Evaluation of Residential Drain Water Heat Recovery Unit

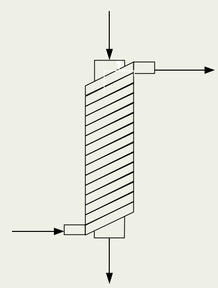
TECHNICAL BRIEF

Energy Conservation and Efficiency

Drain water heat recovery (DWHR) was first applied to shower drains in the 1980s to reduce the domestic hot water heating load. Since then, at least ten new patents with variations of this technology have been filed for the recovery of waste heat energy. DWHR units remove heat from waste drain water, which may have otherwise entered natural water features to degrade cold-water aquatic habitats by indirectly decreasing the availability of dissolved oxygen in the water.

Since the 1990's, the average Canadian household has decreased its water heating energy consumption by 19%. However, this reduction in energy used to heat water has been offset by a growing number of households. This is evidenced by an overall increase of 6% in residential water heating energy use, which accounts for 18% of total household energy consumption in Canada as of 2007 (NRCan, 2009). To compensate for this increase in total household water heating energy consumption, energy conservation technologies and practices need to be better understood, and more broadly implemented.

Total water use (hot and cold) per person per day in Canada is approximately 343 L, which is nine times higher than some European countries. Hot water use per capita is approximately 56 L/day. Of this usage, 60% is drawn from showers and faucets, providing the potential for significant energy recovery.



This project assesses the capacity of drain water heat recovery (DWHR) systems to recover waste energy contained in warm drain water, from sources such as showers, sinks, laundry and/or dishwashers. In one application of DWHR, a short section of copper pipe is used to replace a section of plastic drain pipe. A copper coil, delivering cold municipal water, is then wrapped around the copper pipe section. The cold municipal water is heated as warm water drains down the pipe. Heat is exchanged across the surface of the copper pipe, which has a high thermal conductivity, but the drain water and municipal water do not come into contact. They are typically installed to replace an existing section of the regular vertical piping system. DWHR systems are technologies that are not yet widely employed in residential houses, despite their potential to significantly reduce household energy consumption.

STUDY SITE AND TECHNOLOGY

Two identical DWHR systems were implemented in each of the two Archetype Sustainable Houses. These twin houses – referred to as House A and B - located at the Kortright Living City Campus in Vaughan, are home to a comprehensive demonstration center for energy efficiency, renewable energy, conservation and sustainable technologies. The DWHR units were installed in conjunction with other renewable energy systems. House A is equipped with a flat plate solar thermal collector with a natural gal mini-boiler and DWHR, while House B is equipped with an evacuated tube solar thermal collector with an electric back-up tank and DWHR. The DWHR units are located on the first floor and capture heat from the drain water of the showers and bathroom sinks on the upper floors.

The DWHR unit at the Archetype Sustainable Houses is shown in Figure 1. The length of the copper section of pipe installed in the plastic drain pipe is 91 cm. It is 7.62 cm in diameter and 0.95 cm thick. Wrapped around the pipe is a 3/8" (Type L) tubes with four parallel wraps (PowerPipe R3-36), manufactured by Renewability Inc.

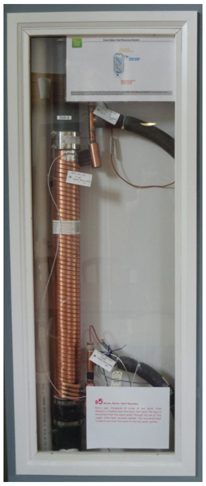


Figure 1. Drain water heat recovery unit at Archetype House B

APPROACH

Data Collection

ASHRAE Building Energy Monitoring Manual (A41-SI) was utilized to establish water use profiles of a single family home. The Archetype Sustainable Houses monitoring and control system uses hardware from National Instruments integrated with Labview software. A custom Labview program was created to control a valve manifold that implemented the standardized hot and cold water draw profile. Monitoring points included the inlet and outlet water temperatures across both the drain and municipal water sections of the PowerPipe, as well as the flow rates through each. These were then used to calculated the heat energy transferred from the drain to the municipal water with the NTU-Effectiveness method. The effectiveness is a ratio between the actual heat transfer rate and the maximum possible heat transfer rate (dimensionless unit ranging from 0 to 1), while number of heat transfer units (NTU) is a dimensionless indication of the 'heat transfer size' of the exchanger, and is represented by the ratio of the overall conductance to the smaller heat capacity rate. Water draw profile testing was only conducted in House B since the units in both houses are identical.

Daily water draw schedule

A TRNSYS model was executed to model the hot water consumption patterns of typical households in major Canadian cities using a standardized event-based hot water draw profile (Table 1) and local weather data. The daily water schedule used for the two houses is a hot water draw for a family of 4, which is 225 L/day, in accordance with IEA Schedule Task 26 mode (Joran & Vajen, 2001). The delivered water temperature to the end user is 48 °C. It was assumed that 180 L of the 225 L daily total (80 %) comprised simultaneous flow between fresh water demand and the drain water flow, representing the volume from which energy can be extracted (Hendron and Burch, 2007).

Table 1. Daily water draw schedule for winter and summer events (in brackets). Units are in GPM.

Events	Cold & Hot Water Flow Rate	Hot Water Flow Rate	Cold Water Flow Rate
Shower	1.9	1.6 (1.5)	0.3 (0.4)
Bathroom Sink	1.2	1	0.2
Kitchen Sink	1.2	1	0.2
Clothes Washer	3	1.6 (1.5)	1.4 (1.5)
Dishwasher	1.3	1.3	0

FINDINGS

The DWHR units performed better in colder months when the source water temperatures were low. Figure 2 displays monthly well, municipal and DWHR exit temperatures in relation to mean daily energy recovery for each month. The well water supply used for this study undergoes seasonal temperature variations (5 °C in February and 16 °C in August). As the summer water inlet temperatures are already relatively high, the DWHR unit does not transfer a significant amount of new energy from the drain water to the potable water. This is evident from the large amount of recovered energy during the winter months when the fresh inlet water temperatures are lowest (i.e. low well temperatures), resulting in large differences between inlet temperatures and desired shower temperatures. If this DWHR system were coupled to a municipal mains supply, energy recovery would be greater in accordance with consistently lower watermain temperatures.

The average flow rates and temperatures for different events are presented in Table 2. During a winter shower event of 400 s, the decrease in drain water temperature after it passes through the heat recovery system is 13.6 °C (11.1 °C for summer) , while the municipal water temperature increase is 11.8 °C (9.7 °C for summer). The larger change in temperature during the winter shower event is reflected in the higher average winter heat recovery rate of 4.55 kW (0.51 kWh), and an average summer heat recovery rate of 3.75 kW (0.42 kWh)on a per event basis. The difference in these average values is illustrated in Figure 3, as the summer heat recovery rate reaches steady-state

Table 2. Summary results for winter, summer and sink events.

	Hot Side Inlet T (°C)	Hot Side Outlet T (°C)	Hot Side T Decrease (°C)	Cold Side Inlet T (°C)	Cold Side Outlet T (°C)	Cold Side T Increase (°C)	T Loss During Recovery (°C)	Drain water flow rate (L/min)	Tempered line from DHW tank T (°C)	Tempered line flow rate (L/min)	Effectivness	NTU	Power Gain to Municipal Water(kW)
February (shower event)	38.5	24.9	13.6	15.2	27.0	11.8	1.8	6.9	46.8	5.6	0.51	0.88	5.76
August (shower event)	39.5	28.4	11.1	19.8	29.5	9.7	1.4	6.9	47.5	5.7	0.49	0.84	4.74
February (sink event, unit not cooled down)	37.4	20.8	16.6	13.0	24.9	11.9	4.7	4.5	47.6	3.8	0.49	0.83	5.81

after 150 seconds at rates between 4.5 and 4 kW. Conversely, the winter heat recovery rate continues to increase beyond 150 seconds and reaches a steady-state between 6 and 7 kW.

DWHR systems installed in higher occupant households will achieve higher per capita performance because the maximum rate of power generation is achieved quicker when the unit is already warmed up. The unit was tested under warmed up conditions for a 150 second sink event in the winter. This resulted in a potable water temperature increase of 11.9 °C, achieved at half the time frame of a shower event (Table 2). This is illustrated in Figure 3, as the rate of heat recovery is consistently higher for the entire duration of the sink event than for the two shower events. Therefore, when the unit is used more consistently (for larger families), higher heat recovery rates can be achieved and the maximum steady-state heat recovery rate will be reached sooner (Van Decker, 2008). The average sink heat recovery rate was 3.1 kW (0.13 kWh), although this number would be higher if the event was also 400 seconds long.

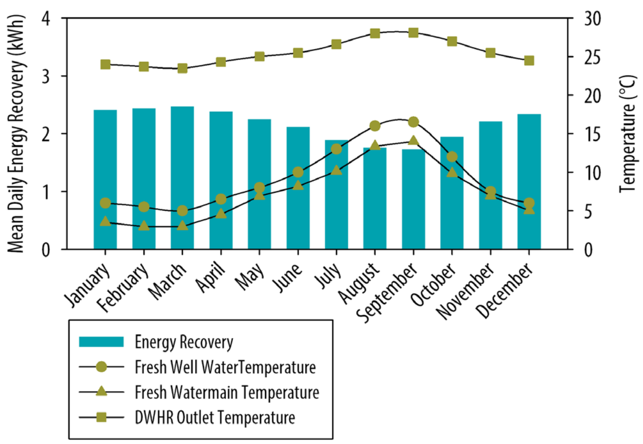


Figure 2. Monthly well , watermain (Solar City, 2012) and DWHR outlet temperatures and mean daily recovered energy.

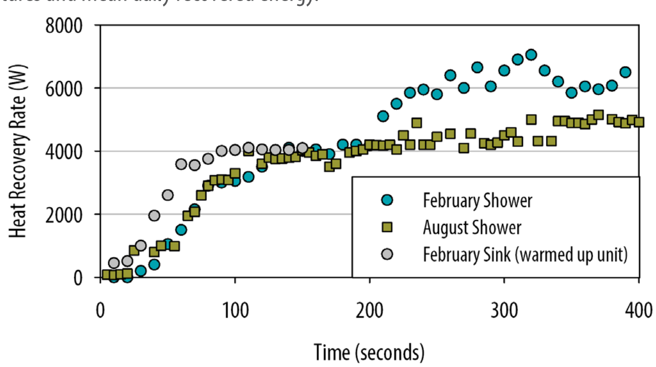


Figure 3. Heat recovery rates for tested events.

The DWHR effectiveness* does not change with increasing inlet temperature. To assess its performance, the DWHR unit was tested for NTU and effectiveness, whereby larger NTU and effectiveness indicate good DWHR performance as a fraction of its rated potential energy recovery (Table 2). The two measures are interrelated, such that the effectiveness largely depends on the configuration of the unit, which will exert the same influence on the NTU measure. The effectiveness remained at approximately 50% for all simulated water draw events, with a 2% increase during the winter shower event despite an 18% improvement in recovered energy. The effectiveness does not significantly vary with inlet temperature due to the nature of the theoretical equation, as a change in the cold inlet temperature will be reflected in the same manner in both the numerator and denominator, resulting in no change in effectiveness (See Tanha, 2011 for equation details).

* Note that good effectiveness is not indicative of large amount of recovered heat, but is primarily a measure of the unit configuration i.e. different units will have different NTU-effectiveness curves.

The DWHR effectiveness and NTU increase with smaller coil to drain flow ratio. The effectiveness and NTU are improved when the drain flow rate is higher than the coil flow rate (i.e. lower coil (i.e. municipal)/drain ratio), common during shower events with simultaneous water flow (Bernier et al., 2004). The effectiveness also increases with increasing drain water temperature, for the cases when the units were warmed up.

DWHR units provide a quick payback on investment, with even better return for inefficient shower and faucet fixtures. These systems are attractive, as they are maintenance-free once installed, and are made of standard plumbing material. A cost savings analysis was conducted with the help of a DWHR calculator tool developed by Natural Resources Canada (http://www.ceati.com/calculator/). For a configuration comparable to that in this study approach, the tool produced annual energy savings within 7% of the experimental results. Table 3 presents annual energy and monetary savings and simple payback years (for unit cost of $605, excluding installation) figures based on different residential setting scenarios. The savings were calculated assuming 4 daily showers (family of four) that are 10 minutes in length with desired shower temperature of 41 °C. The amount of recovered energy increases with larger number of occupants (scenario not shown) and higher inefficiency of shower heads (i.e. high flow rate).

A standard DWHR unit installed in a home with 4 occupants will reduce annual GHG emissions by approximately 126.2 kgCO_2, equivalent to planting 14 trees. The total annual amount of energy recovered by the DWHR unit was 788.54 kWh. With an estimated release of CO_2 of 0.16kgCO_2/kWh for an electric hot water heater (Environment Canada, 2011), the implementation of DWHR unit will reduce annual GHG emissions by 126.2 kgCO_2. If instead the heating source is natural gas with an estimated CO_2 release rate of 1.879 kgCO_2/m^3 (Environment Canada, 2011), the annual reduction in CO_2 emissions will be 144.1 kgCO_2. This clearly illustrates that the incentive for the implementation of DWHR units in a single-family home such as was studied here are both economic and environmental.

Table 3. Energy and monetary savings with associated payback years for multiple flow and energy source scenarios.

Showerhead Type	Annual Savings (energy)	Annual Savings ($)	Simple Payback Years
Electric (Price:12 ¢/kWh; Unit: kWh)			
Low Flow (6.5 L/min)	983	118.01	5.13
Standard Flow (9.5 L/min)	1218	146.13	4.14
Older (15L/min)	1539	184.72	3.28
High Flow (18L/min)	1679	201.54	3.00
Standard Natural Gas (Price: 48.5 ¢/m^3; Unit: m^3)			
Low Flow (6.5 L/min)	122	59.02	10.25
Standard Flow (9.5 L/min)	151	73.08	8.28
Older (15L/min)	190	92.38	6.55
High Flow (18L/min)	208	100.79	6.00
High Efficiency Natural Gas (Price: 48.5 ¢/m^3; Unit: m^3)			
Low Flow (6.5 L/min)	105	51.15	11.83
Standard Flow (9.5 L/min)	131	63.33	9.55
Older (15L/min)	165	80.06	7.56
High Flow (18L/min)	180	87.35	6.93

CONCLUSIONS

A DWHR unit was tested for its performance and energy recovery capability for winter and summer conditions with seasonally fluctuating source water temperatures. It was found that the effectivness and NTU of the DWHR unit increase with decreasing incoming potable water temperature and decreasing municipal/drain pipes ratio. Overall, the amount of energy recovered is highly dependent on home occupancy – how often showers are taken, how long the showers are, what the flow rate of the showers is, all of which will ultimately affect the frequency of simultaneous water flow. A simultaneous water flow would maximize the amount of energy recovered, shown by better energy recovery during shower events that are longer in duration than during sink events. The implementation of a DWHR system is a cost-effective renewable energy initiative with estimated payback periods as low as 3 years. Energy and cost savings results presented here show the feasibility and potential benefits of DWHR units when implemented in residential settings.

REFERENCES

Bernier M, Delisle V, Picard D, Kummert M (2004) On the combined effect of wastewater heat recovery and solar domestic hot water heating. Canadian Solar Buildings Conference. Montreal, QC.

Environment Canada (2011) Fuel Combustion. GHG Emissions Quantification Guidelines.

Jordan U, Vajen K (2001) Realistic Domestic Hot Water Profiles in Different Time Scales. Marburg: Universitat Marburg.

NRCan (2009, September) Energy Efficiency Trends in Canada: 1990 to 2007. Natural Resources Canada (http://oee.nrcan.gc.ca/publications/statistics/trends09/pdf/trends.pdf).

Solar City Partnership (2012) Toronto Fire Station #212: 12.5 kW Solar Water Heating Installation (http://solarcitypartnership.ca/solarfiles/FH212-finalreport.pdf).

Tanha, K (2011) Evaluation the Performance of Two Solar Domestic How Water Systems of the Archetype Sustanainable Houses. Master of Applied Science Thesis, Ryerson University, Toronto, ON.

Van Decker G (2008, February). Analysis of Drain Water Heat Recovery Applications in Northern Minnesota Based on Demographic Characteristics, Supply Water Temperature, and Two Studies by Natural Resources Canada. Renewability (http://www.renewability.com/uploads/documents/en/analysis_dwhr_minnesota.pdf).

For more information on STEP's other projects, visit us online at www.sustainabletechnologies.ca

This technical brief was prepared by the Toronto and Region Conservation Authority's Sustainable Technologies Evaluation Program (STEP) based on an M.A.Sc thesis completed by Kamyar Tanha in 2011, under the supervision of Dr. Alan Fung at Ryerson University. The research was conducted collaboratively between Ryerson University and STEP, with funding support from the MITACS Accelerate Program, BILD, Reliance Home Comfort, Union Gas, Region of Peel, York Region and the City of Toronto. The contents of this report do not necessarily represent the policies of the supporting agencies. For more information about this project, please contact STEP@trca.on.ca.

Toronto and Region Conservation for The Living City