Analysis of Drain Water Heat Recovery Applications in Northern Minnesota Based on Demographic Characteristics, Supply Water Temperature, and Two Studies by Natural Resources Canada

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1. INTRODUCTION

Drain Water Heat Recovery (DWHR) is rapidly gaining acceptance as a practical energy saving measure for single homes, multi-unit residential buildings, commercial facilities and industrial processes. Falling film heat exchangers have emerged as the preferred class of heat exchanger for use in all sectors because of their inherent non-clog, non-fouling design.

Residential DWHR is somewhat different from some other energy saving measures in that total savings is highly dependent on home occupancy. For example, DWHR is very cost effective in homes with three or more occupants and not very cost effective in single person homes. The fact is that single person homes are not part of the real market for DWHR.

Until now, the approach to determining DWHR cost effectiveness for the purposes of utility programs was to assume an average occupancy for a given region, either for an entire country, state/province, or even county. This approach has unfairly penalized DWHR with a portion of the market (single person homes) for which it does not participate in. In effect, it has been like penalizing the implementation of wind energy technology based upon all physically possible sites for wind turbines, without elimination of sites that are in a poor wind regime.

2. SCOPE OF WORK AND CALCULATIONS

The final outcome of this analysis is a defensible case for DWHR in the state of Minnesota. The analysis makes use of an online tool for DWHR (http://www.ceatech.ca/calculator/) developed by Natural Resources Canada (NRCan) and census data for Minnesota available online at: http://www.lmic.state.mn.us/datanetweb/php/census2000/c2000.html. Demographic data for St. Louis County was used because it contains Duluth and is fairly representative of the demographics within Minnesota Power's service area.

The steps and results are as follows:

2.1 SETUP AND ENERGY CALCULATION

a. Establish the metrics for three representative cases for a cross section of homes:
   - Best Case
   - Average Case
   - Worst Case
b. Further segmentation of cases according to two representative DWHR models and new construction versus retrofit resulting in four base installation scenarios: normal DWHR unit in retrofit, small DWHR unit in

retrofit, normal DWHR unit in new construction, and small DWHR unit in new construction.

c. Determination of representative costs for each of the four installation scenarios.

d. Calculate energy savings for each with the NRCan tool using Thunder Bay, Ontario as representative of Minnesota (for fresh water temperature in the model).

The results from these first four steps are summarized in the following 3 tables:

Best Case

Utility:	Minnesota Power DWHR Scenarios				
Primary Water Heater:	Electric Tank, EF=0.92 / Efficiency=100%				
Assumed Electric Rate:	$0.075	per kWh			
Discount Rate:	6%				
Energy Inflation Rate:	4%				
Shower Temperature:	Medium				
Scenario:	Best Case				
	NRCan Report	New Home		Retrofit	
Power-Pipe Model	R3-60	R3-60	R3-36	R3-60	R3-36
City	Several Averaged	Thunder Bay (Duluth)			
Power-Pipe Cost (inc. delivery)	$800	$800	$600	$800	$600
Installation Cost	$150	$100	$100	$200	$200
Total Cost	$950	$900	$700	$1,000	$800
Average Shower Duration [min]*	12	10			
# of Occupants	3	5.40			
# of Showering Occupants	3	5.00			
Percent of Households [%]	100	10.4%			
Showerhead Flowrate [USgpm]	2.5	2.5			
Installation Plumbing	equal flow	equal flow			
Electricity Savings [kWh/year]	1,835	2,667	1,815	2,667	1,815
Electricity Load pre-DWHR [kWh/year]		8,577	8,577	8,577	8,577
Percent Saving on Load		31.1%	21.2%	31.1%	21.2%
Economic Savings	$137.63	$200.03	$136.13	$200.03	$136.13
Net Present Value (TRC)	**$1,339**	**$2,427**	**$1,564**	**$2,327**	**$1,464**

Average Case

Utility:	Minnesota Power DWHR Scenarios				
Primary Water Heater:	Electric Tank, EF=0.92 / Efficiency=100%				
Assumed Electric Rate:	$0.075	per kWh			
Discount Rate:	6%				
Energy Inflation Rate:	4%				
Shower Temperature:	Medium				
Scenario:	Average Case				

	NRCan Report	New Home		Retrofit	
Power-Pipe Model	R3-60	R3-60	R3-36	R3-60	R3-36
City	Several Averaged	Thunder Bay (Duluth)			
Power-Pipe Cost (inc. delivery)	$800	$800	$600	$800	$600
Installation Cost	$150	$100	$100	$200	$200
Total Cost	$950	$900	$700	$1,000	$800
Average Shower Duration [min]*	12	12			
# of Occupants	3	3.47			
# of Showering Occupants	3	3.17			
Percent of Households [%]	100	38.0%			
Showerhead Flowrate [USgpm]	2.5	2.5			
Installation Plumbing	equal flow	equal flow			
Electricity Savings [kWh/year]	1,835	2,240	1,525	2,240	1,525
ectricity Load pre-DWHR [kWh/year]		6,199	6,199	6,199	6,199
Percent Saving on Load		36.1%	24.6%	36.1%	24.6%
Economic Savings	$137.63	$168.00	$114.38	$168.00	$114.38
Net Present Value (TRC)	**$1,339**	**$1,894**	**$1,202**	**$1,794**	**$1,102**

Worst Case

Utility:	Minnesota Power DWHR Scenarios				
Primary Water Heater:	Electric Tank, EF=0.92 / Efficiency=100%				
Assumed Electric Rate:	$0.075	per kWh			
Discount Rate:	6%				
Energy Inflation Rate:	4%				
Shower Temperature:	Medium				
Scenario:	Worst Case				

	NRCan Report	New Home		Retrofit	
Power-Pipe Model	R3-60	R3-60	R3-36	R3-60	R3-36
City	Several Averaged	Thunder Bay (Duluth)			
Power-Pipe Cost (inc. delivery)	$800	$800	$600	$800	$600
Installation Cost	$150	$100	$100	$200	$200
Total Cost	$950	$900	$700	$1,000	$800
Average Shower Duration [min]*	12	8			
# of Occupants	3	2.00			
# of Showering Occupants	3	2.00			
Percent of Households [%]	100	51.7%			
Showerhead Flowrate [USgpm]	2.5	2.5			
Installation Plumbing	equal flow	unequal flow - water heater only			
Electricity Savings [kWh/year]	1,835	713	503	713	503
ectricity Load pre-DWHR [kWh/year]		4,040	4,040	4,040	4,040
Percent Saving on Load		17.6%	12.4%	17.6%	12.4%
Economic Savings	$137.63	$53.48	$37.73	$53.48	$37.73
Net Present Value (TRC)	**$1,339**	**-$11**	**-$73**	**-$111**	**-$173**

2.2 APPLICATION OF DEMOGRAPHIC DATA

e. Aggregation of the household occupancy from census data into the three household sizes, excluding singe person homes.

First, the St. Louis County Census Data was downloaded and summarized.

St. Louis County Household Sizes from 2000 Censue

1-person household	25,804	31.2%
2-person household	29,347	35.5%
3-person household	11,512	13.9%
4-person household	10,057	12.2%
5-person household	4,071	4.9%
6-person household	1,269	1.5%
7-or-more person household	559	0.7%
TOTAL	82,619	100.0%

Next, the households were aggregated into three representative groups, each representing a reasonably large segment of the homes and DWHR markets. Each of these three groups was then used for the Best Case, Average Case, and Worst Case scenarios. For example, the "Medium Occupancy" group of 3.17 showering persons per home represents 38.0% of the DWHR market and is used for the Average Case.

Aggregation of Drainwater Heat Recovery Market into 3 Household Sizes and Representative Occupancies

Household Occupancy	Total Persons	Households Within Market	Showering Persons	% of DWHR Market	Weighted Occupancy by Group	Non-Showering Persons	Showering Persons
2-person household	58,694	29,347	Low Occupancy	51.7%	2.00	0.00	2.00
3-person household	34,536	11,512	Medium Occupancy	38.0%	3.47	0.30	3.17
4-person household	40,228	10,057					
5-person household	20,355	4,071	High Occupancy	10.4%	5.40	0.40	5.00
6-person household	7,614	1,269					
7-or-more person household	3,913	559					

2.3 WEIGHTED AVERAGES AND SUMMARY ENERGY SAVINGS

f. Calculate weighted average savings for each of the three cases according to aggregated household occupancy.
g. Determination of approximate relative portion of the annual market size for each of the four installation scenarios.
h. Calculate weighted average savings of each assumed DWHR model type
i. Calculate weighted average savings of total market.

Summary of Drain Water Heat Recovery Energy Savings (kWh/year) - Weighted Averages by Home Occupancy, Market and Two Models									
			New Home		Retrofit		Install Scenarios Weighted Average		
	Showering Persons per Household	Percent of Homes	Model #R3-60	Model #R3-36	Model #R3-60	Model #R3-36	Model #R3-60	Model #R3-36	Full Market Weighted Average
Worst Case	2.00	51.65%	713	503	713	503	713	503	640
Mid Case	3.17	37.96%	2,240	1,525	2,240	1,525	2,240	1,525	1,992
Best Case	5.00	10.38%	2,667	1,815	2,667	1,815	2,667	1,815	2,371
Weighted Average Annual Electricity Savings of Three Cases			1495.6	1027.2	1495.6	1027.2	1495.6	1027.2	1332.8
Market Breakdown:			14.3%	0.8%	51.0%	34.0%	65.25%	34.75%	100%
Typical Total Installed Cost			$900	$700	$1,000	$800	$978.16	$797.84	$915.50

2.4 FINANCIAL CALCULATIONS

j. Calculate the Total Resource Cost (TRC) or similar financial indicator for all weighted scenarios.

This is extra step to assist other utilities considering implementing a DWHR program. It is understood that the methods for determination of suitability for any particular utility will certainly vary. There is even far more variance in the assumptions for the methods (e.g. utility rates). One common method is a Total Resource Value (TRC) calculation, which is basically Net Present Value (NPV) with internal utility assumptions. The following table summarizes this.

Energy Cost Savings Calculated by Market and Aggregated

			New Home		Retrofit		Average by Model		
	Showering Persons per Household	% of DWHR Market	Model #R3-60	Model #R3-36	Model #R3-60	Model #R3-36	Model #R3-60	Model #R3-36	**Overall Weighted Average**
Worst Case	2.00	51.65%	$53.48	$37.73	$53.48	$37.73	$53.48	$37.73	**$48.00**
Mid Case	3.17	37.96%	$168.00	$114.38	$168.00	$114.38	$168.00	$114.38	**$149.37**
Best Case	5.00	10.38%	$200.03	$136.13	$200.03	$136.13	$200.03	$136.13	**$177.82**
Weighted Average Annual Cost Savings of Three Cases			**$112.17**	**$77.04**	**$112.17**	**$77.04**	**$112.17**	**$77.04**	**$99.96**
Net Present Value (TRC) of Weighted Average Annual Case			**$965**	**$581**	**$865**	**$481**	**$887**	**$483**	**$747**

Financial Assumptions

Assumed TRC Electricity Rate	$0.075	/ kWh
Discount Rate:	6%	
Energy Inflation Rate:	4%	

A significant percentage of the total installed cost of a DWHR unit is due to fixed costs, such as installation, manufacturing setup, and handling; these costs are the same regardless of DWHR unit size for a given brand. It is interesting to point out that the NPV is higher for the longer DWHR unit. This basically means that the incremental efficiency gain more than offsets the incremental variable costs. This point is in contrast to assumptions made in the Natural Resources Canada Phase II report; a statement which was not based upon analysis. In conclusion, it is better for both utilities to encourage installation of longer DWHR units and for consumers to choose them.

It is also interesting to note that the TRC is positive for all four market cases: new home with long unit, new home with short unit, retrofit with long unit, and retrofit with short unit.

2.5 CHECK CALCULATED VERSUS ESTABLISHED HOT WATER LOAD

k. Determination of average annual Domestic Hot Water (DHW) load for Minnesota by weighted occupancy and Comparison with known Minnesota load profiles with adjustment to the assumptions if required..

Actual monthly cold water temperatures in Duluth were used to adjust the calculated load (plus 1.8 °F was added to be conservative and to reflect heat gain during transport of water to homes). Also, the Established Load for EF=0.94 water heaters was adjusted to a more typical EF=0.92 water heaters. The two loads were remarkably close.

DHW Load Numbers Per Natural Resources Canada Phase I Report in Comparison with						
	Proportion of Total Homes	Daily Hot Water Consumption	Annual Hot Water Consumption	Annual DHW Load	Annual Standby Losses with 0.92 EF Tank	Total Annual Electricity Consumption
	[%]	[litres/day[	[litres/year[	[kWh/year]	[kWh/year]	[kWh/year]
1 Person Home (not in NRCan study and not in Market)	31.2%	81.5	29747.5	1844.1	352.3	2196.4
2 Person Home	35.5%	163.0	59495.0	3688.1	352.3	4040.5
3 Person Home	13.9%	245.0	89425.0	5543.5	352.3	5895.9
4 Person Home	12.2%	325.5	118807.5	7365.0	352.3	7717.3
4+ Person Home	7.1%	363.5	132677.5	8224.8	352.3	8577.1
Weighted Average Electricity Consumption from Occupancy Load and Demographics						**4489.6**
Base Annual Electricity Consumption with EF=0.92 Electric Water Heater						**4492.1**
These are very close so it proves the validity our assumptions and that we can use the above LOAD PROFILES by household size.						

3. SUMMARY OF FINDINGS AND PROGRAM DESIGN RECOMENDATIONS

A defensible method for determining the impact of selective Drain Water Heat Recovery technologies upon annual water heating energy consumption has been developed and described. This method is based upon Canadian Government research and household occupancy level census data. Furthermore, the assumptions for water heating load have been verified to be very consistent with known average load profiles, further strengthening the case for the method proposed herein.

Two DWHR model sizes have been investigated: R3-60 and R3-36, each Power-Pipe units. The R3-60 is estimated to deliver an average of 1,496 kWh/year in savings and the R3-36 will deliver about 1,027 kWh/year. When considering where each of these two units can be installed, the total average savings is estimated to be 1,333 kWh/year. It should be noted that while these two units do cover a broad range of the units that would be installed under a program, other units will sometimes be installed. They are representing the broad range of what will be installed.

Finally, based upon the assumptions and simple TRC calculations it appears that DWHR is cost effective for consumers and would qualify for utility DSM (or the like) programs.

First Year Residential Program Design

While it is the author's preference that a utility incentive be "performance based" for the first year with limited rollout, this is not always preferred in order to minimize complexity. The same effect can be achieved by establishing a qualification cutoff such as DWHR efficiency or design. From experience, a successful program will start aggressive yet simple then build upon success year after year. Such a program is now ongoing with Union Gas in Ontario; this program has already resulted in real transformation of both the cost base and supply of DWHR units as well as growing market acceptance of DWHR technology.

Key Elements of a Successful Residential Utility Incentive Program

- Installation training of plumbers/installers
- Sales training of builders, retailers, and distributors
- Enlistment and commitment in writing by key partners which may include plumbers, builders, retailers, and distributors
- Working closely with one or more key manufacturer(s)
- Partner marketing and co-marketing at many levels including: trade shows, special events, magazines, utility bill inserts, direct mail to potential partners, direct and frequent contact with potential partners
- Ensuring that the supply chain will deliver product at a reasonable price and in a timely fashion
- Stable utility program objectives
- Flexible utility program design for first few years
- Focus on both new and existing homes