**	**164.0**	**157.0**

Schedule 2: 3 Persons, 244 litres per day of hot water per day

Draw	Start Time	Event	Specified Draws (L) Hot	Specified Draws (L) Cold	Adjusted Draws (L) Hot	Adjusted Draws (L) Cold
1	6:00	Toilet	0.00	6.50	0	7
2	6:05	Toilet	0.00	6.50	0	7
3	6:10	Toilet	0.00	6.50	0	7
4	6:15	Kitchen	3.79	3.71	4	4
5	6:20	Shower	47.41	28.59	47	28
6	6:30	Lavatory sink	2.52	2.48	3	2
7	6:50	Shower	59.26	35.74	59	36
8	7:00	Lavatory sink	2.52	2.48	3	2
9	7:05	Lavatory sink	2.52	2.48	3	2
10	7:45	Kitchen	12.62	12.38	13	12
11	17:00	Toilet	0.00	6.50	0	7
12	17:05	Kitchen	12.62	12.38	13	12
13	17:30	Lavatory sink	2.52	2.48	2	2
14	18:00	Dishwasher, fill	3.41	0.00	3	0
	18:11	Dishwasher, drain	0.00	0.00	0	0
	18:15	Dishwasher, fill	3.41	0.00	3	0
	18:27	Dishwasher, drain	0.00	0.00	0	0
	18:30	Dishwasher, fill	3.41	1.12	3	0
	18:41	Dishwasher, drain	0.00	0.00	0	0
15	18:50	Bath, fill	43.17	33.33	43	32
	19:05	Bath, drain	0.00	0.00	0	0
16	19:30	Laundry, fill	18.94	18.56	19	19
	19:44	Laundry, drain	0.00	0.00	0	0
	19:50	Laundry, fill	18.94	18.56	19	19
	19:59	Laundry, drain	0.00	0.00	0	0
17	19:35	Toilet	0.00	6.50	0	7
18	20:05	Toilet	0.00	6.50	0	7
19	20:10	Lavatory sink	2.52	2.48	2	2
20	21:00	Toilet	0.00	6.50	0	7
21	21:30	Toilet	0.00	6.50	0	7
22	21:35	Lavatory sink	2.52	2.48	3	2
23	22:00	Toilet	0.00	6.50	0	7
24	22:05	Lavatory sink	2.52	2.48	3	2
Totals			**245**	**240**	**245.0**	**239.0**

Schedule 3: 4 Persons, 325.5 litres of hot water per day

Draw	Start Time	Event	Specified Draws (L) Hot	Specified Draws (L) Cold	Adjusted Draws (L) Hot	Adjusted Draws (L) Cold
1	6:00	Toilet	0.00	6.50	0	7
2	6:05	Toilet	0.00	6.50	0	7
3	6:10	Toilet	0.00	6.50	0	7
4	6:15	Kitchen	5.05	4.95	5	5
5	6:20	Shower	47.41	28.59	47	28
6	6:30	Lavatory sink	2.52	2.48	3	2
7	6:45	Toilet	0.00	6.50	0	7
8	6:50	Shower	47.41	28.59	47	29
9	7:00	Lavatory sink	2.52	2.48	3	2
10	7:05	Lavatory sink	2.52	2.48	3	2
11	7:15	Shower	71.11	42.39	71	42
12	7:30	Lavatory sink	2.52	2.48	3	2
13	7:45	Kitchen	12.62	12.38	13	12
14	11:50	Toilet	0.00	6.50	0	7
15	12:00	Lavatory sink	2.52	2.48	3	2
16	16:00	Toilet	0.00	6.50	0	7
17	16:05	Toilet	0.00	6.50	0	7
18	17:05	Kitchen	12.62	12.38	13	12
13	17:30	Lavatory sink	2.52	2.48	2	2
20	18:00	Dishwasher, fill	3.41	0.00	3	0
	18:11	Dishwasher, drain	0.00	0.00	0	0
	18:15	Dishwasher, fill	3.41	0.00	3	0
	18:26	Dishwasher, drain	0.00	0.00	0	0
	18:30	Dishwasher, fill	3.41	1.12	3	0
	18:41	Dishwasher, drain	0.00	0.00	0	0
21	18:50	Bath, fill	43.17	33.33	43	32
	19:05	Bath, drain	0.00	0.00	0	0
22	19:30	Laundry, fill	25.25	24.75	25	25
	19:44	Laundry, drain	0.00	0.00	0	0
	19:50	Laundry, fill	25.25	24.75	25	25
	19:59	Laundry, drain	0.00	0.00	0	0
23	19:35	Toilet	0.00	6.50	0	7
24	20:05	Toilet	0.00	6.50	0	7
25	20:10	Lavatory sink	2.52	2.48	2	2
26	21:00	Toilet	0.00	6.50	0	7
27	21:30	Toilet	0.00	6.50	0	7
28	21:35	Lavatory sink	2.52	2.48	3	2
29	22:00	Toilet	0.00	6.50	0	7
30	22:05	Lavatory sink	2.52	2.48	3	2
31	22:10	Toilet	0.00	6.50	0	7
32	22:15	Lavatory sink	2.52	2.48	3	2
Totals			**325.32**	**322.53**	**326.0**	**321.0**

Schedule 4: 4 Persons, 363.5 litres of hot water per day (4+ persons)

Schedule 4 is the same as Schedule 3, except that a fourth shower of 113 L (71 L hot & 42 L cold) is substituted for the bath at 18:50.

Appendix II. Comparison of Hot Water Draw Schedules.

The table below compares the hot water draws used in this project with those from a paper by DeOreo and Mayer[8] who measured water use in ten houses in Seattle with an average of 2.6 occupants before the installation of water saving devices. Hot water was measured for the entire houses, and separated into individual uses by flow trace analysis. The results are presented in gallons per person per day. The table show the results as litres per day for houses with two, three and four occupants.

Compared with DeOreo's findings, this project (DWHR) used only 86% as much total hot water. This might indicate that this study underestimates the potential savings from DWHR devices. However, hot water use in showers was 1.5 to two times as high in this project, while use for baths was lower. Since DWHR savings seem to depend entirely on hot water in showers, that would mean that this project overestimated DWHR savings. Hot water uses for most other purposes are similar. Thus, the draws used in this study would appear to be reasonably representative of households in which most occupants take showers rather than baths. These are the households that can best benefit from DWHR devices.

Category	2 persons			3 persons			4 persons		
	DeOreo	DWHR	Diff	DeOreo	DWHR	Diff	DeOreo	DWHR	Diff
Total	190.1	164	86%	285.1	245	86%	380.2	326	86%
Shower	47.7	94	197%	71.5	106	148%	95.4	165	173%
Clothes Washer	29.5	26	88%	44.3	38	86%	59.0	50	85%
Dishwasher	6.8	12	176%	10.2	9	88%	13.6	9	66%
Faucet	65.1	32	49%	97.7	49	50%	130.2	59	45%
Bath	31.8	0	0%	47.7	43	90%	63.6	43	68%

Table A2-1. Comparison of water draws.

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[8] DeOreo, W.B. and P.W. Mayer, no date. *The End Use of Hot Water in Single Family Homes from Flow Trace Analysis*. Aquacraft, Inc., Boulder, CO. Available from: http://aquacraft.com/Publications/hotwater.htm

Appendix III: Short-term & Steady-state Effectiveness.

Device	Configuration A			Configuration B		
	2 to 4 min	2 to 6 min	Steady-State	2 to 4 min	2 to 6 min	Steady-State
Power-Pipe R3-60	0.65	0.67	0.67	0.54	0.54	0.56
Power-Pipe R3-36	0.49	0.50	0.49	0.37	0.38	0.40
GFX G3-60	0.70	0.72	0.70	0.55	0.58	0.61
GFX G3-40	0.51	0.56	0.60	0.48	0.49	0.50
Retherm S3-60	0.58	0.58	0.55	0.45	0.46	0.46

Table A3-1. Measured short-term and steady-state effectiveness values.

This table compares effectiveness values calculated in three ways. All are based on the temperatures in and out of the DWHR devices as measured every ten seconds, and averaged and saved each minute. The 2 to 4 min values are the averages of the effectiveness values for the second, third and forth minute of the shower. The 2 to 6 min minute values are the averages of the effectiveness values for the second through sixth minutes. The first minute of the shower is not used because during most of it the water has not had time to pass through the shower and reach the DWHR device. The steady-state effectiveness is the average of values from the third minute of the shower until the shower temperature dropped below 37°C, or the test was ended, as described in the text.

Appendix IV: Non-shower Gas Savings.

The negative non-shower gas savings shown in Table 8 were calculated from gas use starting at 8:30 am, after the HWT had recovered from the morning draws including the showers at 6:20 and 6:50. We originally calculated these savings from 8:00 am, assuming that the HWT would have recovered by then. Those results are shown in Table A4-1, and show positive non-shower savings for all three units and significant savings for the Retherm. The difference between the two sets of results may be explained by Figure A4-1, which shows a typical morning pattern of natural gas use. If one calculates the non-shower savings starting a 8:00 am, then the benchmark gas use at 8:10 am causes an apparent non-shower saving for that day. If one calculates the non-shower savings from 8:30 am, then the 8:10 am draw is not included in the benchmark, and the test draws at 10:20 am and 10:30 am are enough to produce negative non-shower savings. Non-shower savings could be calculated from other starting times, but the fact that these savings can be reversed by a single cycle of the HWT burner caused by tank loses at times when there are no hot water draws shows that any such savings are insignificant.

Device	Daily gas savings	
	m^3/day	%
PowerPipe	0.008	0.4%
GFX	0.012	0.8%
Retherm	0.082	5.6%

Table A4-1. Non-Shower Gas Savings, Calculated from 8:00 am.

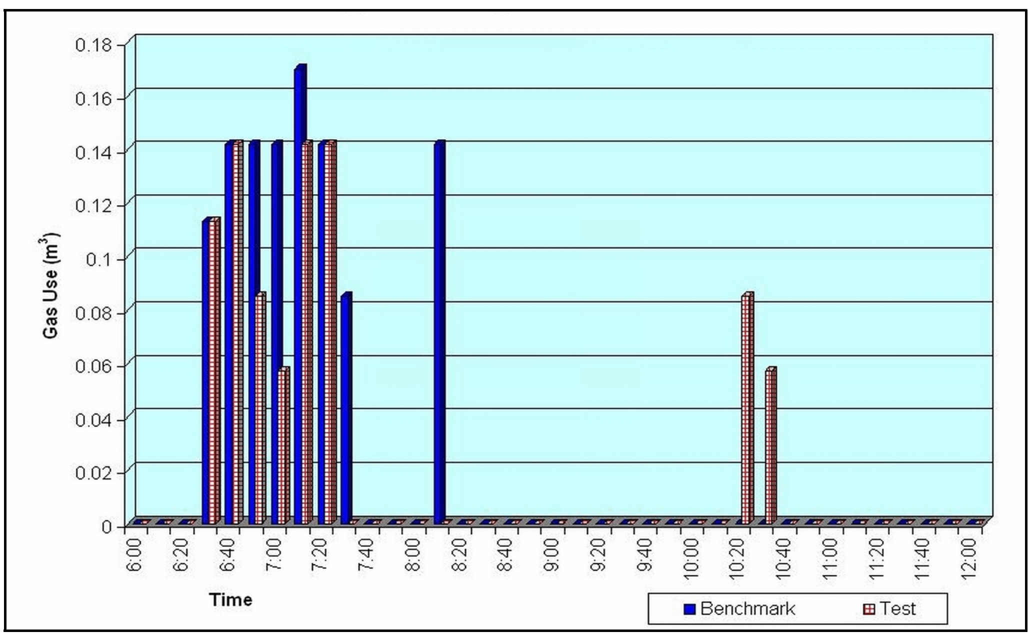

Figure A4-1. Typical morning gas use pattern

Appendix V: Simplified TRC Calculations.

Year	Cost of Gas ($/m^3)	Benefits	Costs	Net Benefit year	Net Benefit Cumm
1	0.477	$ 104.39	$ 750.00	-$ 645.61	-$645.61
2	0.486	$ 100.00	$ -	$ 100.00	-$545.61
3	0.496	$ 95.79	$ -	$ 95.79	-$449.81
4	0.506	$ 91.77	$ -	$ 91.77	-$358.05
5	0.516	$ 87.91	$ -	$ 87.91	-$270.14
6	0.527	$ 84.21	$ -	$ 84.21	-$185.93
7	0.537	$ 80.67	$ -	$ 80.67	-$105.27
8	0.548	$ 77.27	$ -	$ 77.27	-$28.00
9	0.559	$ 74.02	$ -	$ 74.02	$46.03
10	0.571	$ 70.91	$ -	$ 70.91	$116.93
11	0.582	$ 67.93	$ -	$ 67.93	$184.86
12	0.594	$ 65.07	$ -	$ 65.07	$249.93
13	0.606	$ 62.33	$ -	$ 62.33	$312.26
14	0.618	$ 59.71	$ -	$ 59.71	$371.97
15	0.631	$ 57.20	$ -	$ 57.20	$429.16
16	0.643	$ 54.79	$ -	$ 54.79	$483.96
17	0.656	$ 52.49	$ -	$ 52.49	$536.44
18	0.670	$ 50.28	$ -	$ 50.28	$586.72
19	0.683	$ 48.16	$ -	$ 48.16	$634.89
20	0.697	$ 46.14	$ -	$ 46.14	$681.02
21	0.711	$ 44.20	$ -	$ 44.20	$725.22
22	0.725	$ 42.34	$ -	$ 42.34	$767.56
23	0.740	$ 40.56	$ -	$ 40.56	$808.12
24	0.755	$ 38.85	$ -	$ 38.85	$846.97
25	0.770	$ 37.22	$ -	$ 37.22	$884.18
26	0.786	$ 35.65	$ -	$ 35.65	$919.84
27	0.802	$ 34.15	$ -	$ 34.15	$953.99
28	0.818	$ 32.72	$ -	$ 32.72	$986.70
29	0.835	$ 31.34	$ -	$ 31.34	$1,018.04
30	0.851	$ 30.02	$ -	$ 30.02	$1,048.06
Lifetime:		$1,798.06	$ 750.00	$1,048.06	

Table A5-1: TRC for a DWHR Device with Natural Gas.

DWHR equipment life:	30	years.	Discount Rate:	6.5%
Installed Cost:	$750.00			
Annual Gas Savings:	219.00	m^3	(0.6 m^3/day)	
Marginal Cost of Gas:	0.4767	$/m^3 in Year 1		
Fuel inflation rate:	2%			

Year	Cost of Elec ($/kWh)	Benefits	Costs	Net Benefit Year	Net Benefit Cumm
1	0.109	$ 199.11	$ 750.00	-$ 550.89	-$550.89
2	0.111	$ 190.73	$ -	$ 190.73	-$360.16
3	0.114	$ 182.71	$ -	$ 182.71	-$177.45
4	0.116	$ 175.02	$ -	$ 175.02	-$2.43
5	0.118	$ 167.66	$ -	$ 167.66	$165.23
6	0.121	$ 160.61	$ -	$ 160.61	$325.84
7	0.123	$ 153.85	$ -	$ 153.85	$479.70
8	0.125	$ 147.38	$ -	$ 147.38	$627.08
9	0.128	$ 141.18	$ -	$ 141.18	$768.26
10	0.131	$ 135.24	$ -	$ 135.24	$903.50
11	0.133	$ 129.55	$ -	$ 129.55	$1,033.05
12	0.136	$ 124.10	$ -	$ 124.10	$1,157.16
13	0.139	$ 118.88	$ -	$ 118.88	$1,276.04
14	0.141	$ 113.88	$ -	$ 113.88	$1,389.93
15	0.144	$ 109.09	$ -	$ 109.09	$1,499.02
16	0.147	$ 104.50	$ -	$ 104.50	$1,603.52
17	0.150	$ 100.11	$ -	$ 100.11	$1,703.63
18	0.153	$ 95.90	$ -	$ 95.90	$1,799.53
19	0.156	$ 91.86	$ -	$ 91.86	$1,891.39
20	0.160	$ 88.00	$ -	$ 88.00	$1,979.39
21	0.163	$ 84.30	$ -	$ 84.30	$2,063.69
22	0.166	$ 80.75	$ -	$ 80.75	$2,144.44
23	0.169	$ 77.35	$ -	$ 77.35	$2,221.79
24	0.173	$ 74.10	$ -	$ 74.10	$2,295.89
25	0.176	$ 70.98	$ -	$ 70.98	$2,366.88
26	0.180	$ 68.00	$ -	$ 68.00	$2,434.87
27	0.184	$ 65.14	$ -	$ 65.14	$2,500.01
28	0.187	$ 62.40	$ -	$ 62.40	$2,562.41
29	0.191	$ 59.77	$ -	$ 59.77	$2,622.18
30	0.195	$ 57.26	$ -	$ 57.26	$2,679.44
Lifetime:		$3,429.44	$ 750.00	$2,679.44	

Table A5-2: TRC for a DWHR Device with Electricity.

DWHR equipment life:	30 years.		Discount Rate:	6.5%
Installed Cost:	$750.00			
Annual Electical Savings:	1,825.00	kWh		
Marginal Cost of Electricity:	0.109	$/kWh in Year 1		
Fuel inflation rate:	2%			