PowerPipe™ Drain Water Heat Recovery Systems: Effectiveness Testing of Residential (R) Units

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Prepared for:

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Disclaimer

The information contained in this report the results of measurements performed by the University of Waterloo, Solar Thermal Research Laboratory. Some general opinion on how the user may meet specified goals may also have been expressed.

The Author has tested the systems reported here using the test procedure specified by Natural Resources Canada (NRCan, 2008). Where deviations from that test procedure have occurred, an explanation has been provided.

The Author does not accept any third party liability for any damages or losses whatsoever, arising out of, or in any way related to, the use of this information.

Notes

*This report replaces a previous report entitled '**Effectiveness Testing of Powerpipe Drain Water Heat Recovery Systems**' (dated March / 2009).*

A number of the results quoted in that report remain the same. All other results are for previously untested units.

1.0 Procedure and Methodology

The test apparatus, test procedure, and data analysis generally follows the test standard described by Natural Resources Canada (NRCan, 2008). That document will henceforth be referred to as the Standard.

Any deviations from the Standard will be fully explained in the text.

1.1 Equipment

The test apparatus was modeled on the device described in the Standard. The reader is referred to that document for more detail. A brief description of the apparatus follows.

Potable Water Side (Cold-Side): Mains water entered the system after passing through a pressure regulator. Mains temperature remained constant at approximately 5.5^{o}C (41.9 F) throughout the test period, so it was heated to bring it to standard test conditions (8°C or 46.4 F). Some mains water was diverted to an electric water heater before being mixed with the remaining mains water at the flow control panel using two gate valves.

The cold-side flow rate, temperature, and pressure were measured between the mixing point and the inlet to the heat exchanger. Cold-side temperature and pressure were measured immediately after the heat exchanger. (see Figure 1)

Figure 1: Drain Water Heat Recovery Apparatus; Cold Stream Data Acquisition. Inlet on Left. Outlet on Right.

All cold-side pipes and fittings are nominal ¾” copper or PEX.

Drain Water Side (Hot-Side): The cold-side outlet was divided into two streams. Part was sent to a gas fired water heater and then remixed with the remaining portion via a thermostatic mixing valve. The gas heater was sufficient to provide hot water for the duration of the tests.

The water was then conditioned prior to entry into the heat exchanger. A shower was simulated by allowing the water to flow into a small catchment basin. The shower was located 0.5 m (20 in) from the centerline of the heat exchanger. Following this, the water temperature is measured. Finally, a heat exchanger entry region (flow conditioner) consisted of a 0.305 m (1 ft) horizontal run, followed by a Y transition to a 0.610 m (2 ft) vertical run, both of equal diameter to the heat exchanger being tested. To accomplish this, three flow conditioners were built at 2”, 3”, and 4” nominal diameters (Figure 2).

Figure 2: Drain Water Heat Recovery Apparatus; 2” and 3” Hot-Side Flow Conditioner.

The hot-side inlet and outlet temperatures were measured in immersion wells. The inlet temperature was measured directly after the simulated shower, and before the flow conditioner. The outlet temperature was measured at the bottom of the heat exchanger. Hot-side data acquisition points are shown in Figure 3.

Figure 2: Drain Water Heat Recovery Apparatus; Hot Stream Data Acquisition. Inlet on Left. Outlet on Right.

Hot-side pipes and fitting are nominal ¾” copper or PEX except those noted above, which are made from ABS pipe.

Temperature Measurements: All temperature measurements were performed using Resistance Temperature Devices (RTD's) purchased from Omega. All measurements were 4-wire and taken using OMEGA process controllers, and output to an OMEGA Data Acquisition System (DAQ). The RTD measurements were calibrated by comparing data recorded via the DAQ to the digital readout of the process controller values. Quoted temperature measurements are considered accurate to +/- 0.1 ^{o}C (0.2 F).

Care was taken to ensure that the RTD probes were fully immersed into the fluid and not located in regions where the fluid may stagnate. Temperatures were measured as close as possible to the inlets and outlets of the heat exchanger.

Pressure Measurements: Pressure measurements were performed using pressure gauges from OMEGA (DPG1000B-100G). It is considered accurate to +/- 0.25%[1]. Pressure measurements were recorded manually every 20 seconds during data acquisition periods.

To accommodate different sizes of heat exchanger, there was as much as 3 or 4 meters (10 to 13 ft) of piping added between the pressure gauges and heat exchanger. The static pressure head between the sensor locations, and the pressure drop caused by flow through the connector pipes and fittings was determined by bypassing the heat exchanger (i.e. connecting the cold-side inlet to the cold-side outlet), and recording the pressure difference at the flow rate of interest.

Flow Measurements: Flow measurements were taken using a Hall Effect flowmeter purchased from OMEGA (FTB-4605), and connected to the DAQ. It is considered accurate to +/- 1.5% of the reading[1]. A second flowmeter was also installed, but not required in the current tests.

The flowmeter was re-calibrated using a gravimetric technique.

Deviations:
The following deviations from the equipment described in the Standard are noted:

- Hot-side temperature was measured in an immersion well and not by a sensor affixed to the heat exchanger wall before the heat exchanger. It was found that the suggested technique was problematic at low flow rates where there was significant potential for that sensor to not be in contact with the water.

[1] Accuracy quoted by OMEGA documents provided with device.

1.2 Procedure

Installation:

- The hot-side inlet flow conditioner was installed depending on the diameter of the heat exchanger to be tested.
- The heat exchanger was connected to the test rig. The hot water-side connections were made using rubber couplings in the same manner as used in an actual installation. A coupling also connected the hot-side outlet to the hot-side outlet temperature well.
- The unit was checked for vertical orientation and secured to the test frame.
- Cold-side connections were made using SharkBite fittings.

Test Start-Up:

- The system was pressurized and air was allowed to bleed from the system.
- The flowrate was set using a gate valve located at the cold-side inlet.
- Cold-side and hot-side temperatures were set manually. The cold-side was controlled via two gate valves until a setpoint of 8 ^{o}C +/- 0.3 ^{o}C (46.4 F +/- 0.5 F) was achieved. The hot-side temperature was controlled via a thermostatic mixing valve until a setpoint of 36 ^{o}C +/- 0.3 ^{o}C (96.8 F +/- 0.5 F) was achieved.
- The system was allowed to operate until all temperature readings stabilized. The final temperature difference between the hot and cold side inlets was checked to ensure that the temperature difference was within the specified conditions of 28 ^{o}C +/-1 ^{o}C (50.4 F +/- 1.8 F).
- The heat balance between the hot- and cold-sides of the heat exchanger was checked to ensure that equilibrium was achieved.
- Temperature readings were monitored for approximately 5 minutes (10 minutes for the 4 L/min / 0.88 gpm tests) to ensure that temperature measurements were stable, and that fluctuations in temperature did not exhibit any trending.
- Data was recorded for the next 5 minutes.

This procedure test was repeated at nominal flowrates of 4, 8, 11, and 14 L/min +/- 0.5 L/min (0.88, 1.76., 2.42, and 3.08 gpm +/- 0.11 gpm).

Data Analysis:

- The collected data was plotted to ensure stability, and average values were produced for the test period.
- The temperature difference between the hot-side and cold-side was checked for balance. The balance had to be within 5% for the data to be accepted.

- The effectiveness of the heat exchanger was calculated using
$$\varepsilon = \frac{\left(T_{c,out} - T_{c,in}\right)}{\left(T_{h,in} - T_{c,in}\right)}$$
This equation is valid due to the equal flow condition.
- The heat transfer and pressure drop from the cold-side of the heat exchanger was calculated. The heat transfer was given by
$$q = \dot{m}C_p\left(T_{c,out} - T_{c,in}\right)$$
- The pressure drop was corrected to account for static head between the sensors and pressure loss in the connection piping and fittings (see Section 1.1).

The results from all four flowrates were collected, and the effectiveness, pressure drop, and heat recovery rate were calculated for the nominal operating condition of 9.5 L/min (2.09 gpm), 8 ^{o}C (46.4 F) cold-side inlet temperature, and 36 ^{o}C (96.8 F) hot side inlet temperature. Results are also reported for 9.2 L/min as required by some European Standards.

The engineering uncertainty in all measurements was calculated using the method described in Kline and McClintock (1953).

<u>Deviations:</u>

- Heat recovery rates were not used to determine if flow equilibrium was achieved as suggested by the Standard. Heat recovery rates were seen to balance even when the system was clearly not at steady state. A more rigorous condition was applied instead. i.e., all base readings had stabilized, and no trends were observed in the fluctuation of those measurements for five minutes prior to the data collection period.

1.3 Samples

Forty-six heat exchangers were tested for RenewABILITY Energy Inc. The products tested are:

- 2” nominal diameter units: 12”, 18”, 24”, 30”, 36”, 42”, 48”, 54”, 60”, 66”, 72”, 84”, 96”, 108”, 120”
- 3” nominal diameter units: 12”, 18”, 24”, 30”, 36”, 42”, 48”, 54”, 60”, 66”, 72”, 78”, 84”, 96”, 108”, 120”
- 4” nominal diameter units: 12”, 18”, 24”, 30”, 36”, 42”, 48”, 54”, 60”, 66”, 72”, 84”, 96”, 108”, 120”

All units had a 3/8” Type L wrap tube with 4 parallel wraps.

2.0 Results

The test results are summarized in the following tables. Table 1 represents results are for the standard test condition of 9.5 L/min flowrate, 8°C mains water inlet temperature, and 36°C drain water inlet temperature. Table 2 represents results are for the test condition of 9.2 L/min flowrate, 8°C mains water inlet temperature, and 36°C drain water inlet temperature.

Complete test reports are included as Appendices A (2" diameter units), B (3" diameter units), and C (4"diameter units).

3.0 References

Natural Resources Canada, *Testing Method for Measuring Efficiency of Drain Water Heat Recovery Units*, December 2008.

Kline, S.J., and McClintock, F.A. *Describing Experimental Uncertainties in Single Sample Experiments*. **Mechanical Engineering**, Vol. 73, pp. 3-8, 1953.

Table 1: Results at standard test condition of 9.5 L/min flowrate, 8°C mains water inlet temperature, and 36°C drain water inlet temperature.

Model	Nominal Diameter (m / in)	Length (m / ft)	Effectiveness (%)	Pressure Loss (kPa / PSI)	Heat Recovery (kW / BTU/hr)
R2-12	0.05 / 2	0.30 / 1.0	9.0	1.42 / 0.21	1.70 / 5816.6
R2-18	0.05 / 2	0.46 / 1.5	14.4	2.47 / 0.36	2.62 / 8955.1
R2-24	0.05 / 2	0.61 / 2.0	21.1	3.37 / 0.49	3.94 / 13455.2
R2-30	0.05 / 2	0.76 / 2.5	28.4	4.36 / 0.63	5.37 / 18333.0
R2-36	0.05 / 2	0.91 / 3.0	31.6	4.75 / 0.69	5.84 / 19954.1
R2-42	0.05 / 2	1.07 / 3.5	36.7	6.05 / 0.88	6.78 / 23163.5
R2-48	0.05 / 2	1.22 / 4.0	36.9	6.62 / 0.96	6.75 / 23059.7
R2-54	0.05 / 2	1.37 / 4.5	41.1	8.79 / 1.27	7.59 / 25926.7
R2-60	0.05 / 2	1.52 / 5.0	46.4	8.06 / 1.17	7.85 / 26805.4
R2-66	0.05 / 2	1.68 / 5.5	47.8	10.5 / 1.47	8.89 / 30375.0
R2-72	0.05 / 2	1.83 / 6.0	52.7	11.49 / 1.67	9.78 / 33408.4
R2-84	0.05 / 2	2.13 / 7.0	55.5	10.45 / 1.52	10.29 / 35153.6
R2-96	0.05 / 2	2.44 / 8.0	60.5	13.42 / 1.95	11.10 / 37893.2
R2-108	0.05 / 2	2.74 / 9.0	63.4	15.32 / 2.22	11.18 /38175.5
R2-120	0.05 / 2	3.05 / 10.0	63.4	15.61 / 2.26	11.36 / 38795.8
R3-12	0.08 / 3	0.30 / 1.0	6.9	2.05 / 0.30	1.23 / 4196.6
R3-18	0.08 / 3	0.46 / 1.5	18.6	3.43 / 0.50	3.42 / 11696.5
R3-24	0.08 / 3	0.61 / 2.0	27.2	5.32 / 0.77	4.88 / 16656.0
R3-30	0.08 / 3	0.76 / 2.5	32.9	6.57 / 0.95	5.94 / 20285.0
R3-36	0.08 / 3	0.91 / 3.0	37.9	7.55 / 1.10	7.07 / 24132.4
R3-42	0.08 / 3	1.07 / 3.5	42.4	8.22 / 1.19	7.79 / 26602.3
R3-48	0.08 / 3	1.22 / 4.0	47.3	10.76 / 1.56	8.60 / 29378.8
R3-54	0.08 / 3	1.37 / 4.5	49.2	12.14 / 1.76	8.96 / 30615.1
R3-60	0.08 / 3	1.52 / 5.0	53.7	12.83 / 1.86	9.88 / 33725.3
R3-66	0.08 / 3	1.68 / 5.5	55.0	14.52 / 2.11	10.09 / 34458.8
R3-72	0.08 / 3	1.83 / 6.0	58.8	16.60 / 2.41	10.79 / 36838.1
R3-84	0.08 / 3	2.13 / 7.0	60.7	16.87 / 2.45	11.01 / 37588.7
R3-96	0.08 / 3	2.44 / 8.0	65.6	19.63 / 2.85	12.10 / 41325.3
R3-108	0.08 / 3	2.74 / 9.0	67.1	22.09 / 3.20	12.40 / 42361.8
R3-120	0.08 / 3	3.05 / 10.0	67.7	26.73 / 3.88	12.42 / 42431.5
R4-12	0.10 / 4	0.30 / 1.0	6.9	1.47 / 0.21	1.26 / 4298.8
R4-18	0.10 / 4	0.46 / 1.5	21.5	2.48 / 0.36	3.98 / 13597.4
R4-24	0.10 / 4	0.61 / 2.0	31.5	6.62 / 0.96	5.81 / 19834.9
R4-30	0.10 / 4	0.76 / 2.5	40.4	6.67 / 0.97	7.36 / 25136.1
R4-36	0.10 / 4	0.91 / 3.0	42.4	8.63 / 1.25	7.85 / 26800.4
R4-42	0.10 / 4	1.07 / 3.5	46.1	7.51 / 1.09	8.59 / 29320.6
R4-48	0.10 / 4	1.22 / 4.0	52.7	11.33 / 1.64	9.71 / 33161.4
R4-54	0.10 / 4	1.37 / 4.5	54.7	13.08 / 1.90	9.97 / 34035.0
R4-60	0.10 / 4	1.52 / 5.0	58.4	13.81 / 2.00	10.74 / 36664.4
R4-66	0.10 / 4	1.68 / 5.5	59.9	16.35 / 2.37	11.07 / 37822.9
R4-72	0.10 / 4	1.83 / 6.0	62.9	16.79 / 2.44	11.63 / 39727.3
R4-84	0.10 / 4	2.13 / 7.0	66.3	16.54 / 2.40	12.05 / 41143.9
R4-96	0.10 / 4	2.44 / 8.0	68.6	19.17 / 2.78	12.84 / 43861.9
R4-108	0.10 / 4	2.74 / 9.0	69.4	22.74 / 3.30	12.81 / 43761.5
R4-120	0.10 / 4	3.05 / 10.0	72.2	27.47 / 3.98	13.36 / 45641.0

Table 2: Results at test condition of 9.2 L/min flowrate, 8°C mains water inlet temperature, and 36°C drain water inlet temperature.

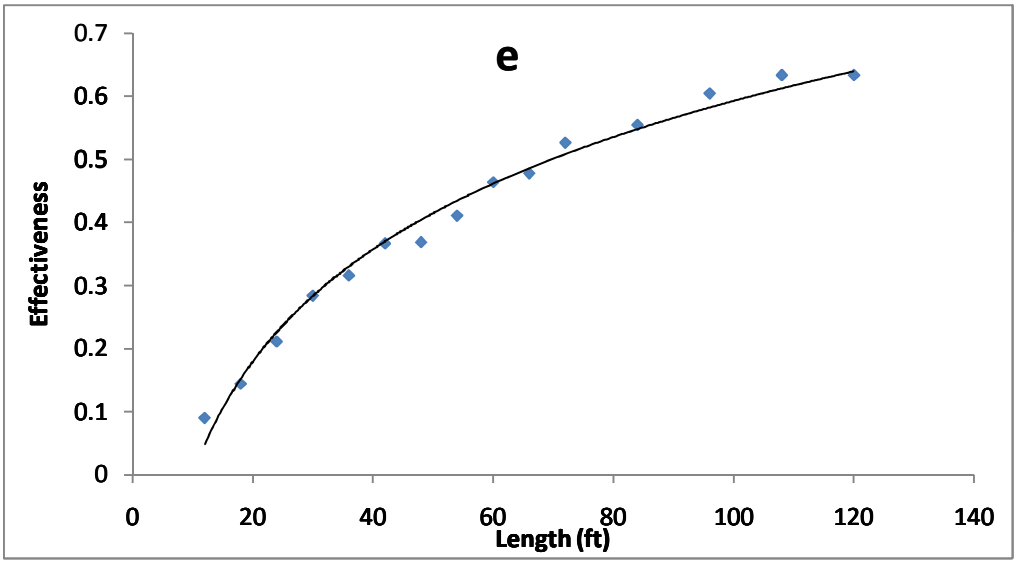
Model	Nominal Diameter (m / in)	Length (m / ft)	Effectiveness (%)	Pressure Loss (kPa / PSI)	Heat Recovery (kW / BTU/hr)
R2-12	0.05 / 2	0.30 / 1.0	9.3	1.26 / 0.18	1.69 / 5776.1
R2-18	0.05 / 2	0.46 / 1.5	14.7	2.35 / 0.34	2.58 / 8809.2
R2-24	0.05 / 2	0.61 / 2.0	21.5	3.19 / 0.46	3.89 / 13288.0
R2-30	0.05 / 2	0.76 / 2.5	28.7	4.12 / 0.60	5.29 / 18052.9
R2-36	0.05 / 2	0.91 / 3.0	32.2	4.46 / 0.65	5.77 / 19692.5
R2-42	0.05 / 2	1.07 / 3.5	37.3	5.67 / 0.82	6.67 / 22767.2
R2-48	0.05 / 2	1.22 / 4.0	37.4	6.25 / 0.91	6.62 / 22623.2
R2-54	0.05 / 2	1.37 / 4.5	41.7	8.33 / 1.21	7.48 / 25536.6
R2-60	0.05 / 2	1.52 / 5.0	47.0	7.67 / 1.11	7.80 / 26644.0
R2-66	0.05 / 2	1.68 / 5.5	48.5	9.51 / 1.38	8.71 / 29758.9
R2-72	0.05 / 2	1.83 / 6.0	53.3	10.86 / 1.58	9.56 / 32636.2
R2-84	0.05 / 2	2.13 / 7.0	56.1	9.94 / 1.44	10.05 / 34318.8
R2-96	0.05 / 2	2.44 / 8.0	61.0	12.71 / 1.84	10.84 / 37020.2
R2-108	0.05 / 2	2.74 / 9.0	63.6	14.59 / 2.12	10.85 / 37057.8
R2-120	0.05 / 2	3.05 / 10.0	64.0	14.88 / 2.16	11.03 / 37661.4
R3-12	0.08 / 3	0.30 / 1.0	7.1	1.93 / 0.28	1.22 / 4183.5
R3-18	0.08 / 3	0.46 / 1.5	18.8	3.24 / 0.47	3.38 / 11548.8
R3-24	0.08 / 3	0.61 / 2.0	27.7	5.11 / 0.74	4.77 / 16306.0
R3-30	0.08 / 3	0.76 / 2.5	33.3	6.24 / 0.91	5.85 / 19974.9
R3-36	0.08 / 3	0.91 / 3.0	38.4	7.21 / 1.05	6.90 / 23571.7
R3-42	0.08 / 3	1.07 / 3.5	42.9	7.75 / 1.12	7.62 / 26009.5
R3-48	0.08 / 3	1.22 / 4.0	47.8	10.25 / 1.49	8.43 / 28773.8
R3-54	0.08 / 3	1.37 / 4.5	49.7	11.55 / 1.67	8.81 / 30093.2
R3-60	0.08 / 3	1.52 / 5.0	54.3	12.20 / 1.77	9.63 / 32877.9
R3-66	0.08 / 3	1.68 / 5.5	55.5	13.76 / 2.00	9.86 / 33687.4
R3-72	0.08 / 3	1.83 / 6.0	59.2	15.75 / 2.28	10.51 / 35894.1
R3-84	0.08 / 3	2.13 / 7.0	61.2	16.08 / 2.33	10.77 / 36771.8
R3-96	0.08 / 3	2.44 / 8.0	66.1	18.71 / 2.71	11.77 / 40205.0
R3-108	0.08 / 3	2.74 / 9.0	67.5	21.01 / 3.05	12.11 / 41365.4
R3-120	0.08 / 3	3.05 / 10.0	67.8	25.41 / 3.69	12.06 / 41197.7
R4-12	0.10 / 4	0.30 / 1.0	7.0	1.39 / 0.20	1.24 / 4229.1
R4-18	0.10 / 4	0.46 / 1.5	21.6	2.34 / 0.34	3.88 / 13250.2
R4-24	0.10 / 4	0.61 / 2.0	31.8	6.53 / 0.95	5.71 / 19486.5
R4-30	0.10 / 4	0.76 / 2.5	40.9	6.40 / 0.93	7.20 / 24577.8
R4-36	0.10 / 4	0.91 / 3.0	42.8	8.30 / 1.20	7.68 / 26242.2
R4-42	0.10 / 4	1.07 / 3.5	46.4	7.18 / 1.04	8.30 / 28359.8
R4-48	0.10 / 4	1.22 / 4.0	53.2	10.71 / 1.55	9.47 / 32341.7
R4-54	0.10 / 4	1.37 / 4.5	55.3	12.41 / 1.80	9.74 / 33262.3
R4-60	0.10 / 4	1.52 / 5.0	58.8	13.13 / 1.90	10.48 / 35782.9
R4-66	0.10 / 4	1.68 / 5.5	60.3	15.49 / 2.25	10.76 / 36747.4
R4-72	0.10 / 4	1.83 / 6.0	63.3	16.01 / 2.32	11.30 / 38578.6
R4-84	0.10 / 4	2.13 / 7.0	66.7	15.72 / 2.28	11.72 / 40022.9
R4-96	0.10 / 4	2.44 / 8.0	68.9	18.19 / 2.64	12.52 / 42744.5
R4-108	0.10 / 4	2.74 / 9.0	69.5	21.63 / 3.14	12.40 / 42346.6
R4-120	0.10 / 4	3.05 / 10.0	72.3	26.17 / 3.80	13.00 / 44399.8

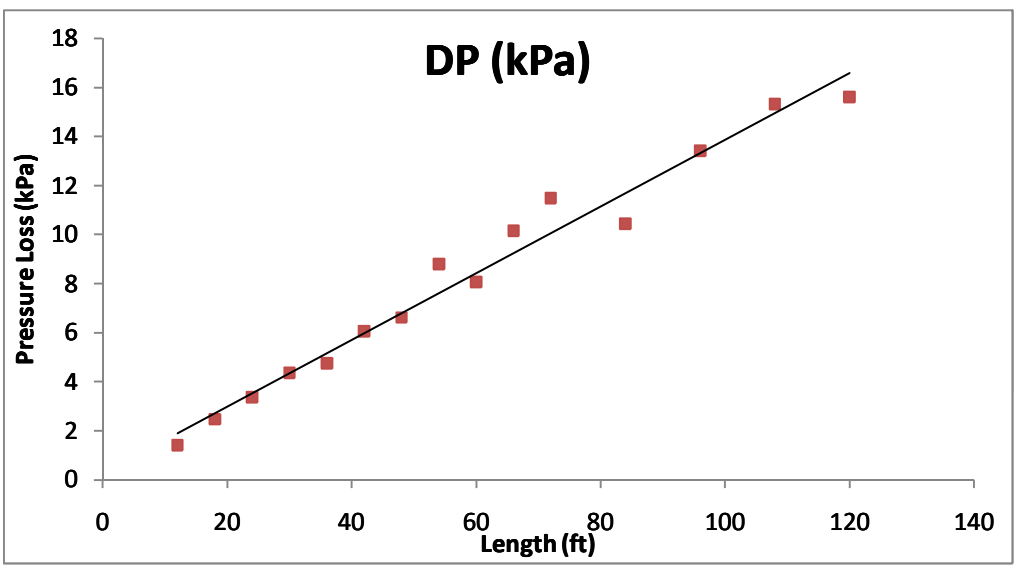
Appendix A

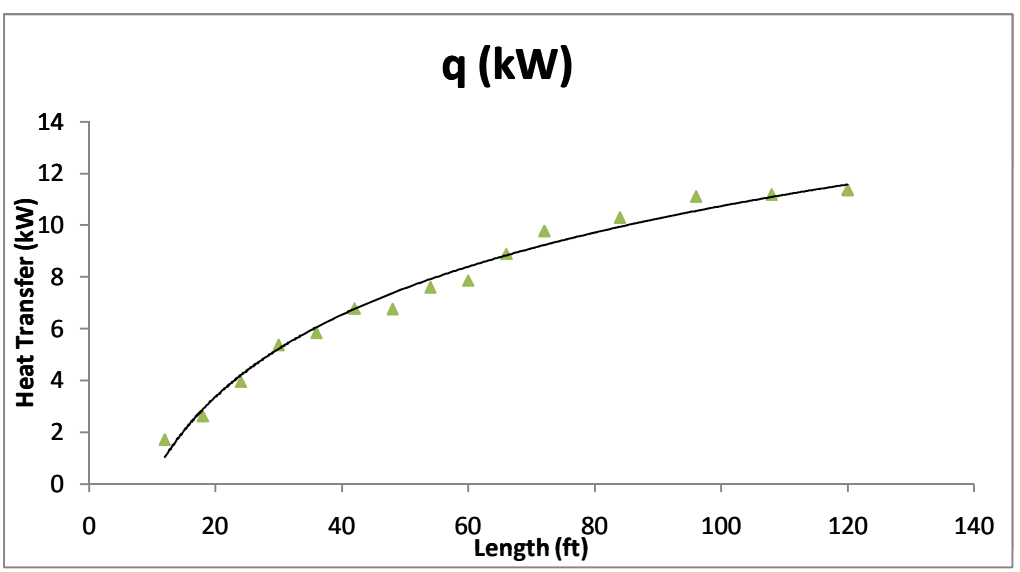
Test Reports – 2” Nominal Diameter Units

Effectiveness and Pressure Drop at Standard Conditions (9.5 L/min - 8°C Mains, 36 °C Shower)

L (ft)	ε	ΔP (kPa)	q (kW)
12	0.09	1.42	1.7
18	0.144	2.47	2.62
24	0.211	3.37	3.94
30	0.284	4.36	5.37
36	0.316	4.75	5.84
42	0.367	6.05	6.78
48	0.369	6.62	6.75
54	0.411	8.79	7.59
60	0.464	8.06	7.85
66	0.478	10.15	8.89
72	0.527	11.49	9.78
84	0.555	10.45	10.29
96	0.605	13.42	11.1
108	0.634	15.32	11.18
120	0.634	15.61	11.36







UNIVERSITY OF Waterloo

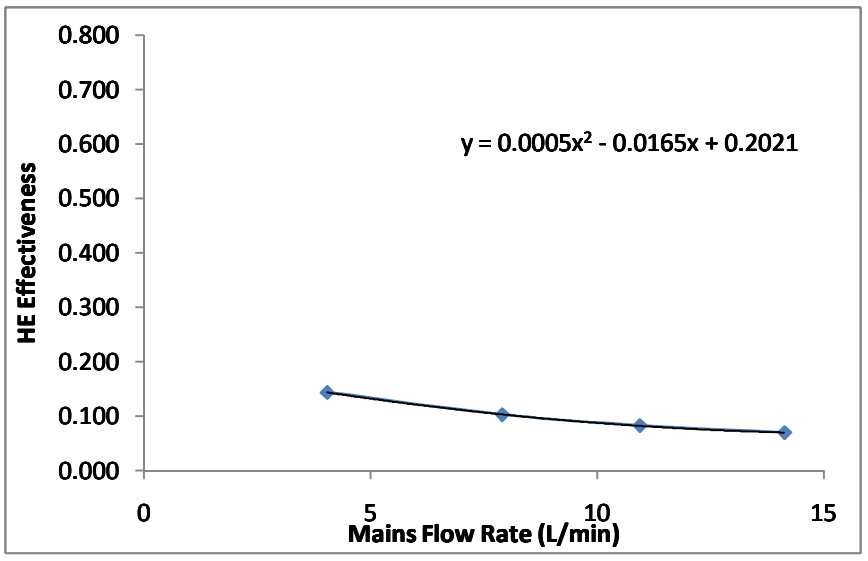
Product: 12in R2in
Manufacturer: Renewability
Test Date: April 1 / 2011

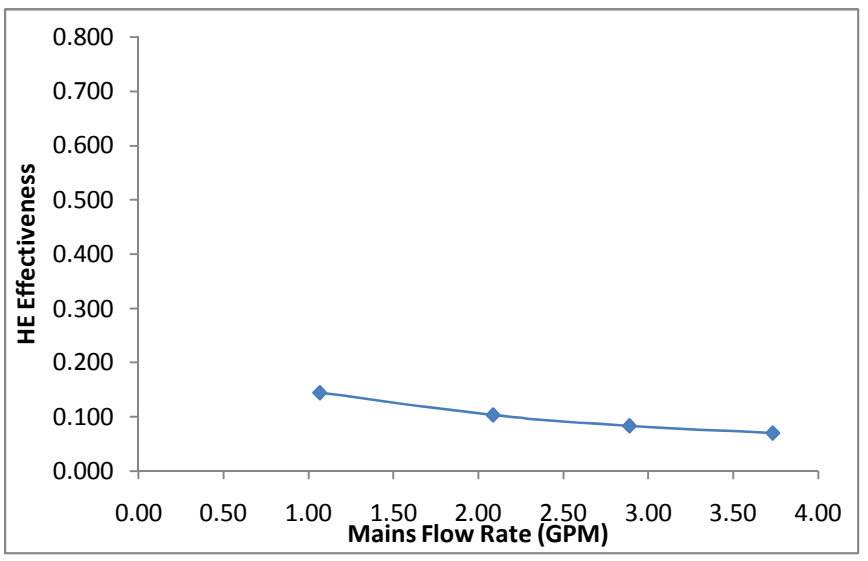
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.04	0.144	1.15	0.48
7.9	0.103	1.64	0.58
10.94	0.083	1.76	2.17
14.13	0.070	1.97	2.58

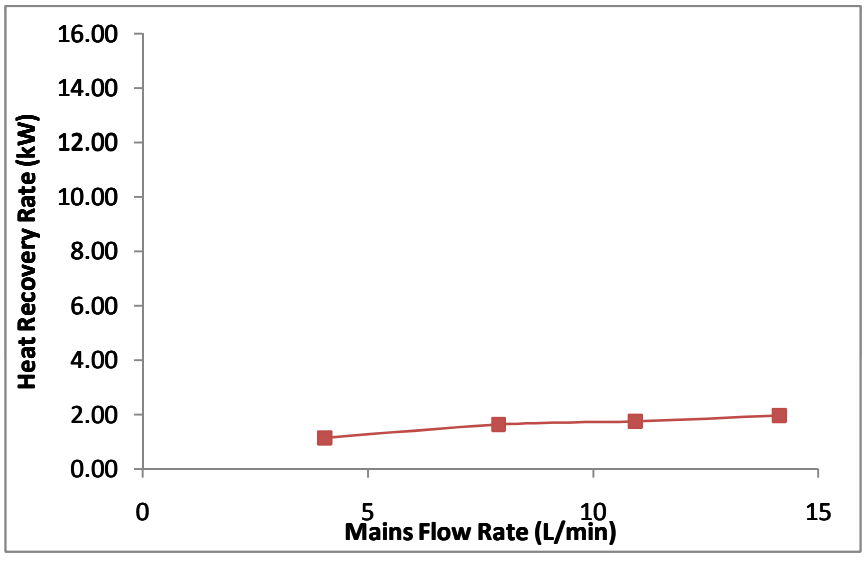
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.07	0.144	3927.46	0.07
2.09	0.103	5600.89	0.08
2.89	0.083	6010.72	0.31
3.73	0.070	6727.90	0.37

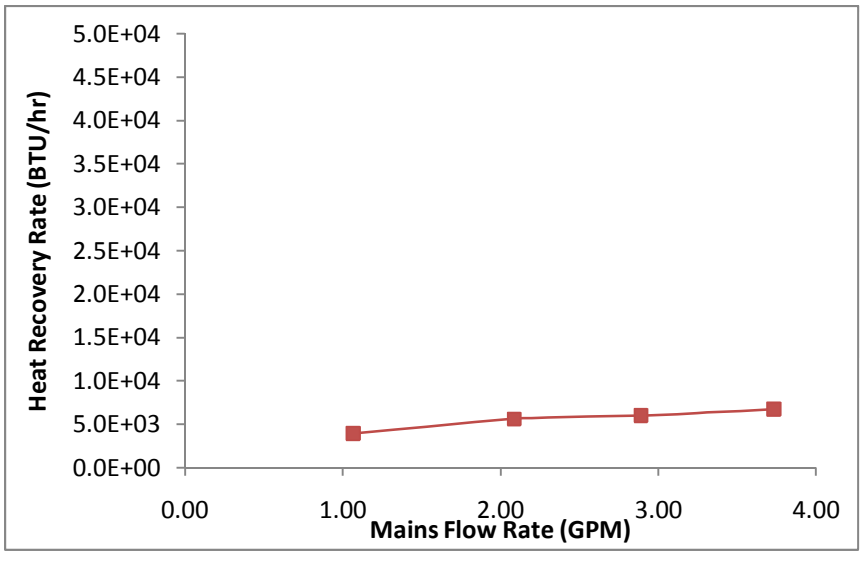
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

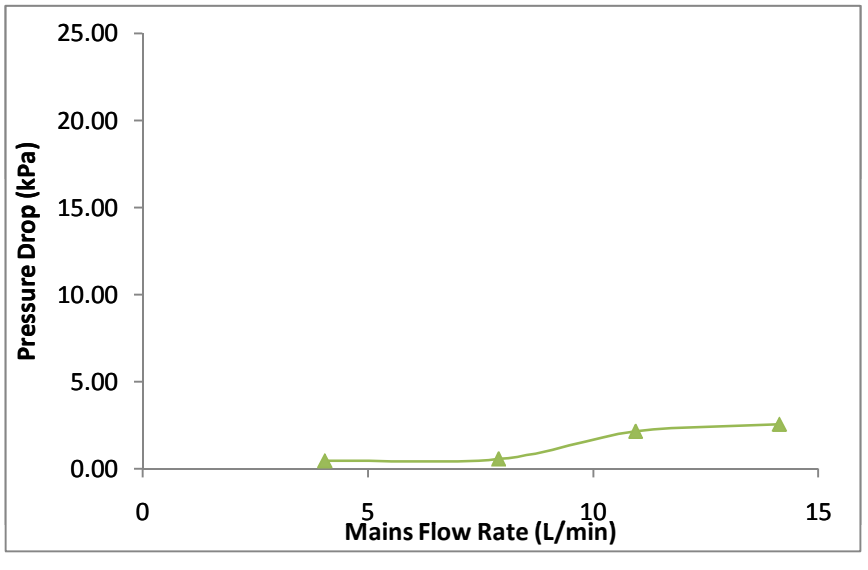
Effectiveness	0.090			
Heat Recovery	1.70	kW	5816.6	BTU/hr
Pressure Drop	1.42	kPa	0.21	PSI

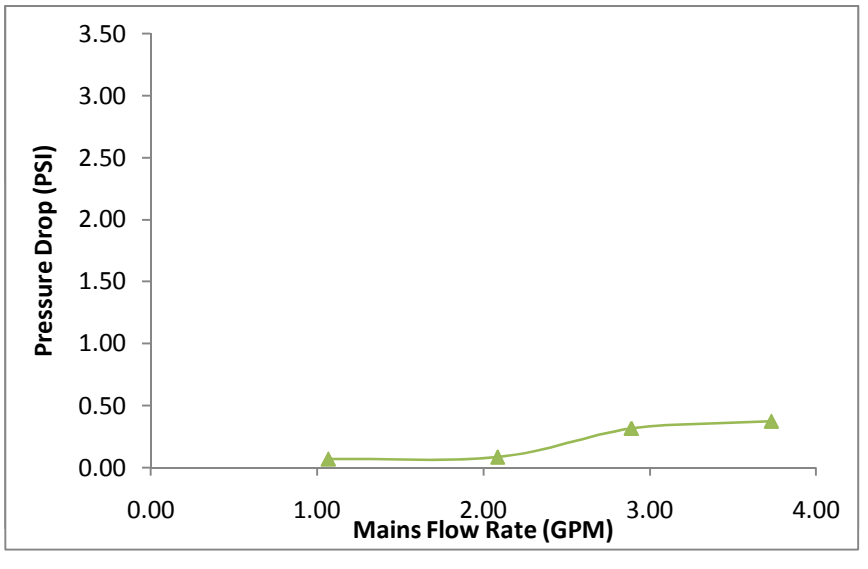












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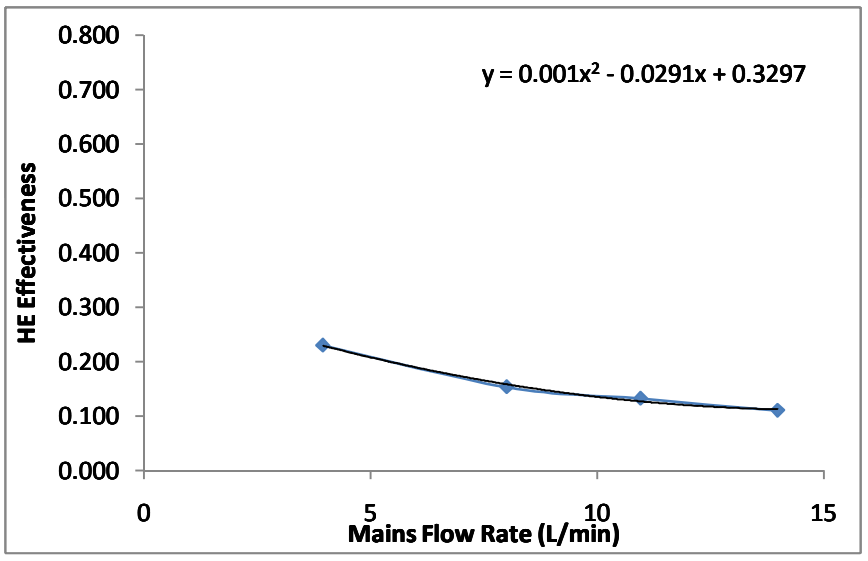
Product: 18in R2in
Manufacturer: Renewability
Test Date: April 1 / 2011

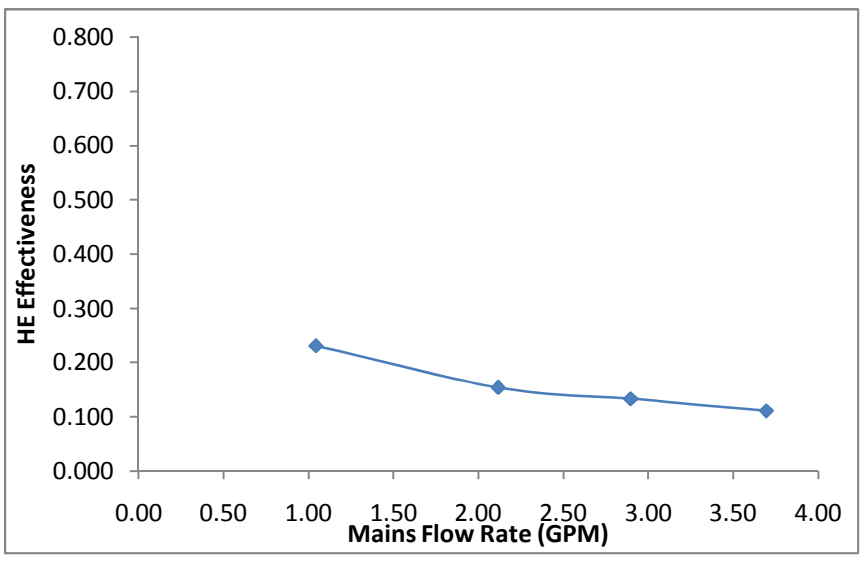
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.95	0.231	1.76	0.50
8.01	0.154	2.41	1.86
10.96	0.133	2.83	3.07
13.98	0.111	3.08	4.52

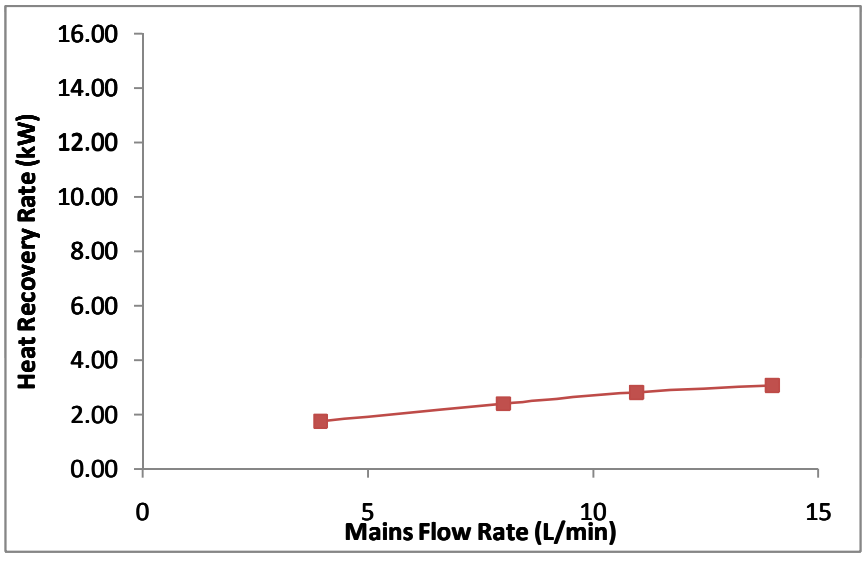
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.04	0.231	6010.72	0.07
2.12	0.154	8230.58	0.27
2.90	0.133	9664.96	0.45
3.69	0.111	10518.75	0.66

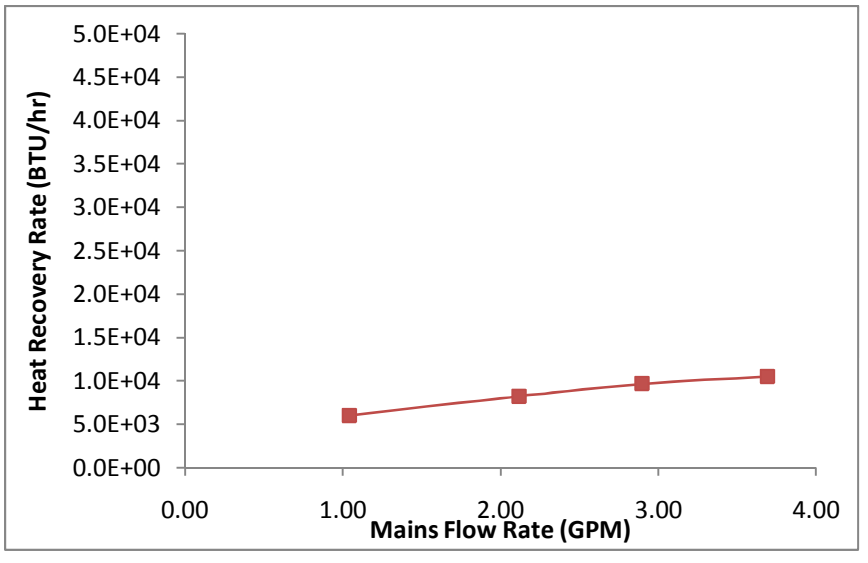
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

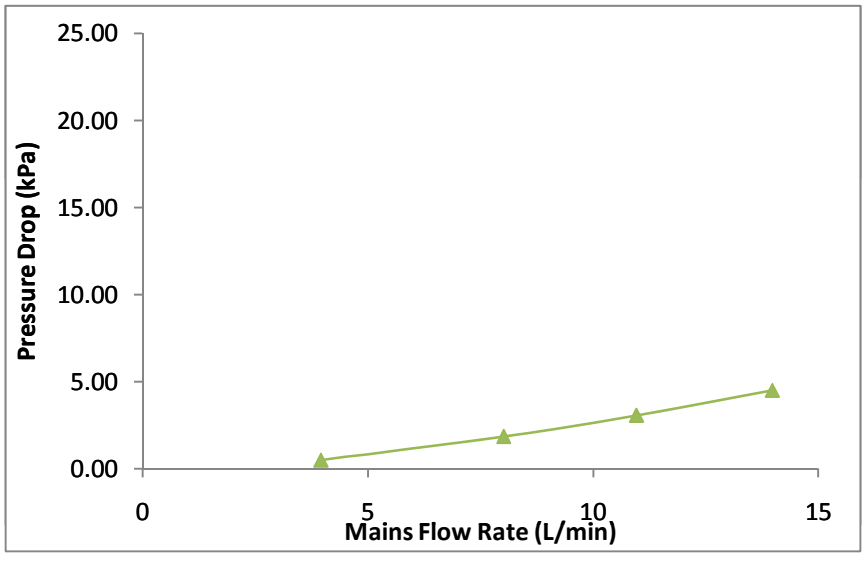
Effectiveness	0.144			
Heat Recovery	2.62	kW	8955.1	BTU/hr
Pressure Drop	2.47	kPa	0.36	PSI

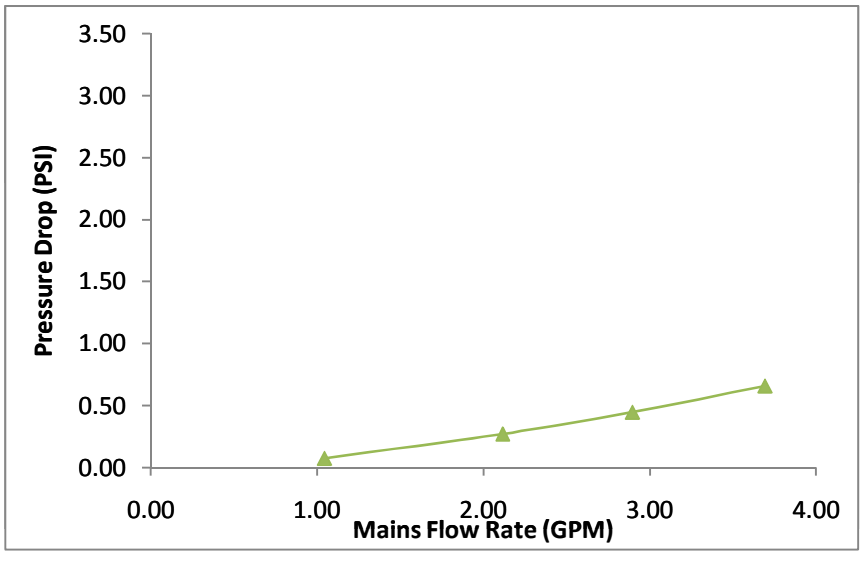












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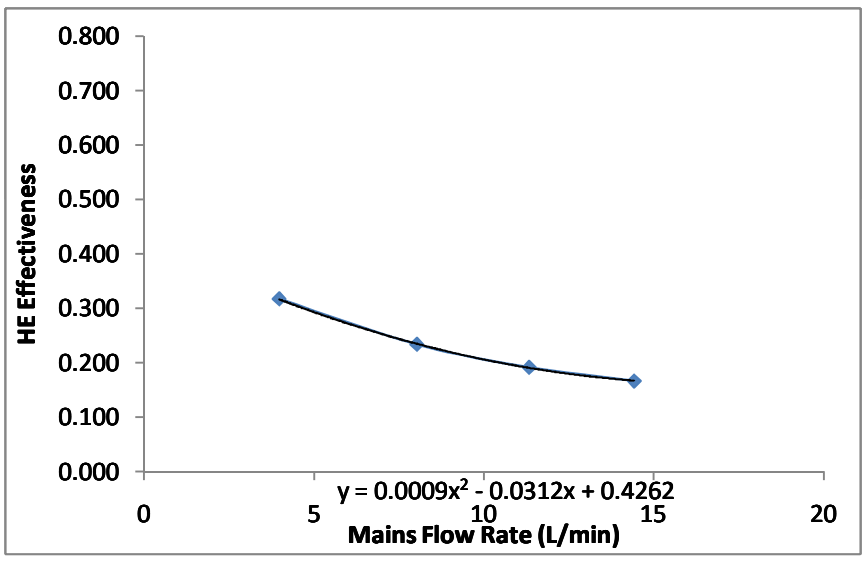
Product: 24in R2in
Manufacturer: Renewability
Test Date: February 8 / 2011

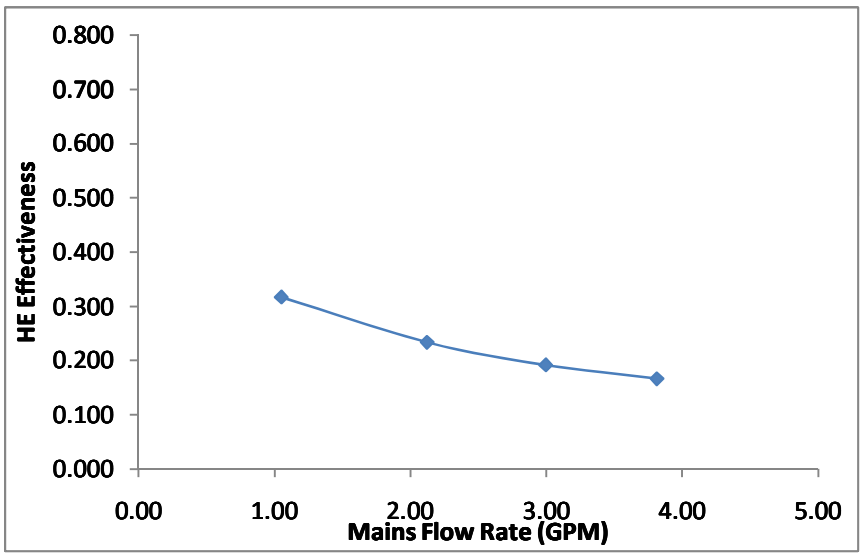
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.98	0.317	2.50	1.19
8.03	0.234	3.70	2.48
11.34	0.192	4.24	4.48
14.43	0.167	4.86	7.27

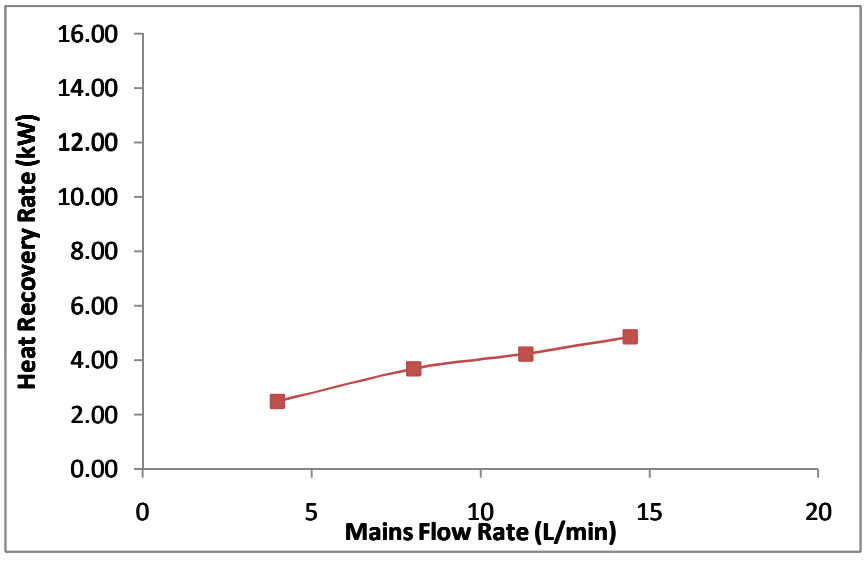
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.317	8537.95	0.17
2.12	0.234	12636.16	0.36
3.00	0.192	14480.36	0.65
3.81	0.167	16597.77	1.05

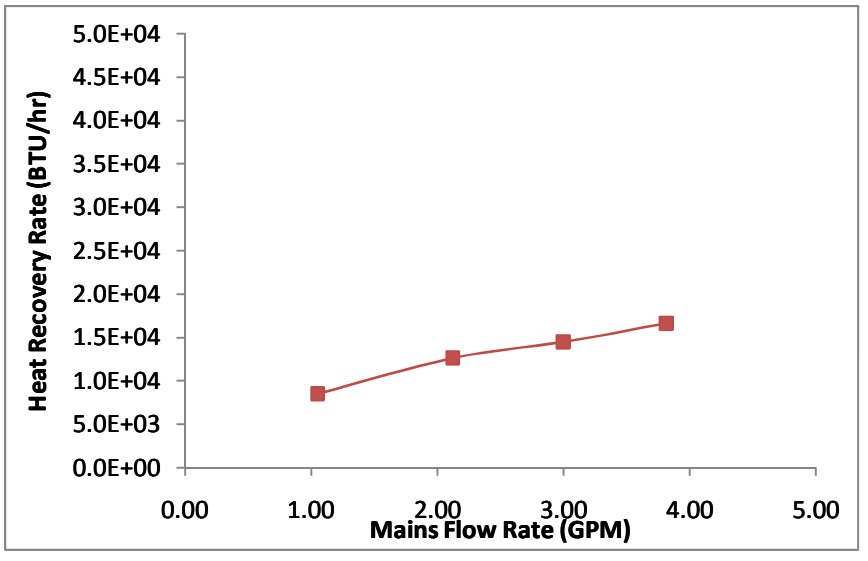
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

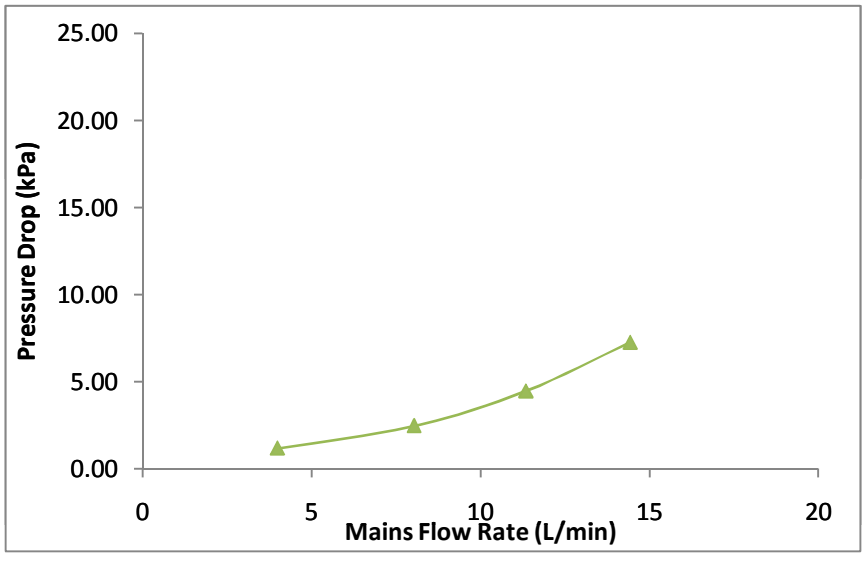
Effectiveness	0.211			
Heat Recovery	3.94	kW	13455.2	BTU/hr
Pressure Drop	3.37	kPa	0.49	PSI

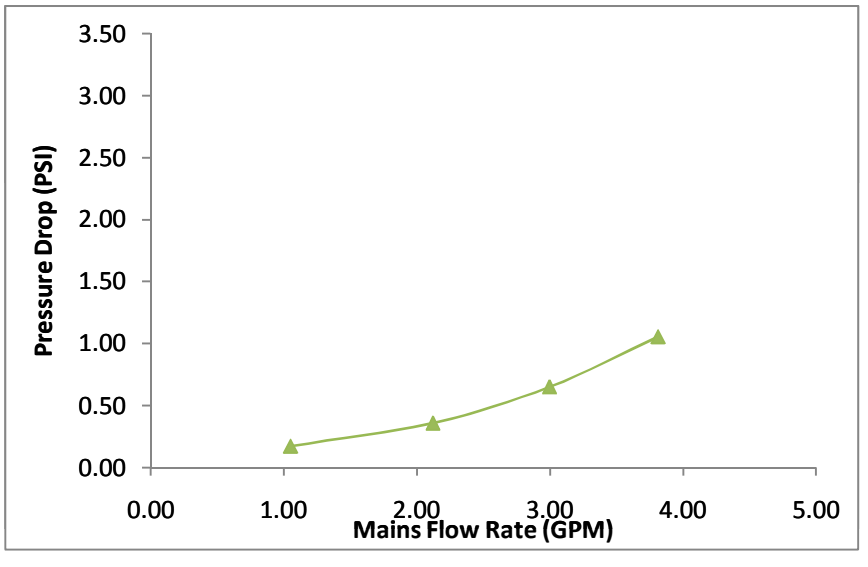












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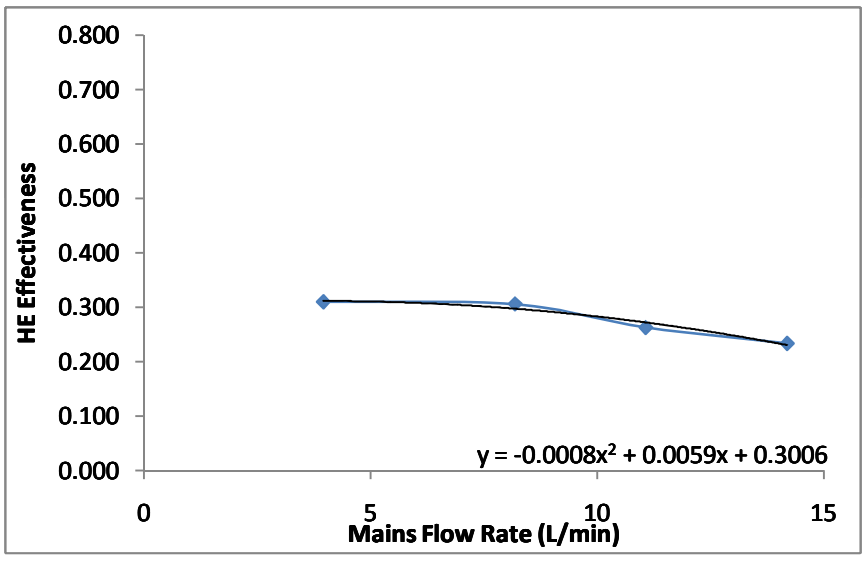
Product: 30in R2in
Manufacturer: Renewability
Test Date: February 9 / 2011

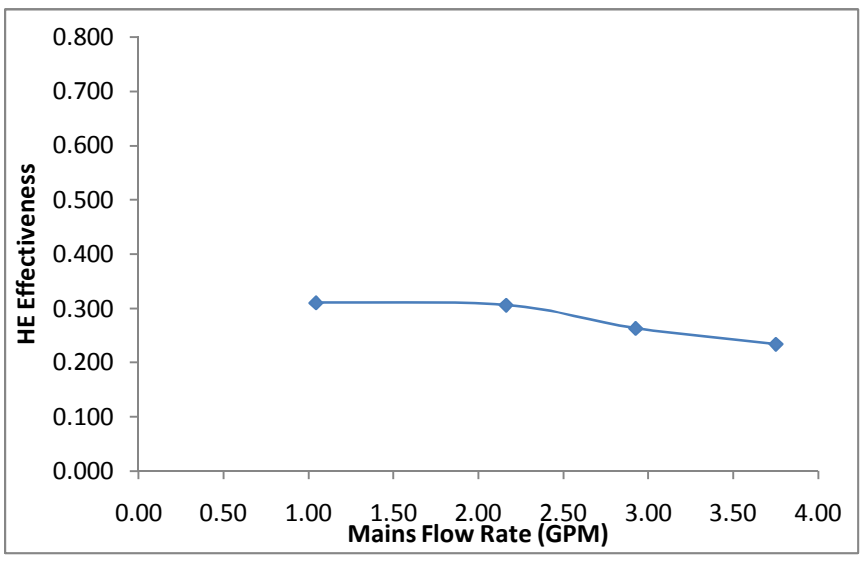
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.96	0.310	2.39	1.25
8.19	0.306	5.01	3.33
11.08	0.263	5.80	5.60
14.2	0.234	6.59	8.85

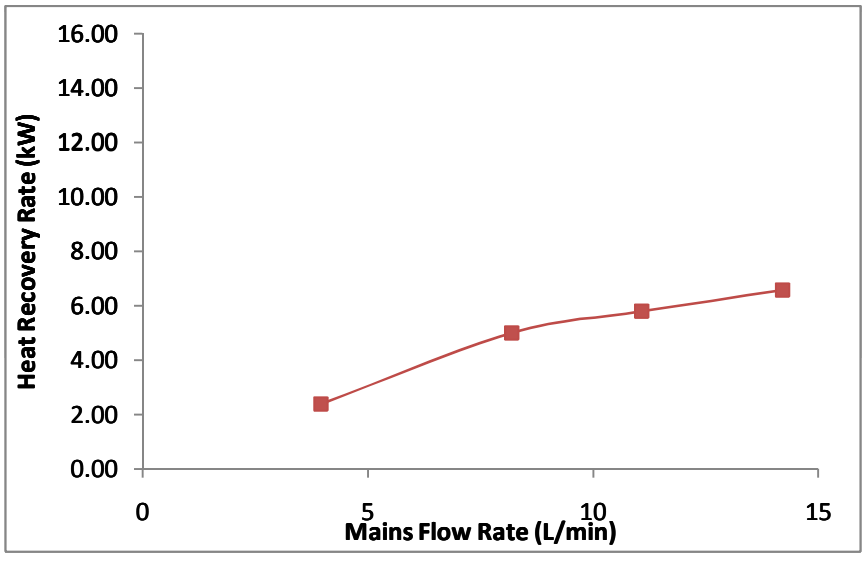
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.310	8162.28	0.18
2.16	0.306	17110.05	0.48
2.93	0.263	19808.04	0.81
3.75	0.234	22506.03	1.28

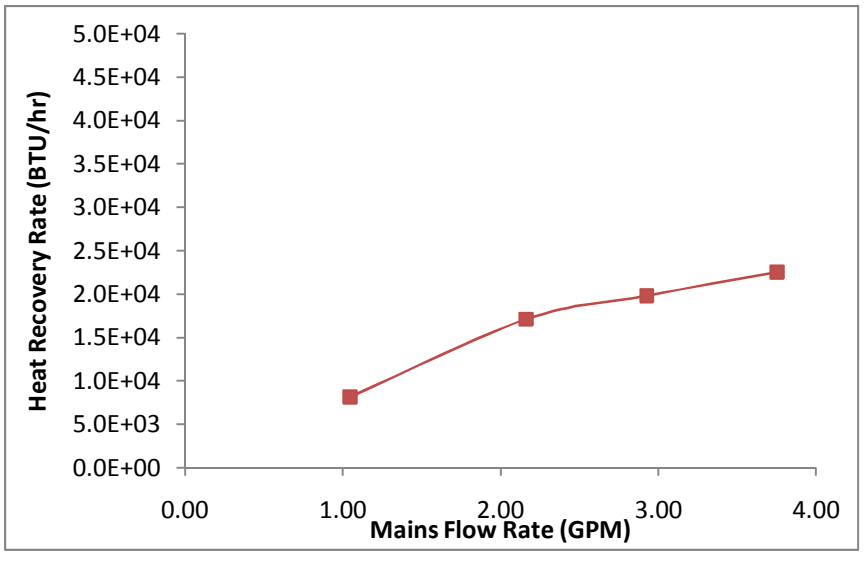
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

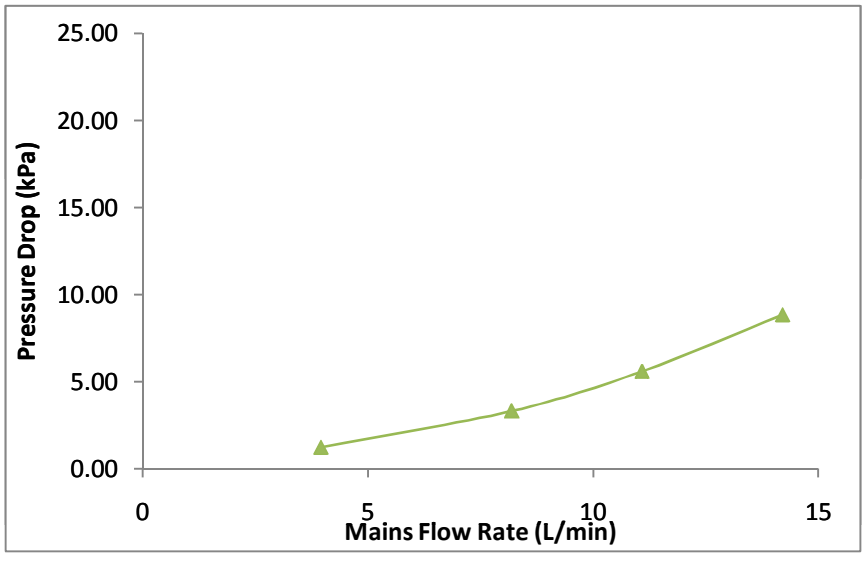
Effectiveness	0.284			
Heat Recovery	5.37	kW	18333.0	BTU/hr
Pressure Drop	4.36	kPa	0.63	PSI

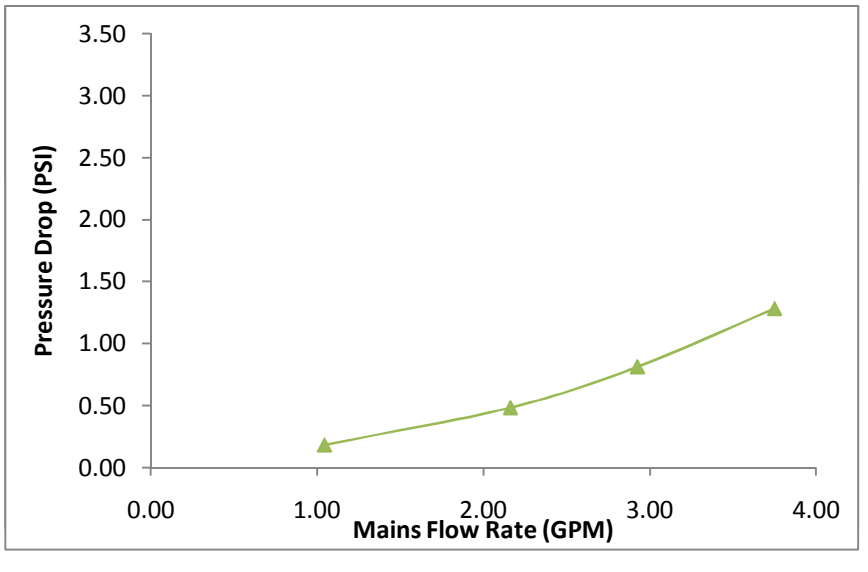












UNIVERSITY OF Waterloo

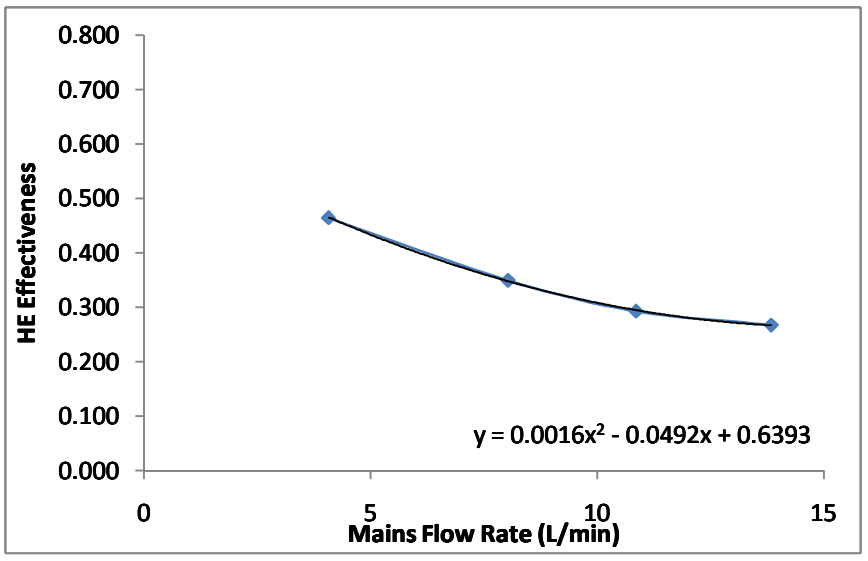
Product: 36in R2in
Manufacturer: Renewability
Test Date: March 4 / 2009

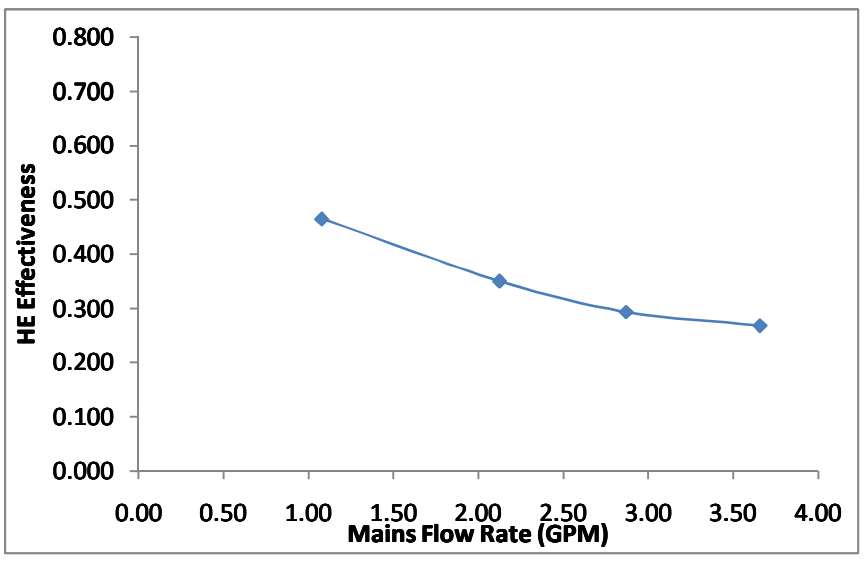
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.08	0.465	3.72	1.33
8.04	0.350	5.47	3.34
10.86	0.293	6.19	6.06
13.84	0.268	7.25	9.32

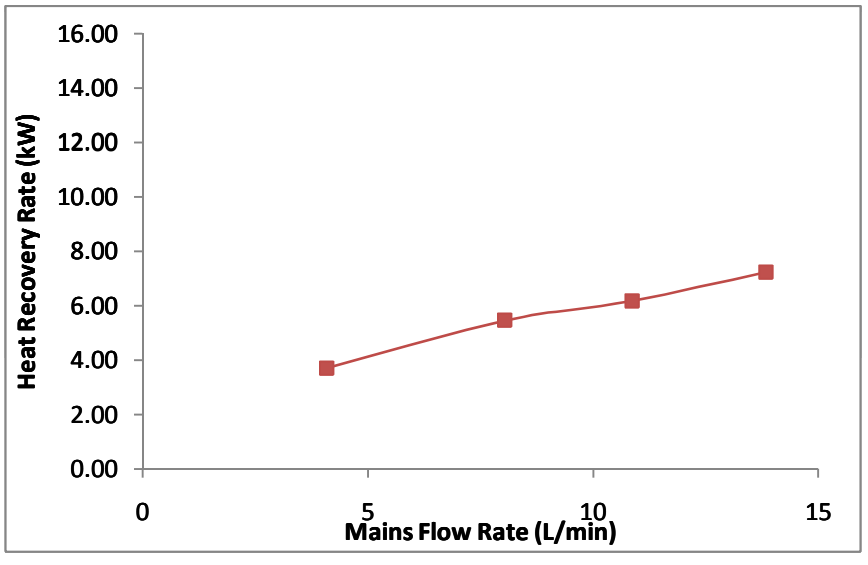
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.08	0.465	12704.47	0.19
2.12	0.350	18681.03	0.48
2.87	0.293	21139.96	0.88
3.66	0.268	24760.05	1.35

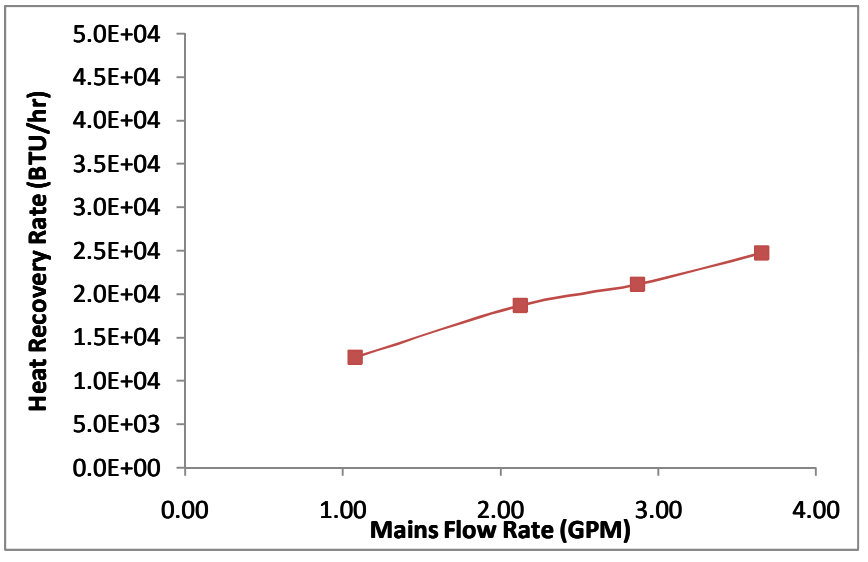
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

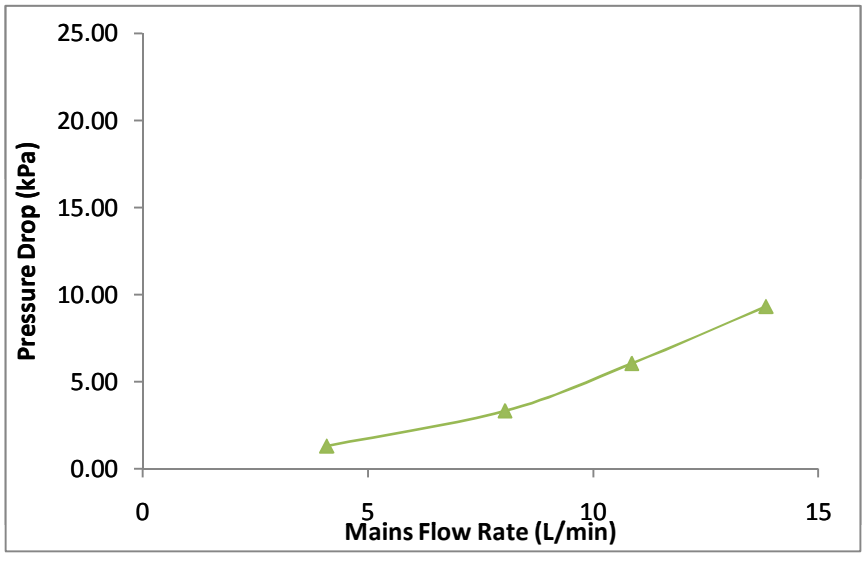
Effectiveness	0.316			
Heat Recovery	5.84	kW	19954.1	BTU/hr
Pressure Drop	4.75	kPa	0.69	PSI

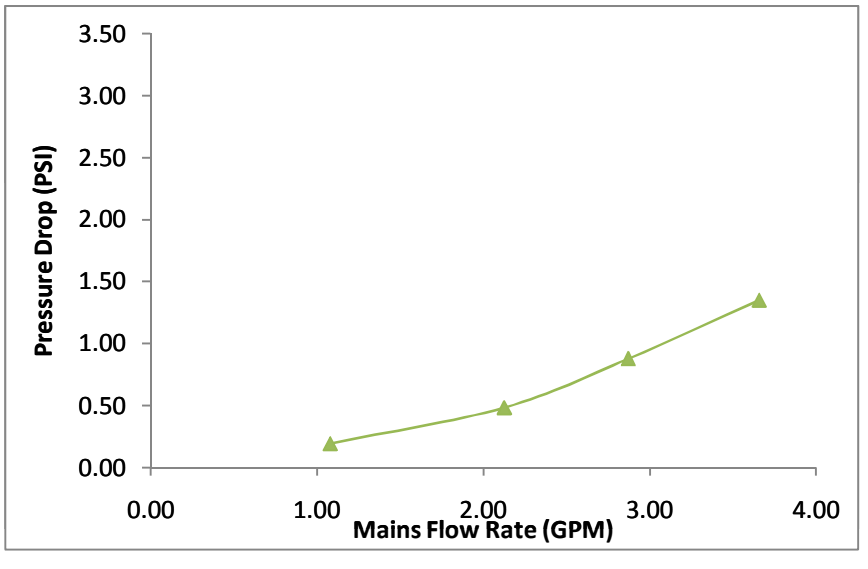












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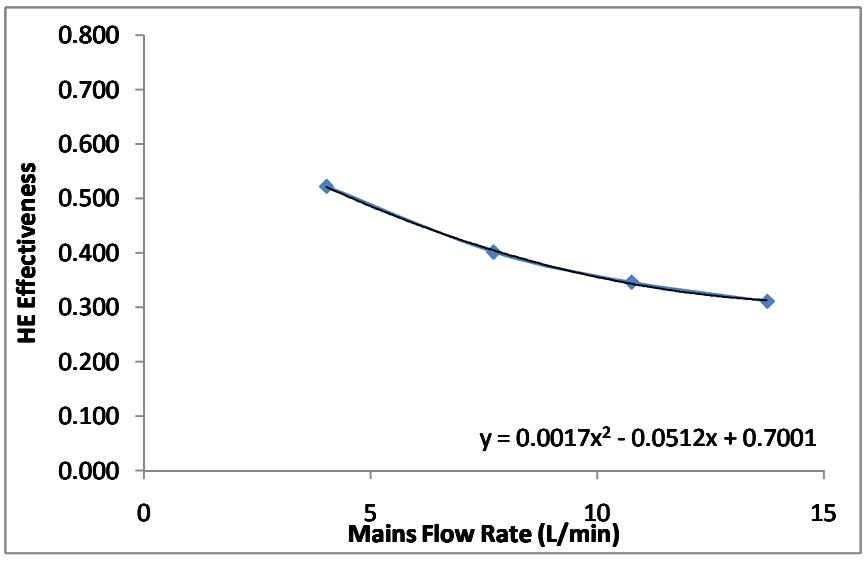
Product: 42in R2in
Manufacturer: Renewability
Test Date: March 11 / 2009 (14 L/min - April 2 / 2009)

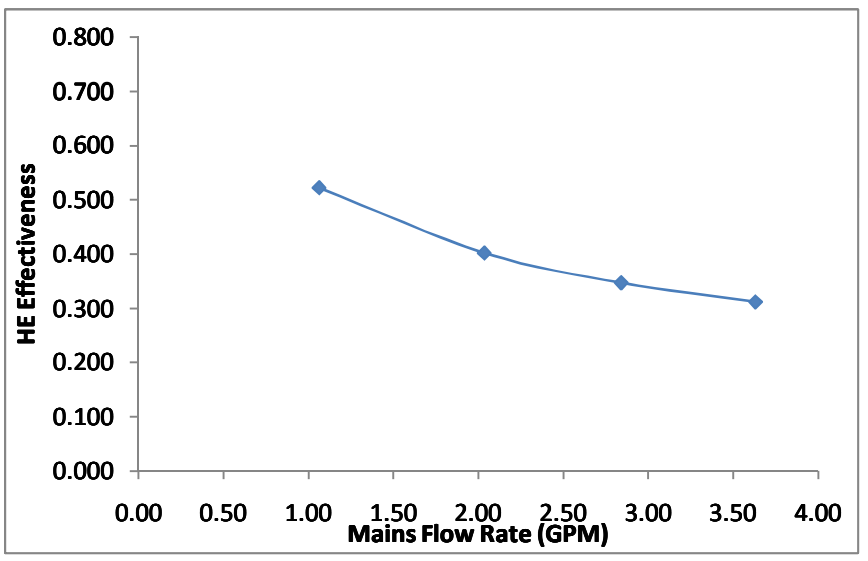
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.03	0.522	4.10	1.17
7.71	0.402	6.09	3.76
10.76	0.347	7.27	7.66
13.75	0.312	8.61	9.95

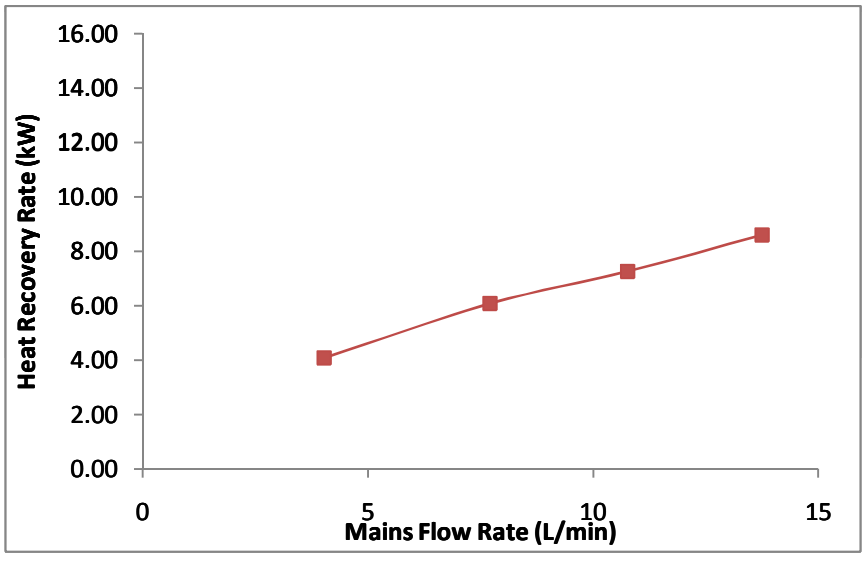
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.522	14002.23	0.17
2.04	0.402	20798.44	0.55
2.84	0.347	24828.35	1.11
3.63	0.312	29404.69	1.44
			0.00

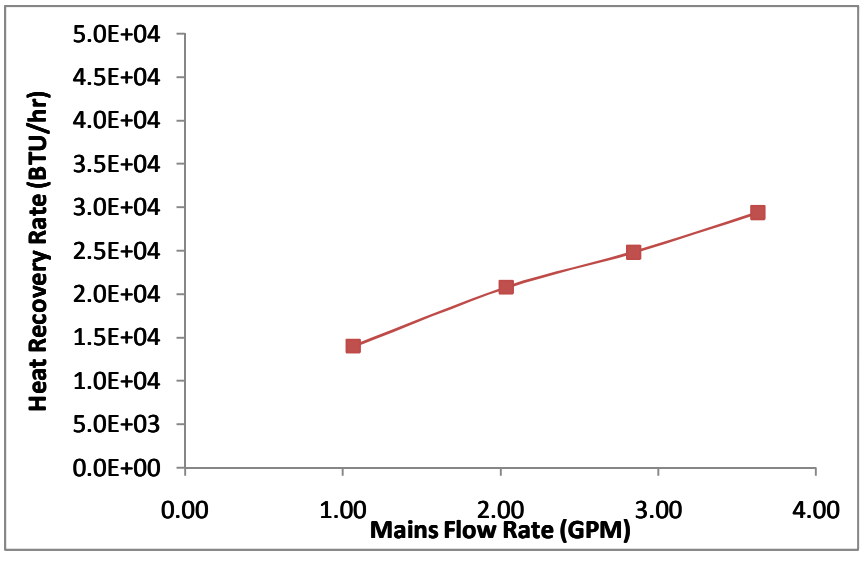
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

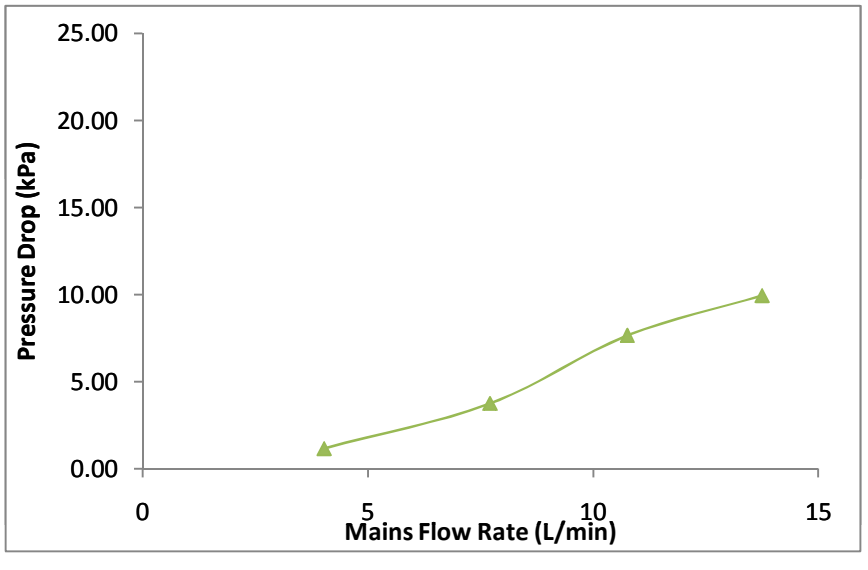
Effectiveness	0.367			
Heat Recovery	6.78	kW	23163.5	BTU/hr
Pressure Drop	6.05	kPa	0.88	PSI

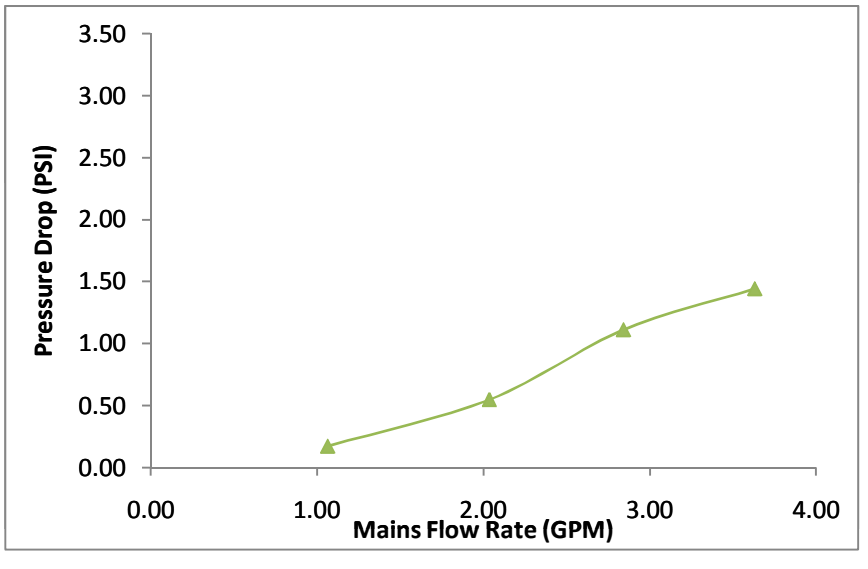












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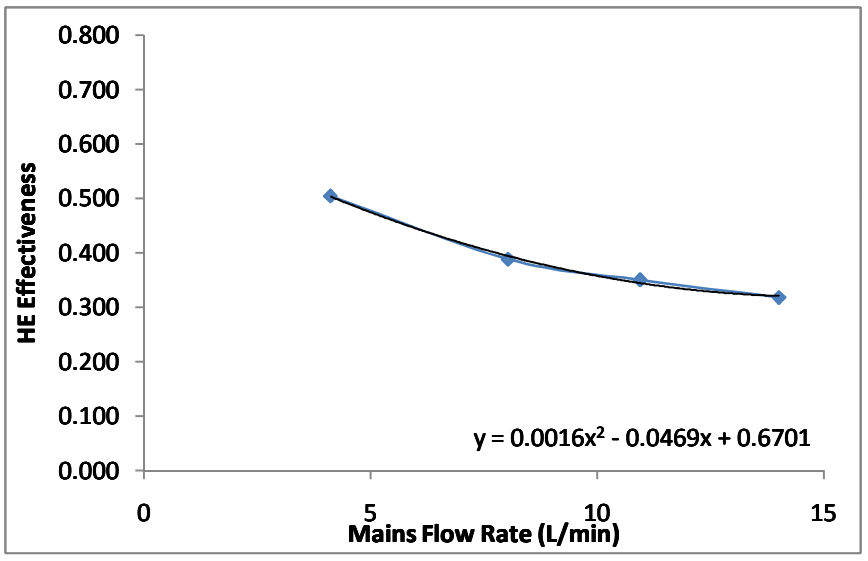
Product: 48in R2in
Manufacturer: Renewability
Test Date: March 7 / 2009

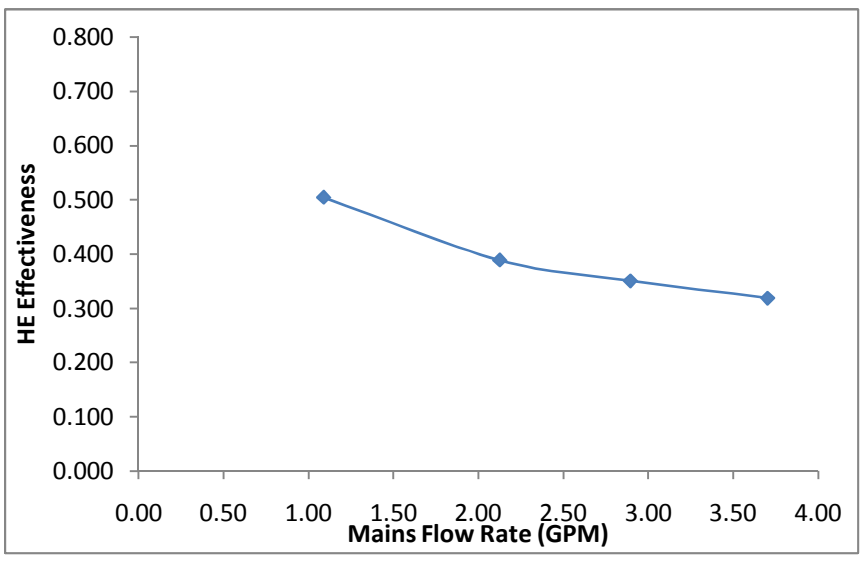
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.12	0.505	4.09	2.51
8.04	0.389	6.13	4.81
10.95	0.351	7.37	8.42
14.01	0.319	8.71	13.68

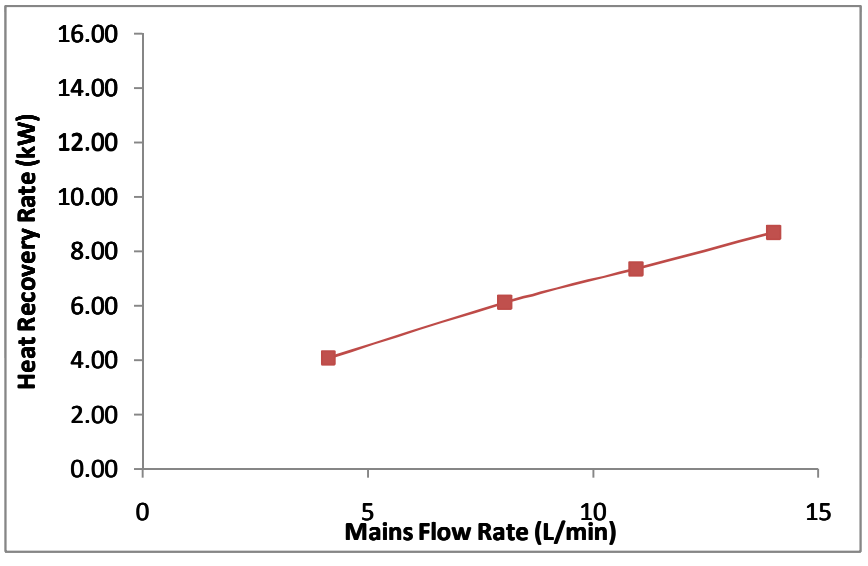
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.09	0.505	13968.08	0.36
2.12	0.389	20935.05	0.70
2.89	0.351	25169.87	1.22
3.70	0.319	29746.21	1.98

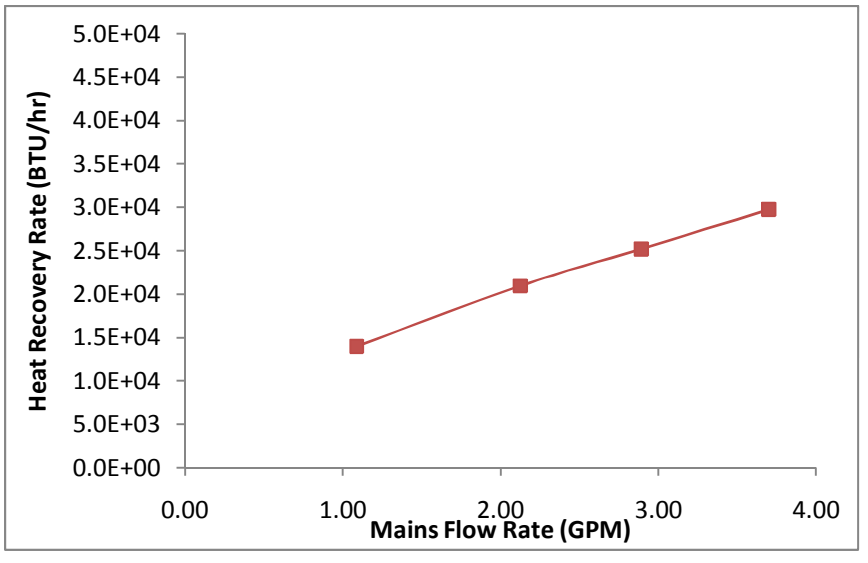
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

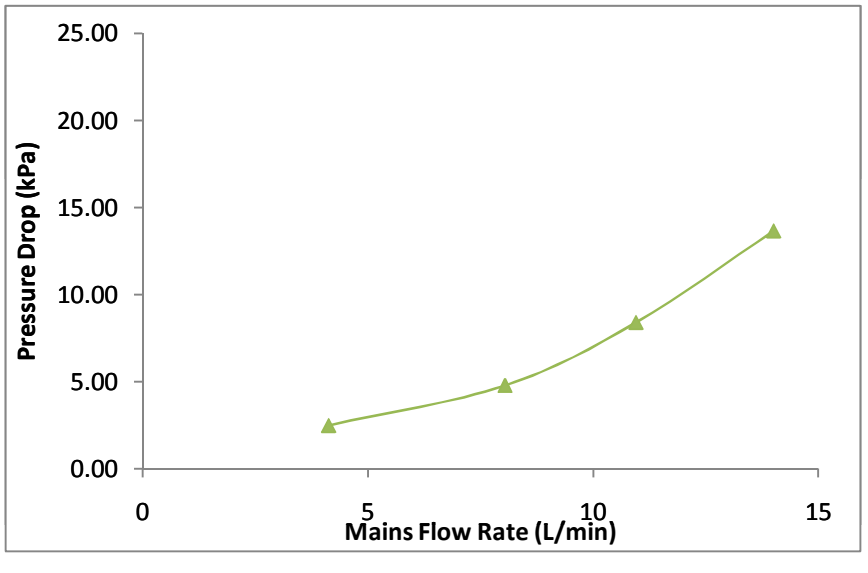
Effectiveness	0.369			
Heat Recovery	6.75	kW	23059.7	BTU/hr
Pressure Drop	6.62	kPa	0.96	PSI

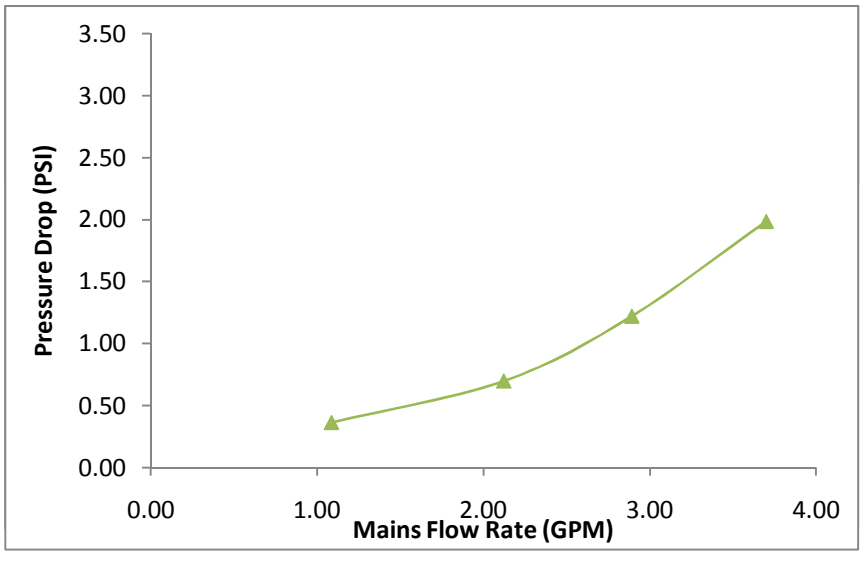












UNIVERSITY OF Waterloo

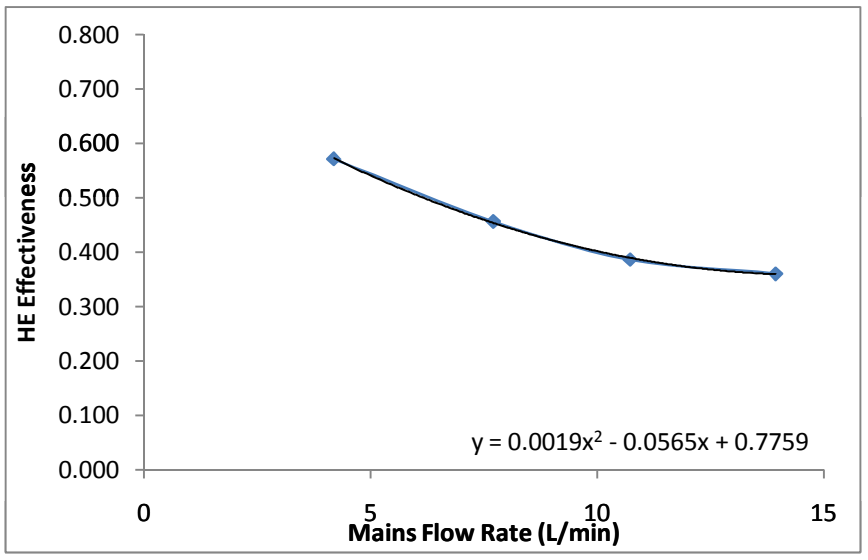
Product: 54in R2in
Manufacturer: Renewability
Test Date: March 11 / 2009 (14 L/min - April 1 /2009)

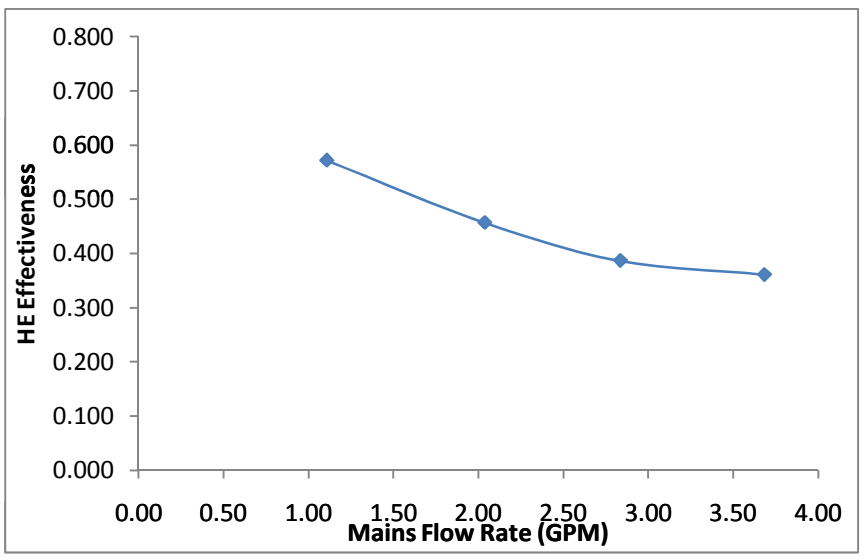
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.19	0.572	4.63	2.01
7.71	0.457	6.91	6.04
10.73	0.387	8.06	10.68
13.94	0.361	9.88	14.00

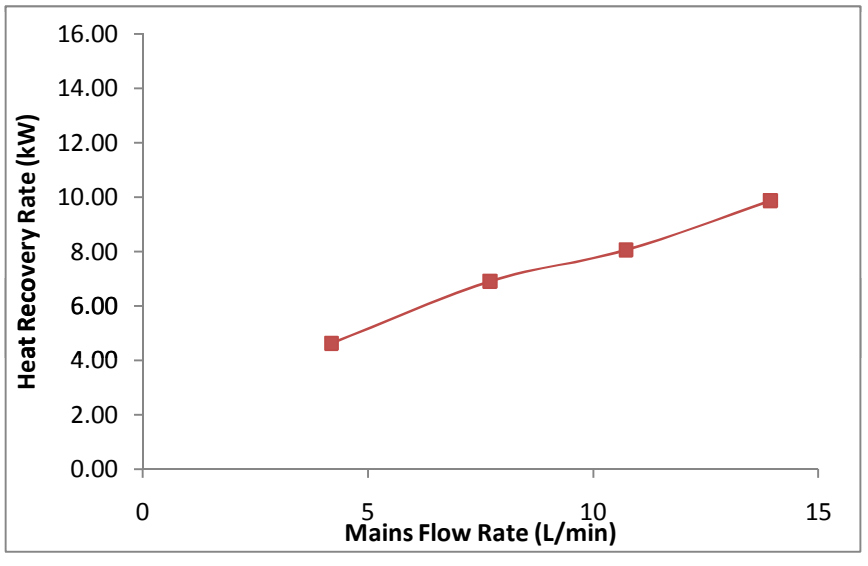
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.11	0.572	15812.28	0.29
2.04	0.457	23598.89	0.88
2.83	0.387	27526.34	1.55
3.68	0.361	33741.97	2.03

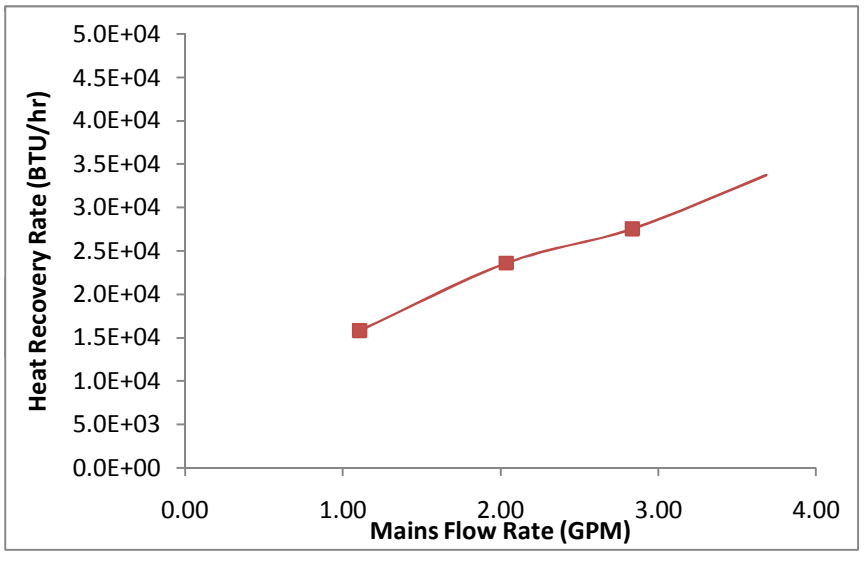
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

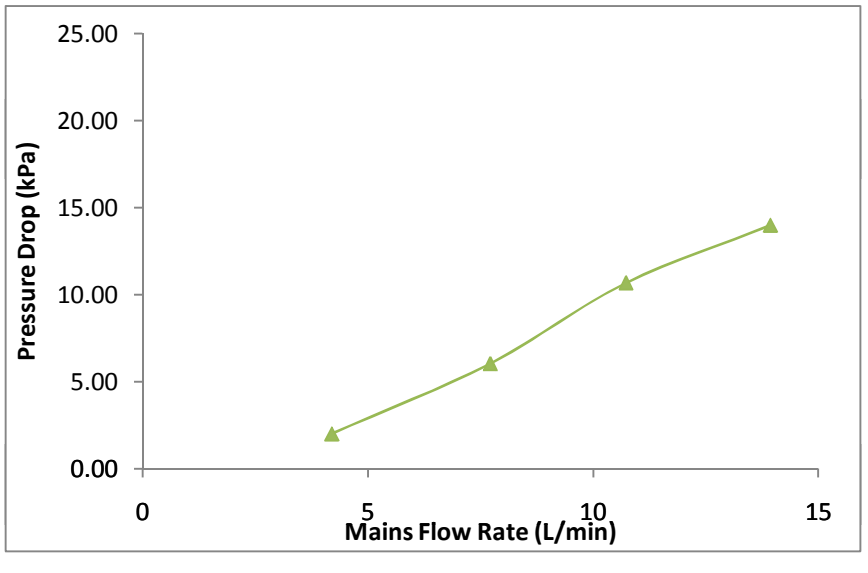
Effectiveness	0.411			
Heat Recovery	7.59	kW	25926.7	BTU/hr
Pressure Drop	8.79	kPa	1.27	PSI

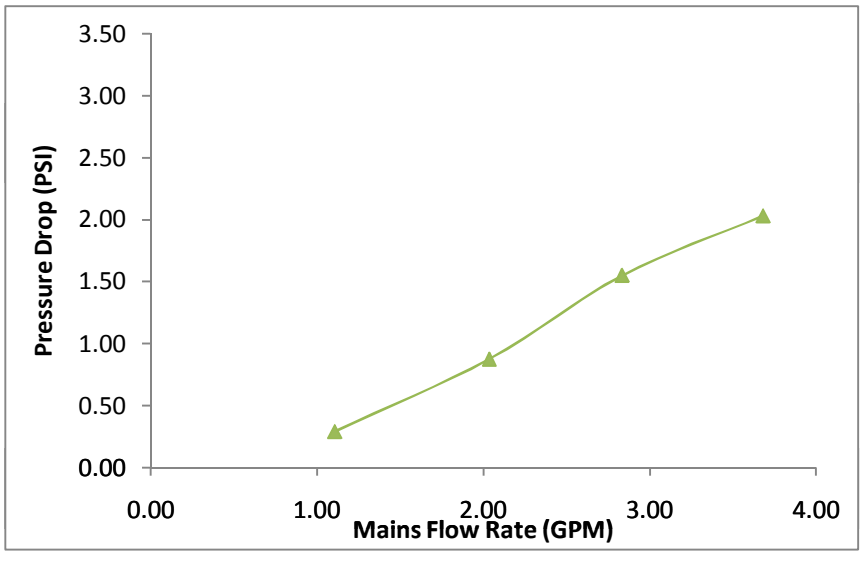












UNIVERSITY OF Waterloo

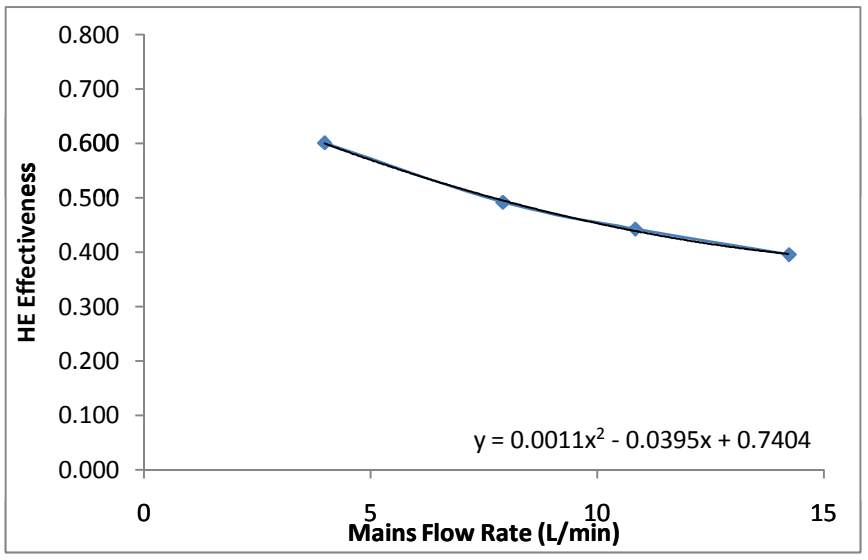
Product: 60in R2in
Manufacturer: Renewability
Test Date: March 11 / 2009 (14 L/min - April 1 / 2009)

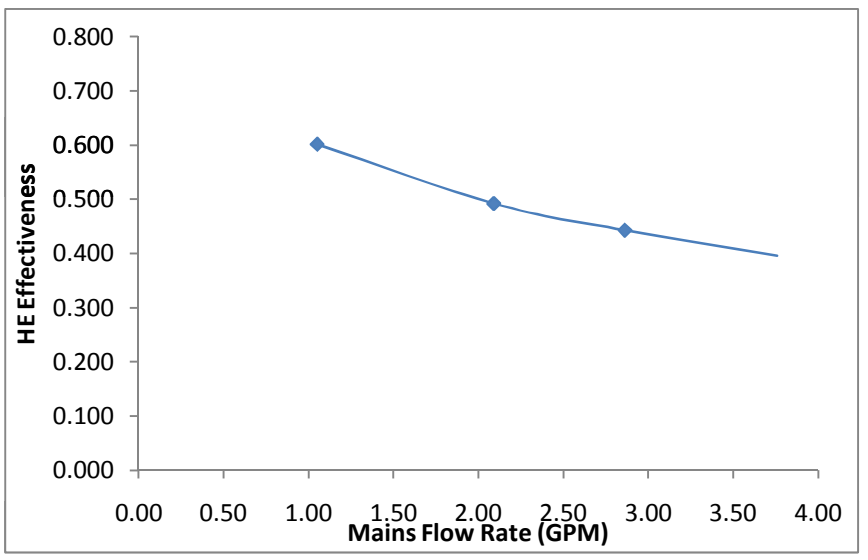
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.99	0.601	4.61	1.28
7.92	0.492	7.60	5.97
10.84	0.443	8.06	9.84
14.23	0.396	10.86	16.68

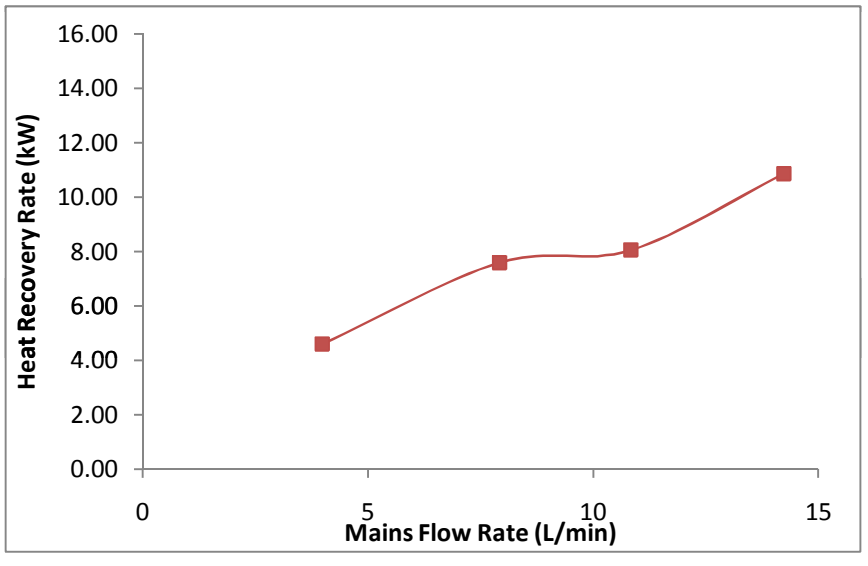
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.601	15743.98	0.19
2.09	0.492	25955.36	0.87
2.86	0.443	27526.34	1.43
3.76	0.396	37088.84	2.42

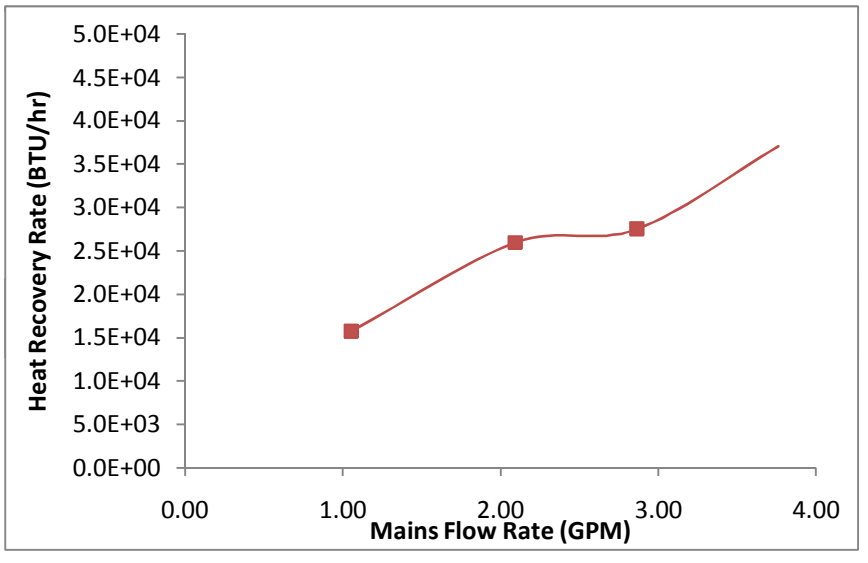
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

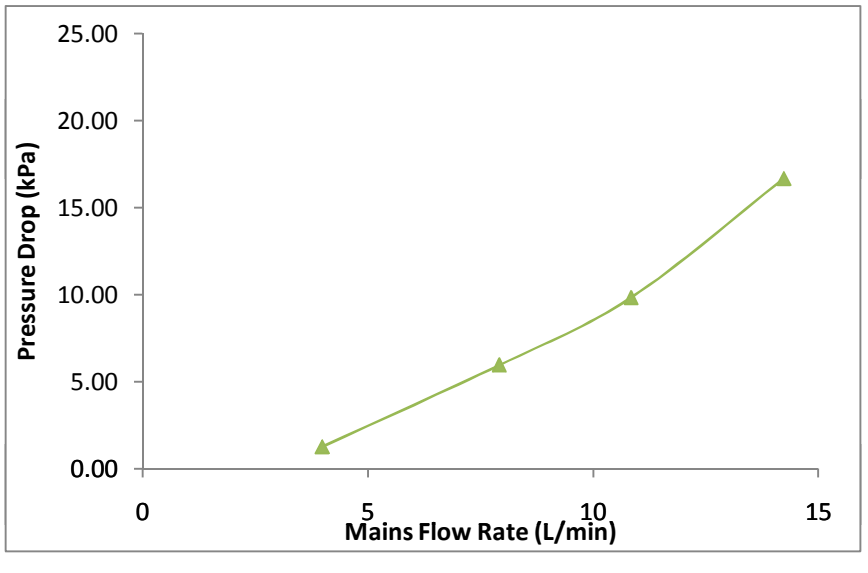
Effectiveness	0.464			
Heat Recovery	7.85	kW	26805.4	BTU/hr
Pressure Drop	8.06	kPa	1.17	PSI

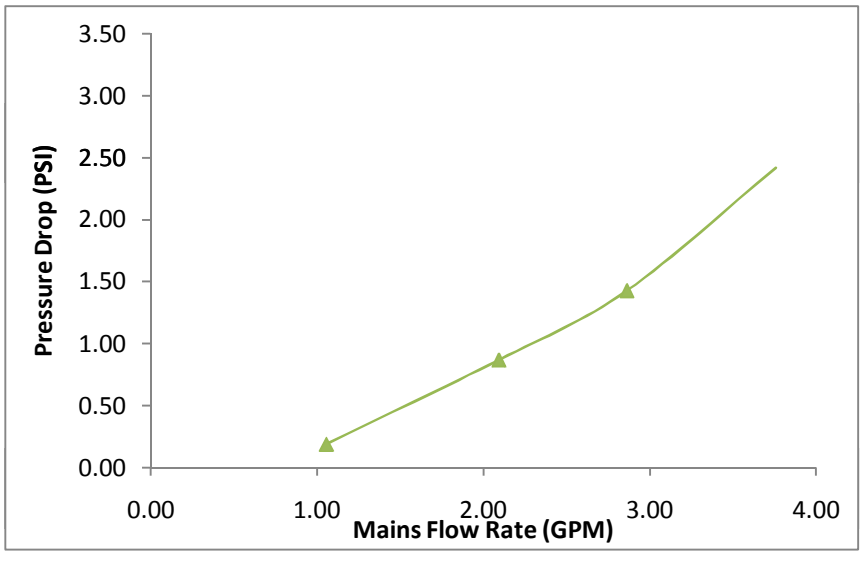












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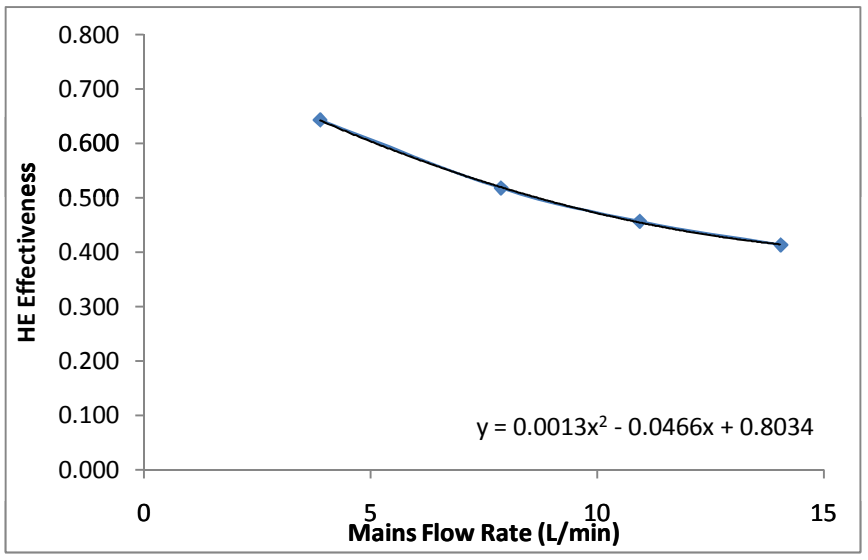
Product: 66in R2in
Manufacturer: Renewability
Test Date: March 24 / 2009

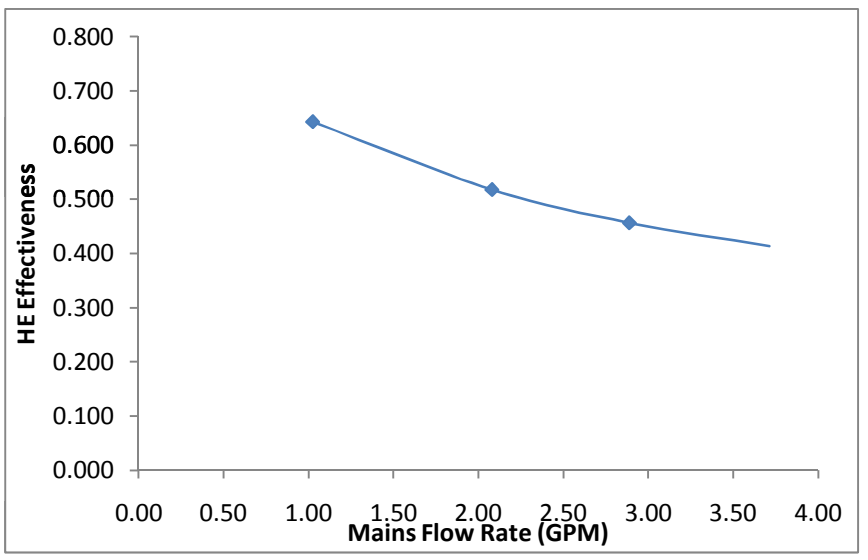
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.89	0.643	4.82	2.61
7.88	0.518	7.92	6.67
10.94	0.457	9.76	13.25
14.05	0.414	11.41	19.23

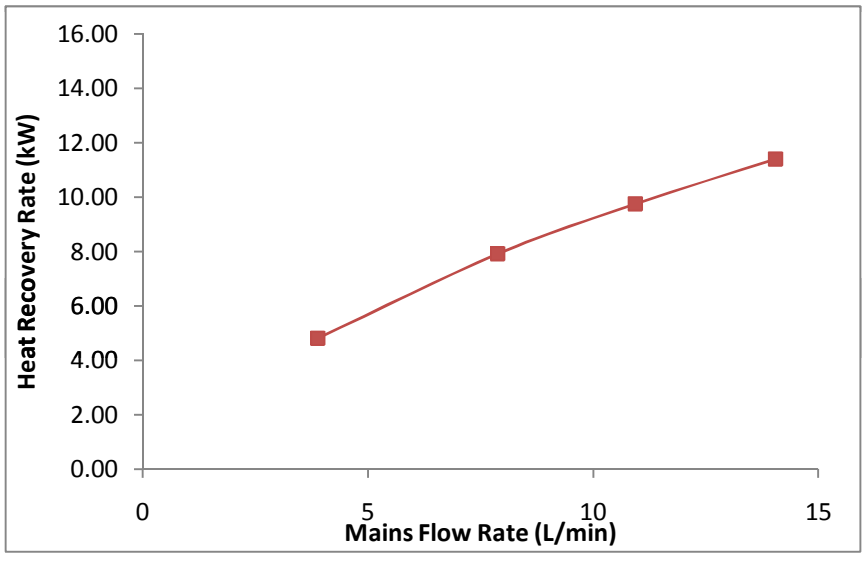
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.03	0.643	16461.16	0.38
2.08	0.518	27048.22	0.97
2.89	0.457	33332.15	1.92
3.71	0.414	38967.19	2.79

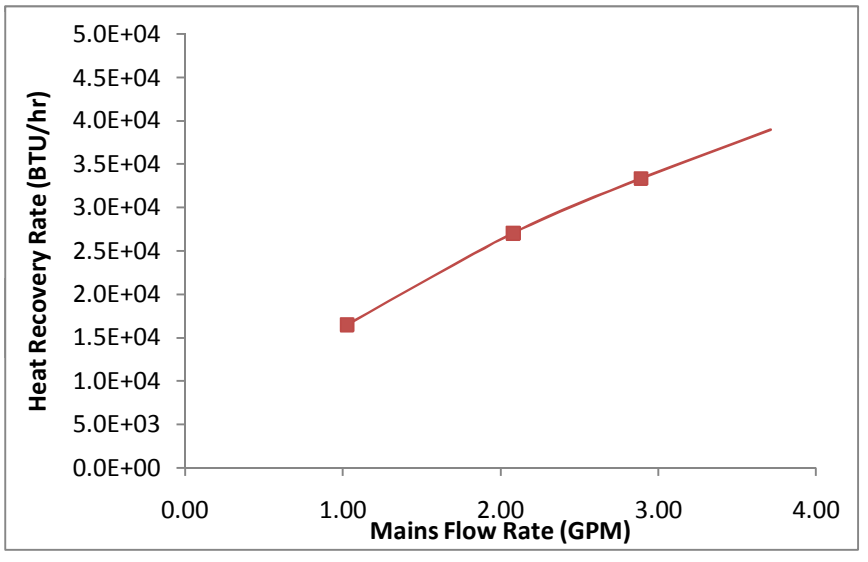
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

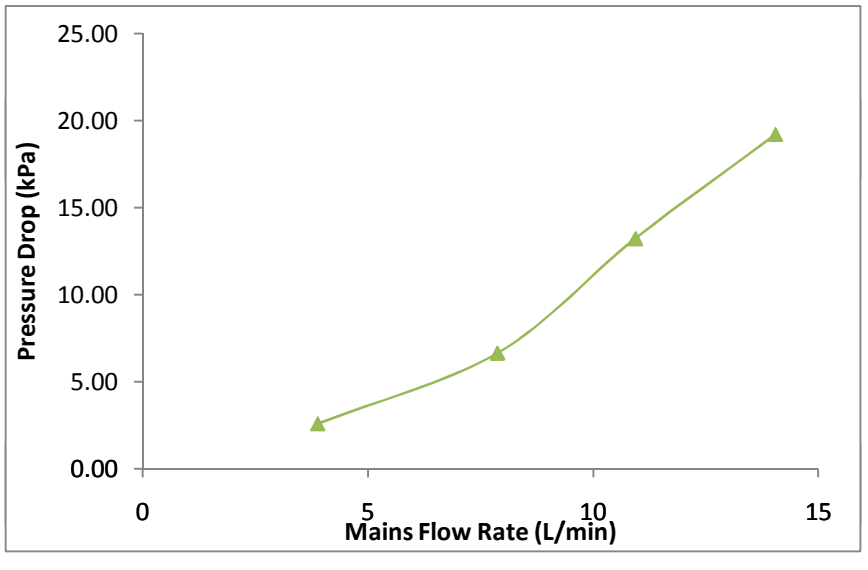
Effectiveness	0.478			
Heat Recovery	8.89	kW	30375.0	BTU/hr
Pressure Drop	10.15	kPa	1.47	PSI

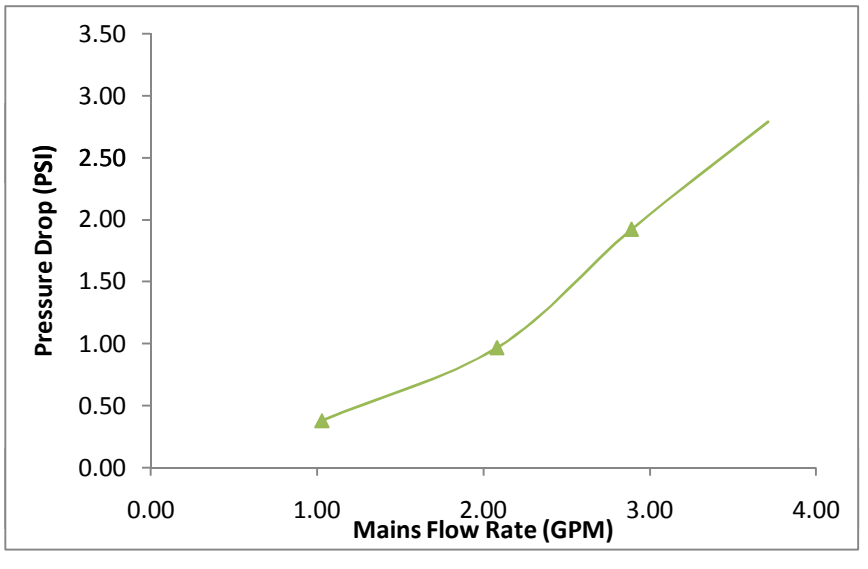












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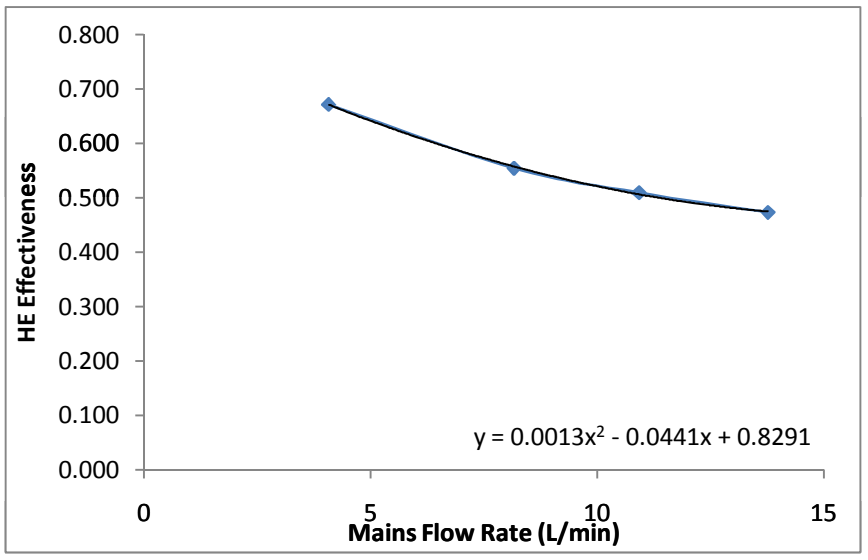
Product: 72in R2in
Manufacturer: Renewability
Test Date: March 10 / 2009

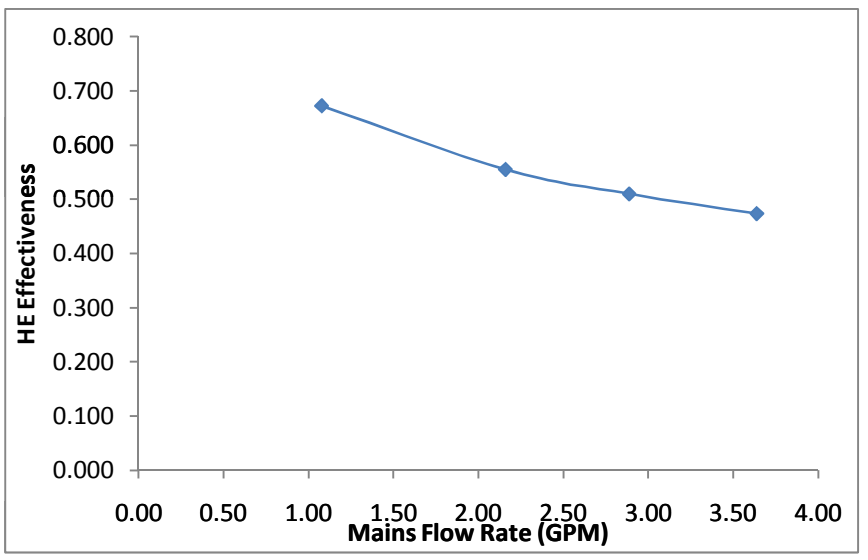
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.08	0.672	5.37	2.82
8.17	0.555	8.78	8.68
10.93	0.510	10.86	14.52
13.77	0.474	12.63	22.00

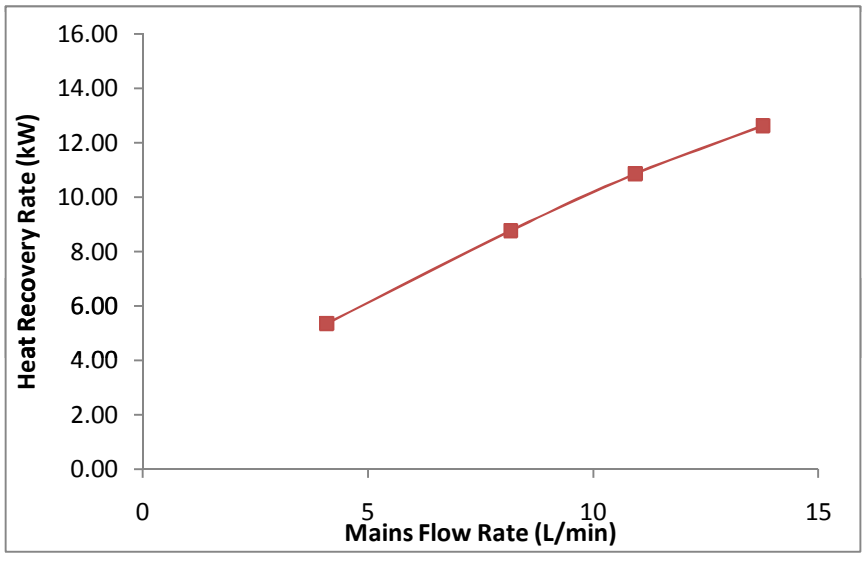
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.08	0.672	18339.51	0.41
2.16	0.555	29985.27	1.26
2.89	0.510	37088.84	2.11
3.64	0.474	43133.71	3.19

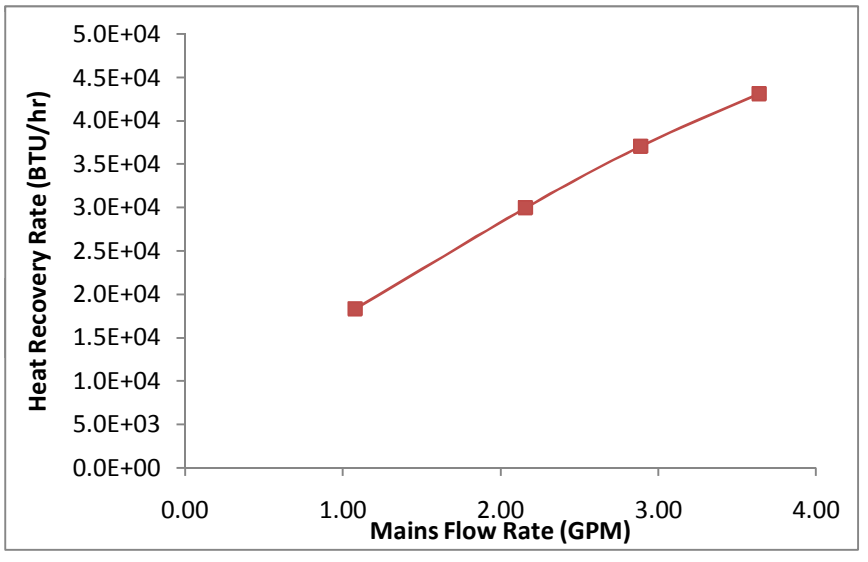
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

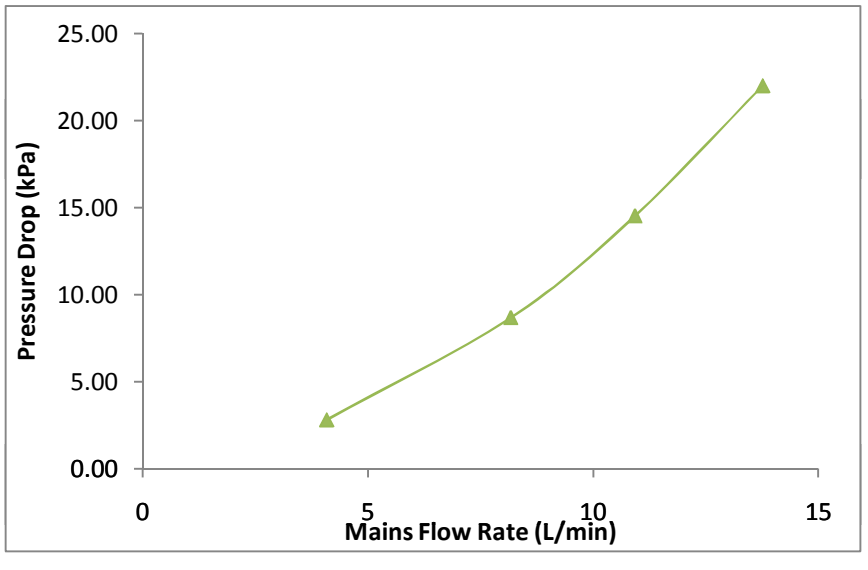
Effectiveness	0.527			
Heat Recovery	9.78	kW	33408.4	BTU/hr
Pressure Drop	11.49	kPa	1.67	PSI

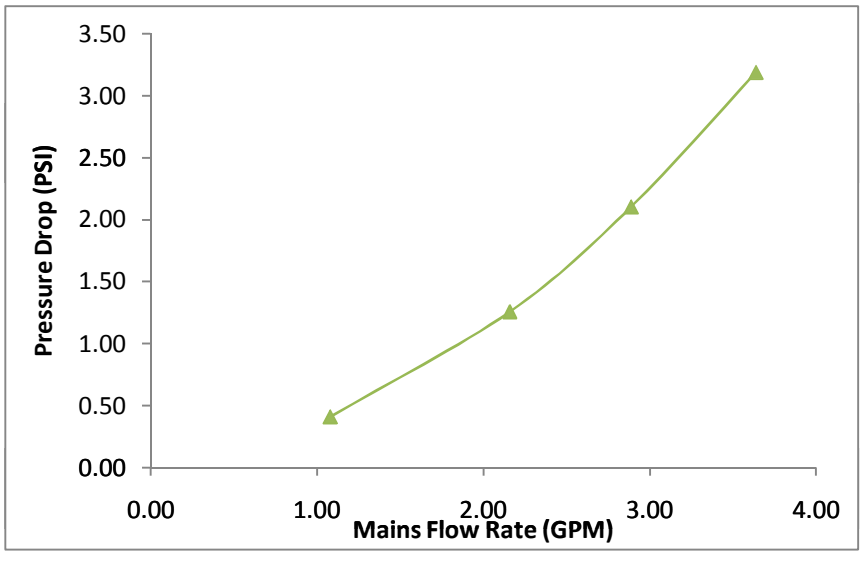












UNIVERSITY OF Waterloo

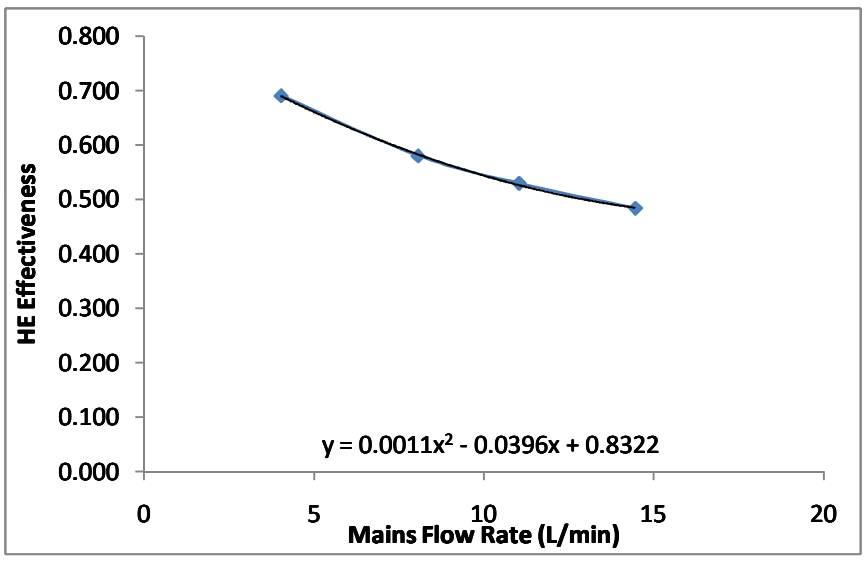
Product: 84in R2in
Manufacturer: Renewability
Test Date: February 25 / 2011

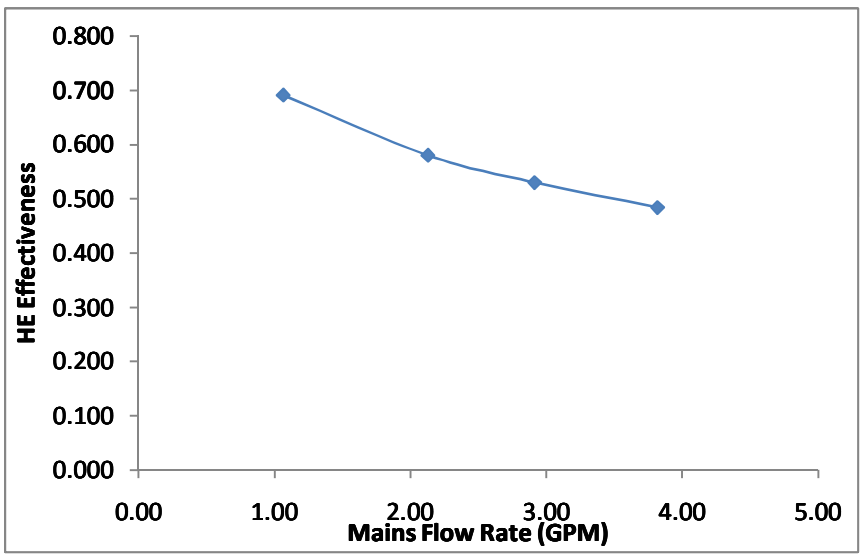
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.03	0.691	5.34	3.19
8.06	0.580	9.12	8.01
11.03	0.530	11.54	13.04
14.45	0.484	13.76	20.72

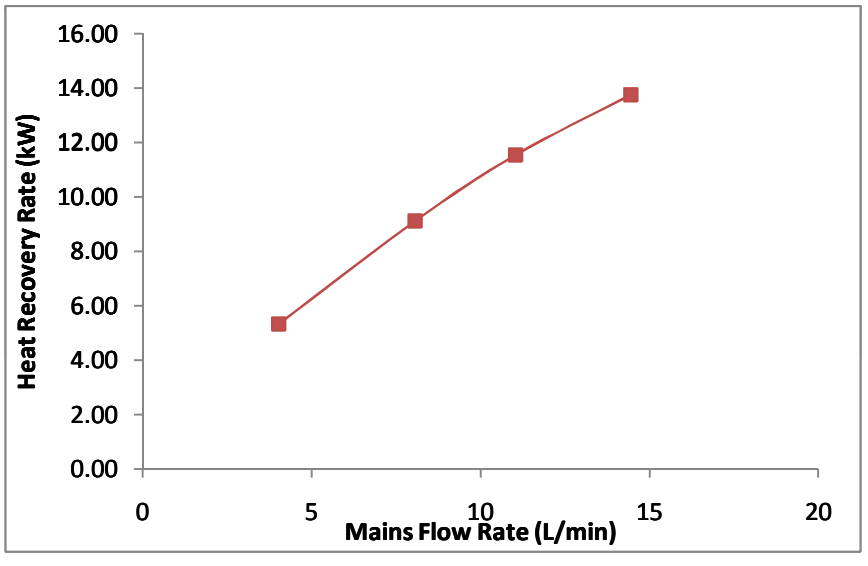
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.691	18237.06	0.46
2.13	0.580	31146.43	1.16
2.91	0.530	39411.17	1.89
3.82	0.484	46992.86	3.01

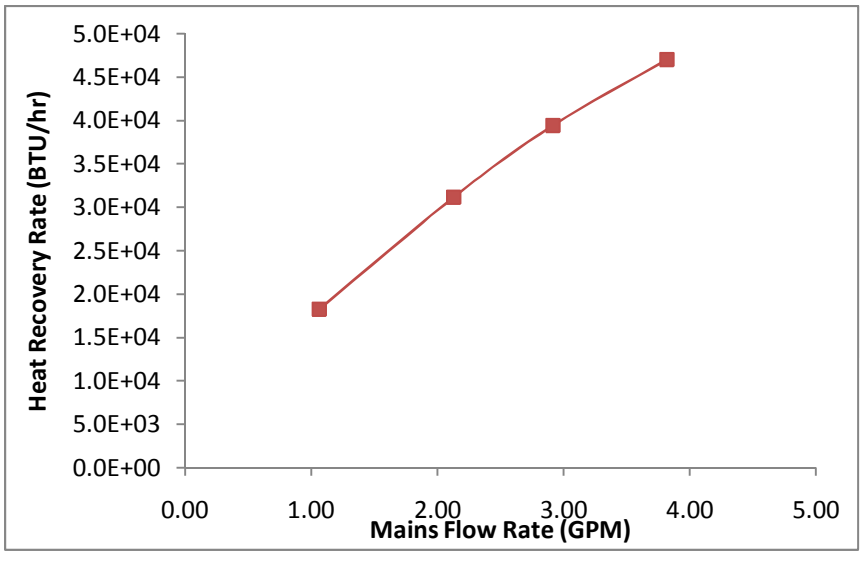
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

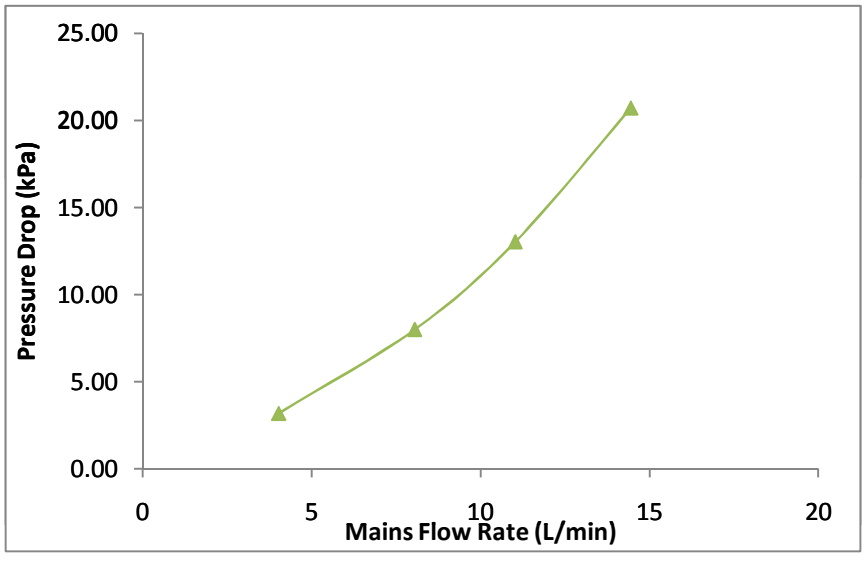
Effectiveness	0.555			
Heat Recovery	10.29	kW	35153.6	BTU/hr
Pressure Drop	10.45	kPa	1.52	PSI

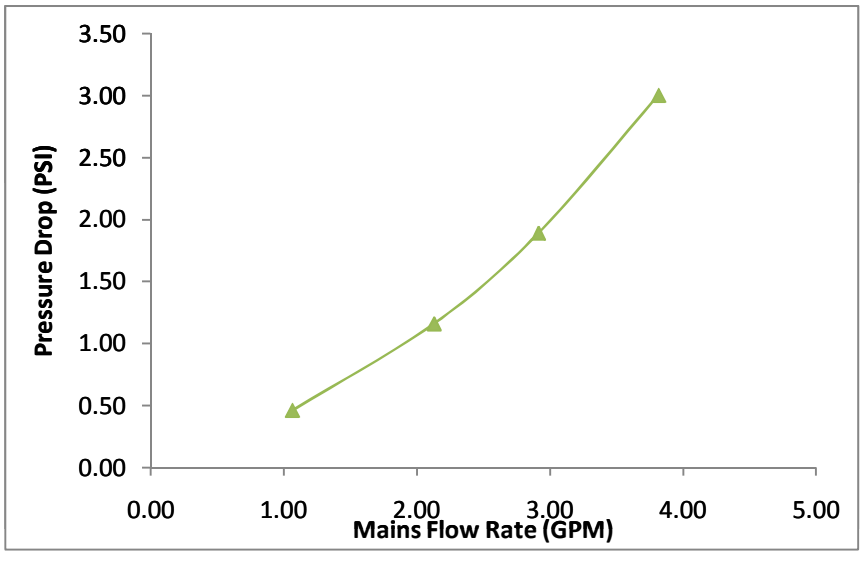












UNIVERSITY OF Waterloo

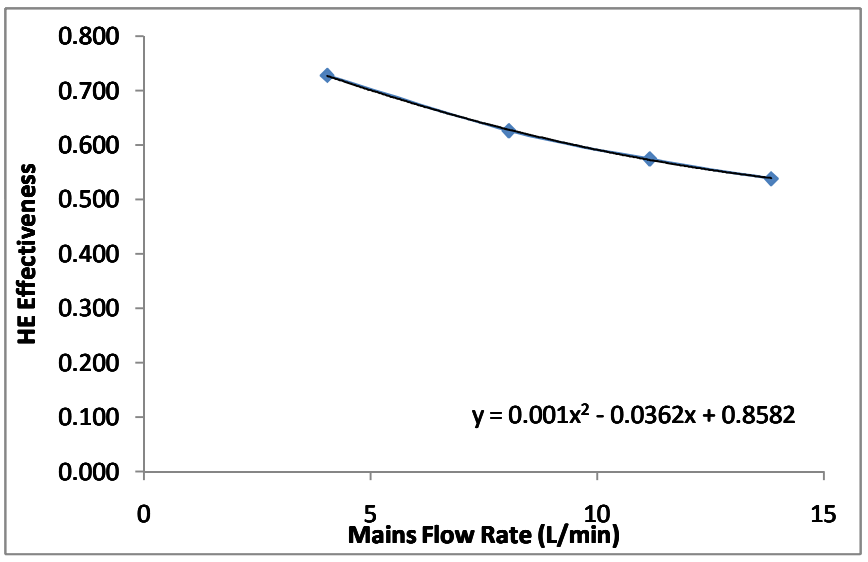
Product: 96in R2in
Manufacturer: Renewability
Test Date: February 9 / 2011

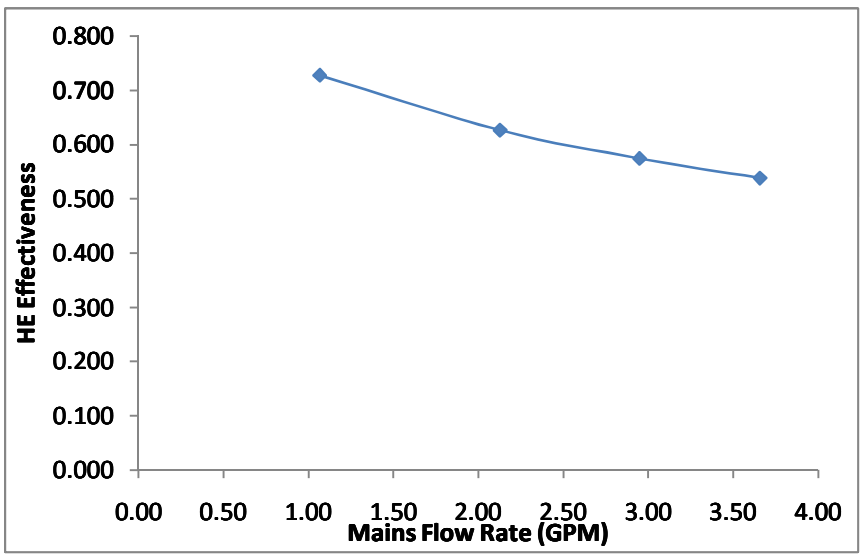
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.04	0.728	5.77	3.43
8.05	0.627	9.86	10.00
11.16	0.575	12.51	17.34
13.84	0.539	14.63	23.80

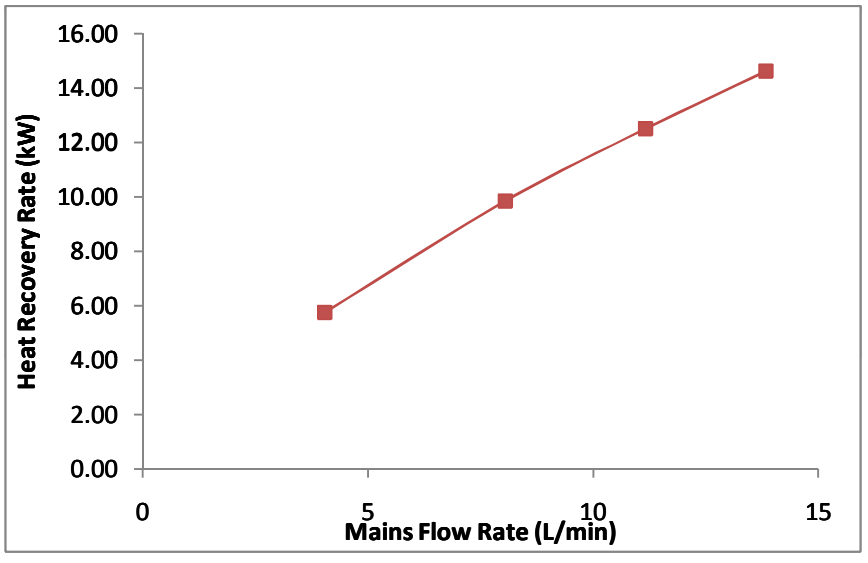
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.07	0.728	19705.58	0.50
2.13	0.627	33673.66	1.45
2.95	0.575	42723.89	2.51
3.66	0.539	49964.07	3.45

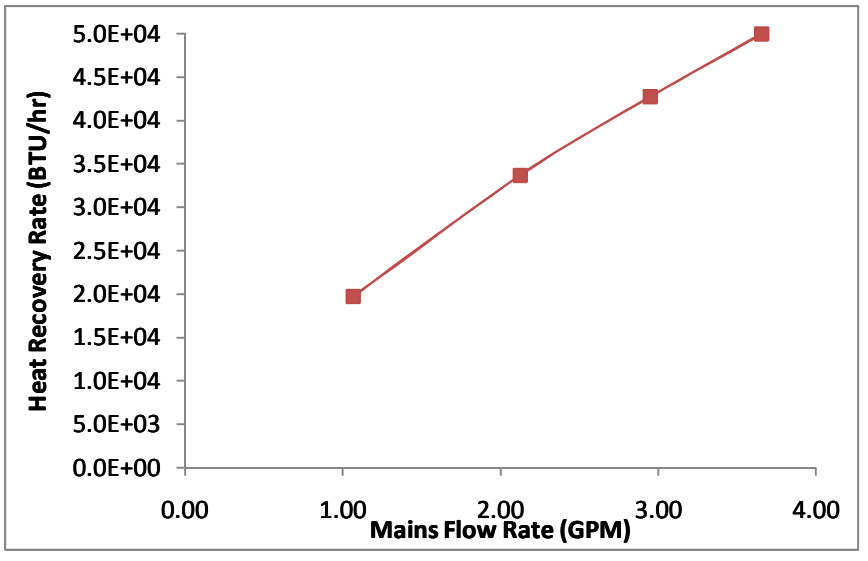
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

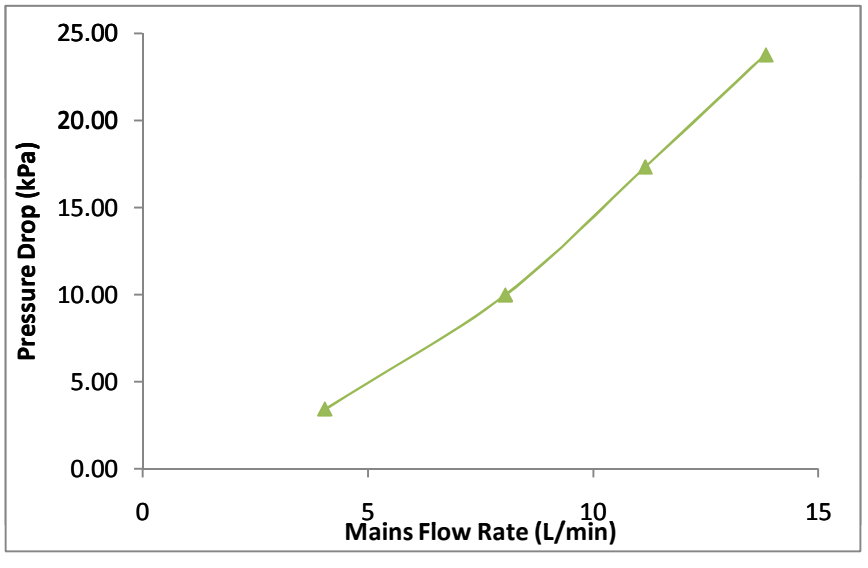
Effectiveness	0.605			
Heat Recovery	11.10	kW	37893.2	BTU/hr
Pressure Drop	13.42	kPa	1.95	PSI

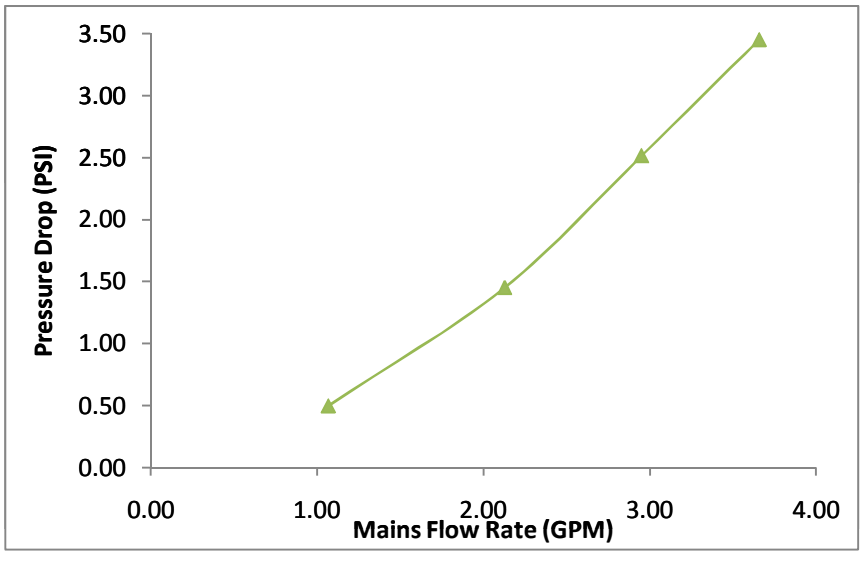












UNIVERSITY OF Waterloo

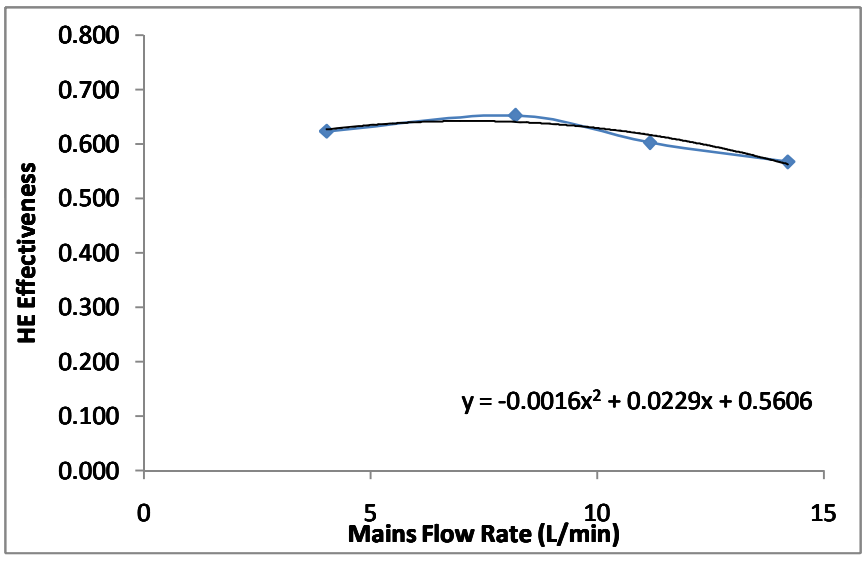
Product: 108in R2in
Manufacturer: Renewability
Test Date: February 9 / 2011

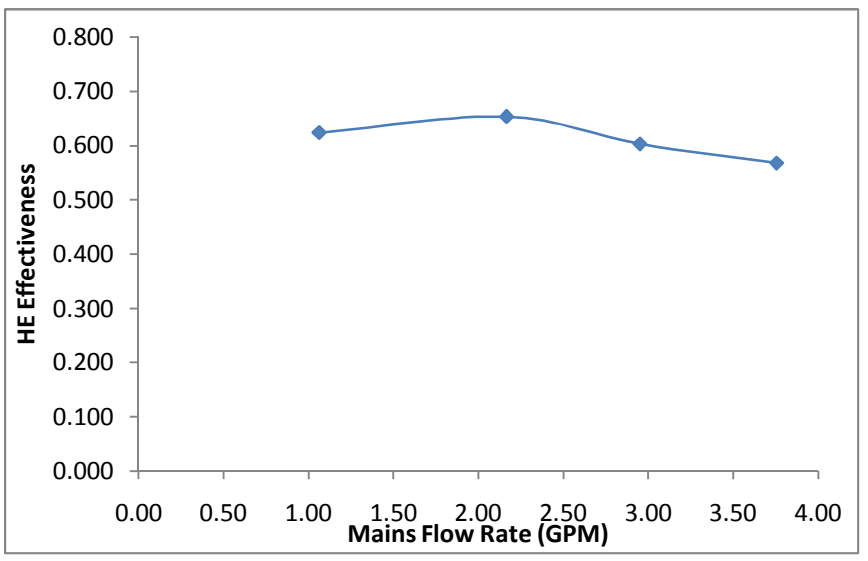
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.03	0.624	4.90	4.36
8.2	0.653	9.76	12.15
11.17	0.603	13.00	19.39
14.21	0.568	14.21	27.88

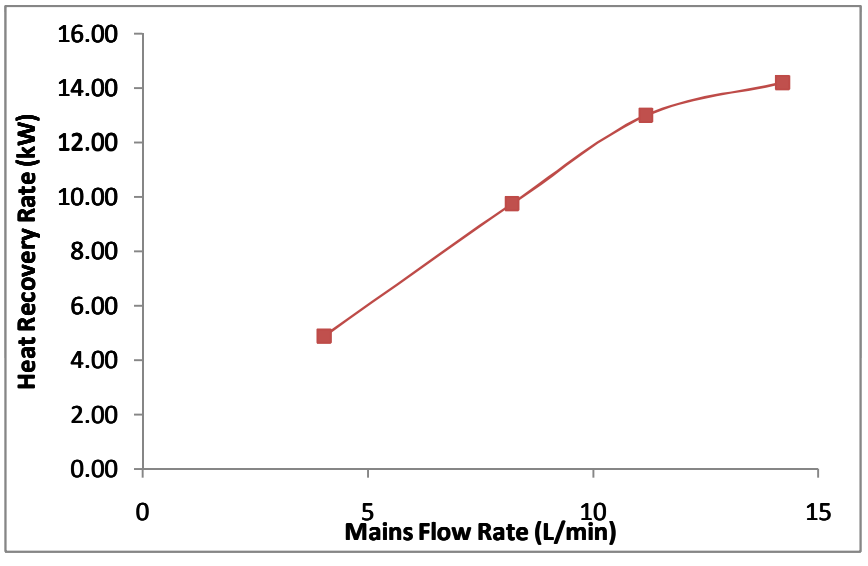
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.624	16734.38	0.63
2.17	0.653	33332.15	1.76
2.95	0.603	44397.33	2.81
3.75	0.568	48529.69	4.04

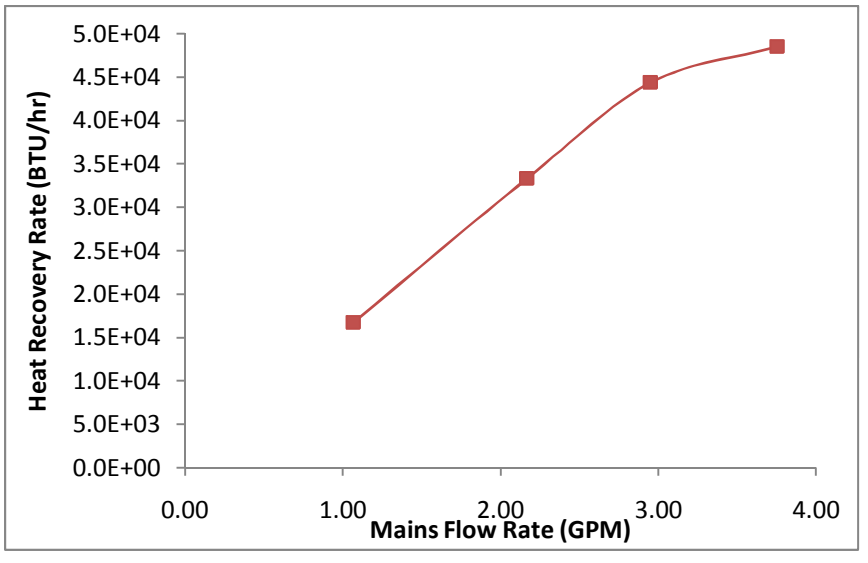
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

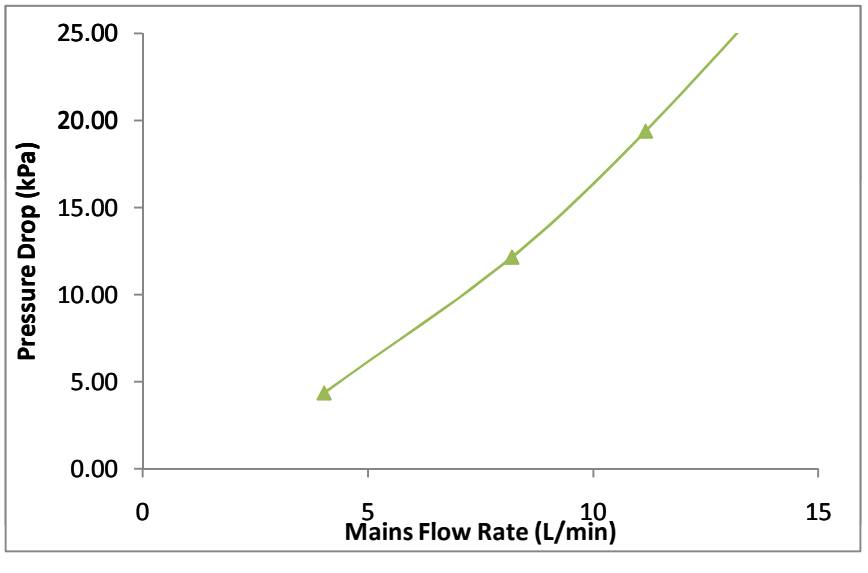
Effectiveness	0.634			
Heat Recovery	11.18	kW	38175.5	BTU/hr
Pressure Drop	15.32	kPa	2.22	PSI

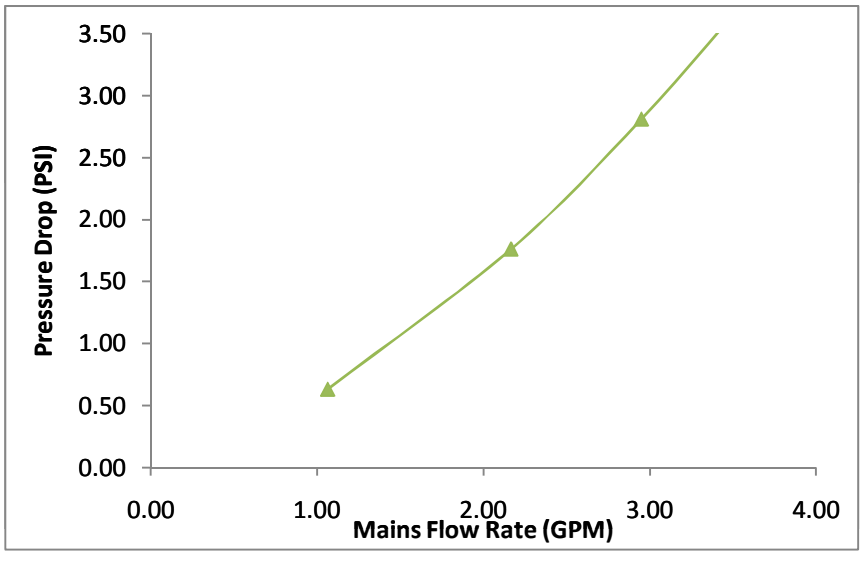












UNIVERSITY OF Waterloo

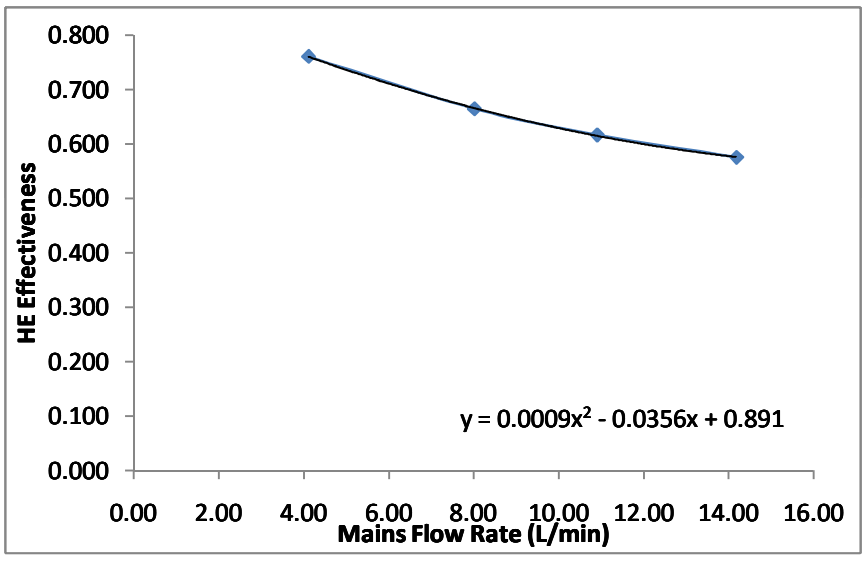
Product: 120in R2in
Manufacturer: Renewability
Test Date: February 25 / 2011

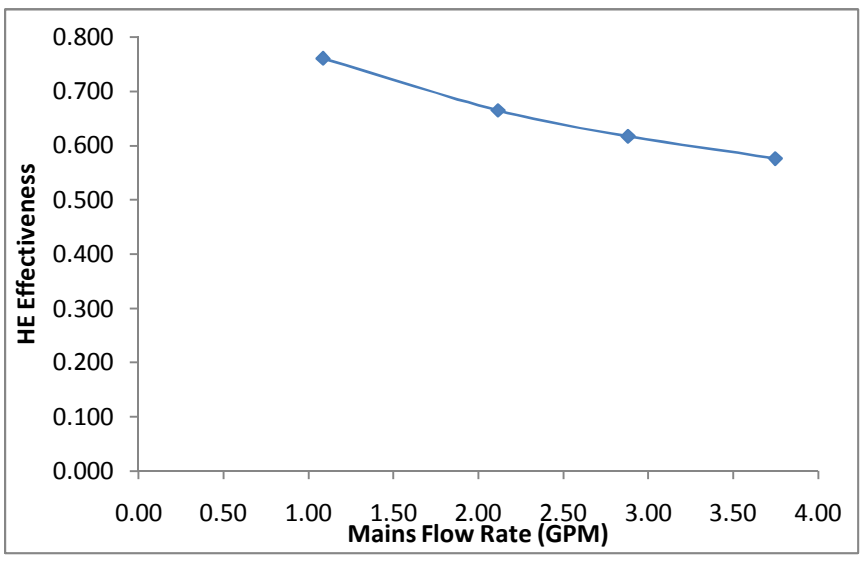
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.11	0.761	5.91	4.43
8.01	0.665	9.71	11.98
10.90	0.617	12.91	19.02
14.18	0.576	15.94	29.03

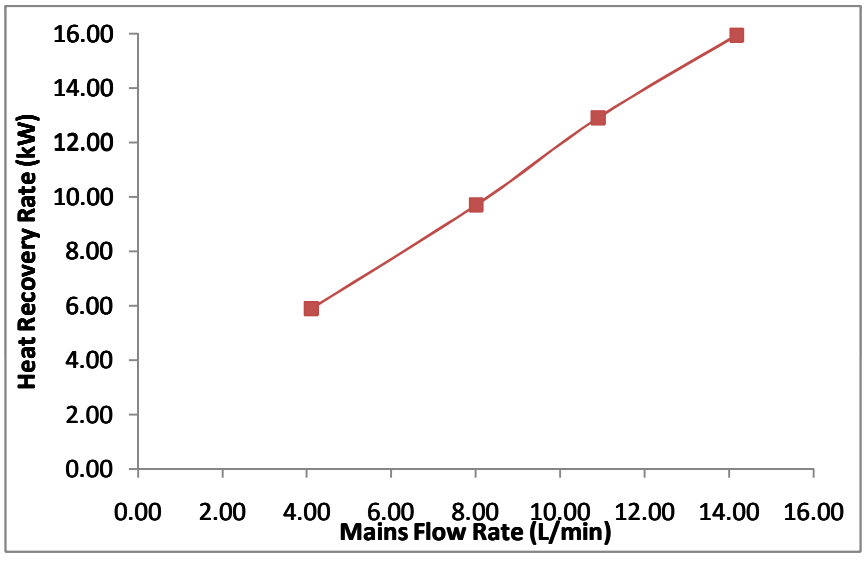
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.09	0.761	20183.71	0.64
2.12	0.665	33161.39	1.74
2.88	0.617	44089.96	2.76
3.75	0.576	54437.95	4.21

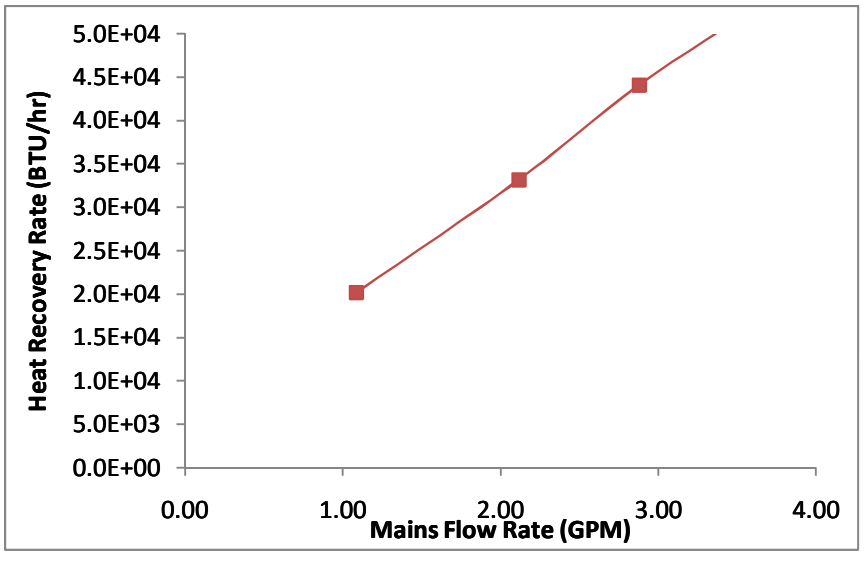
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

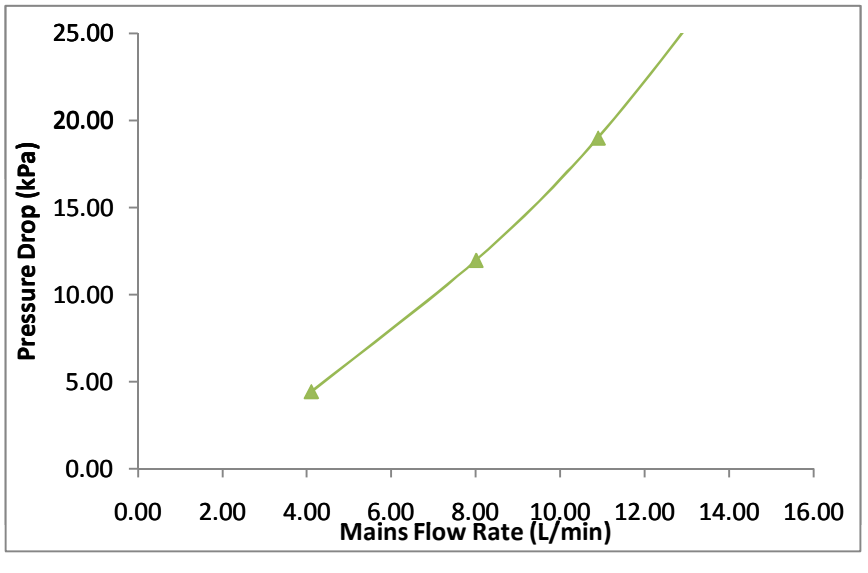
Effectiveness	0.634			
Heat Recovery	11.36	kW	38795.8	BTU/hr
Pressure Drop	15.61	kPa	2.26	PSI

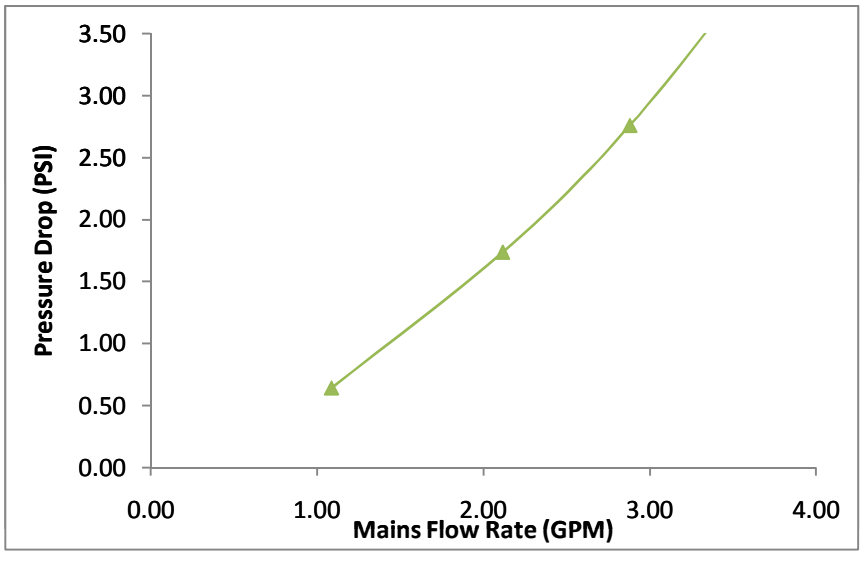










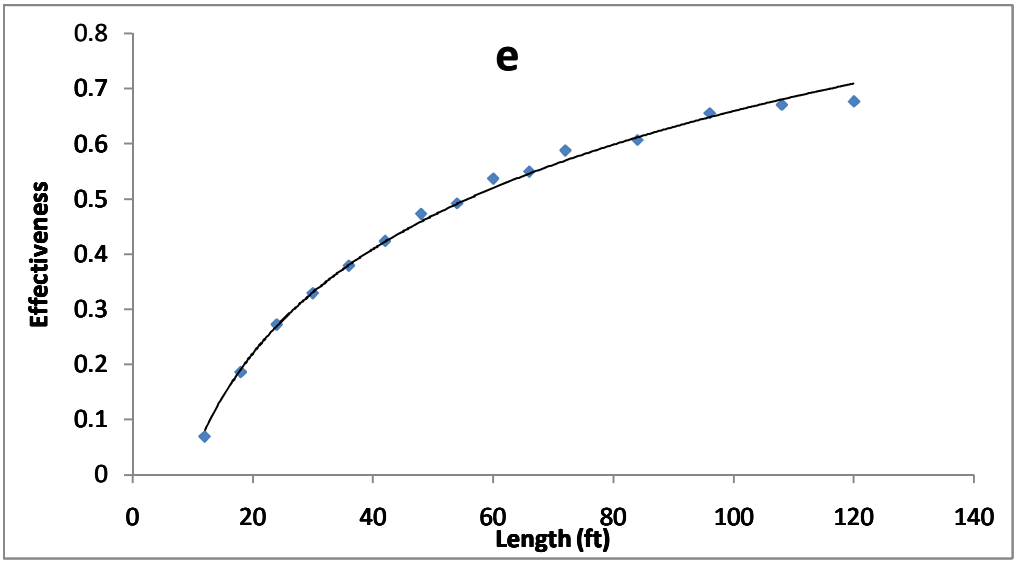


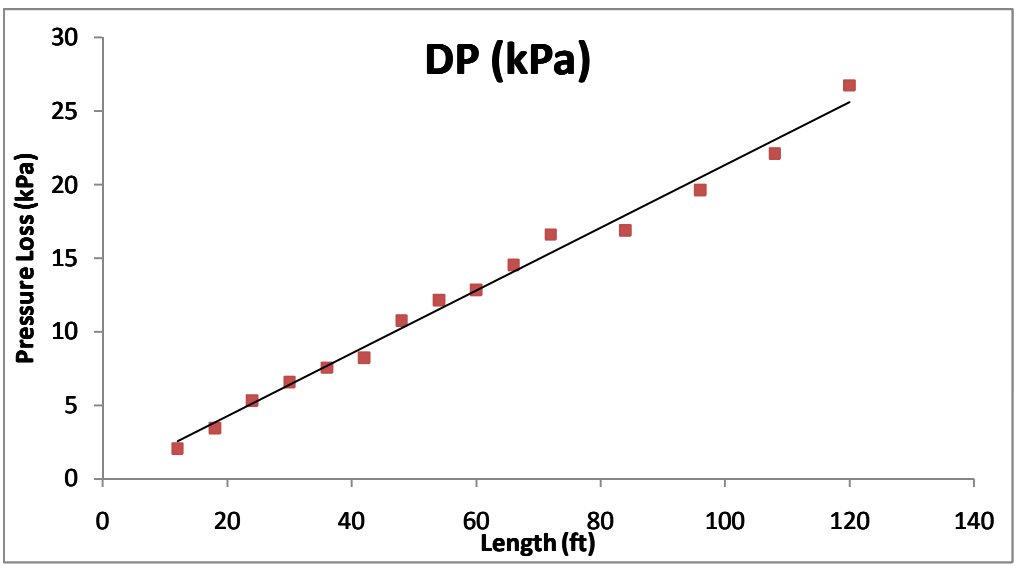
Appendix B

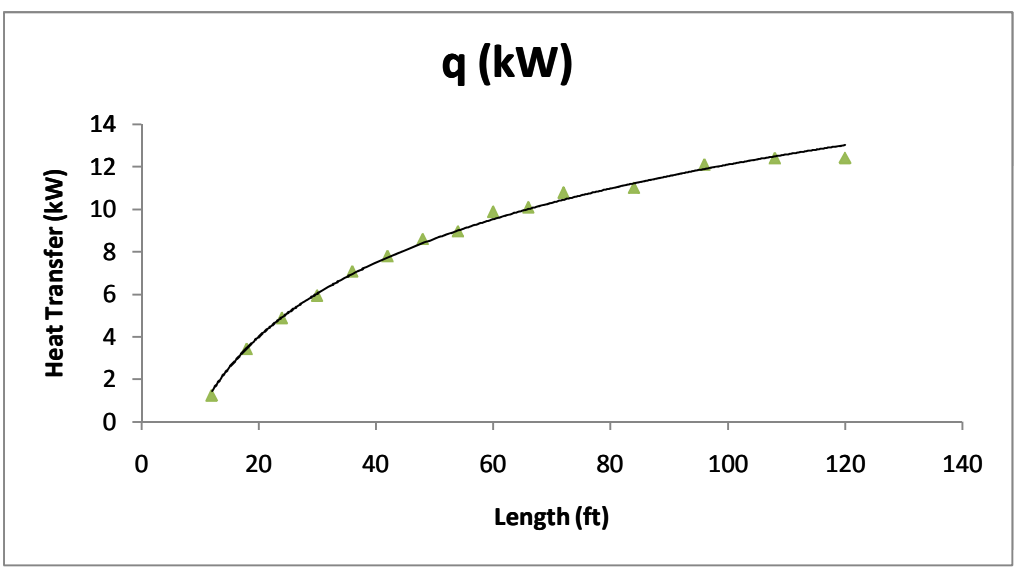
Test Reports – 3” Nominal Diameter Units

Effectiveness and Pressure Drop at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

L (ft)	ε	ΔP (kPa)	q (kW)
12	0.069	2.05	1.23
18	0.186	3.43	3.42
24	0.272	5.32	4.88
30	0.329	6.57	5.94
36	0.379	7.55	7.07
42	0.424	8.22	7.79
48	0.473	10.76	8.60
54	0.492	12.14	8.96
60	0.537	12.83	9.88
66	0.550	14.52	10.09
72	0.588	16.60	10.79
84	0.607	16.87	11.01
96	0.656	19.63	12.10
108	0.671	22.09	12.40
120	0.677	26.73	12.42







UNIVERSITY OF Waterloo

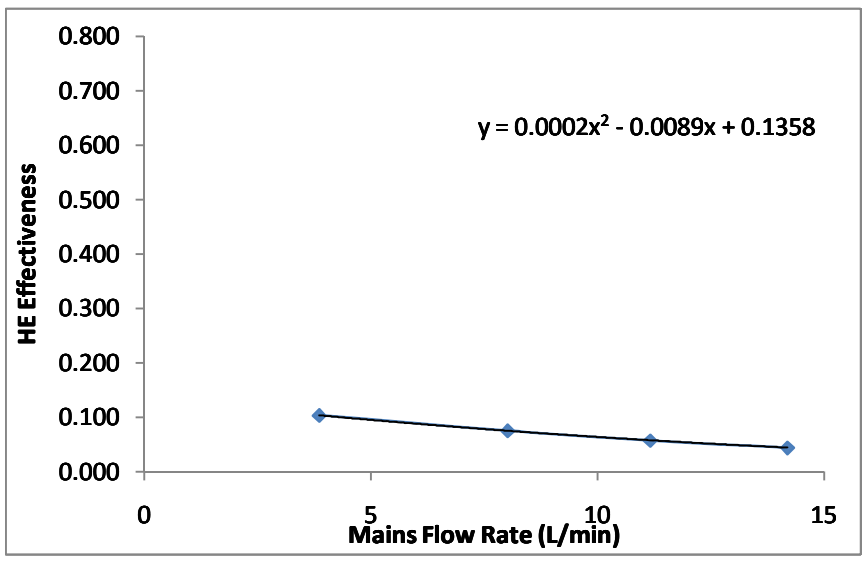
Product: 12in R3in
Manufacturer: Renewability
Test Date: February 24 / 2011

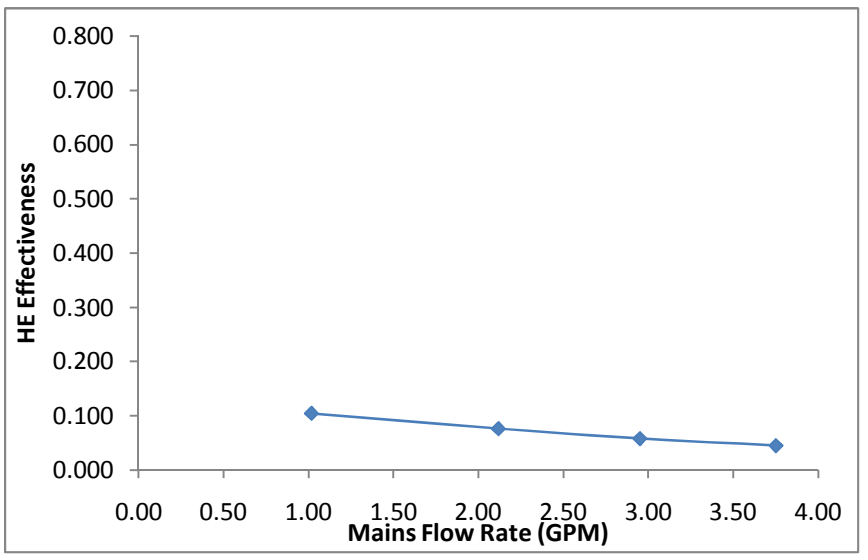
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.86	0.104	0.79	0.82
8.02	0.076	1.21	1.45
11.17	0.058	1.25	2.73
14.2	0.045	1.30	5.35

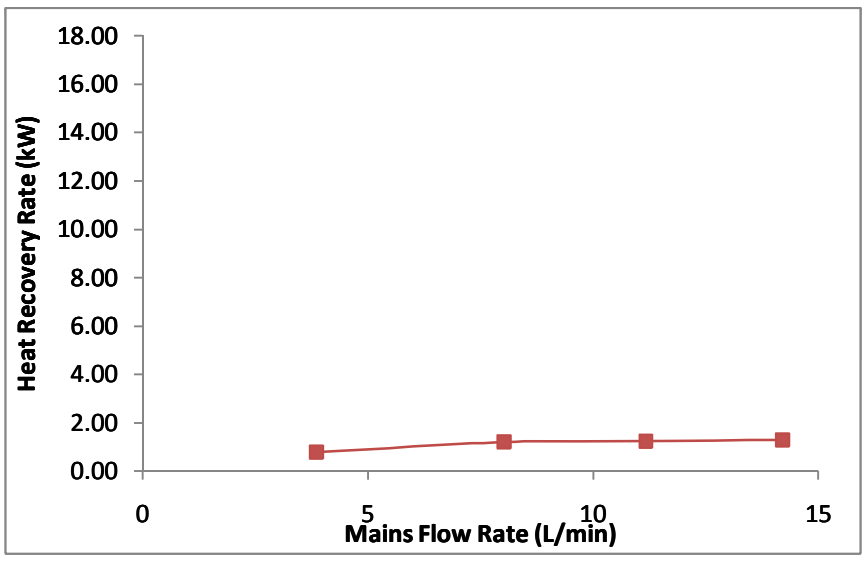
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.02	0.104	2697.99	0.12
2.12	0.076	4132.37	0.21
2.95	0.058	4268.97	0.40
3.75	0.045	4439.73	0.78

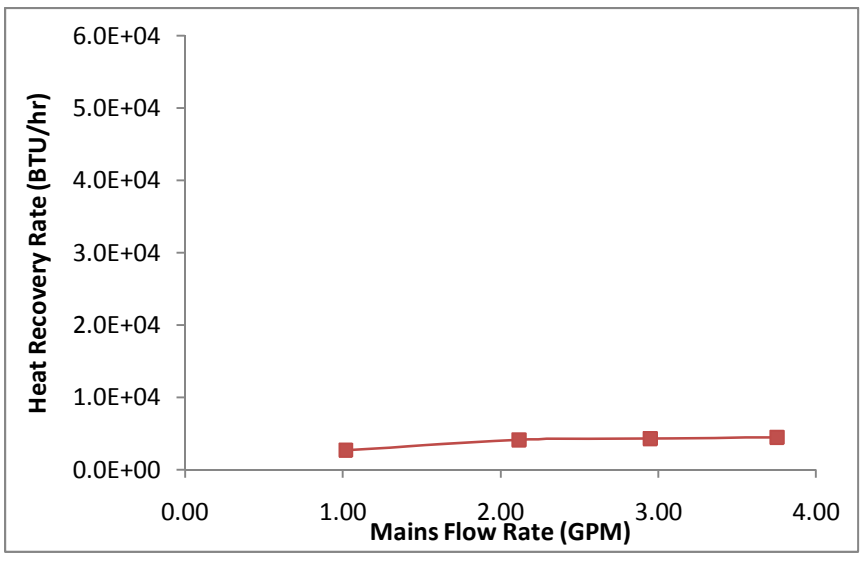
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

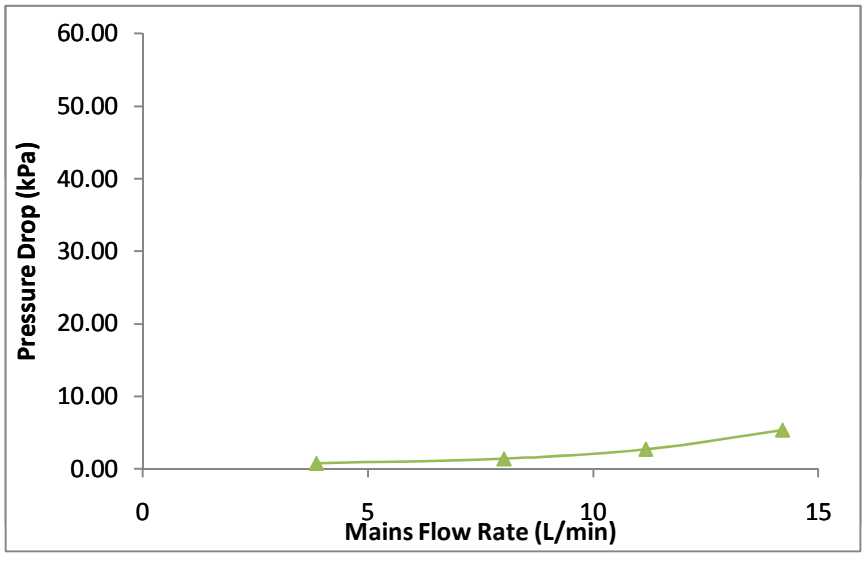
Effectiveness	0.069			
Heat Recovery	1.23	kW	4196.6	BTU/hr
Pressure Drop	2.05	kPa	0.30	PSI

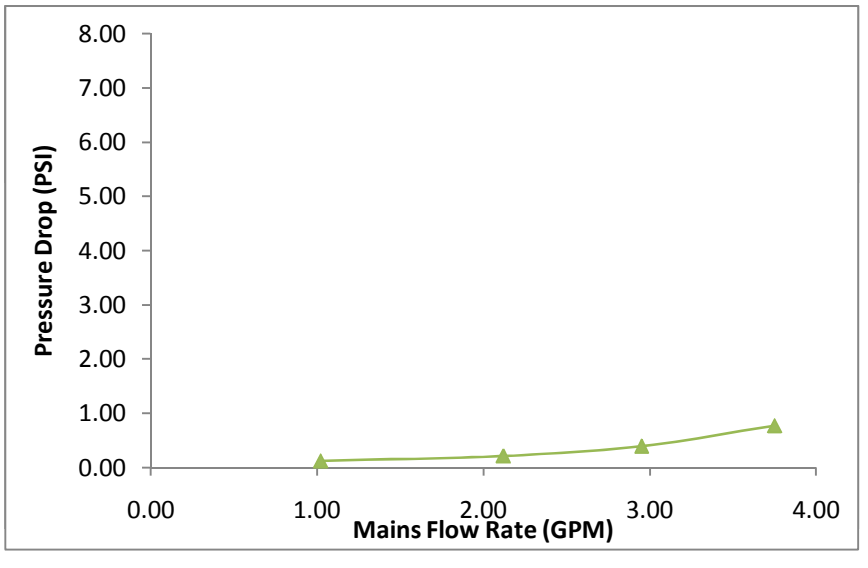












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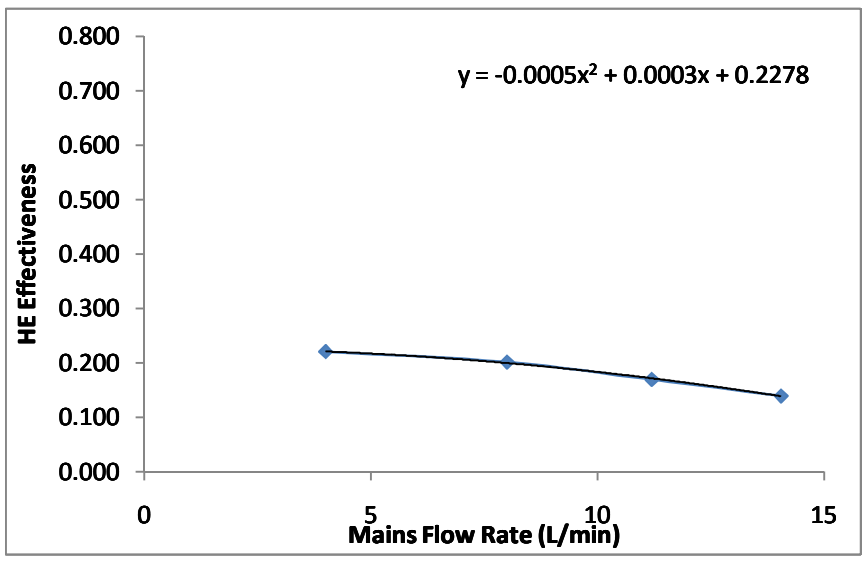
Product: 18in R3in
Manufacturer: Renewability
Test Date: February 24 / 2011

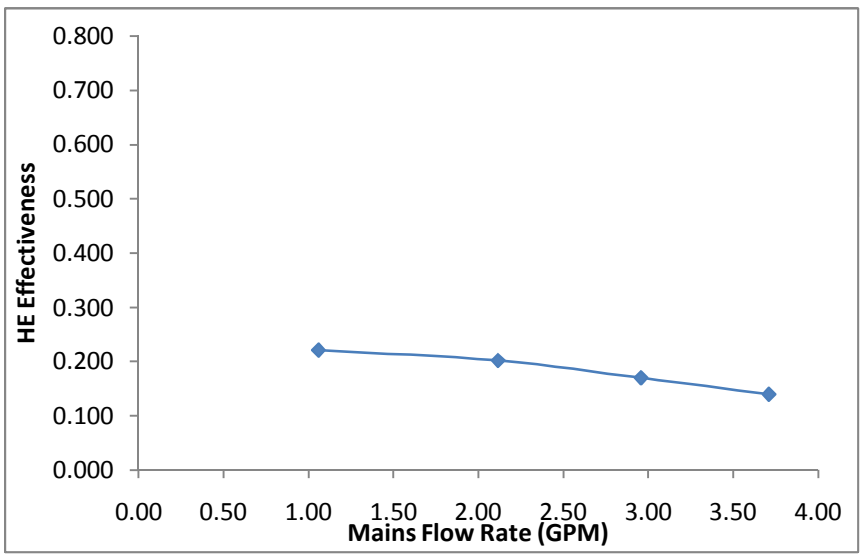
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.01	0.221	1.71	0.49
8.01	0.202	3.21	2.49
11.2	0.170	3.67	4.50
14.05	0.140	3.92	6.48

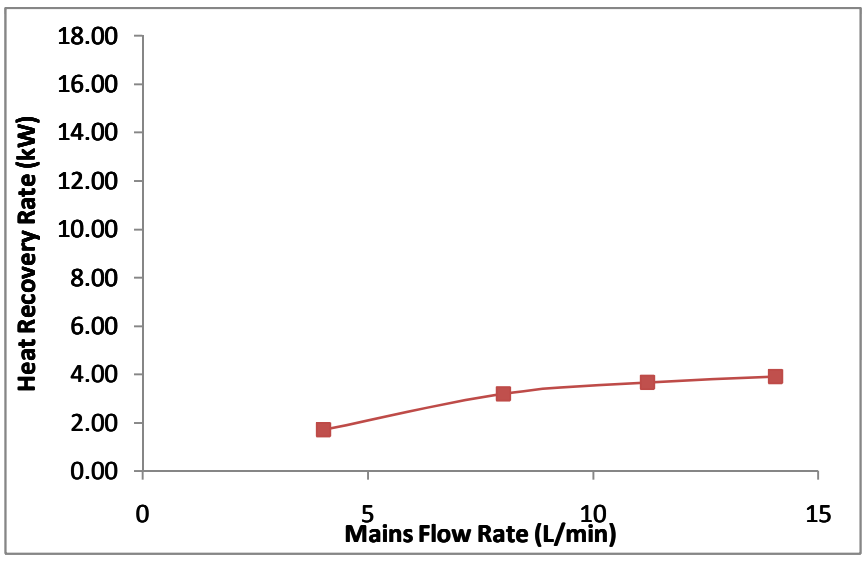
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.221	5839.96	0.07
2.12	0.202	10962.72	0.36
2.96	0.170	12533.71	0.65
3.71	0.140	13387.50	0.94

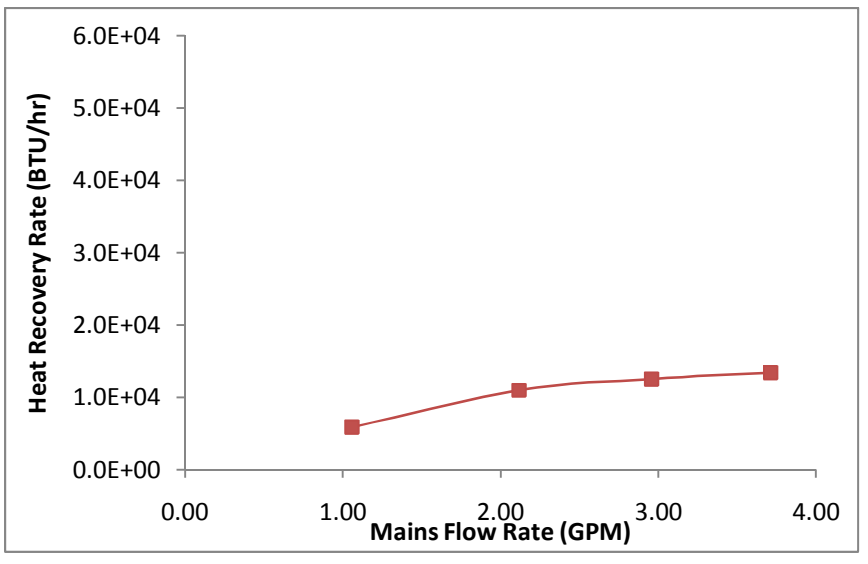
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

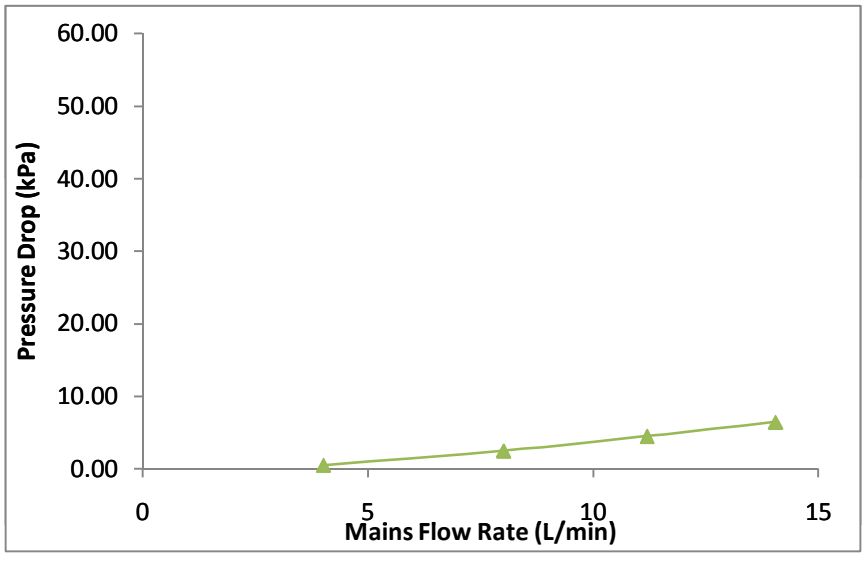
Effectiveness	0.186			
Heat Recovery	3.42	kW	11696.5	BTU/hr
Pressure Drop	3.43	kPa	0.50	PSI

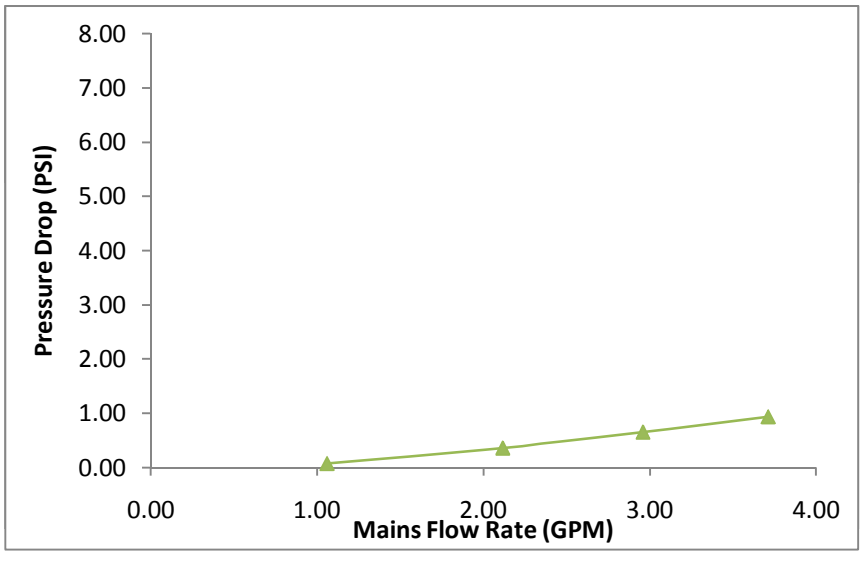












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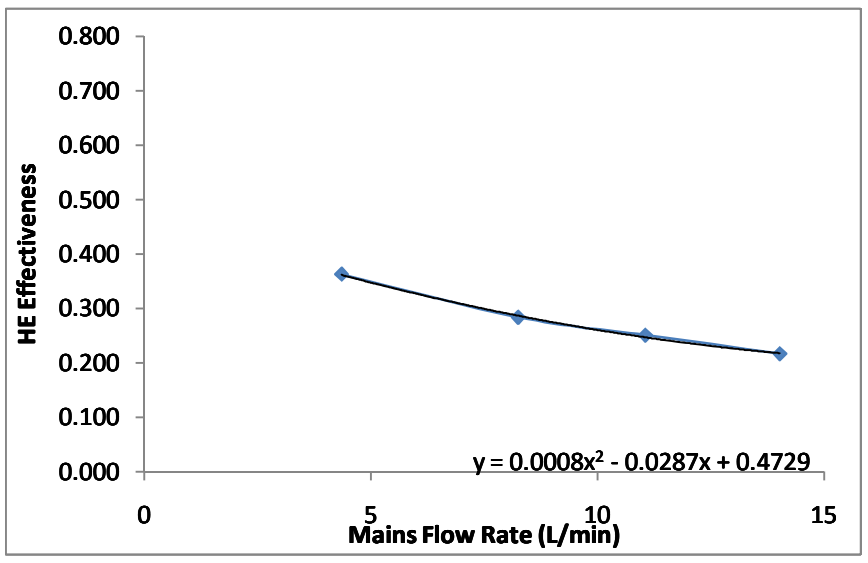
Product: 24in R3in
Manufacturer: Renewability
Test Date: January 27 / 2011

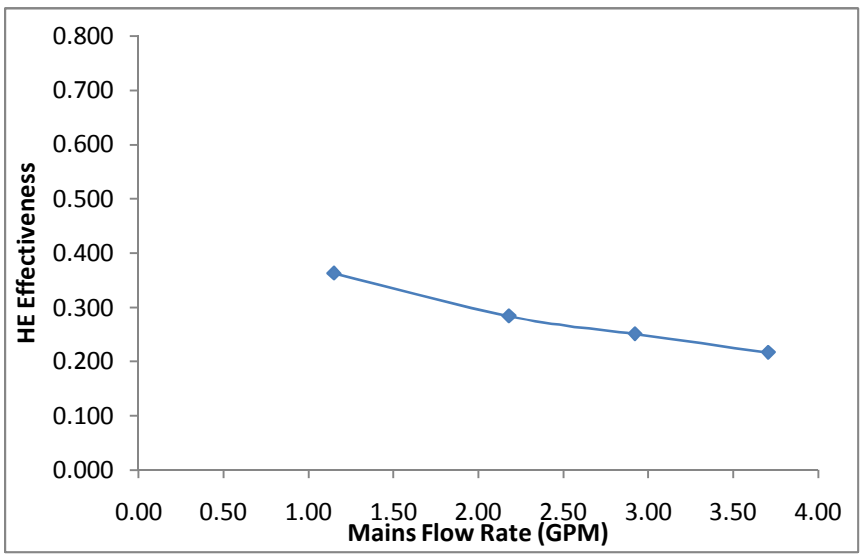
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.35	0.363	3.00	2.23
8.25	0.284	4.45	4.45
11.06	0.251	5.41	6.41
14.03	0.217	5.86	9.14

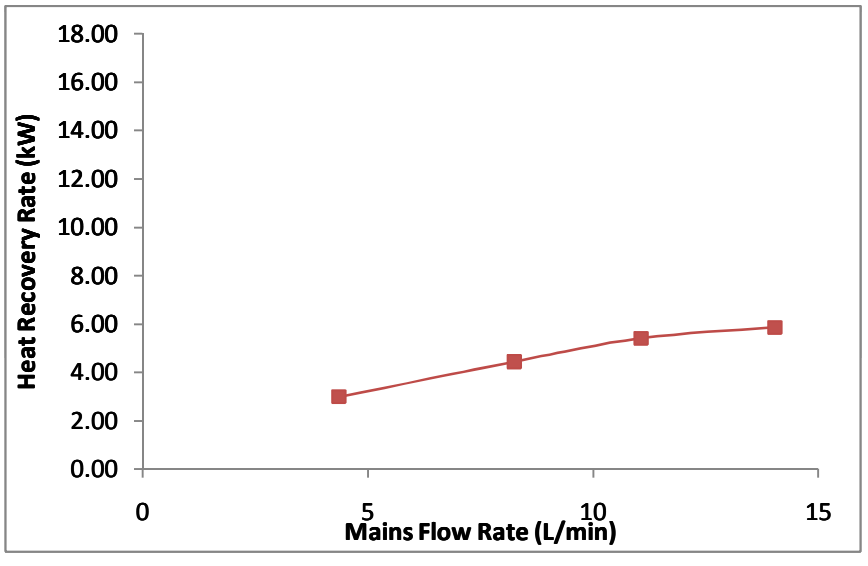
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.15	0.363	10245.54	0.32
2.18	0.284	15197.55	0.65
2.92	0.251	18476.12	0.93
3.71	0.217	20012.95	1.33

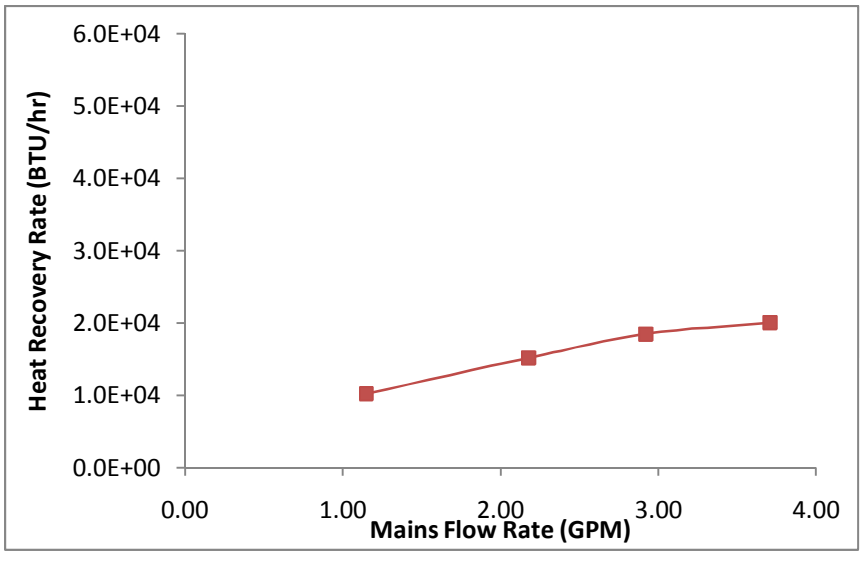
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

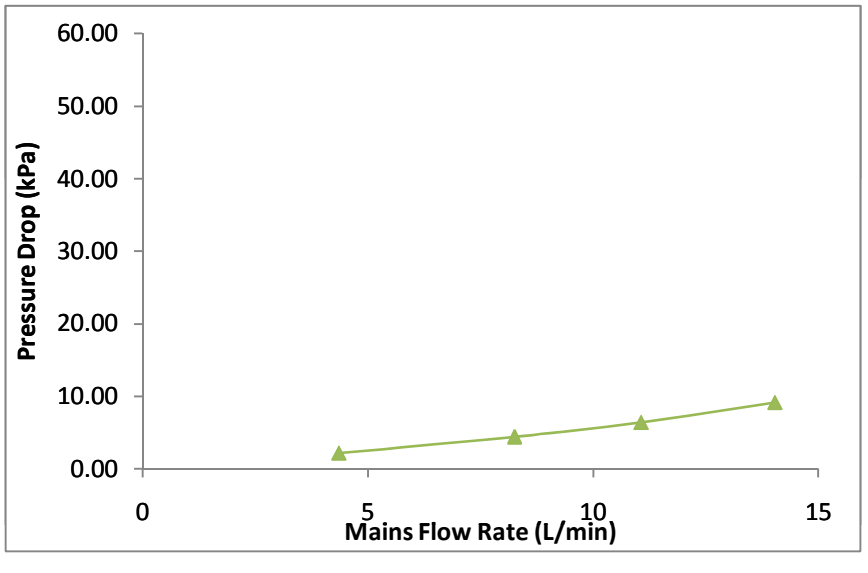
Effectiveness	0.272			
Heat Recovery	4.88	kW	16656.0	BTU/hr
Pressure Drop	5.32	kPa	0.77	PSI

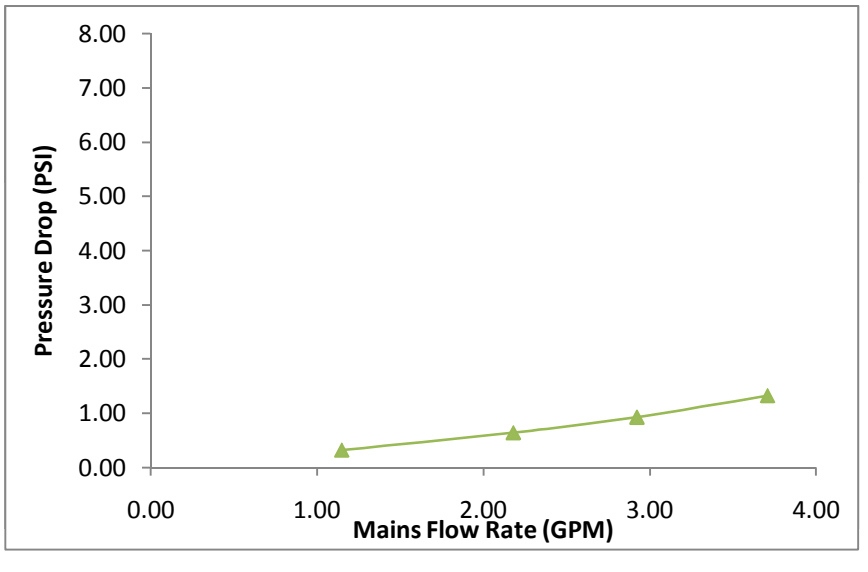












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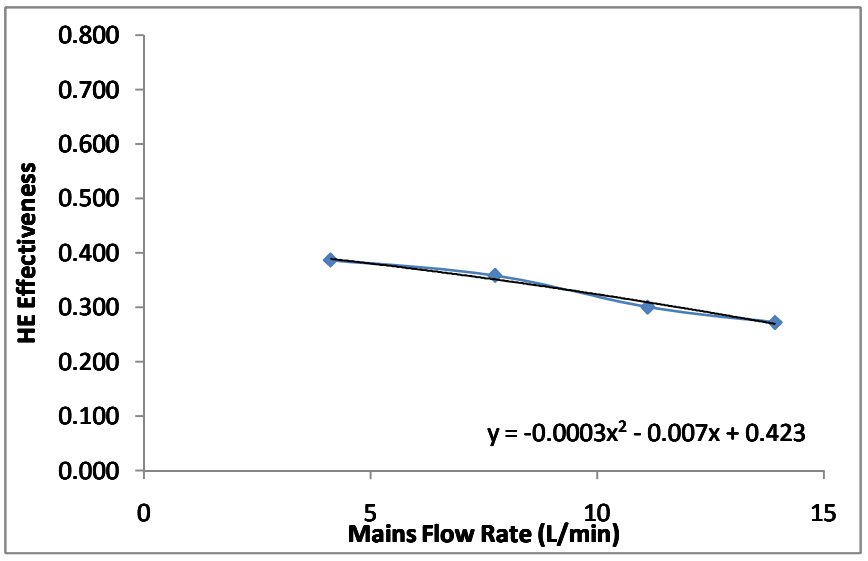
Product: 30in R3in
Manufacturer: Renewability
Test Date: March 8 / 2009 (14 L/min - April 8 / 2009)

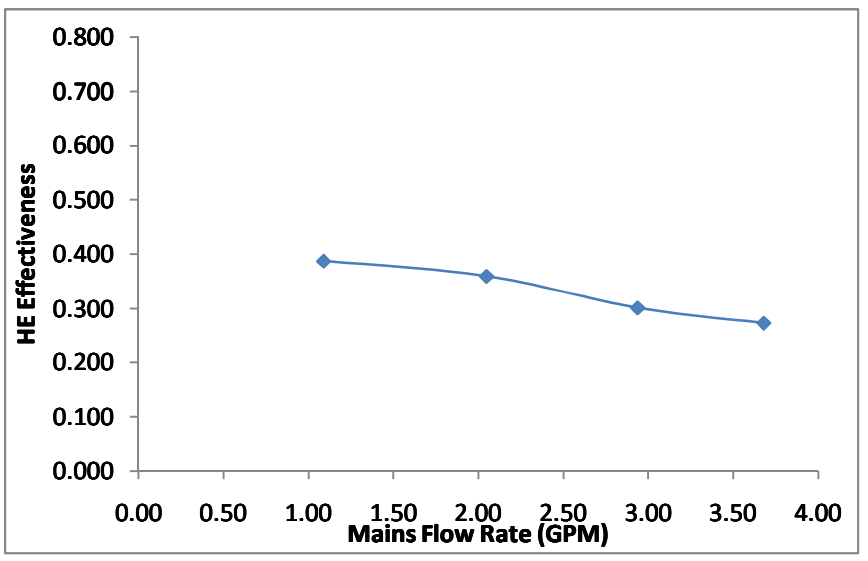
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.12	0.387	3.02	2.41
7.75	0.359	5.41	4.67
11.12	0.301	6.43	8.33
13.93	0.273	7.41	11.04

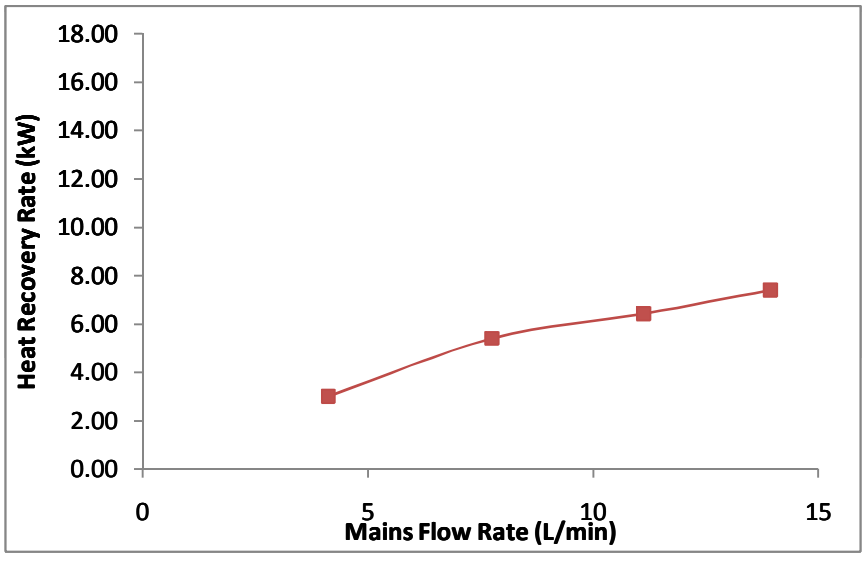
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.09	0.387	10313.84	0.35
2.05	0.359	18476.12	0.68
2.94	0.301	21959.60	1.21
3.68	0.273	25306.48	1.60

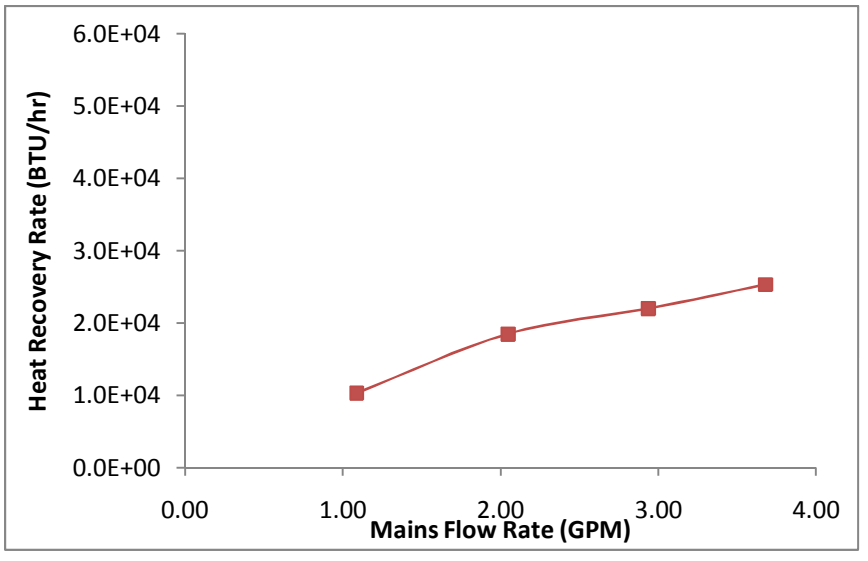
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

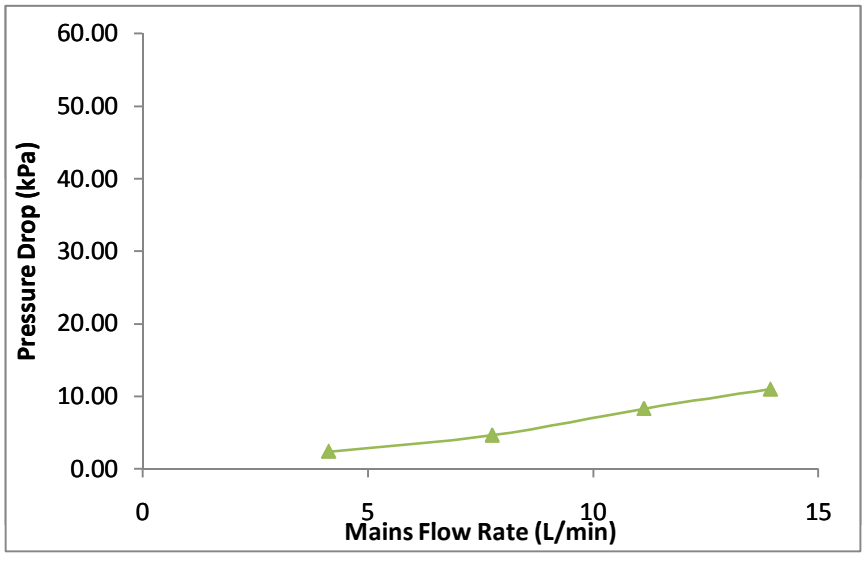
Effectiveness	0.329			
Heat Recovery	5.94	kW	20285.0	BTU/hr
Pressure Drop	6.57	kPa	0.95	PSI

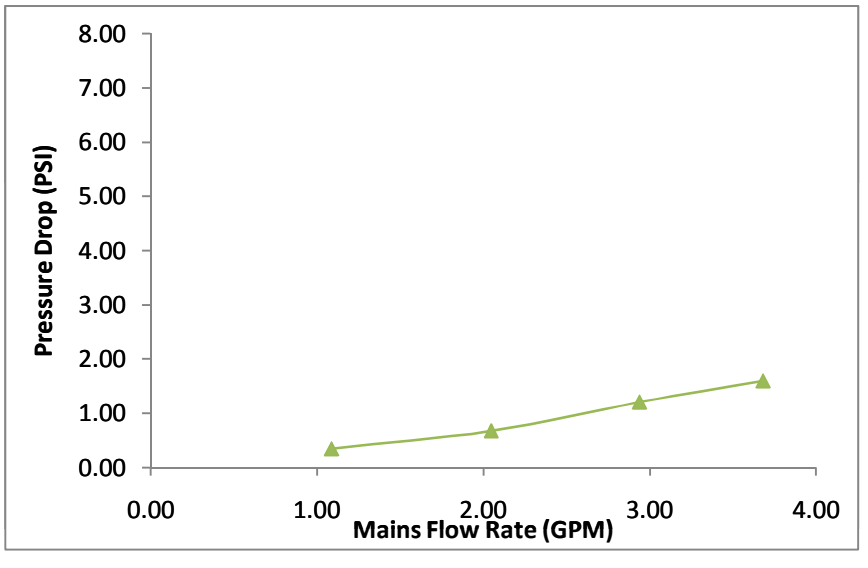












UNIVERSITY OF Waterloo

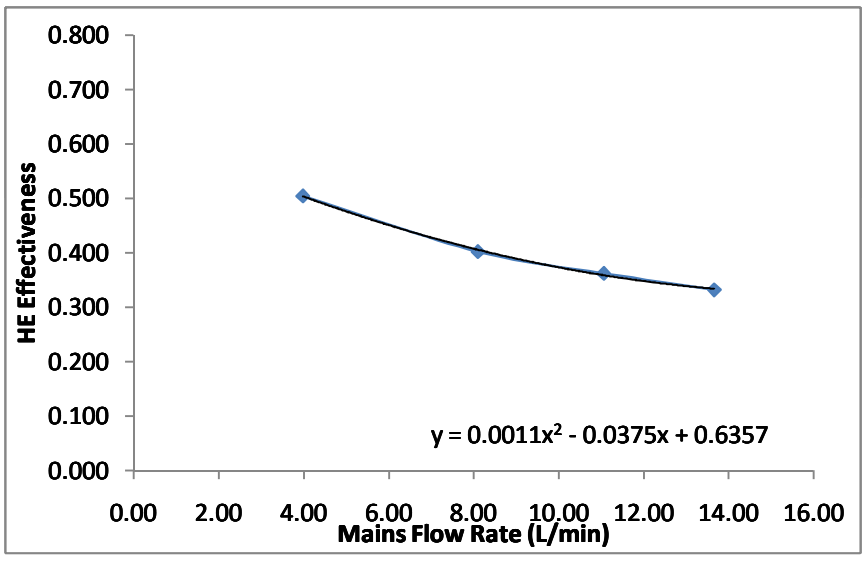
Product: 36in R3in
Manufacturer: Renewability
Test Date: March 8 / 2009

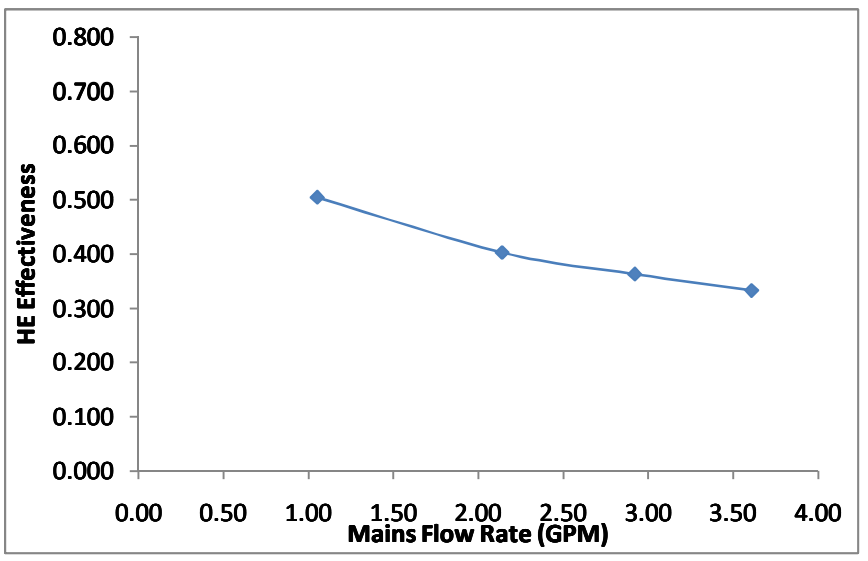
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.98	0.505	3.82	3.02
8.10	0.403	6.30	5.95
11.06	0.363	7.92	9.34
13.66	0.333	9.00	14.20

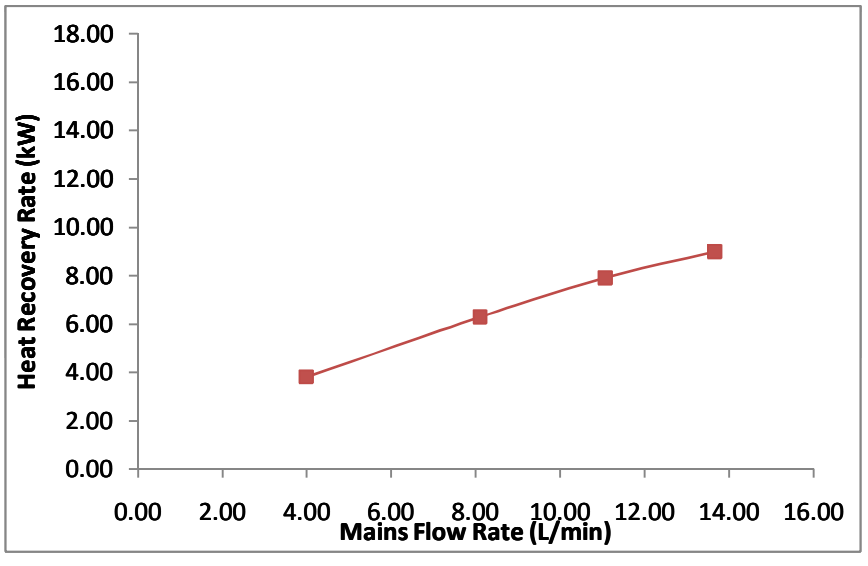
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.505	13045.98	0.44
2.14	0.403	21515.63	0.86
2.92	0.363	27048.22	1.35
3.61	0.333	30736.61	2.06

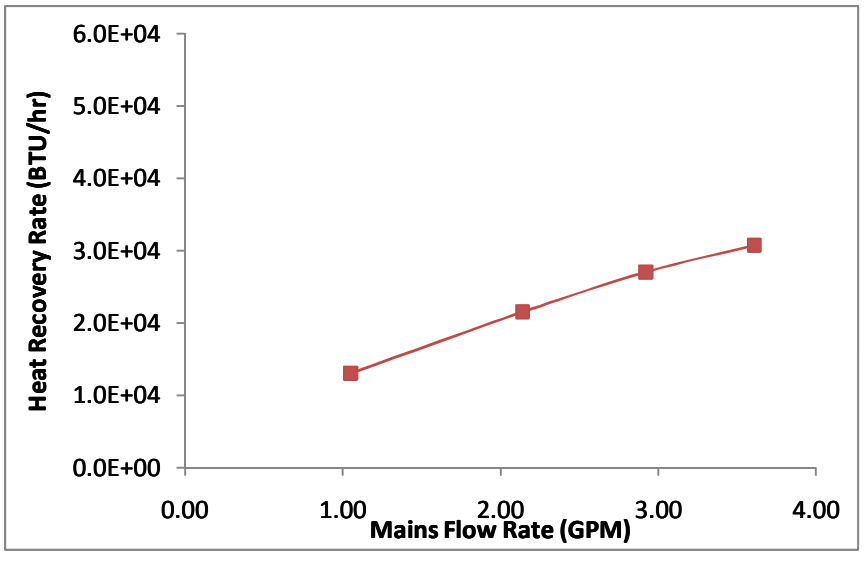
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

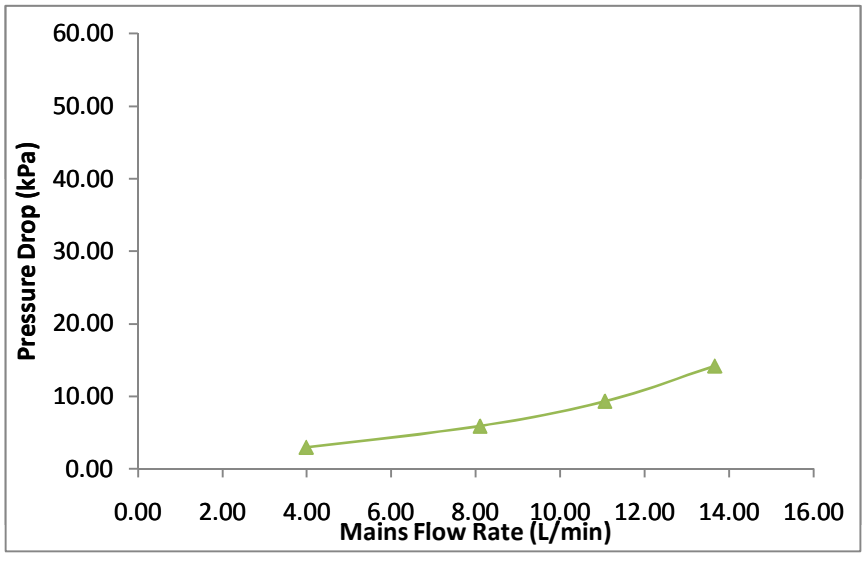
Effectiveness	0.379			
Heat Recovery	7.07	kW	24132.4	BTU/hr
Pressure Drop	7.55	kPa	1.10	PSI

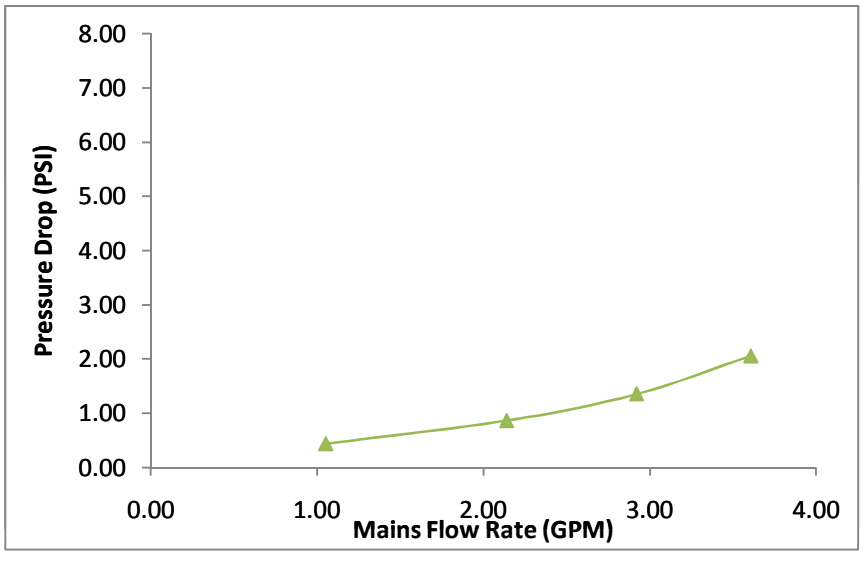












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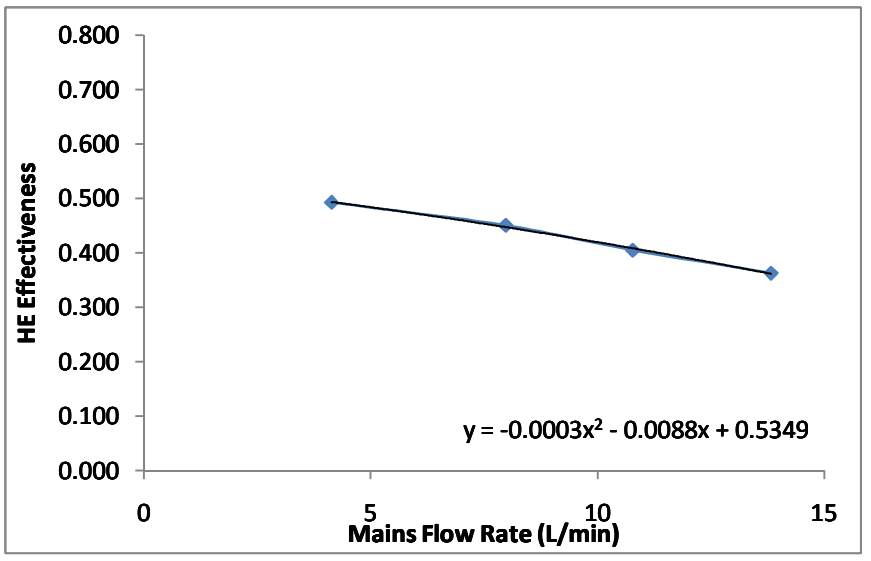
Product: 42in R3in
Manufacturer: Renewability
Test Date: March 9 / 2009

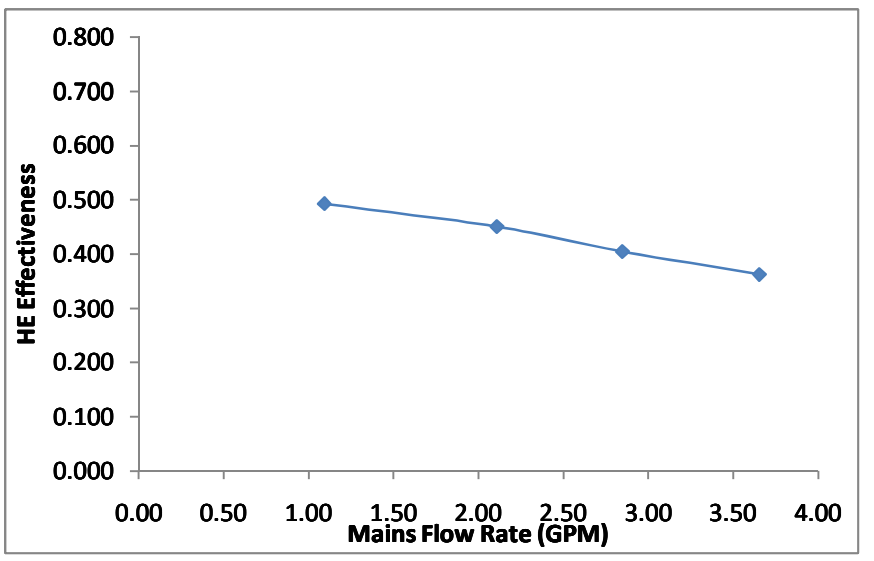
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.14	0.493	3.94	2.86
7.98	0.451	6.91	5.83
10.78	0.405	8.53	10.23
13.83	0.363	9.83	12.77

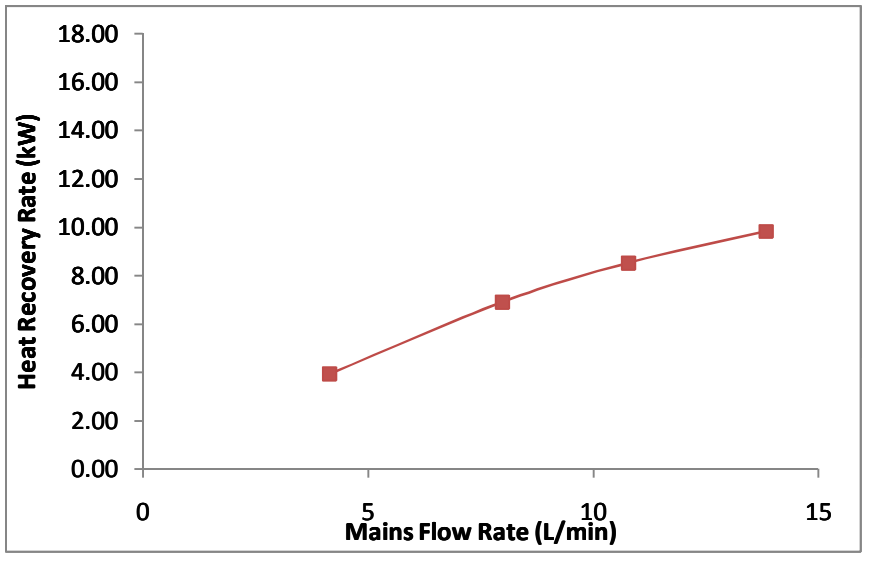
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.09	0.493	13455.81	0.41
2.11	0.451	23598.89	0.85
2.85	0.405	29131.48	1.48
3.65	0.363	33571.21	1.85

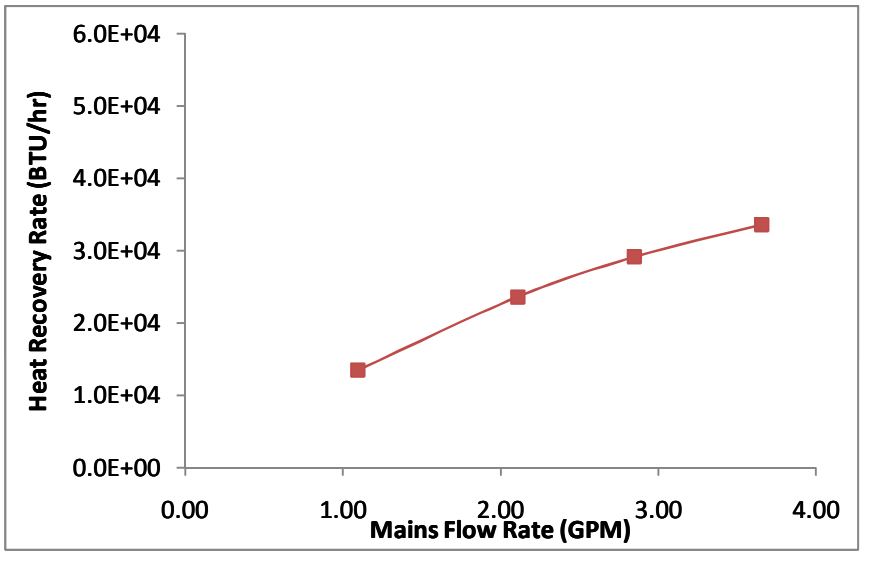
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

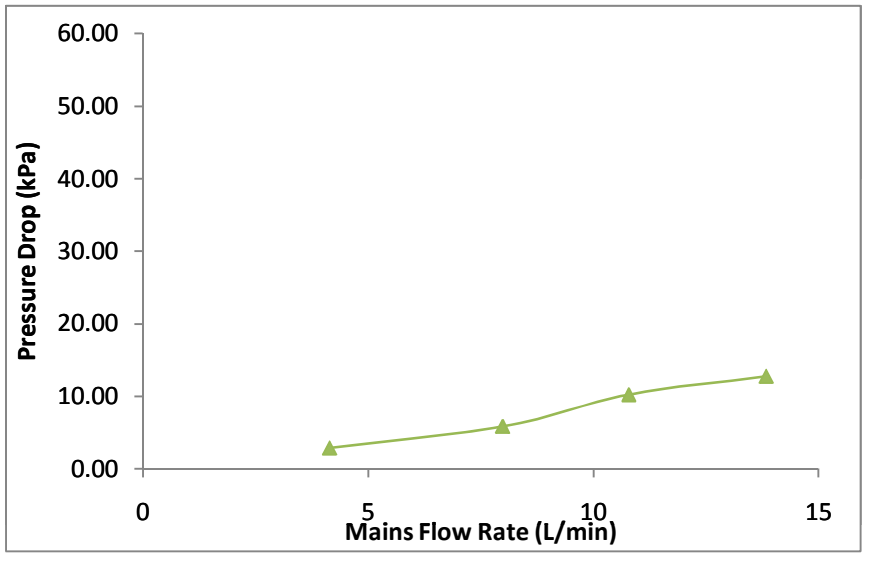
Effectiveness	0.424			
Heat Recovery	7.79	kW	26602.3	BTU/hr
Pressure Drop	8.22	kPa	1.19	PSI

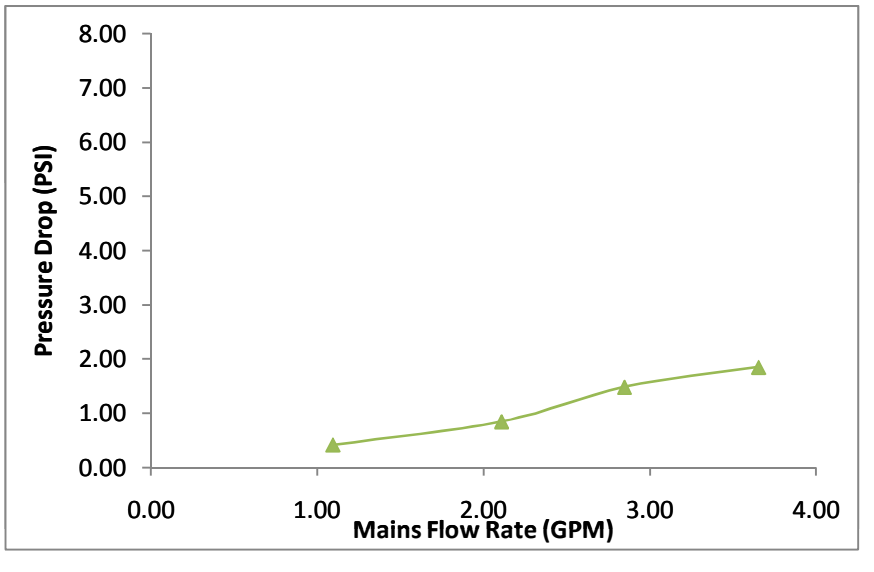












UNIVERSITY OF Waterloo

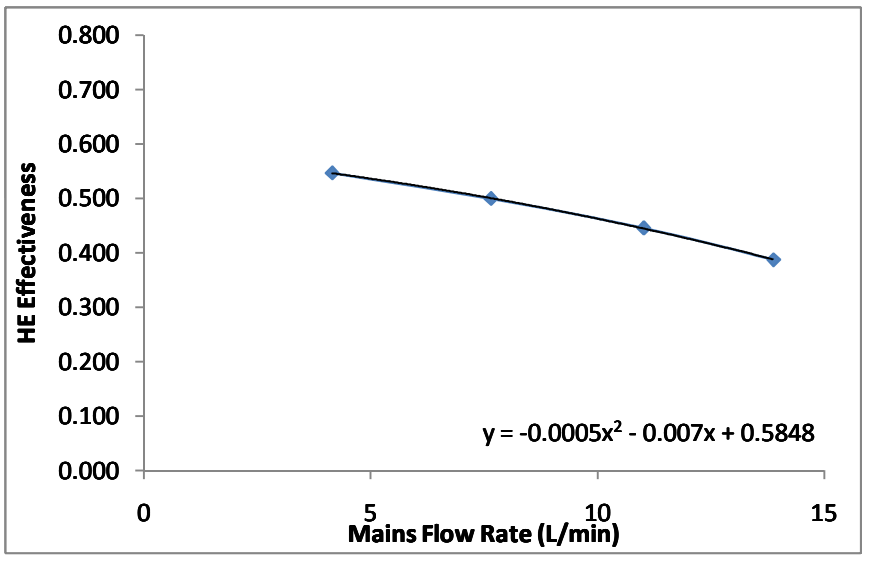
Product: 48in R3in
Manufacturer: Renewability
Test Date: March 6 / 2009 (14 L/min - April 8 / 2009)

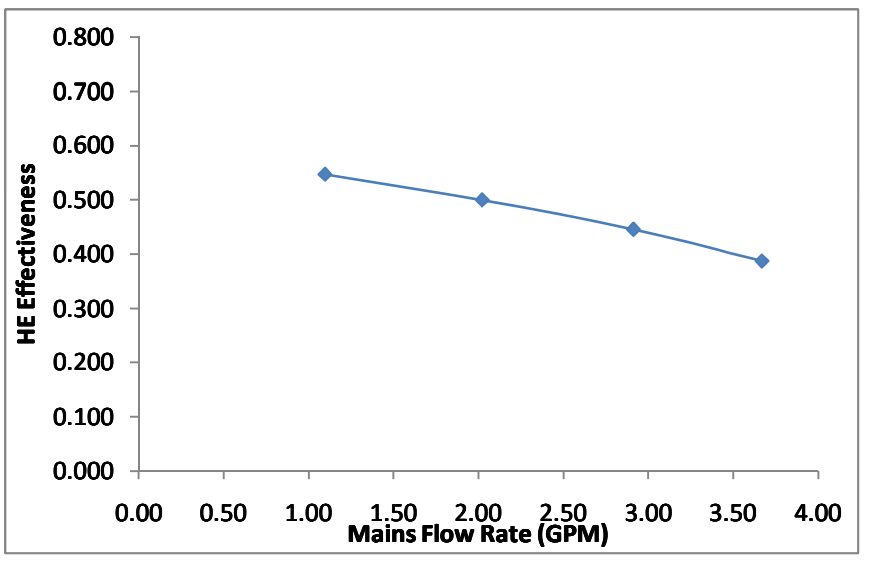
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.15	0.547	4.45	1.87
7.65	0.500	7.51	7.62
11.02	0.446	9.50	13.34
13.88	0.388	10.61	17.59

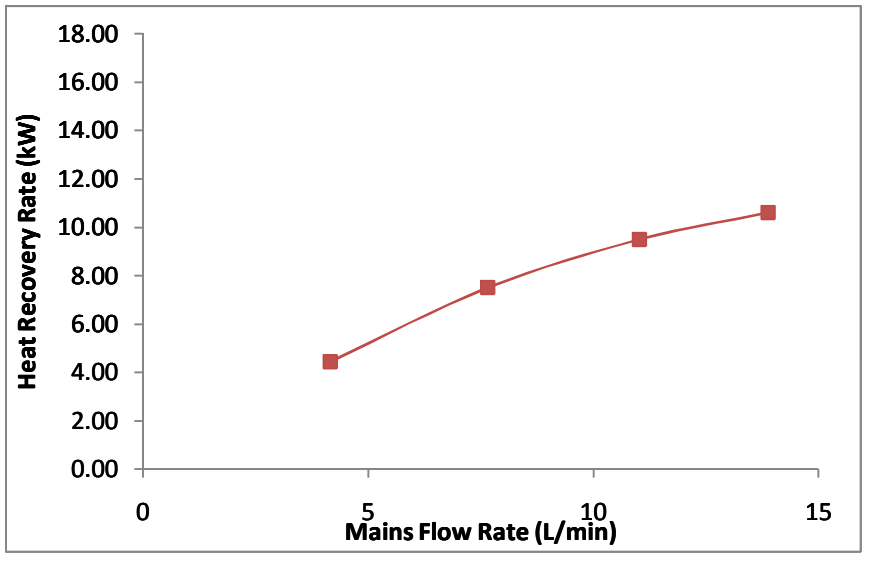
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.10	0.547	15197.55	0.27
2.02	0.500	25647.99	1.11
2.91	0.446	32444.20	1.93
3.67	0.388	36235.05	2.55

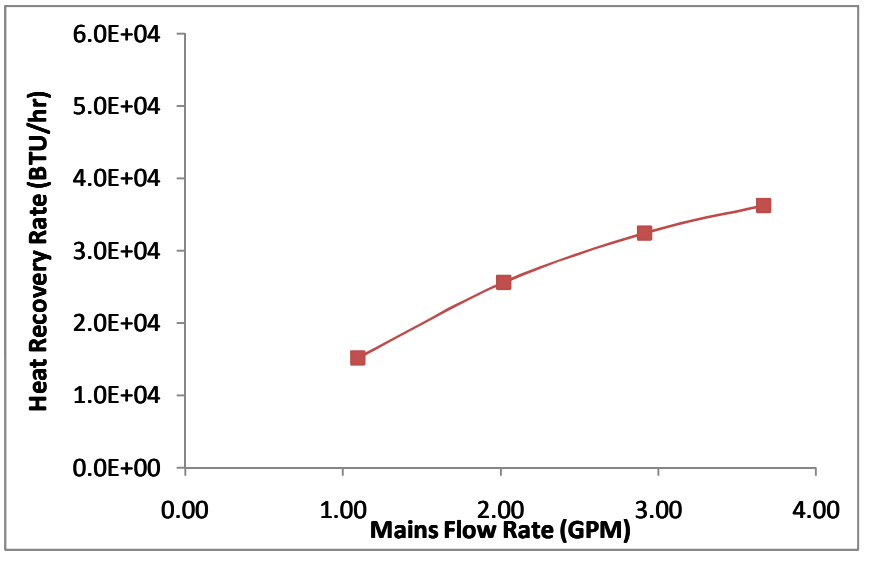
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

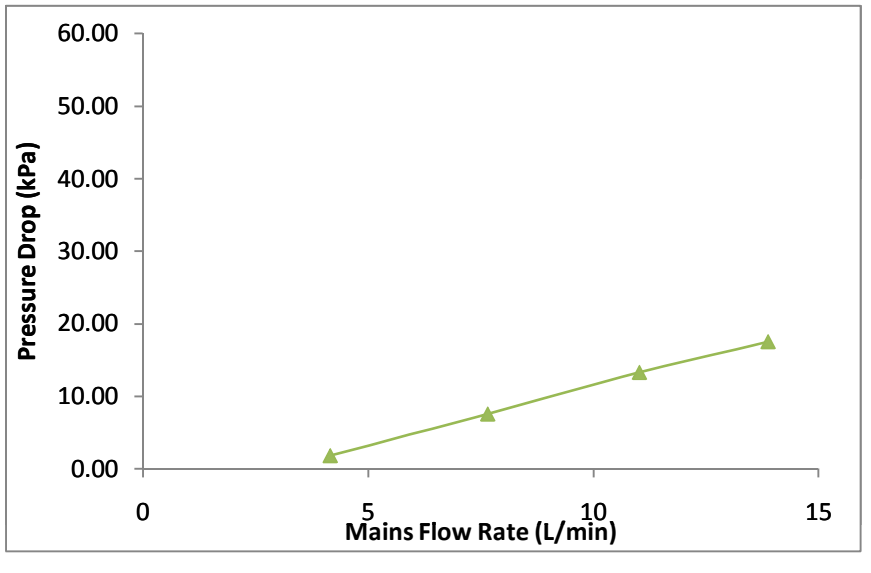
Effectiveness	0.473			
Heat Recovery	8.60	kW	29378.8	BTU/hr
Pressure Drop	10.76	kPa	1.56	PSI

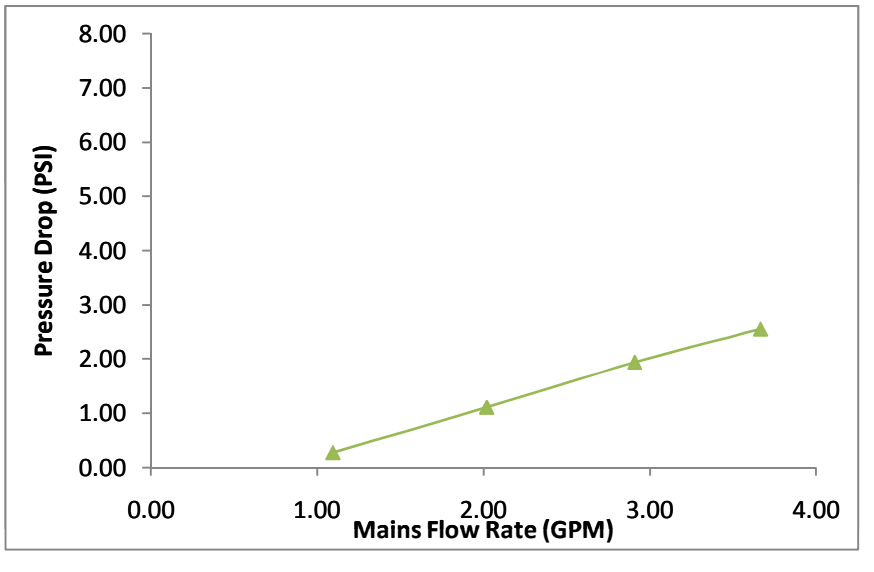












UNIVERSITY OF Waterloo

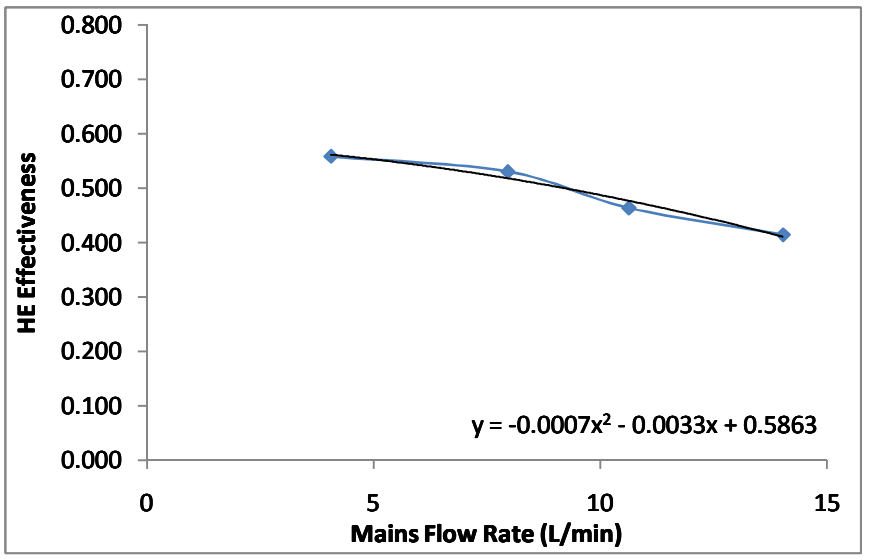
Product: 54in R3in
Manufacturer: Renewability
Test Date: March 7 / 2009 (4 L/min - March 26 / 2009)

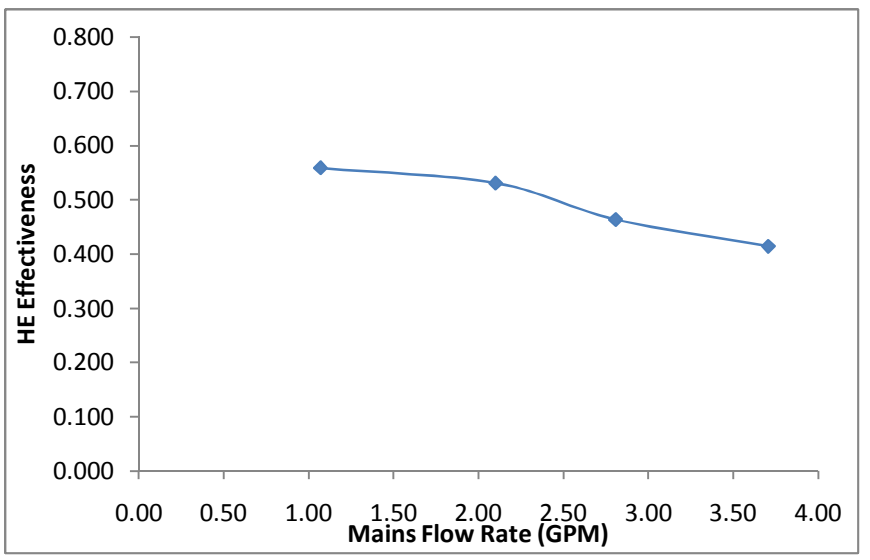
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.06	0.559	4.45	3.47
7.96	0.531	8.18	9.07
10.63	0.464	9.54	14.40
14.03	0.415	11.50	21.49

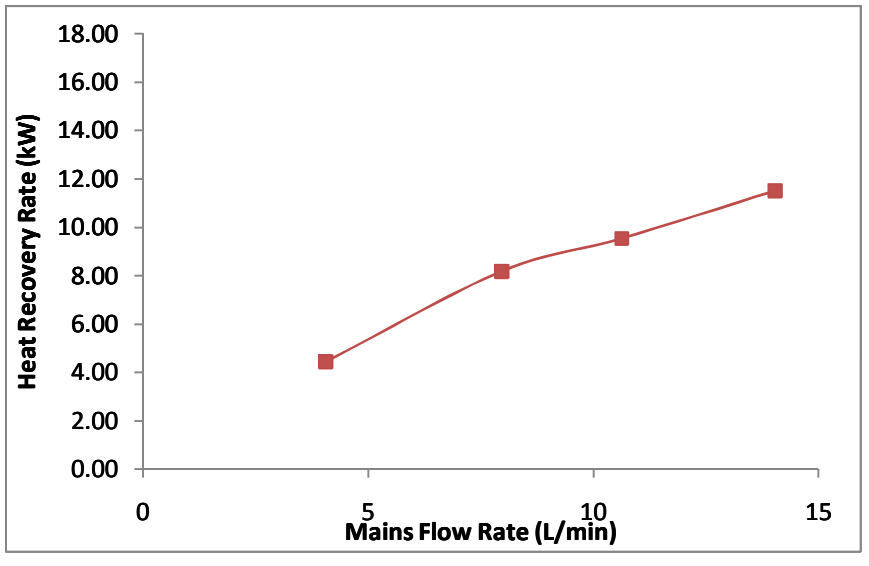
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.07	0.559	15197.55	0.50
2.10	0.531	27936.16	1.32
2.81	0.464	32580.81	2.09
3.71	0.415	39274.56	3.12

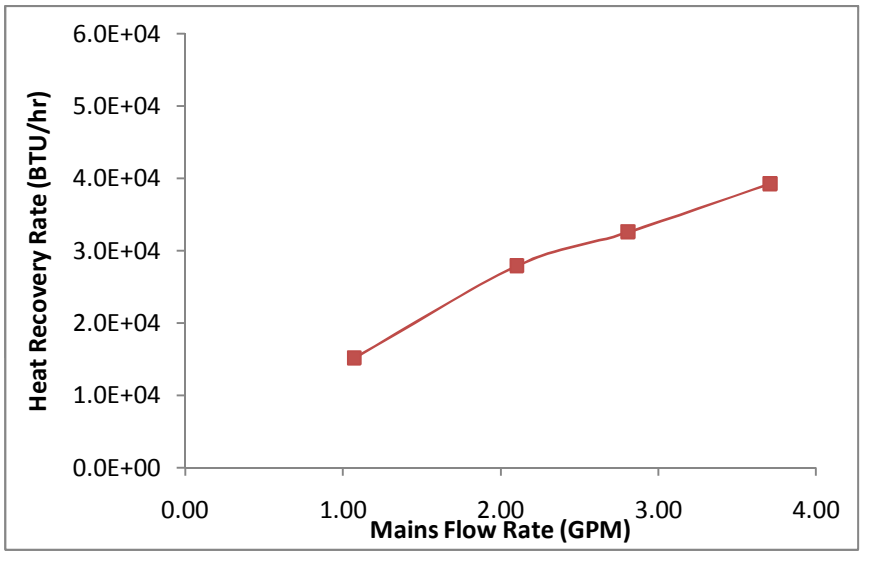
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

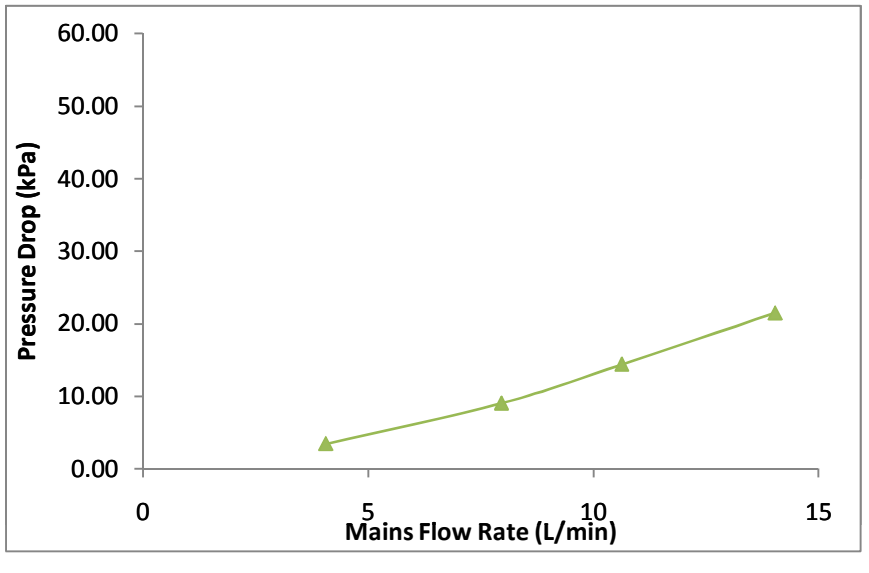
Effectiveness	0.492			
Heat Recovery	8.96	kW	30615.1	BTU/hr
Pressure Drop	12.14	kPa	1.76	PSI

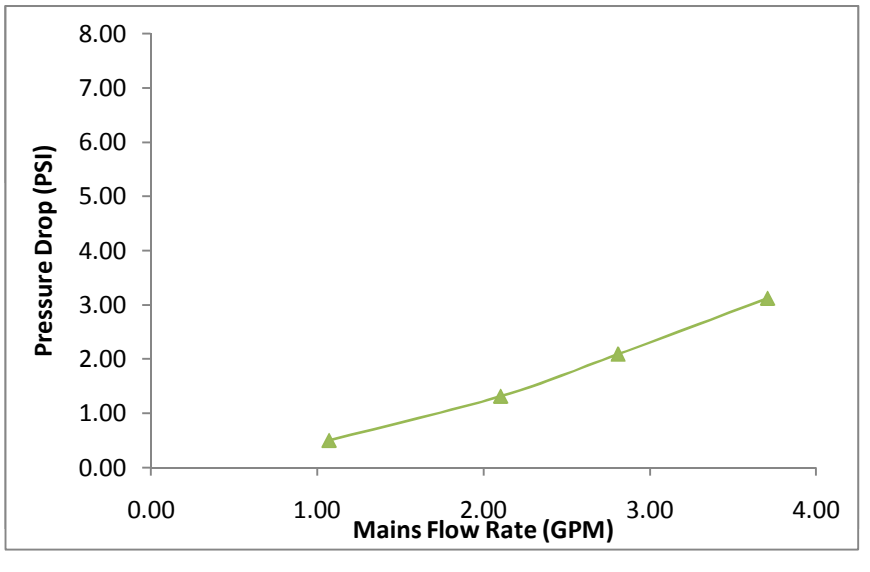












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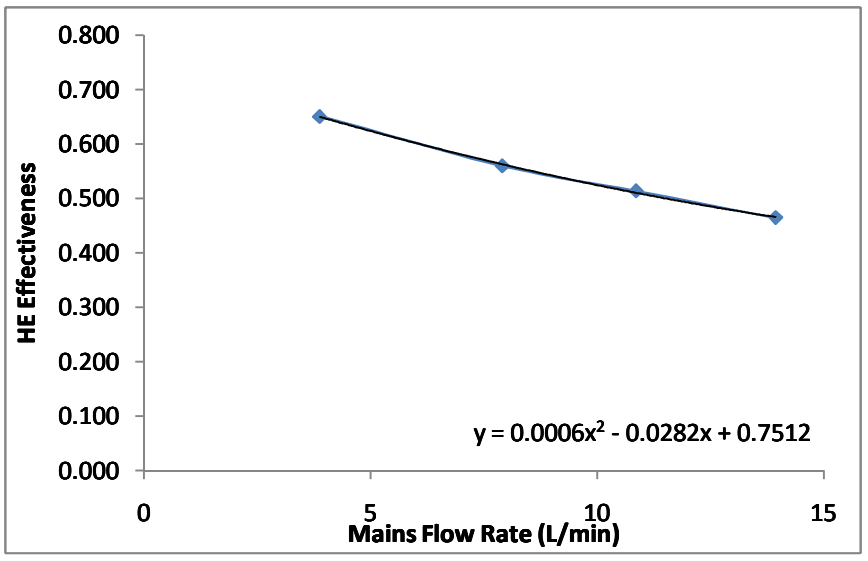
Product: 60in R3in
Manufacturer: Renewability
Test Date: March 5 / 2009 (4 L/min - March 26 / 2009 : 14 L/min - April 2 / 2009)

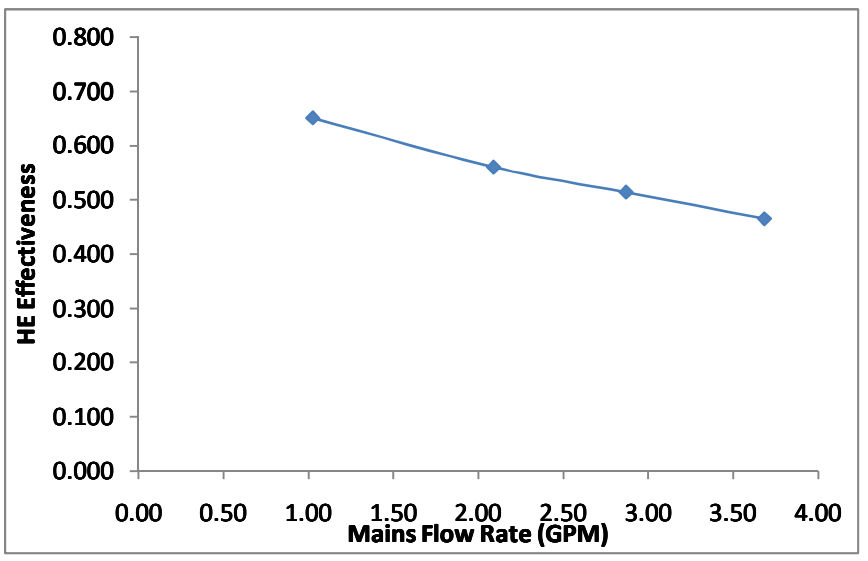
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.88	0.651	4.89	3.44
7.91	0.560	8.56	9.48
10.86	0.514	11.00	15.69
13.94	0.465	12.60	22.50

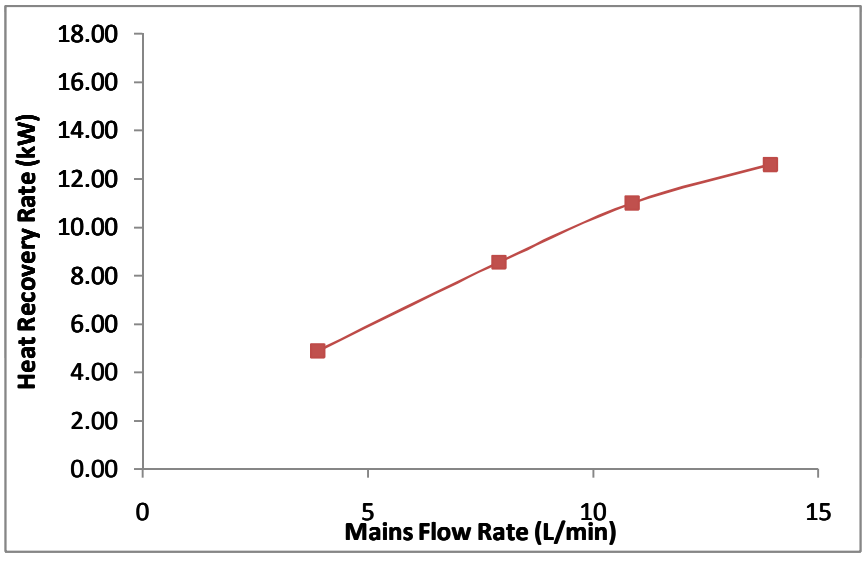
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.02	0.651	16700.23	0.50
2.09	0.560	29233.93	1.37
2.87	0.514	37566.97	2.28
3.68	0.465	43031.26	3.26

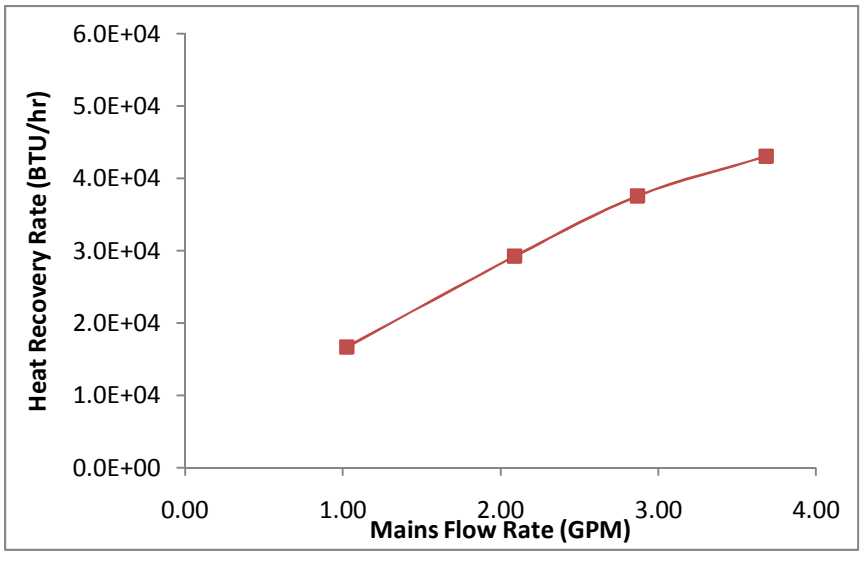
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

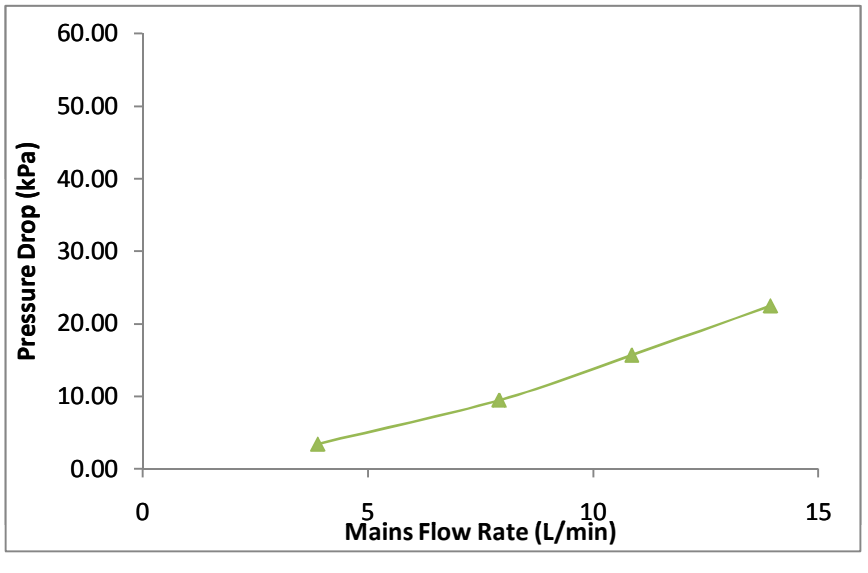
Effectiveness	0.537			
Heat Recovery	9.88	kW	33725.3	BTU/hr
Pressure Drop	12.83	kPa	1.86	PSI

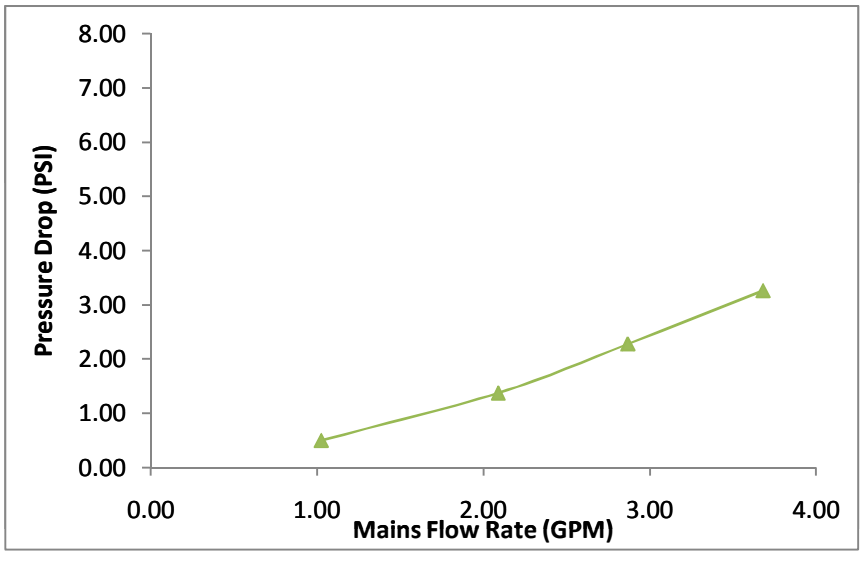












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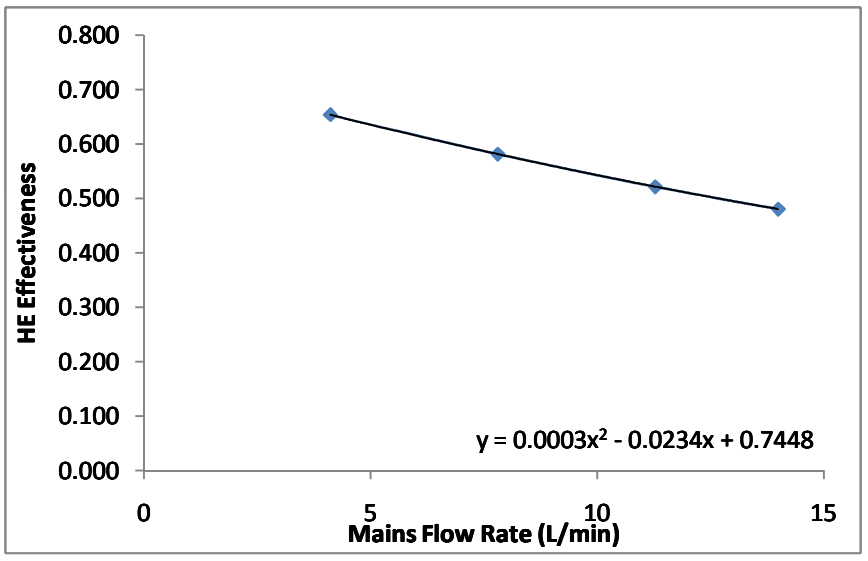
Product: 66in R3in
Manufacturer: Renewability
Test Date: March 5 / 2009 (4 L/min - March 26 / 2009 : 14 L/min - April 2 / 2009)

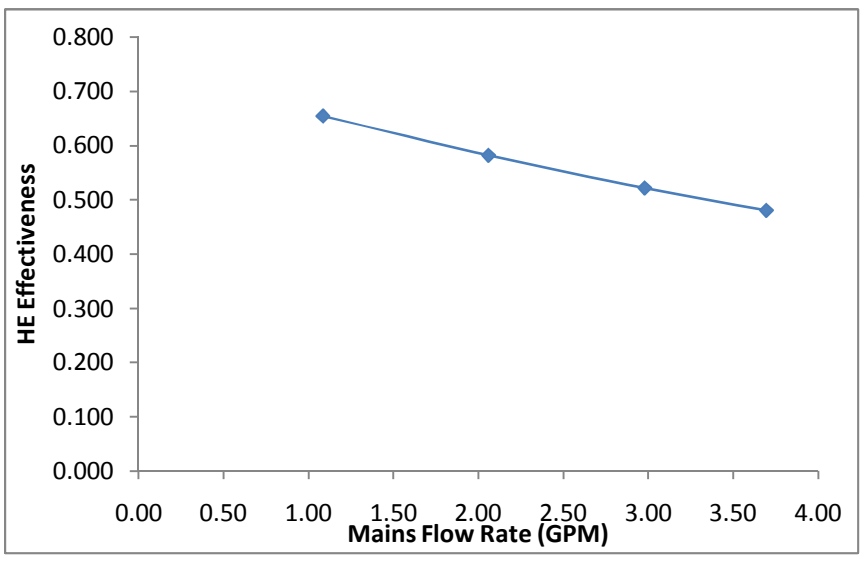
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.11	0.654	5.24	3.82
7.80	0.582	8.81	10.20
11.28	0.522	11.43	19.04
13.99	0.481	13.19	24.77

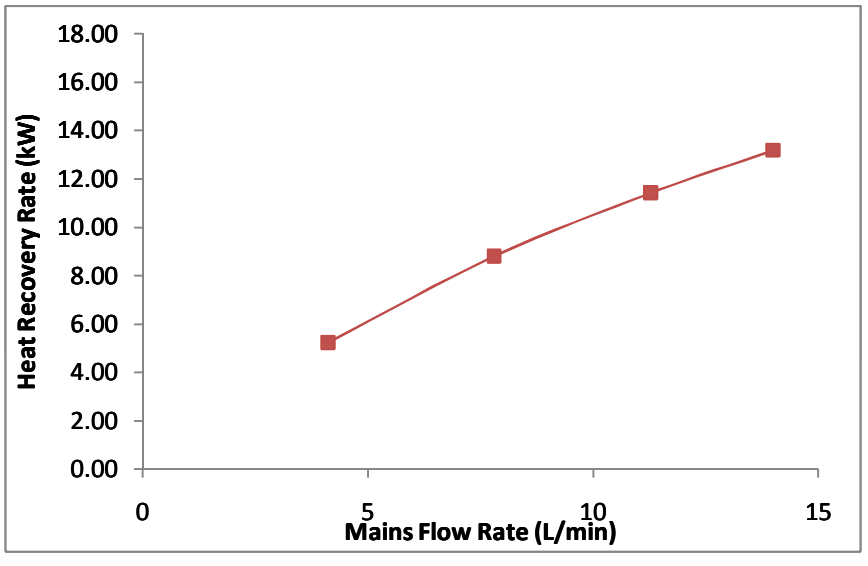
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.09	0.654	17895.54	0.55
2.06	0.582	30087.73	1.48
2.98	0.522	39035.50	2.76
3.70	0.481	45046.21	3.59

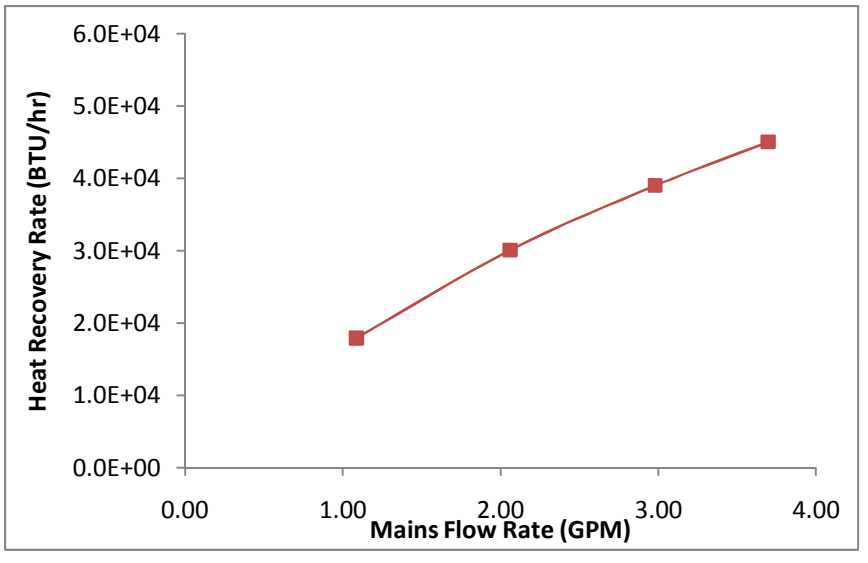
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

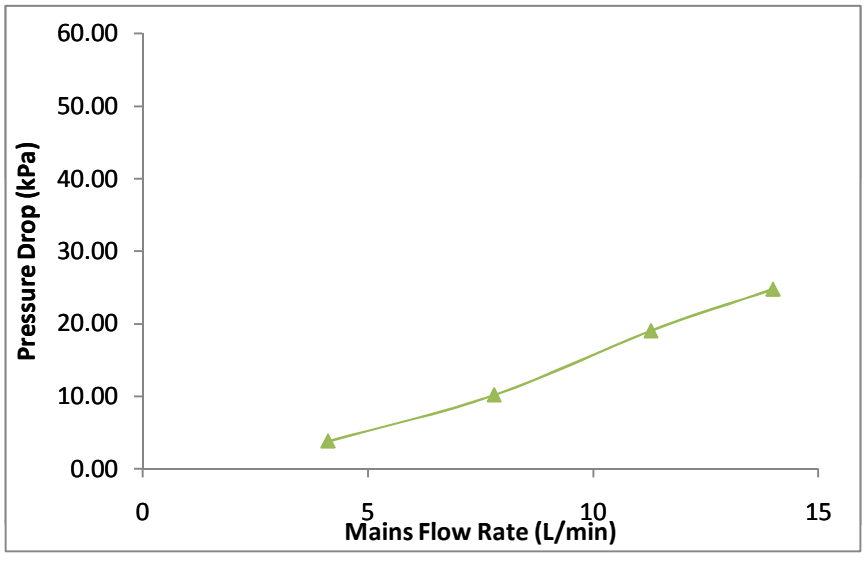
Effectiveness	0.550			
Heat Recovery	10.09	kW	34458.8	BTU/hr
Pressure Drop	14.52	kPa	2.11	PSI

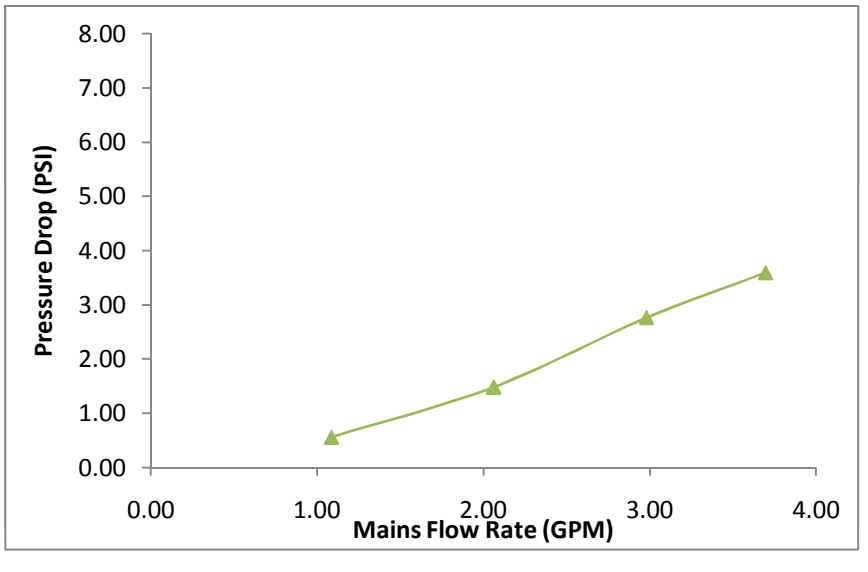












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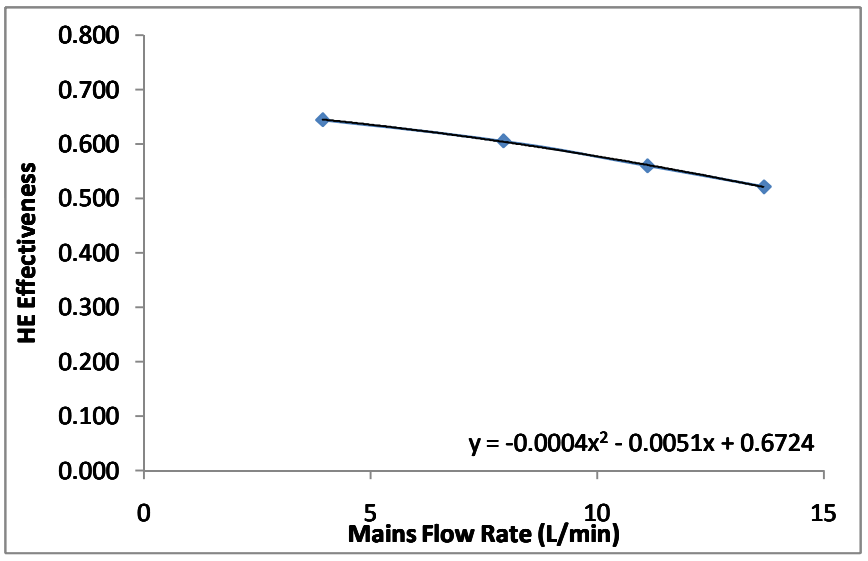
Product: 72in R3in
Manufacturer: Renewability
Test Date: March 5 / 2009

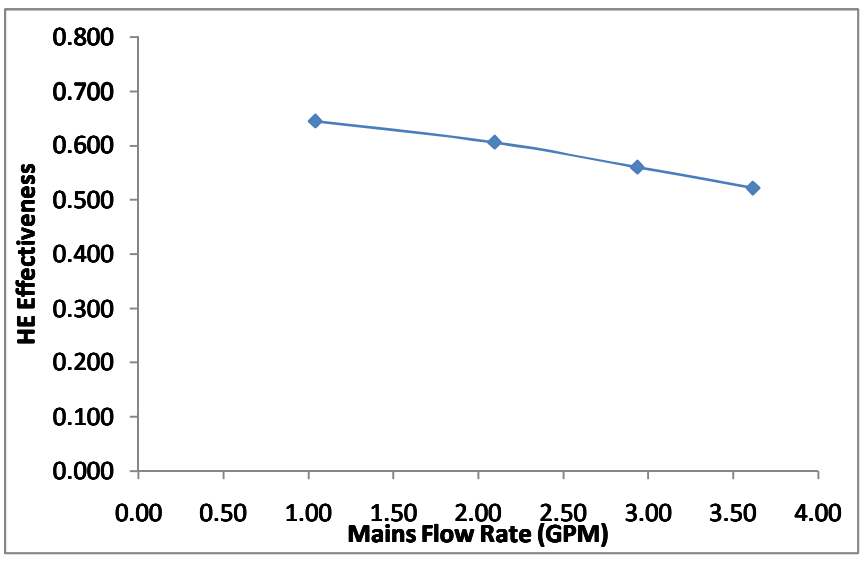
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.94	0.645	4.90	4.93
7.93	0.606	9.34	12.15
11.11	0.560	12.27	21.17
13.68	0.522	13.91	29.63

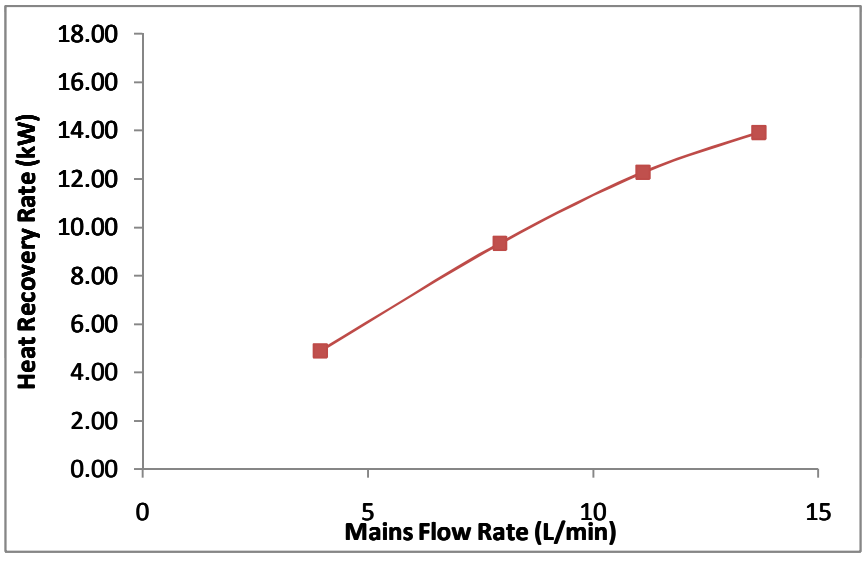
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.04	0.645	16734.38	0.72
2.09	0.606	31897.77	1.76
2.93	0.560	41904.25	3.07
3.61	0.522	47505.14	4.30

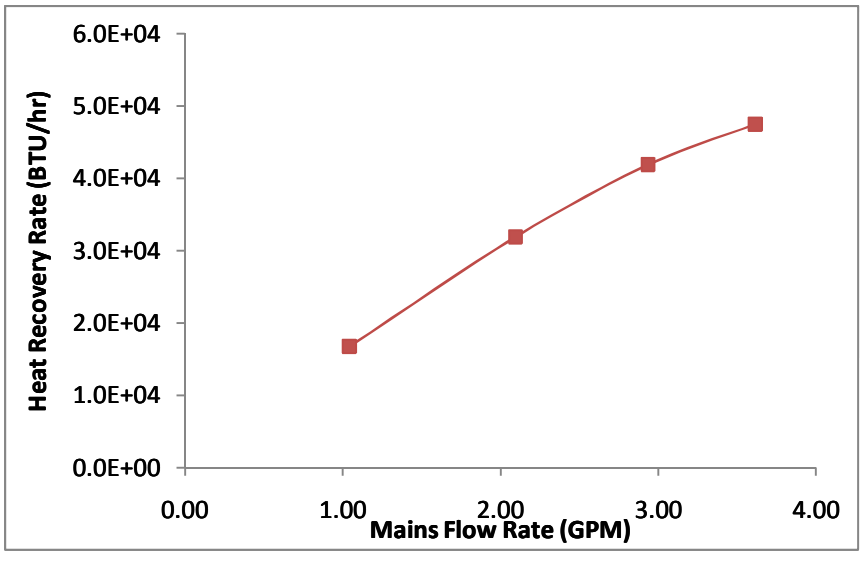
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

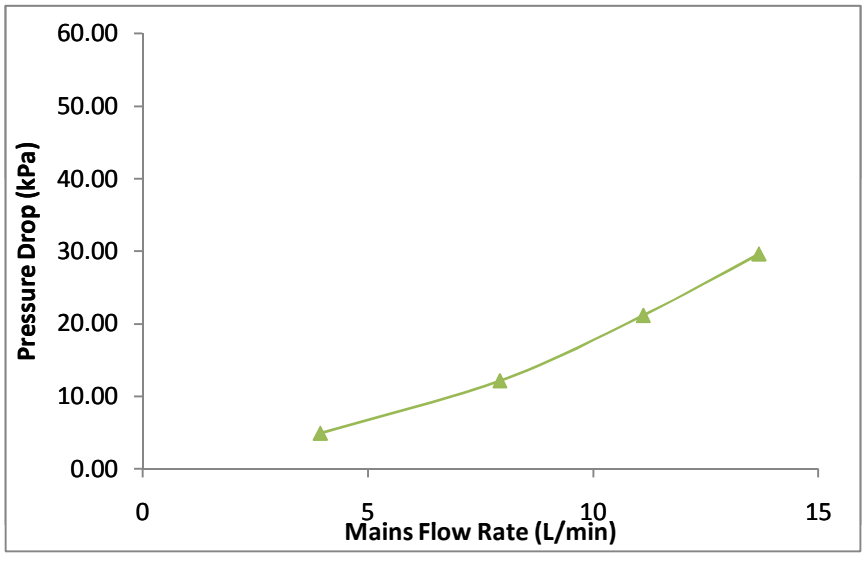
Effectiveness	0.588			
Heat Recovery	10.79	kW	36838.1	BTU/hr
Pressure Drop	16.60	kPa	2.41	PSI

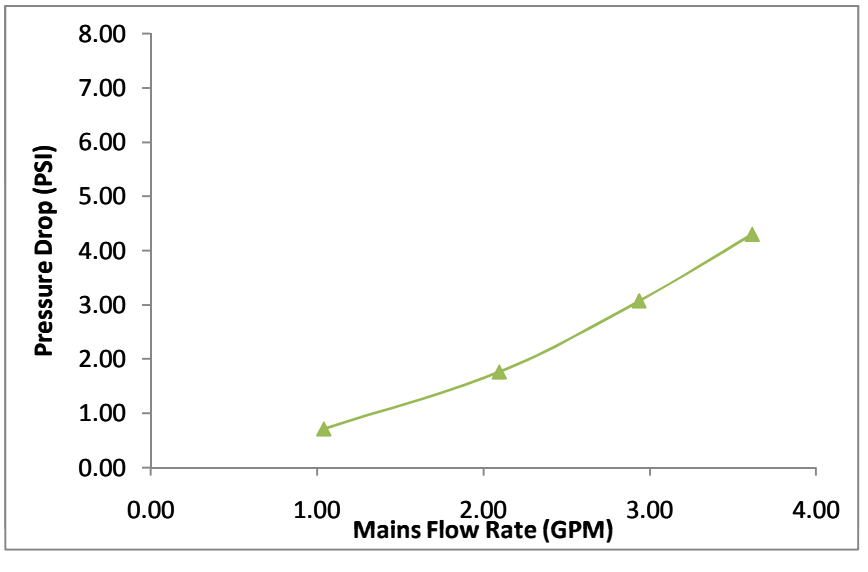












UNIVERSITY OF Waterloo

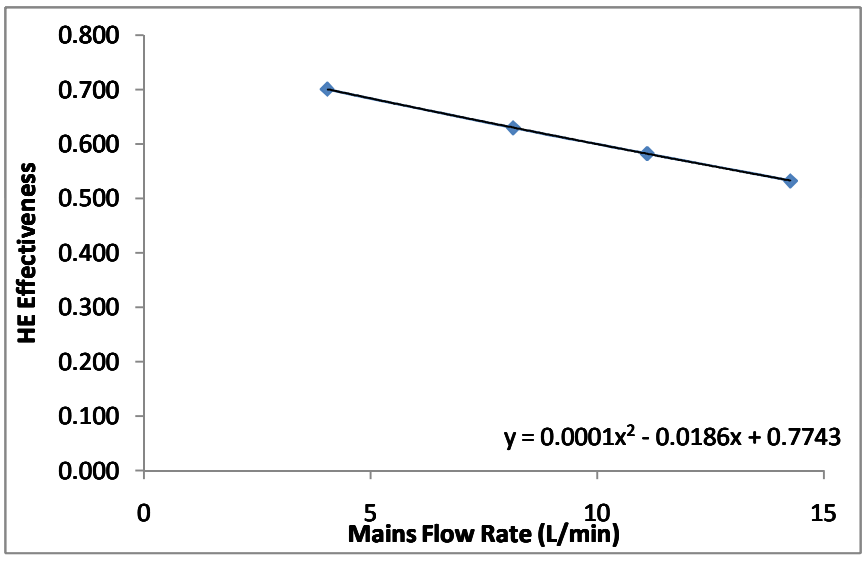
Product: 84in R3in
Manufacturer: Renewability
Test Date: January 27 / 2011

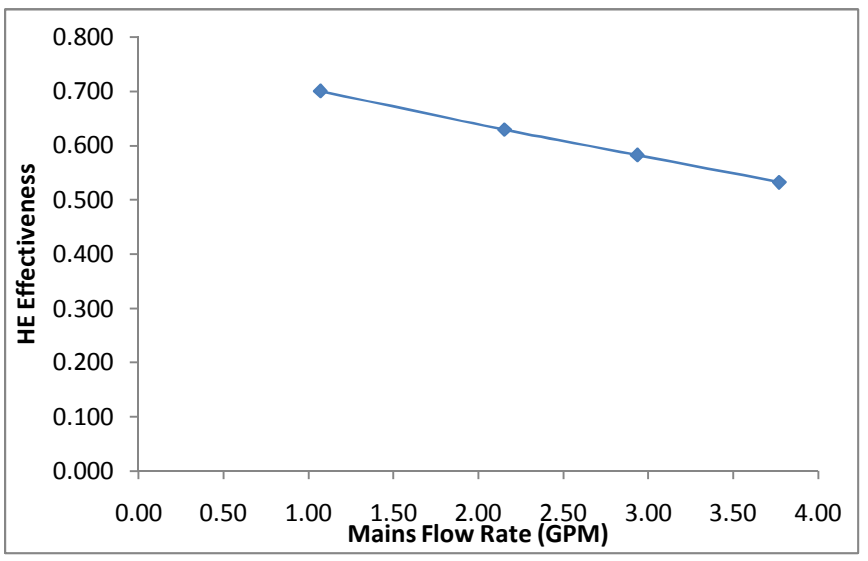
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.05	0.701	5.61	4.68
8.15	0.630	9.93	13.32
11.11	0.583	12.29	21.11
14.27	0.533	14.27	31.44

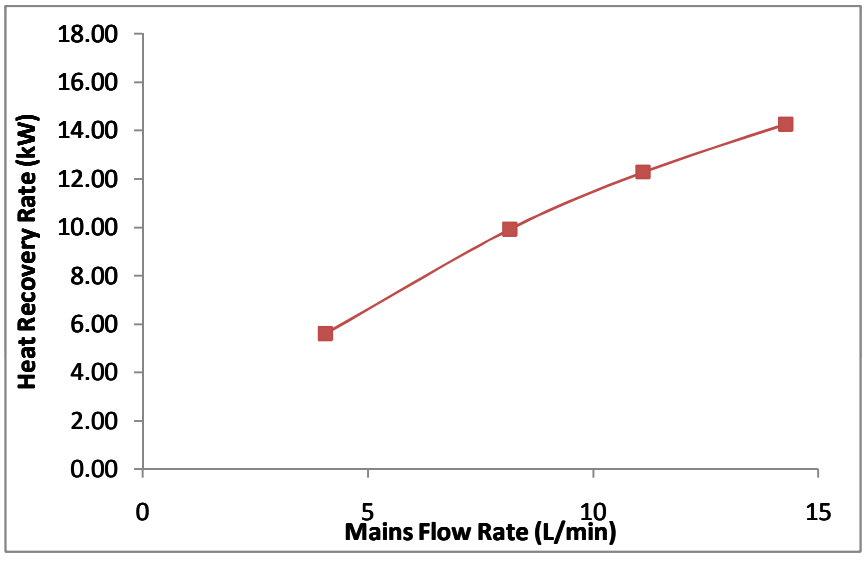
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.07	0.701	19159.15	0.68
2.15	0.630	33912.73	1.93
2.93	0.583	41972.55	3.06
3.77	0.533	48734.60	4.56

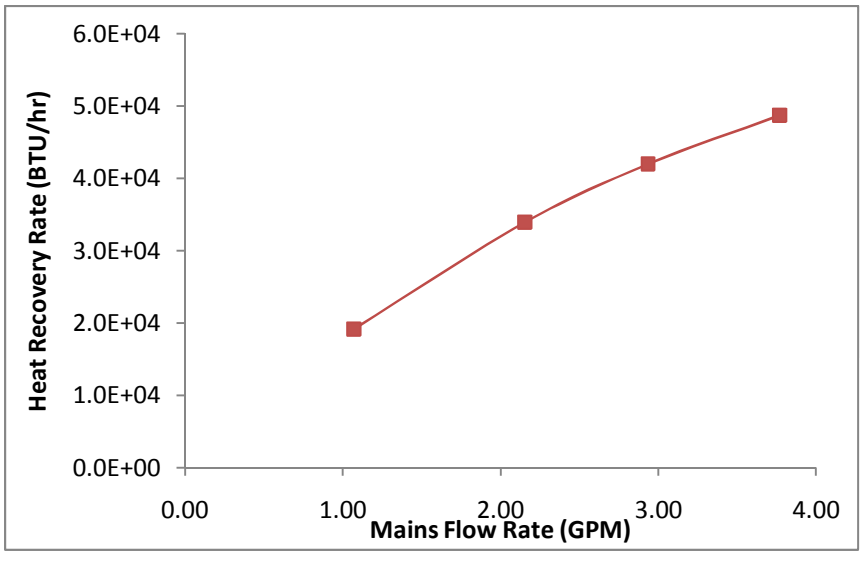
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

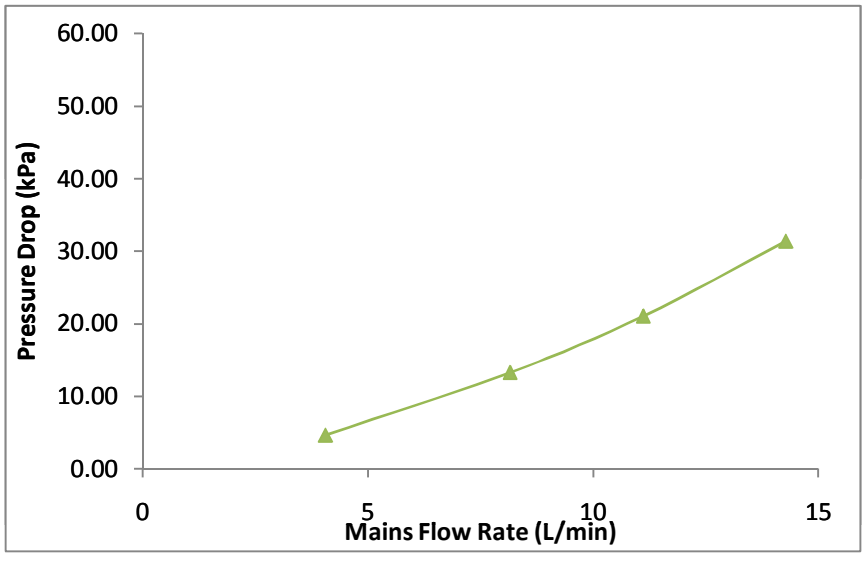
Effectiveness	0.607			
Heat Recovery	11.01	kW	37588.7	BTU/hr
Pressure Drop	16.87	kPa	2.45	PSI

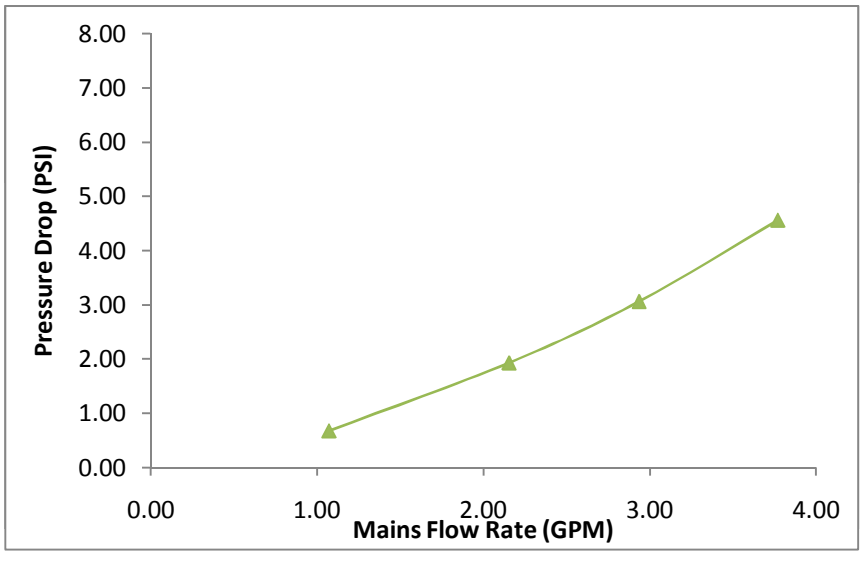












UNIVERSITY OF Waterloo

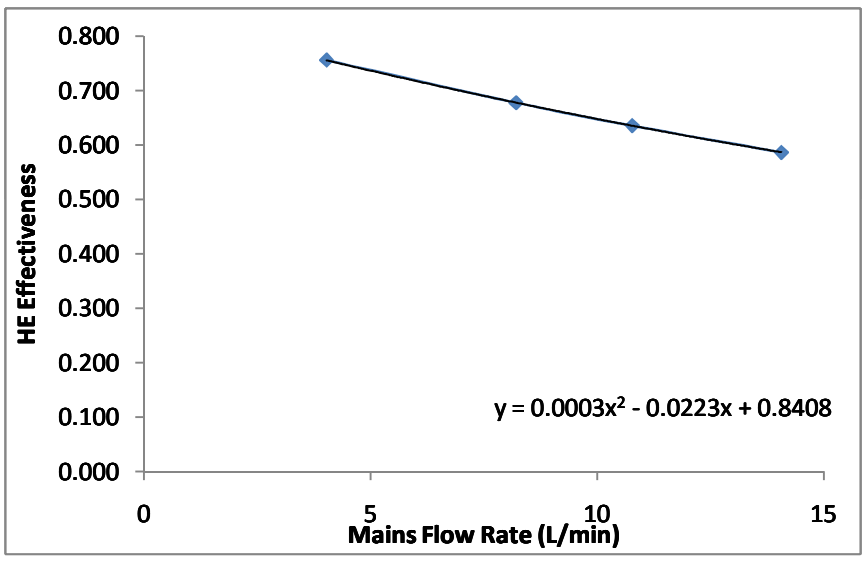
Product: 96in R3in
Manufacturer: Renewability
Test Date: January 27 / 2011

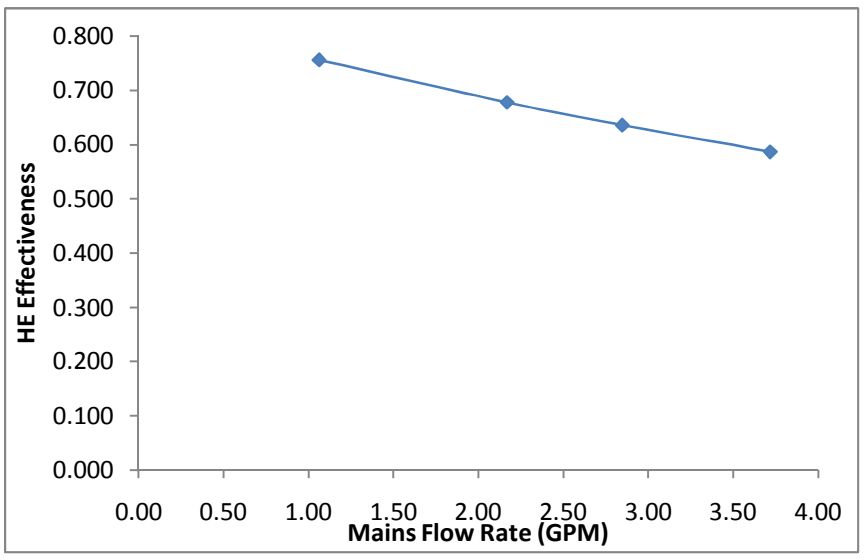
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.03	0.756	5.86	6.25
8.21	0.678	10.69	15.68
10.78	0.636	13.50	23.55
14.07	0.587	15.93	34.93

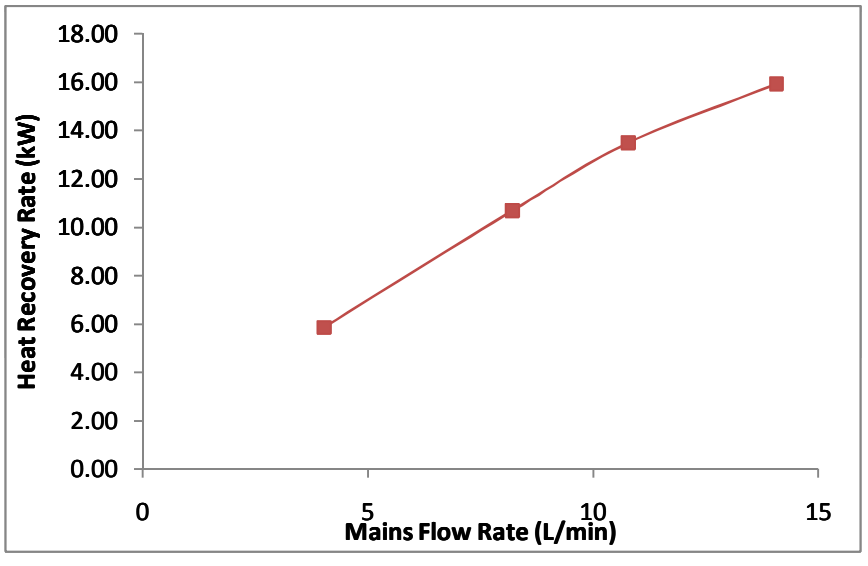
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.756	20012.95	0.91
2.17	0.678	36508.26	2.27
2.85	0.636	46104.92	3.42
3.72	0.587	54403.80	5.07

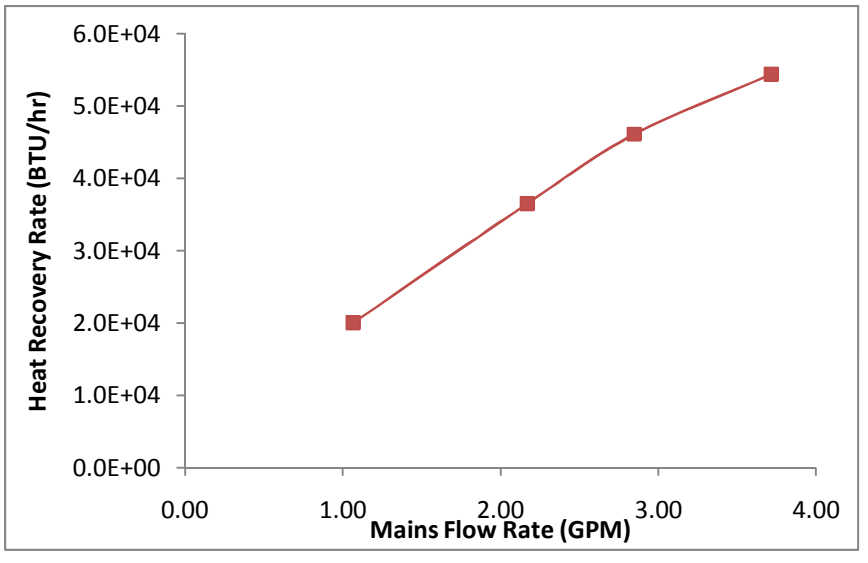
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

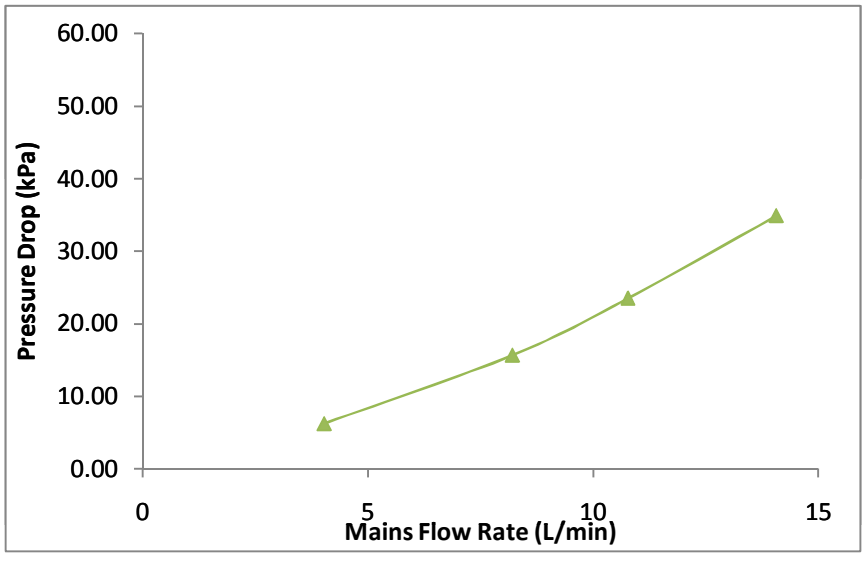
Effectiveness	0.656			
Heat Recovery	12.10	kW	41325.3	BTU/hr
Pressure Drop	19.63	kPa	2.85	PSI

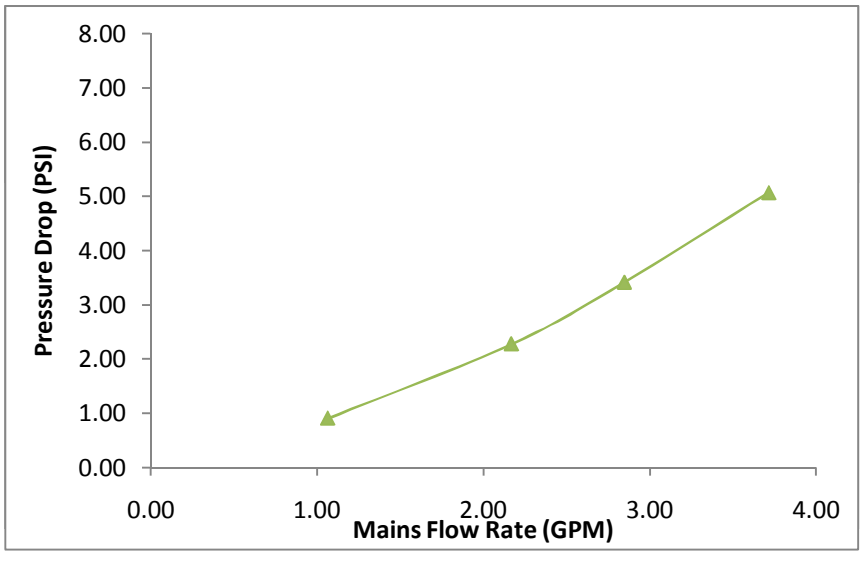












UNIVERSITY OF Waterloo

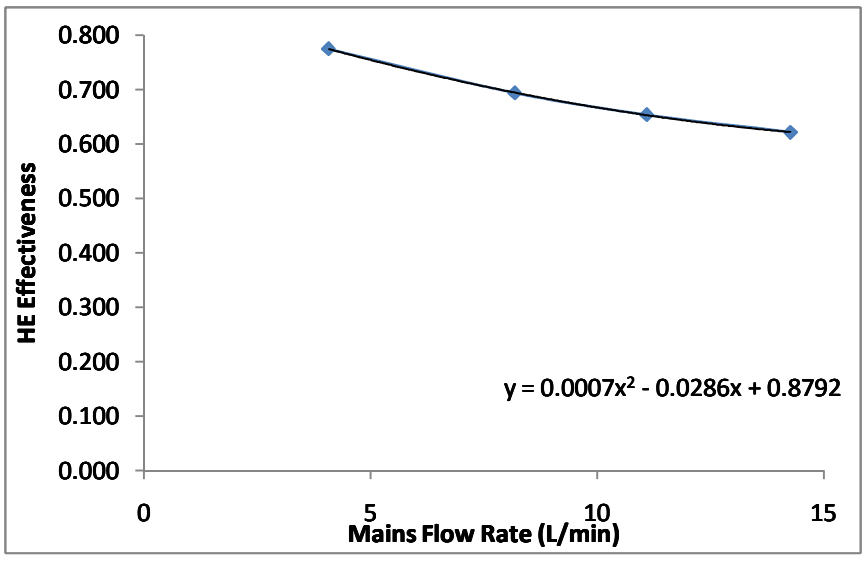
Product: 108in R3in
Manufacturer: Renewability
Test Date: January 27 / 2011

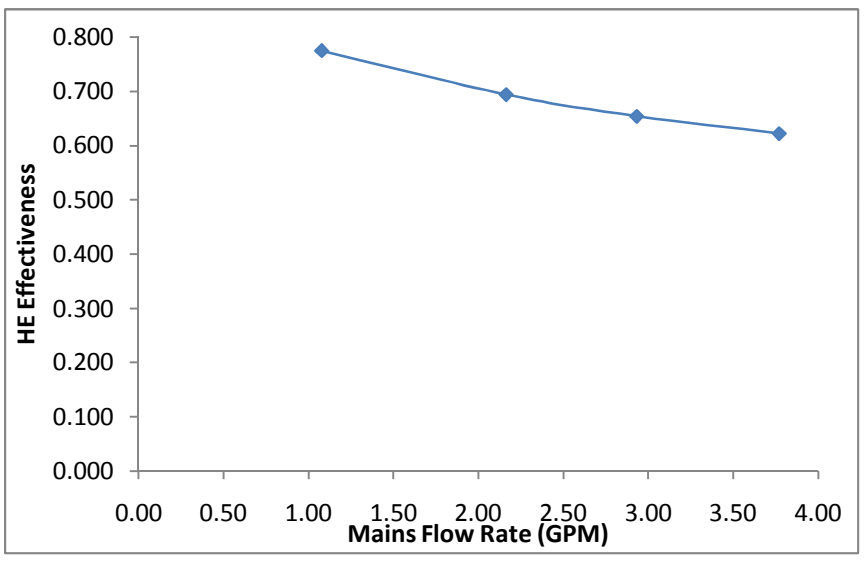
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.08	0.775	6.02	6.59
8.19	0.694	11.13	17.39
11.1	0.654	13.96	27.82
14.27	0.622	17.43	41.06

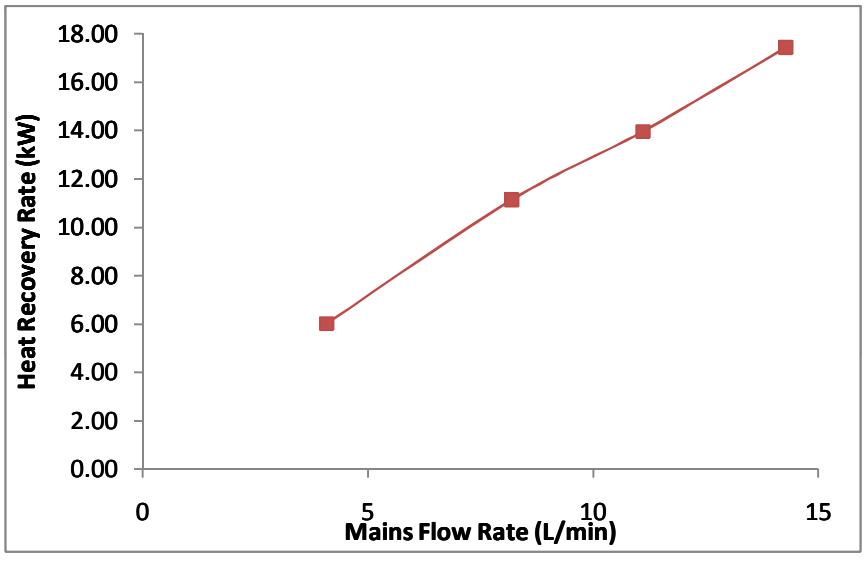
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.08	0.775	20559.38	0.96
2.16	0.694	38010.94	2.52
2.93	0.654	47675.90	4.03
3.77	0.622	59526.57	5.96

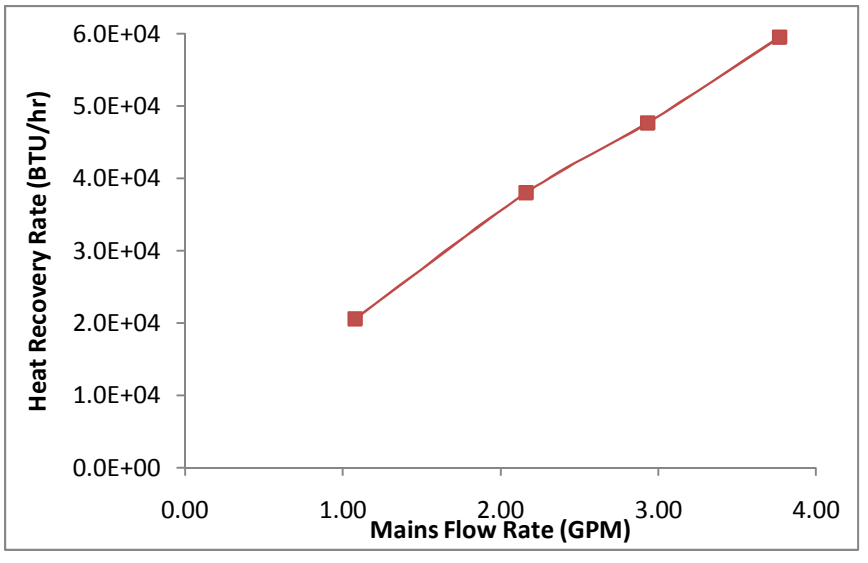
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

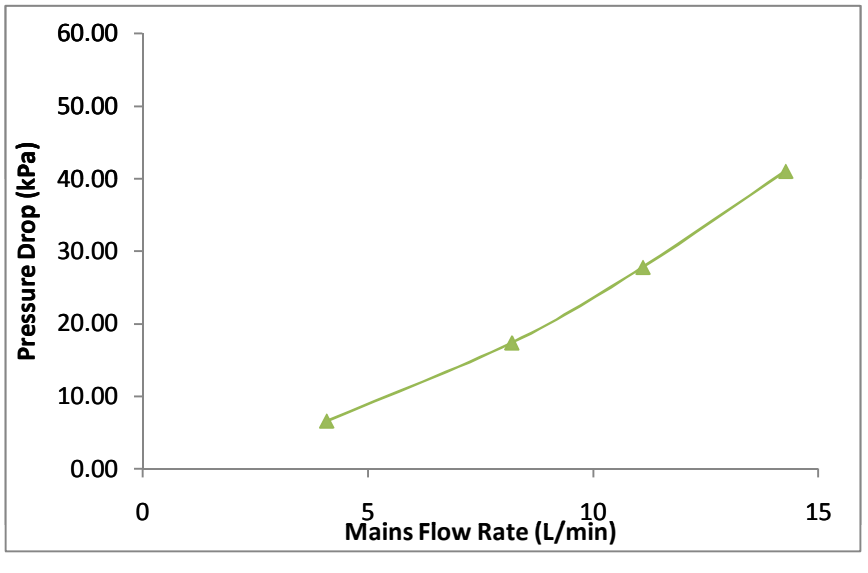
Effectiveness	0.671			
Heat Recovery	12.40	kW	42361.8	BTU/hr
Pressure Drop	22.09	kPa	3.20	PSI

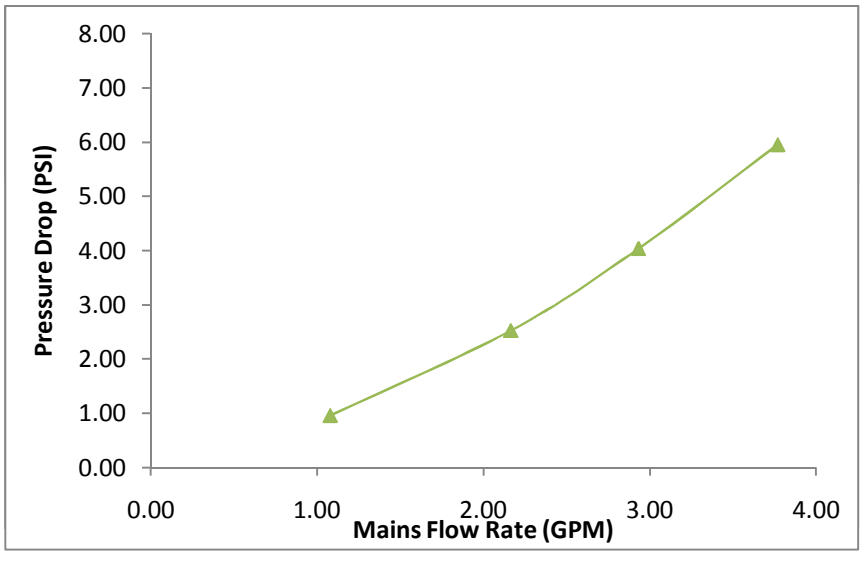












UNIVERSITY OF Waterloo

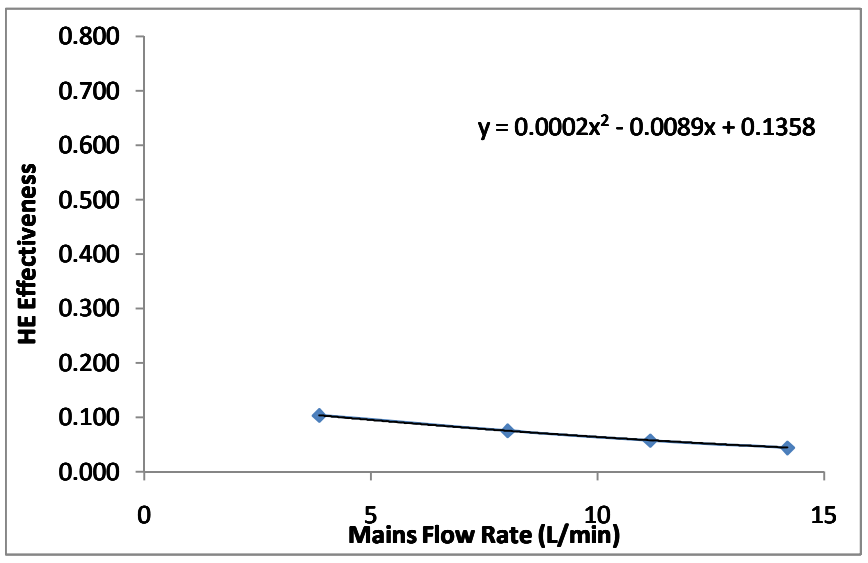
Product: 12in R3in
Manufacturer: Renewability
Test Date: February 24 / 2011

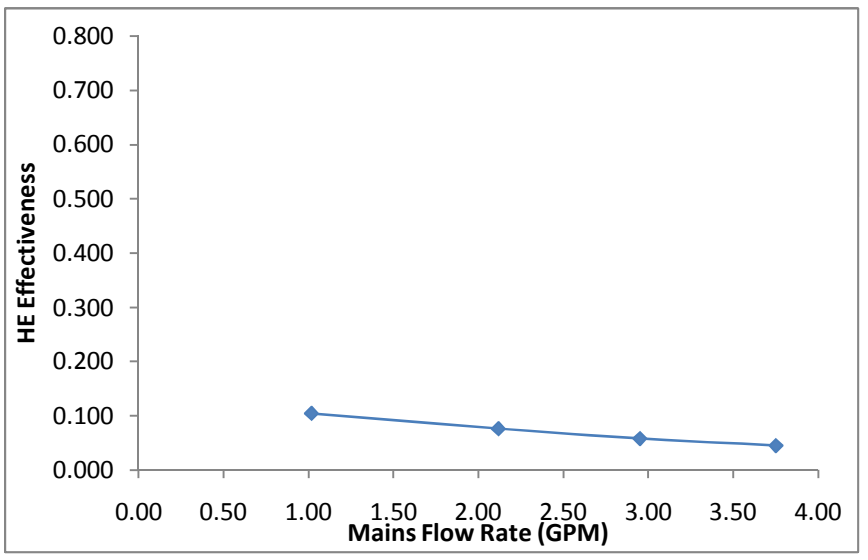
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.86	0.104	0.79	0.82
8.02	0.076	1.21	1.45
11.17	0.058	1.25	2.73
14.2	0.045	1.30	5.35

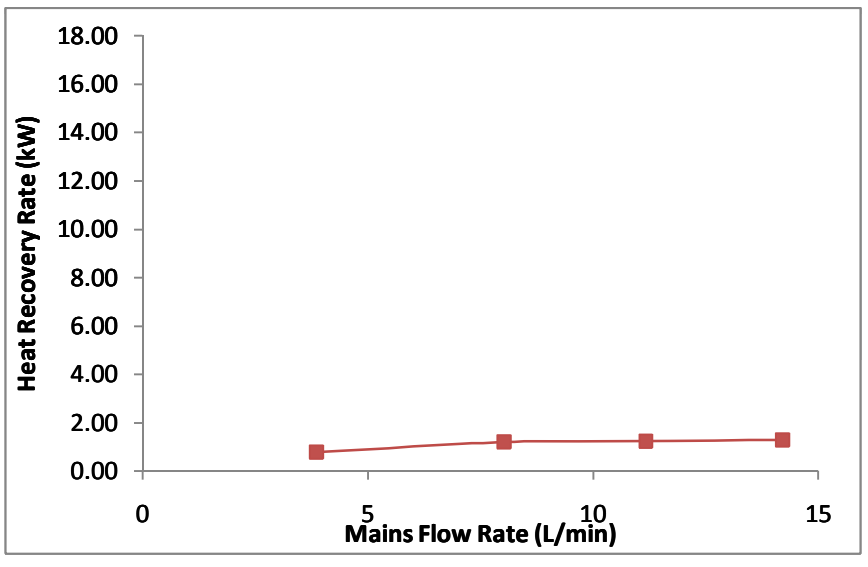
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.02	0.104	2697.99	0.12
2.12	0.076	4132.37	0.21
2.95	0.058	4268.97	0.40
3.75	0.045	4439.73	0.78

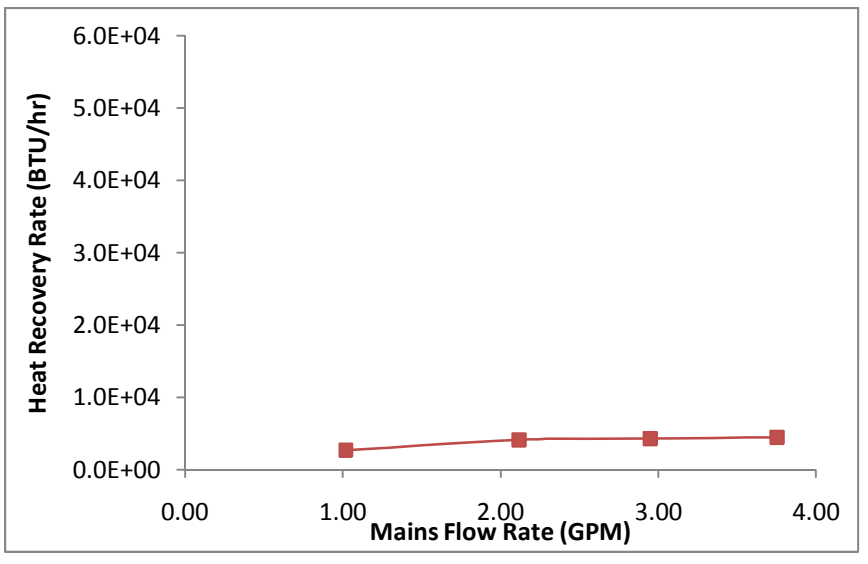
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

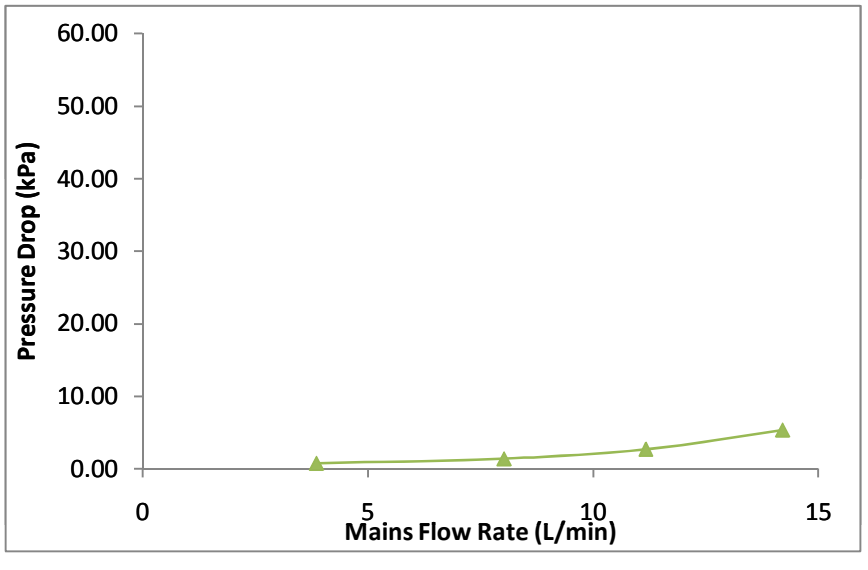
Effectiveness	0.069			
Heat Recovery	1.23	kW	4196.6	BTU/hr
Pressure Drop	2.05	kPa	0.30	PSI

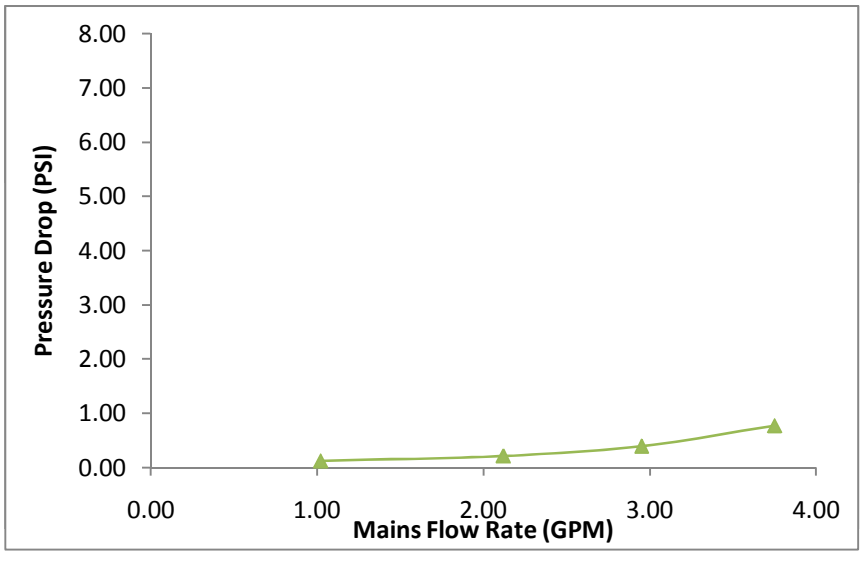












UNIVERSITY OF Waterloo

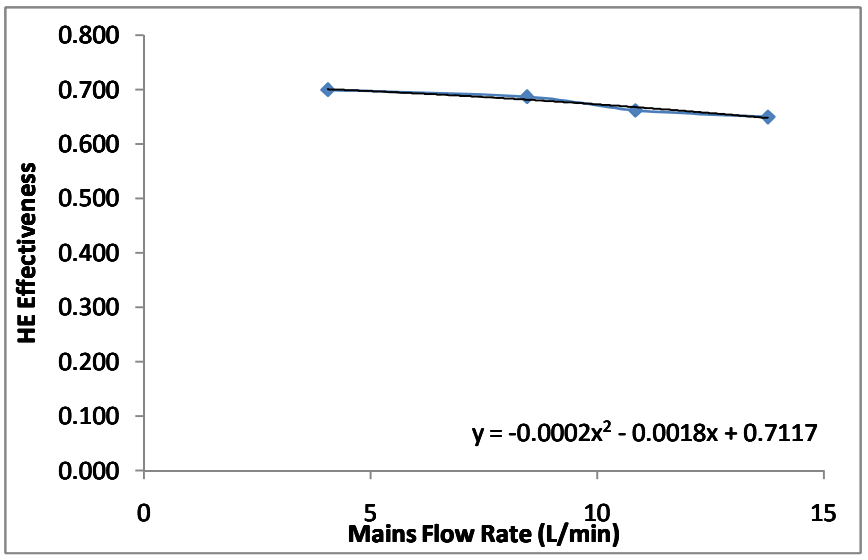
Product: 120in R3in
Manufacturer: Renewability
Test Date: March 4 / 2009 (14 L/min - April 9 /2009)

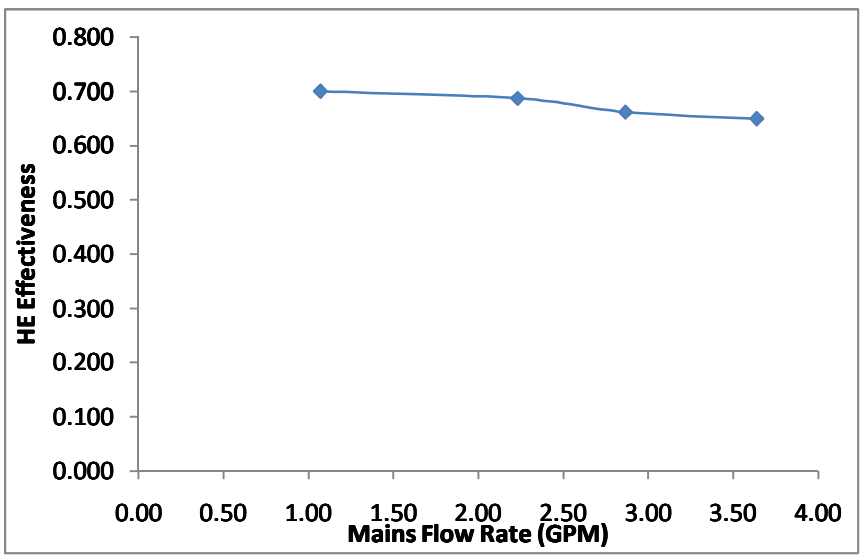
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.06	0.700	5.58	6.95
8.45	0.687	11.16	22.12
10.85	0.662	14.05	32.66
13.77	0.650	17.52	44.41

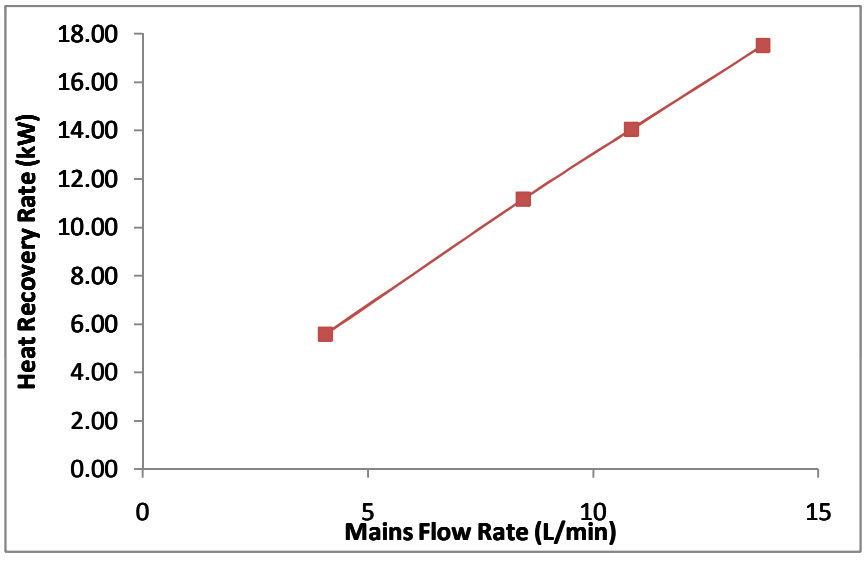
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.07	0.700	19056.70	1.01
2.23	0.687	38113.40	3.21
2.87	0.662	47983.26	4.74
3.64	0.650	59833.94	6.44

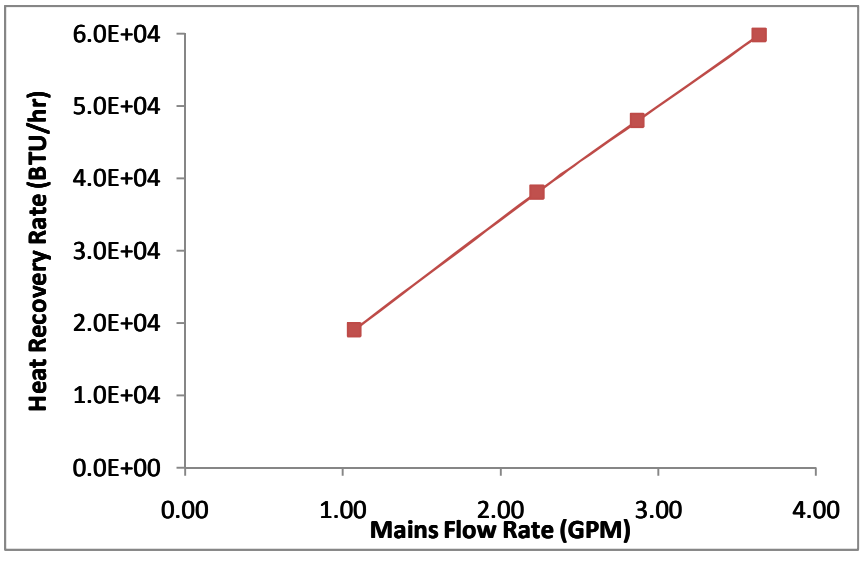
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

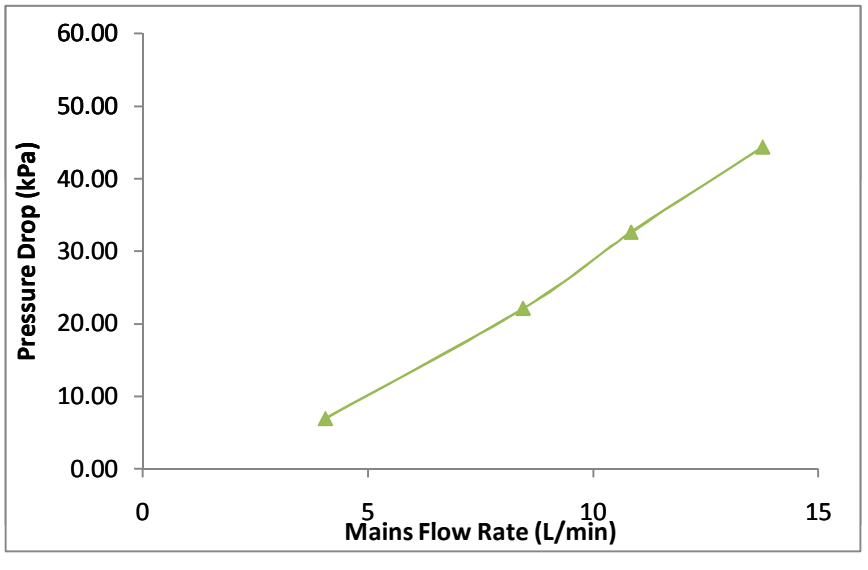
Effectiveness	0.677			
Heat Recovery	12.42	kW	42431.5	BTU/hr
Pressure Drop	26.73	kPa	3.88	PSI

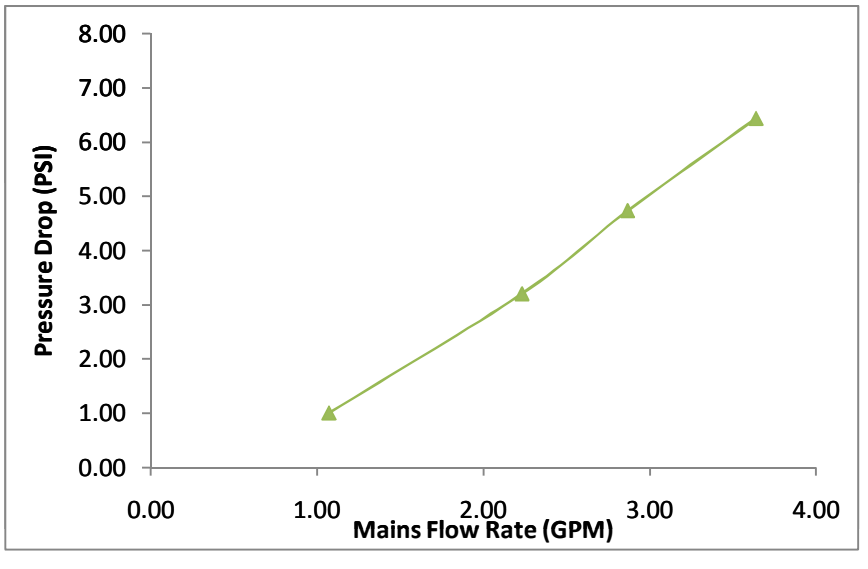










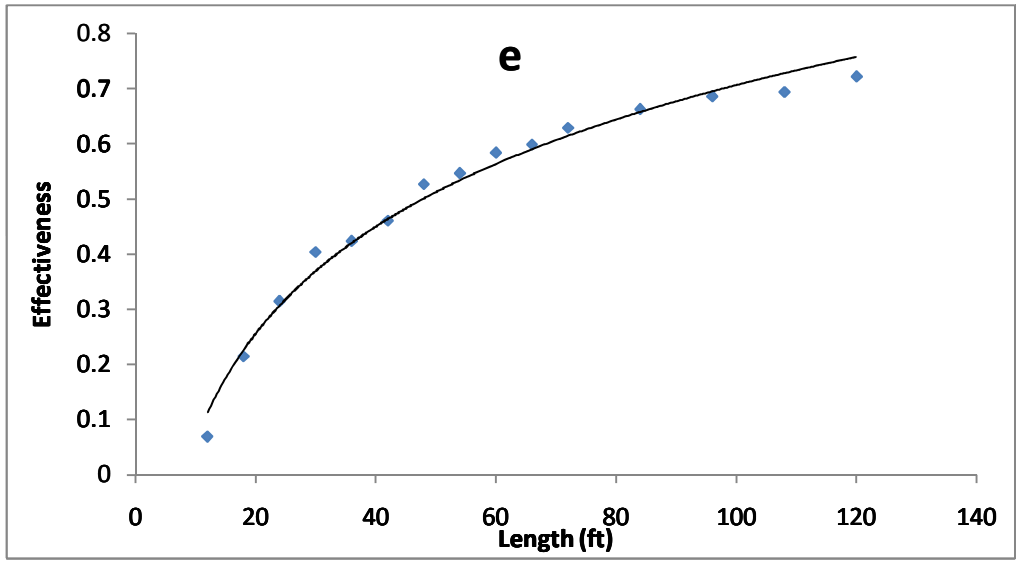


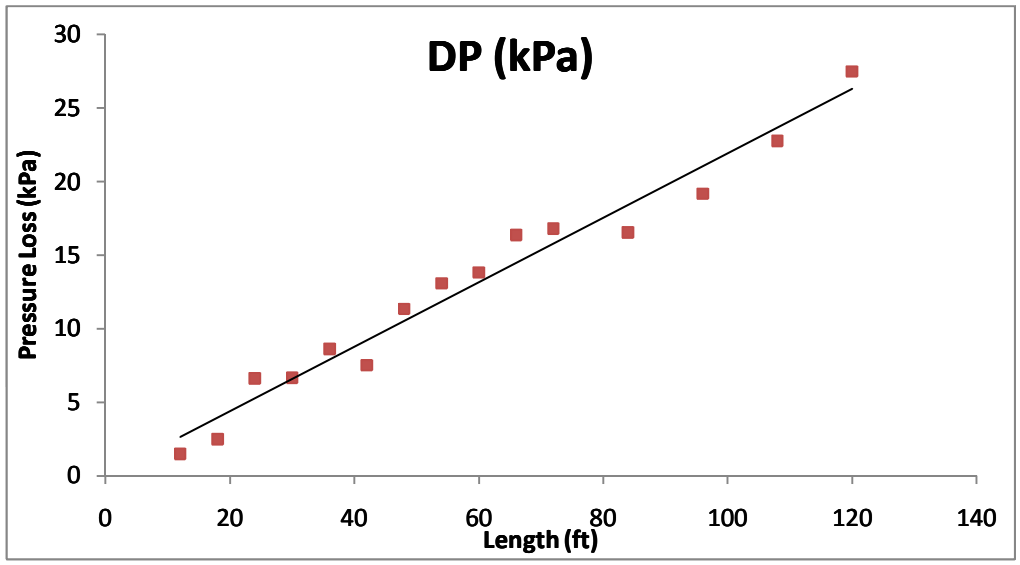
Appendix C

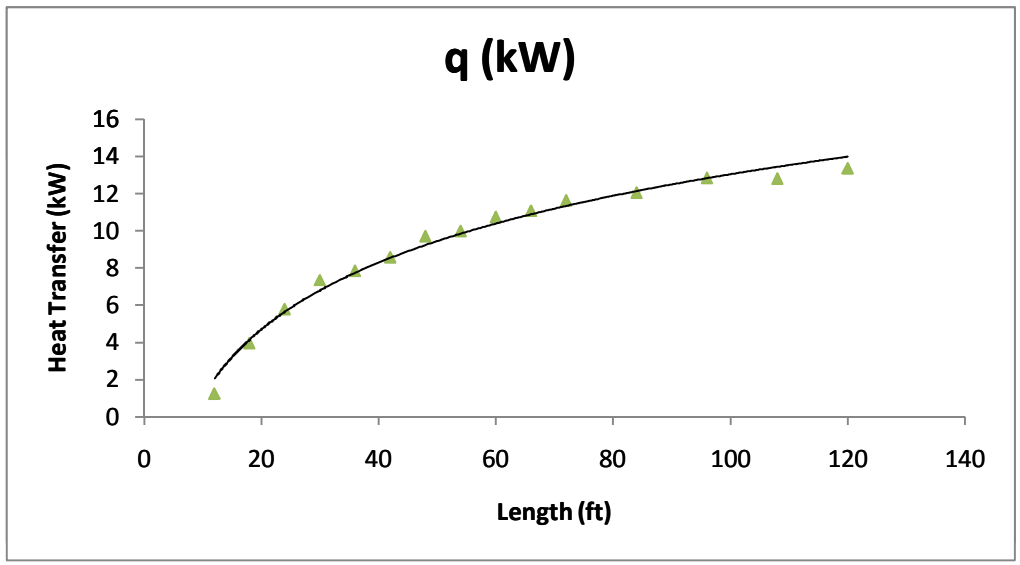
Test Reports – 4” Nominal Diameter Units

Effectiveness and Pressure Drop at Standard Conditions (9.5 L/min - 8°C Mains, 36 °C Shower)

L (ft)	ε	ΔP (kPa)	q (kW)
12	0.07	1.47	1.26
18	0.215	2.48	3.98
24	0.315	6.62	5.81
30	0.404	6.67	7.36
36	0.424	8.63	7.85
42	0.461	7.51	8.59
48	0.527	11.33	9.71
54	0.547	13.08	10.00
60	0.584	13.81	10.74
66	0.599	16.35	11.07
72	0.629	16.79	11.63
84	0.663	16.54	12.05
96	0.686	19.17	12.84
108	0.694	22.74	12.81
120	0.722	27.47	13.36







UNIVERSITY OF Waterloo

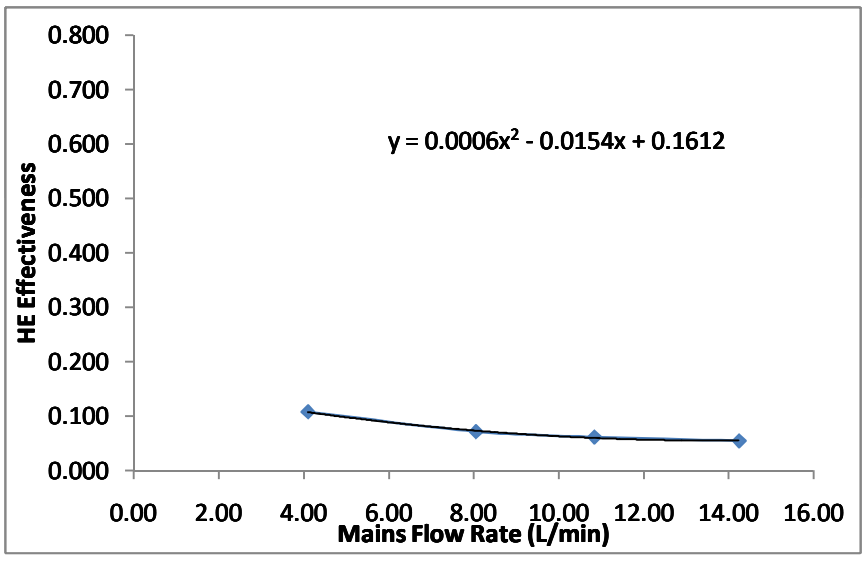
Product: 12in R4in
Manufacturer: Renewability
Test Date: April 1 / 2011

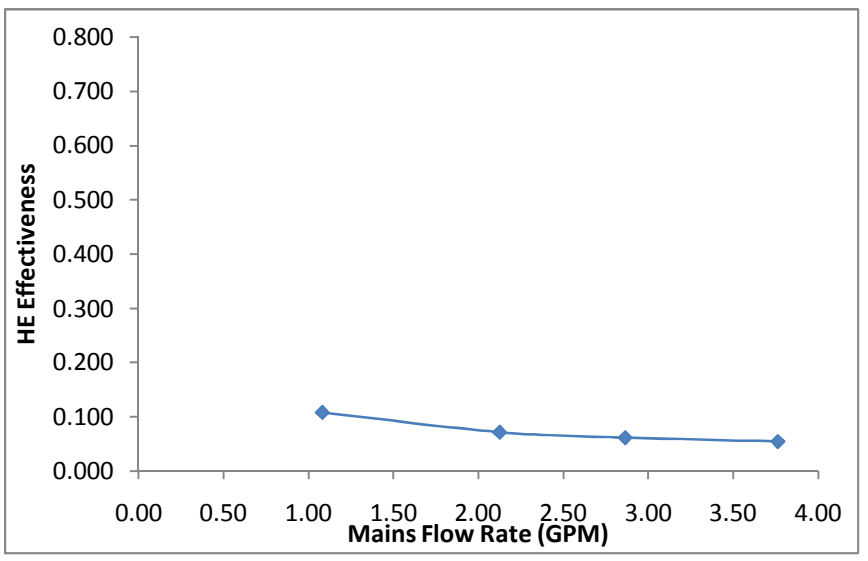
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.10	0.108	0.87	0.00
8.05	0.072	1.16	1.09
10.84	0.062	1.35	1.82
14.24	0.055	1.57	3.08

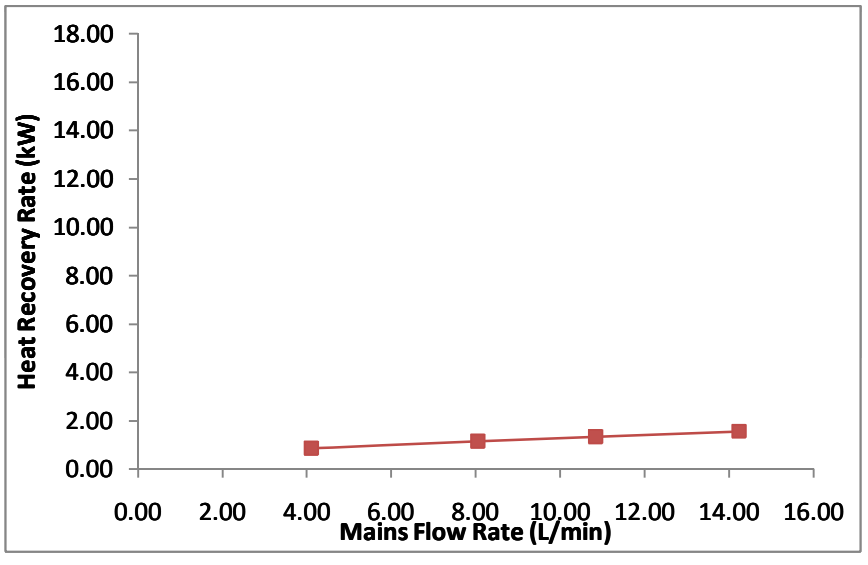
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.08	0.108	2971.21	0.00
2.13	0.072	3961.61	0.16
2.86	0.062	4610.49	0.26
3.76	0.055	5361.83	0.45

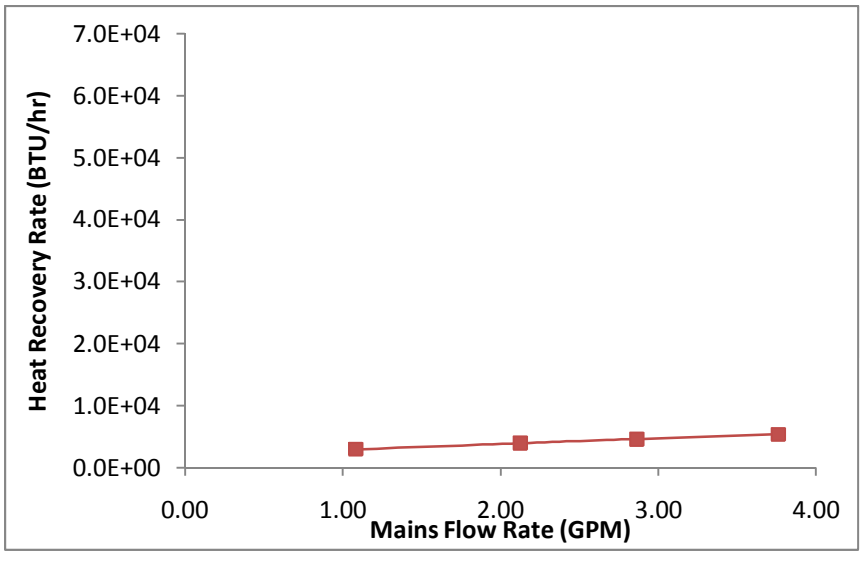
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

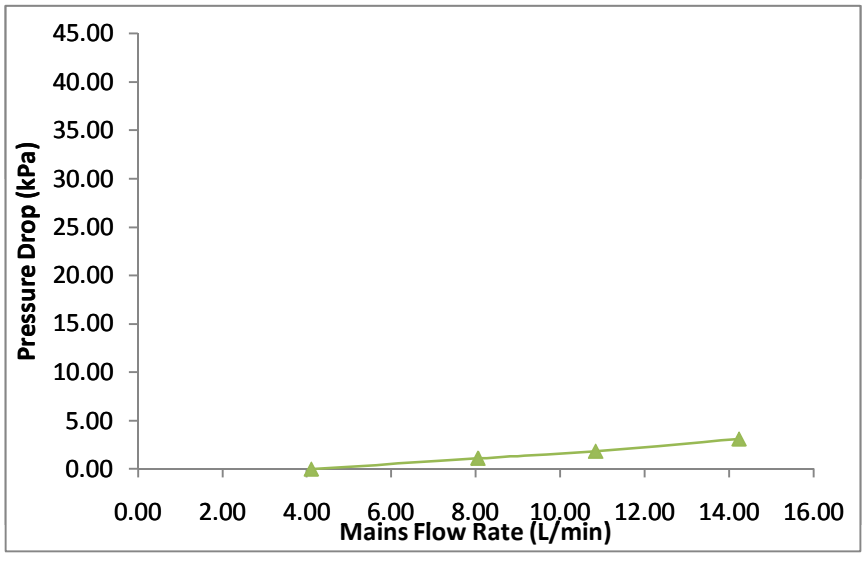
Effectiveness	0.069			
Heat Recovery	1.26	kW	4298.8	BTU/hr
Pressure Drop	1.47	kPa	0.21	PSI

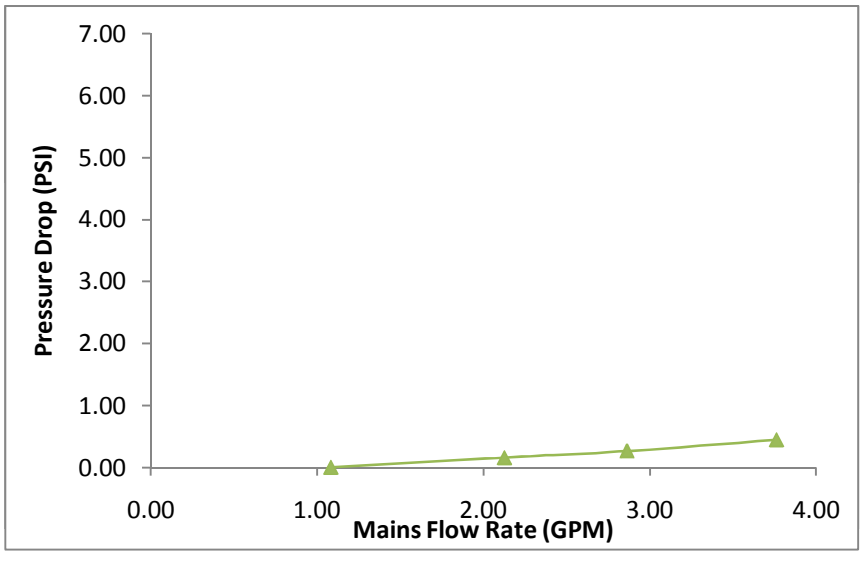












UNIVERSITY OF Waterloo

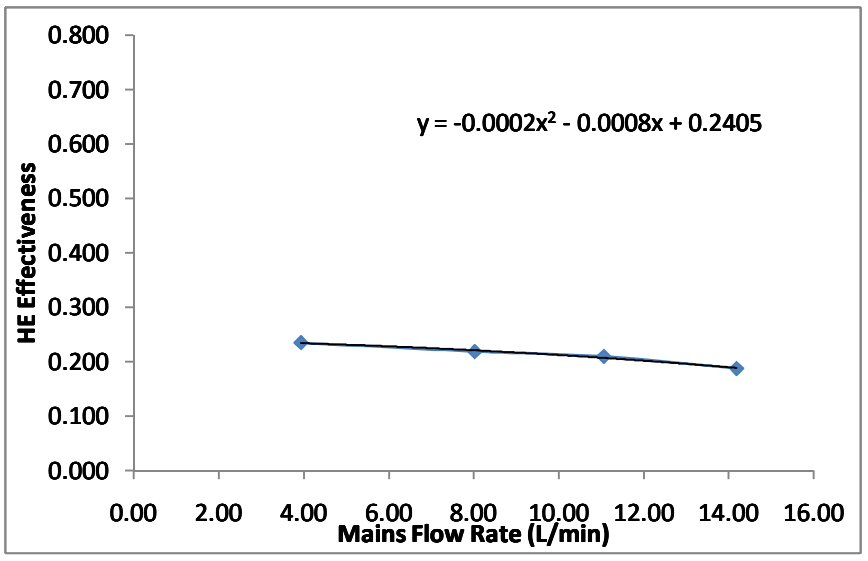
Product: 18in R4in
Manufacturer: Renewability
Test Date: April 1 / 2011

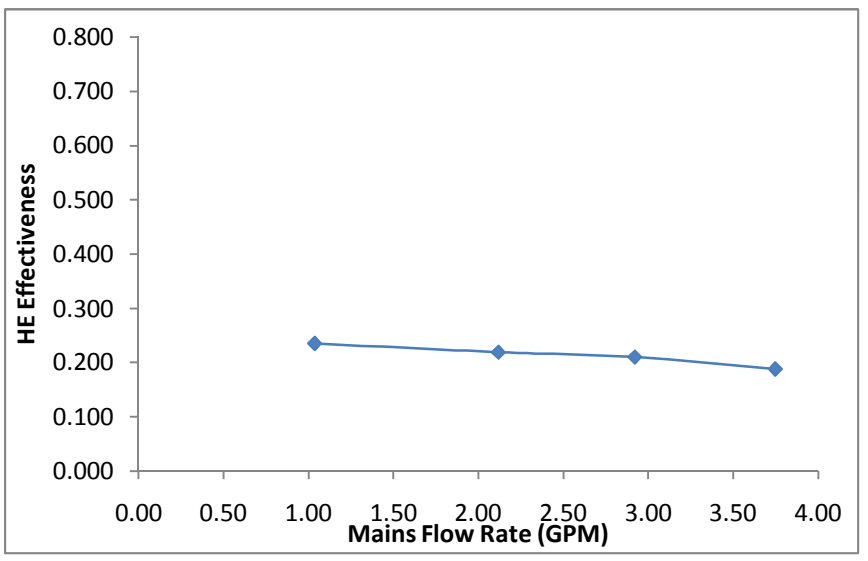
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.93	0.235	1.77	0.00
8.02	0.219	3.48	1.80
11.06	0.210	4.51	3.19
14.19	0.188	5.29	5.99

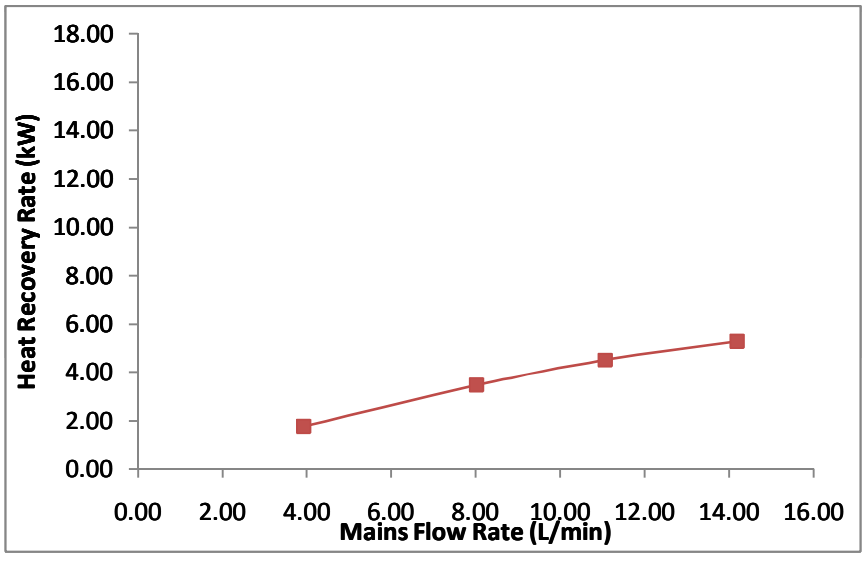
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.04	0.235	6044.87	0.00
2.12	0.219	11884.82	0.26
2.92	0.210	15402.46	0.46
3.75	0.188	18066.30	0.87

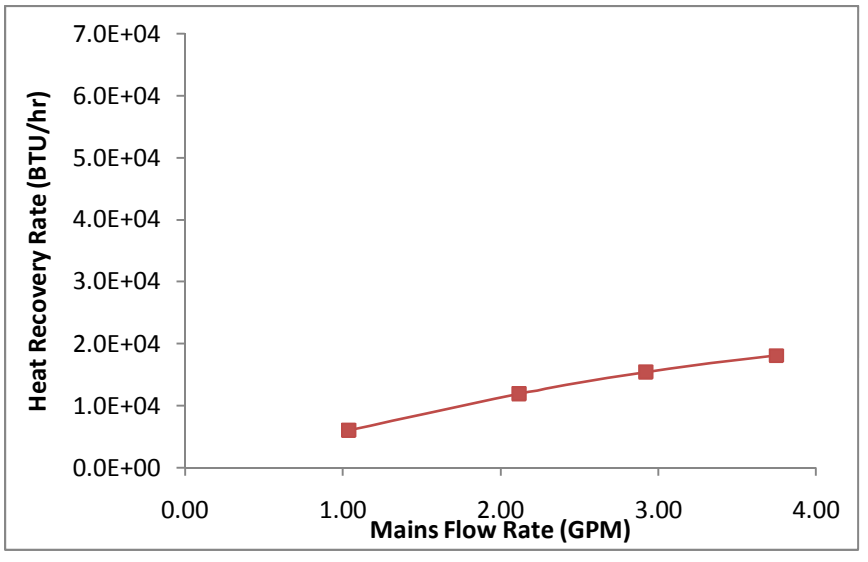
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

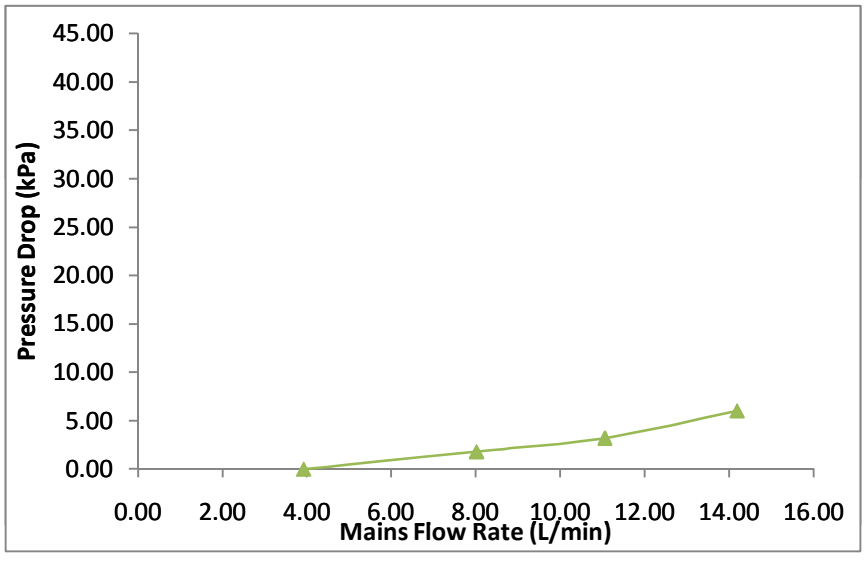
Effectiveness	0.215			
Heat Recovery	3.98	kW	13597.4	BTU/hr
Pressure Drop	2.48	kPa	0.36	PSI

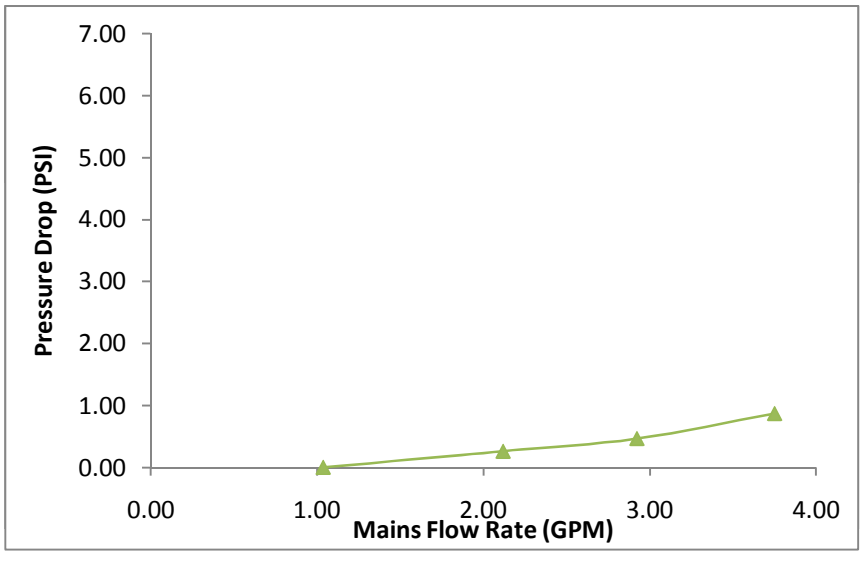












UNIVERSITY OF Waterloo

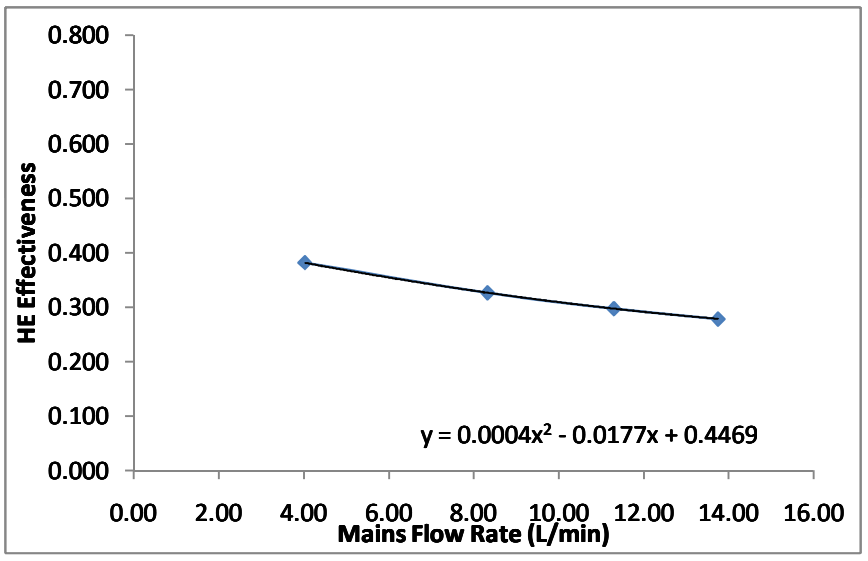
Product: 24in R4in
Manufacturer: Renewability
Test Date: March 2 / 2009

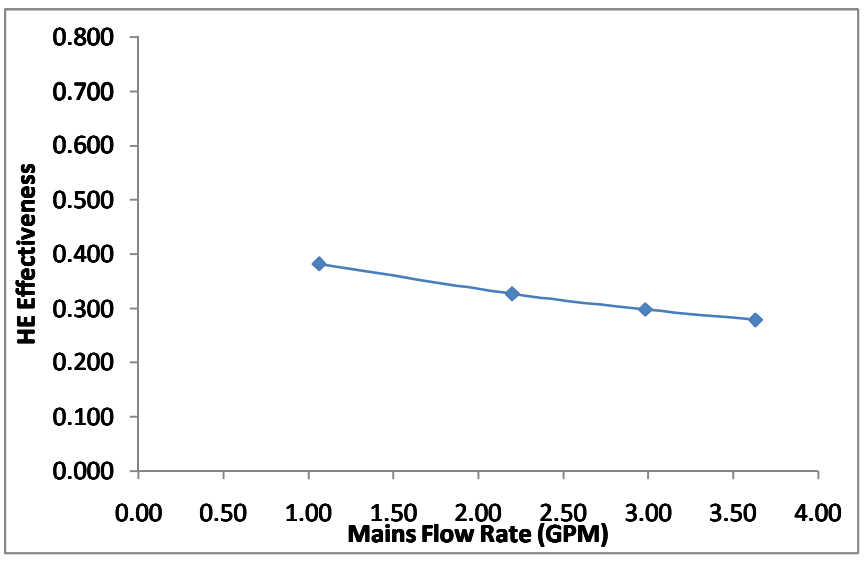
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.03	0.382	3.05	2.09
8.33	0.327	5.41	6.25
11.30	0.298	6.42	7.20
13.75	0.279	7.56	9.14

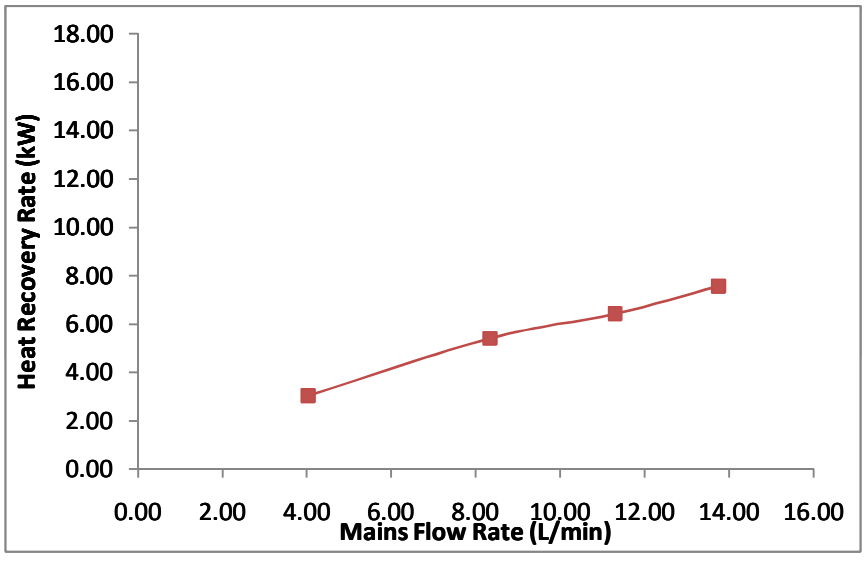
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.382	10416.30	0.30
2.20	0.327	18476.12	0.91
2.99	0.298	21925.45	1.04
3.63	0.279	25818.75	1.33

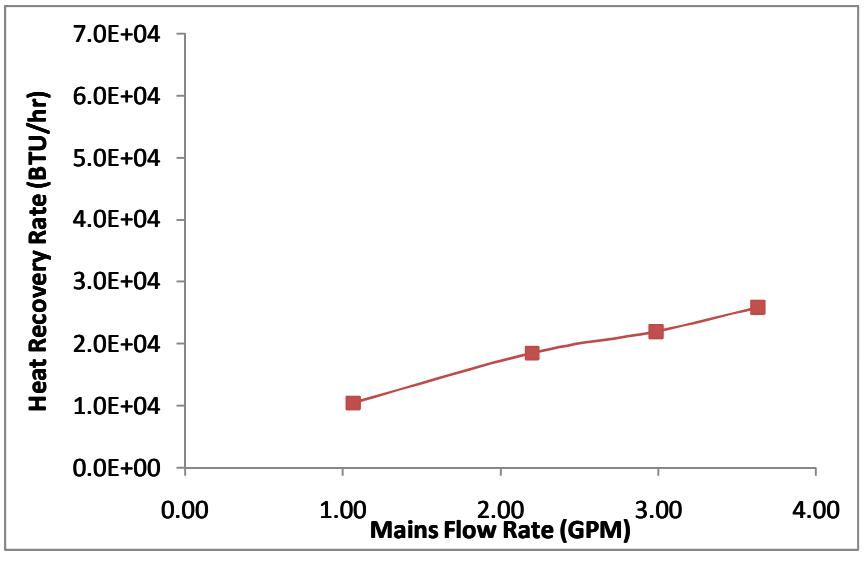
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

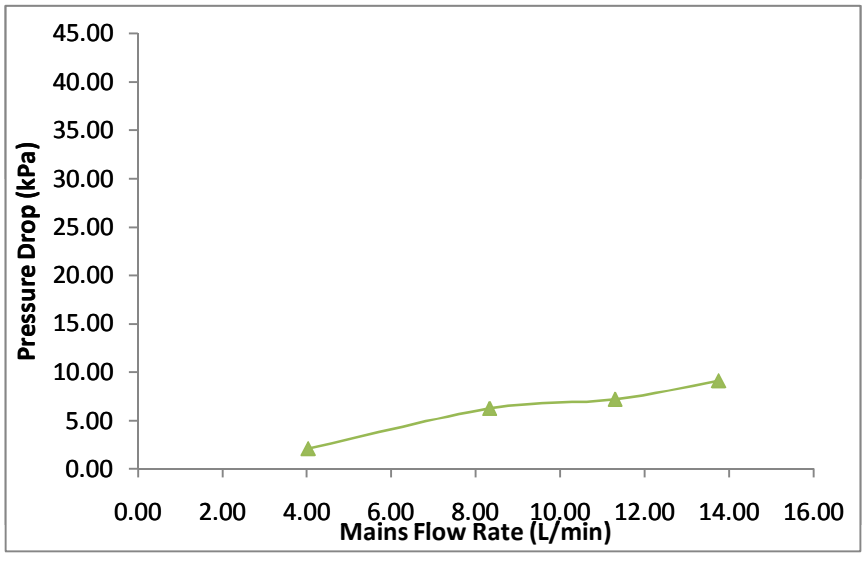
Effectiveness	0.315			
Heat Recovery	5.81	kW	19834.9	BTU/hr
Pressure Drop	6.62	kPa	0.96	PSI

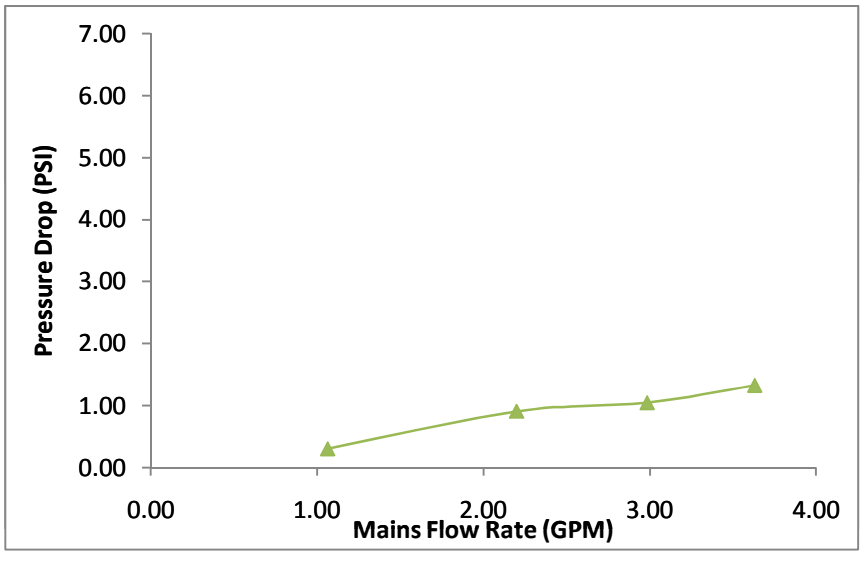












UNIVERSITY OF Waterloo

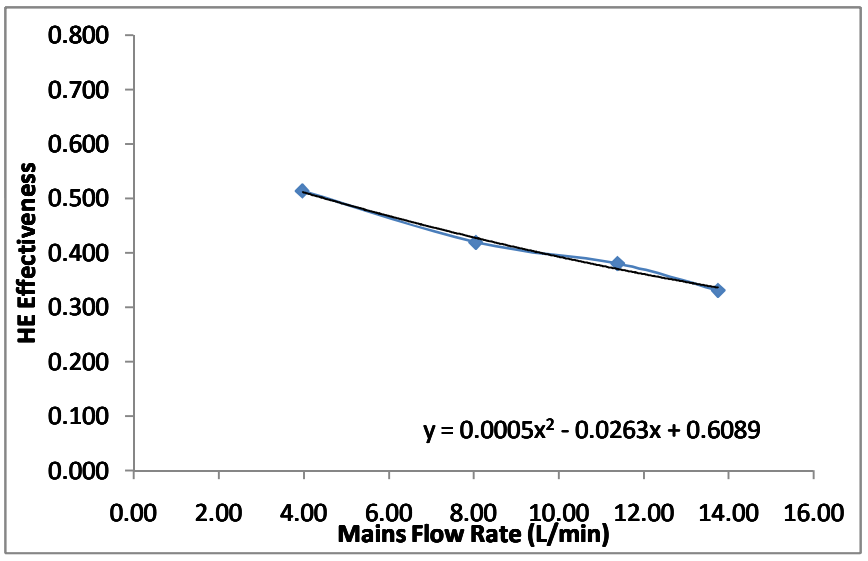
Product: 30in R4in
Manufacturer: Renewability
Test Date: March 3 / 2009 (14 L/min - April 9 / 2009)

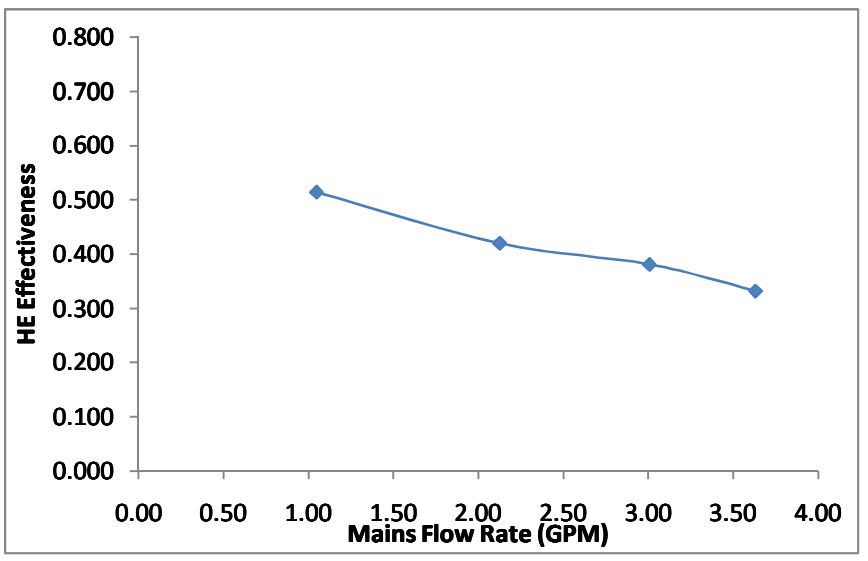
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.97	0.514	3.88	3.03
8.05	0.420	6.57	5.34
11.39	0.381	8.39	8.41
13.75	0.332	9.00	10.12

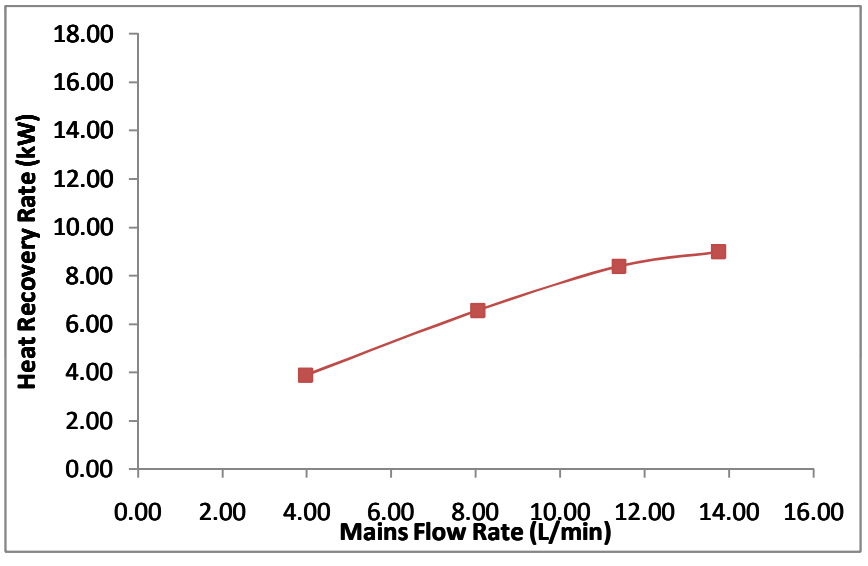
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.514	13250.89	0.44
2.13	0.420	22437.73	0.77
3.01	0.381	28653.35	1.22
3.63	0.332	30736.61	1.47

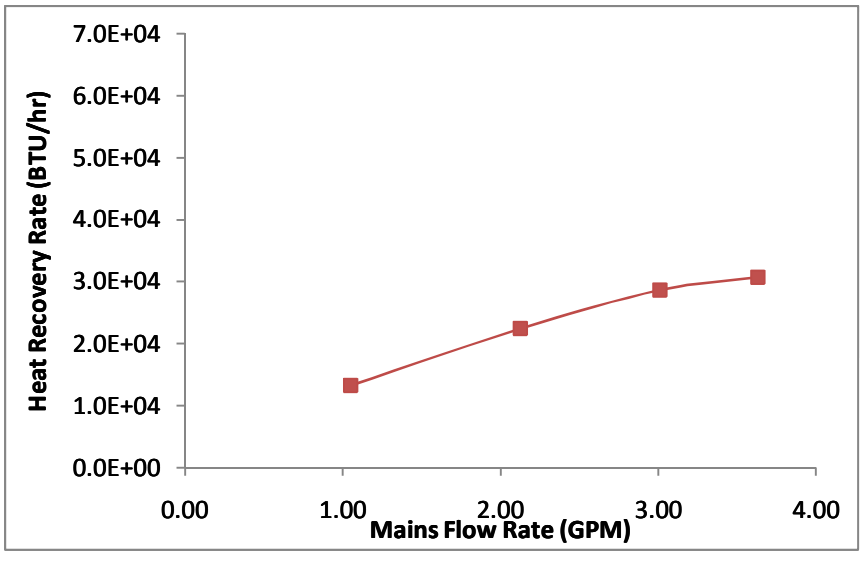
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

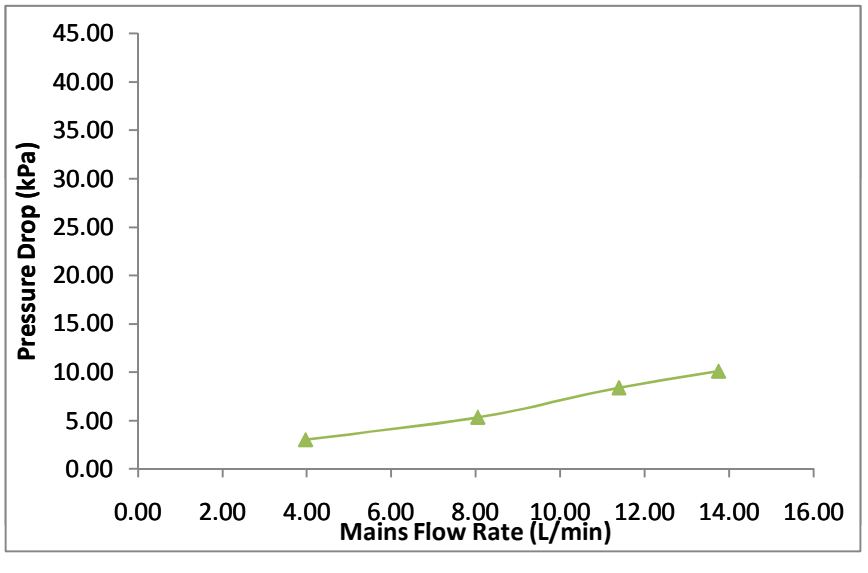
Effectiveness	0.404			
Heat Recovery	7.36	kW	25136.1	BTU/hr
Pressure Drop	6.67	kPa	0.97	PSI

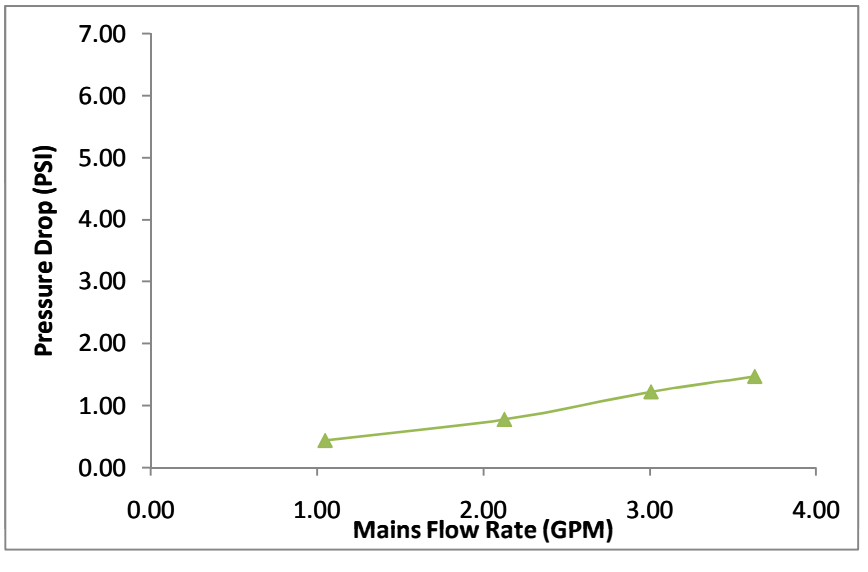












UNIVERSITY OF Waterloo

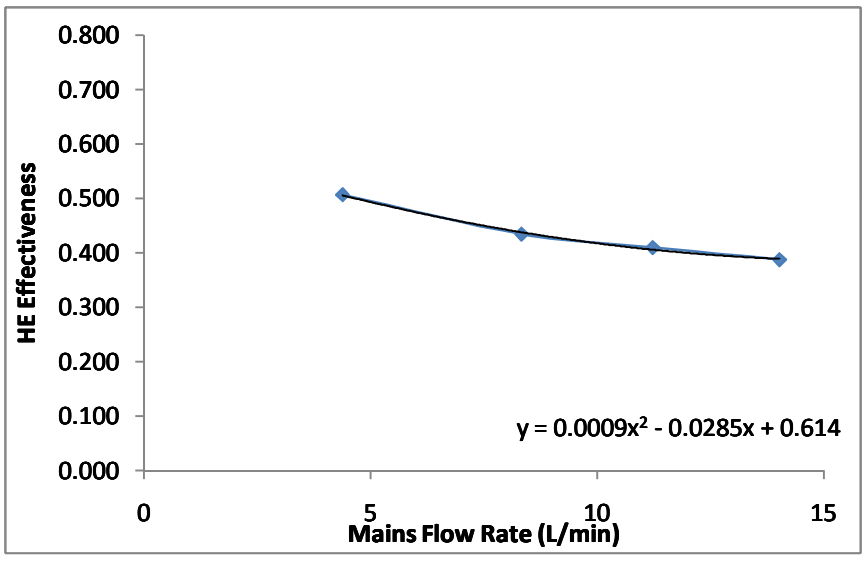
Product: 36in R4in
Manufacturer: Renewability
Test Date: March 2 / 2009 (14 L/min - April 13 / 2009)

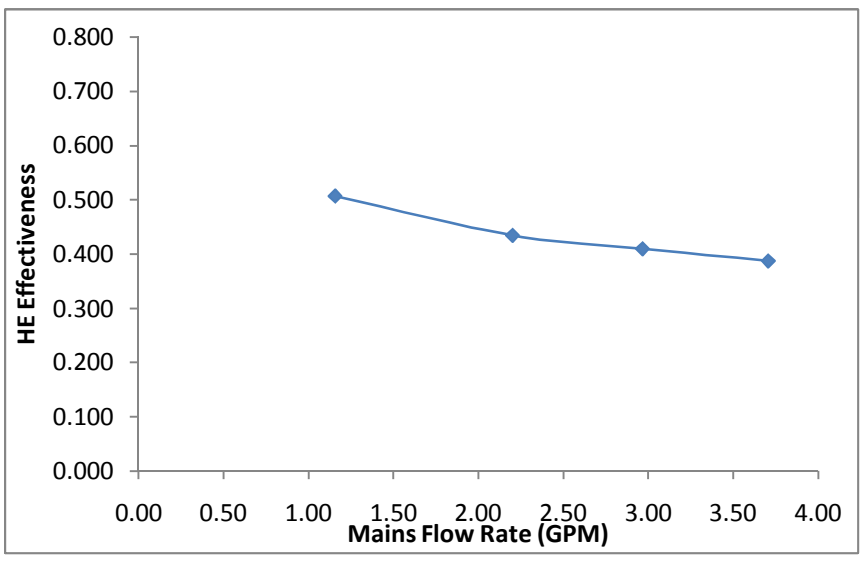
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.38	0.507	4.42	7.62
8.33	0.435	7.21	7.35
11.23	0.410	8.79	10.52
14.03	0.388	10.51	12.93

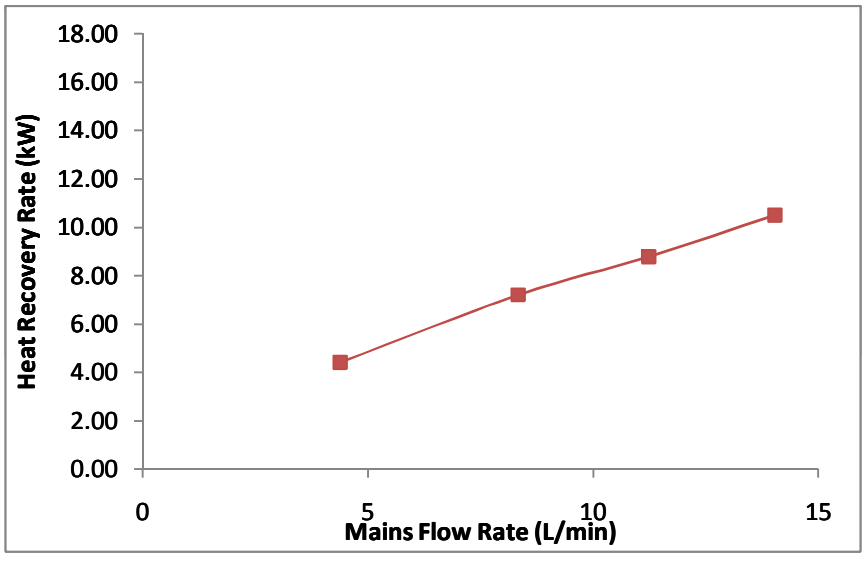
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.16	0.507	15095.09	1.11
2.20	0.435	24623.44	1.07
2.97	0.410	30019.42	1.53
3.71	0.388	35893.53	1.88

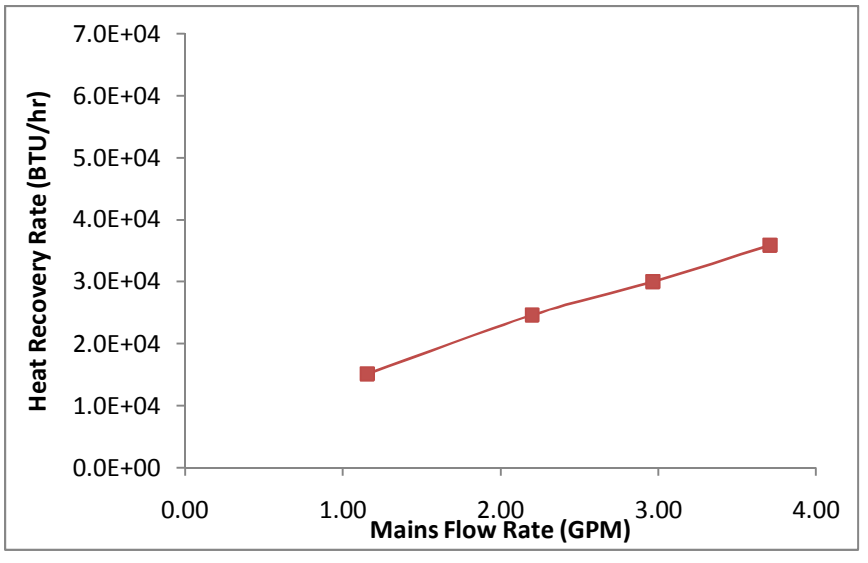
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

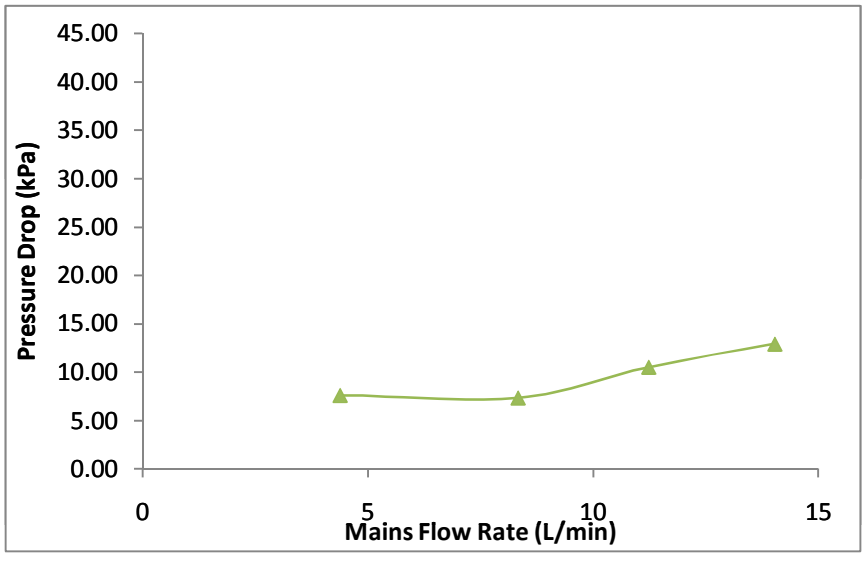
Effectiveness	0.424			
Heat Recovery	7.85	kW	26800.4	BTU/hr
Pressure Drop	8.63	kPa	1.25	PSI

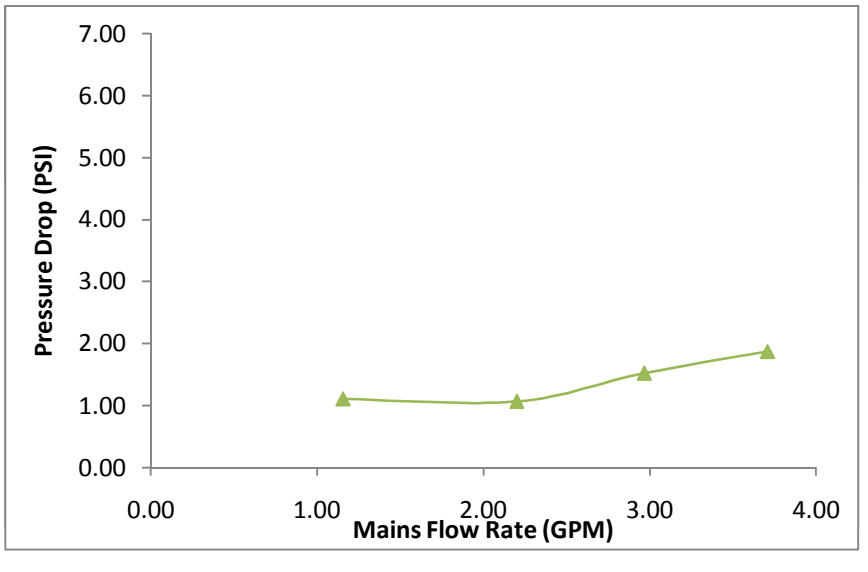












UNIVERSITY OF Waterloo

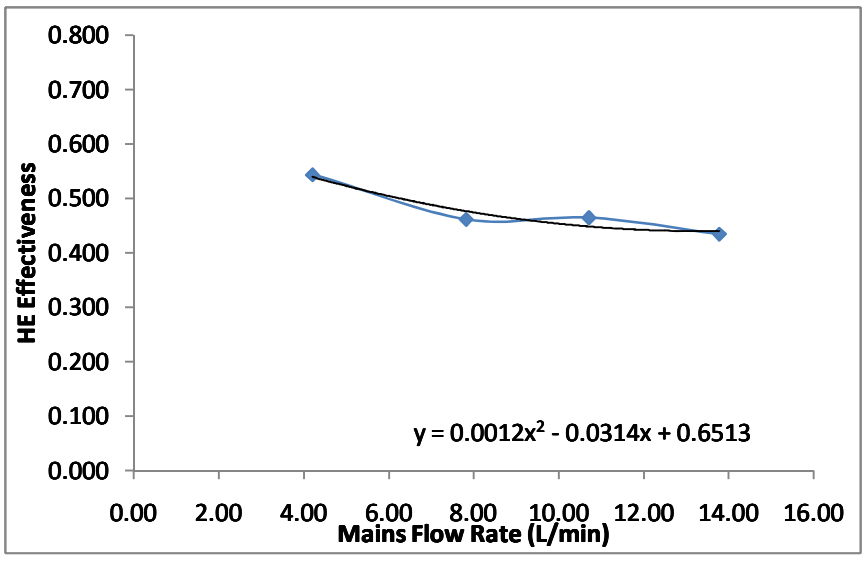
Product: 42in R4in
Manufacturer: Renewability
Test Date: March 9 / 2009 (14 L/min - April 9 / 2009)

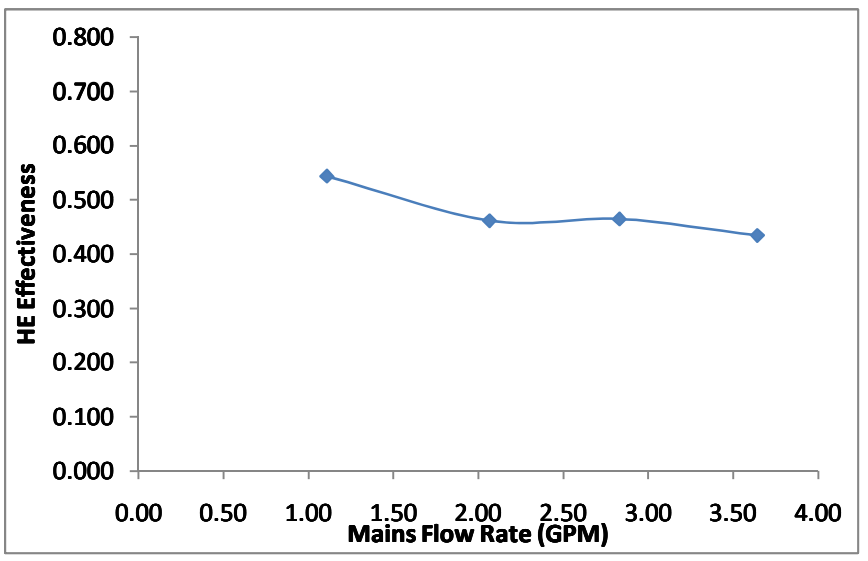
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.20	0.544	4.40	1.81
7.82	0.462	7.01	5.67
10.71	0.465	9.72	8.84
13.78	0.435	11.71	13.26

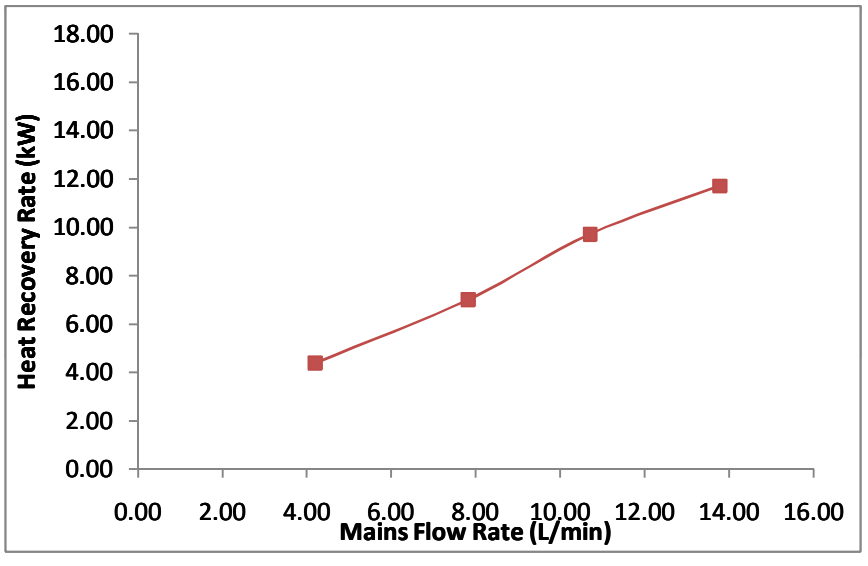
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.11	0.544	15026.79	0.26
2.07	0.462	23940.40	0.82
2.83	0.465	33195.54	1.28
3.64	0.435	39991.75	1.92

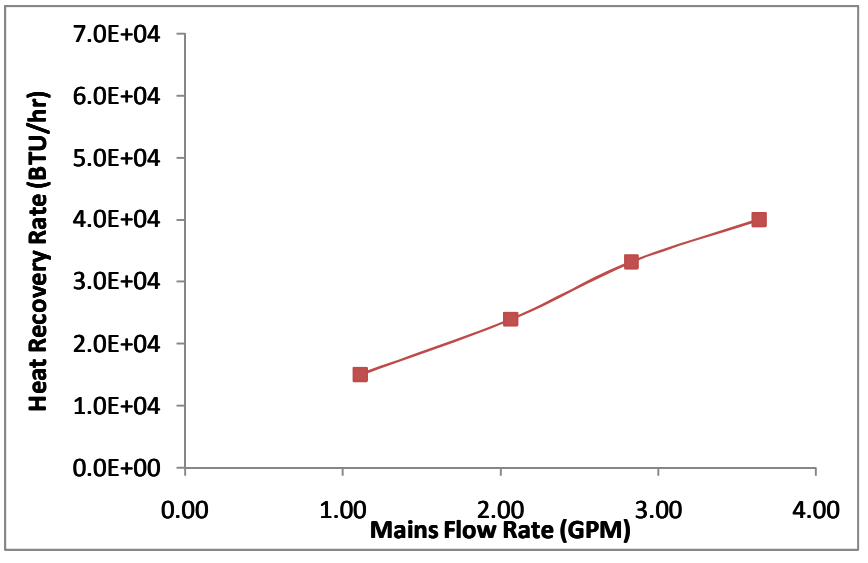
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

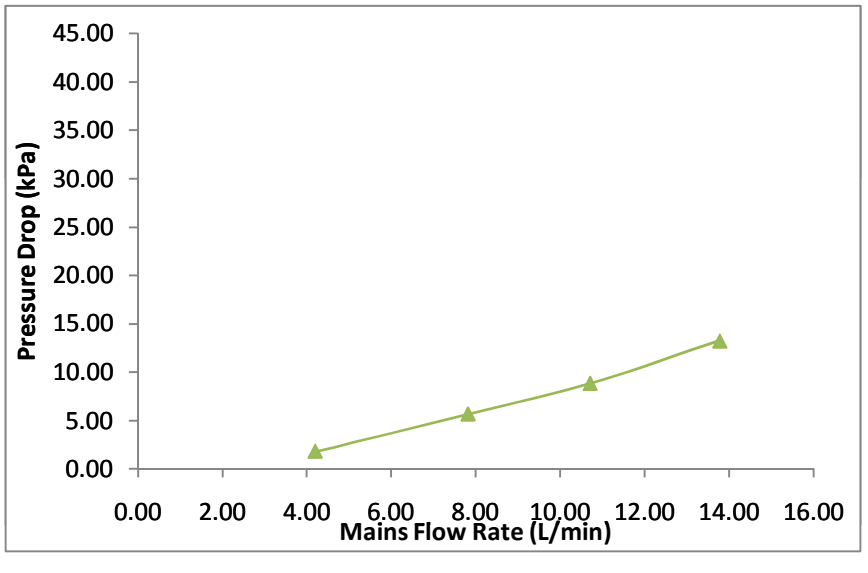
Effectiveness	0.461			
Heat Recovery	8.59	kW	29320.6	BTU/hr
Pressure Drop	7.51	kPa	1.09	PSI

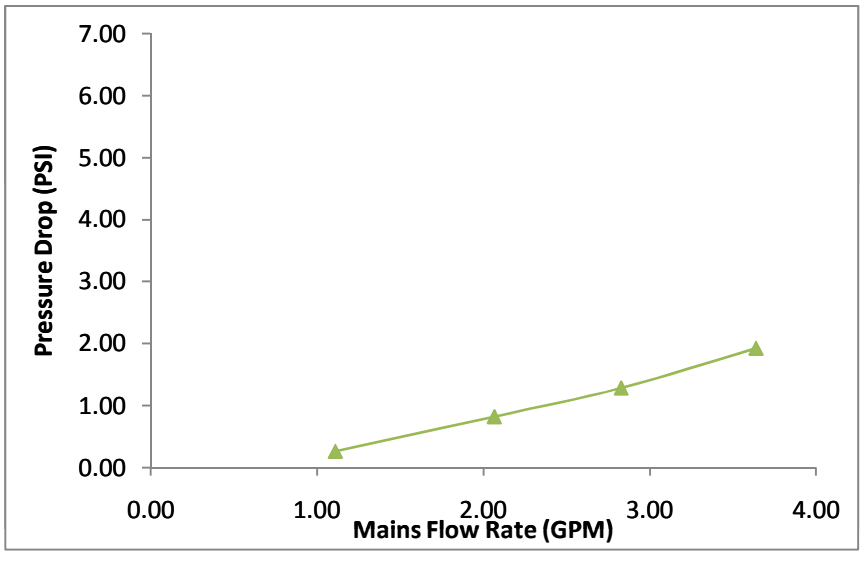












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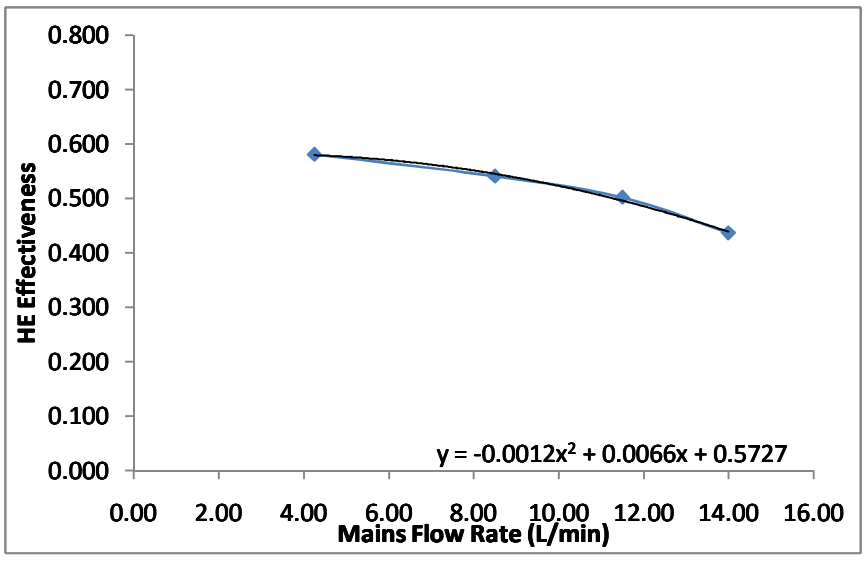
Product: 48in R4in
Manufacturer: Renewability
Test Date: March 3 / 2009 (14 L/min - April 9 / 2009)

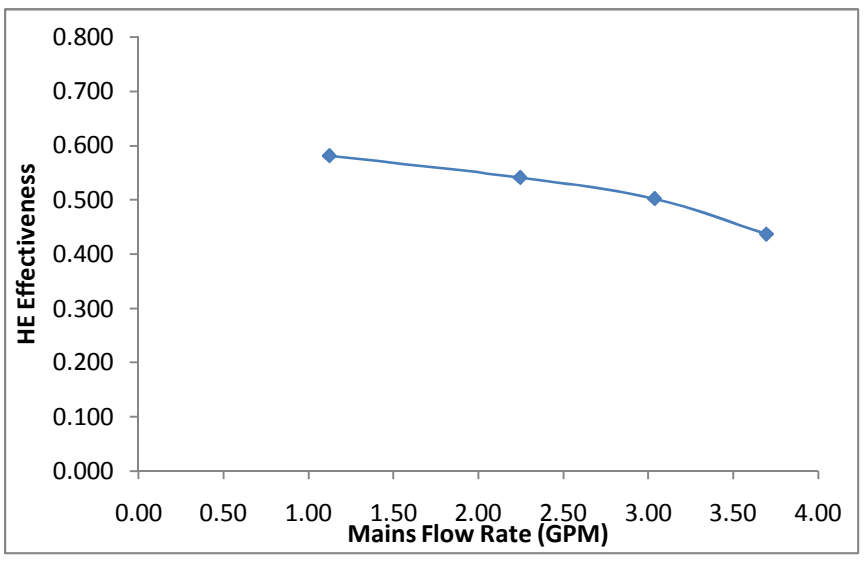
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.25	0.581	4.77	5.18
8.50	0.541	8.91	9.26
11.50	0.502	11.31	15.47
13.99	0.437	11.74	18.63

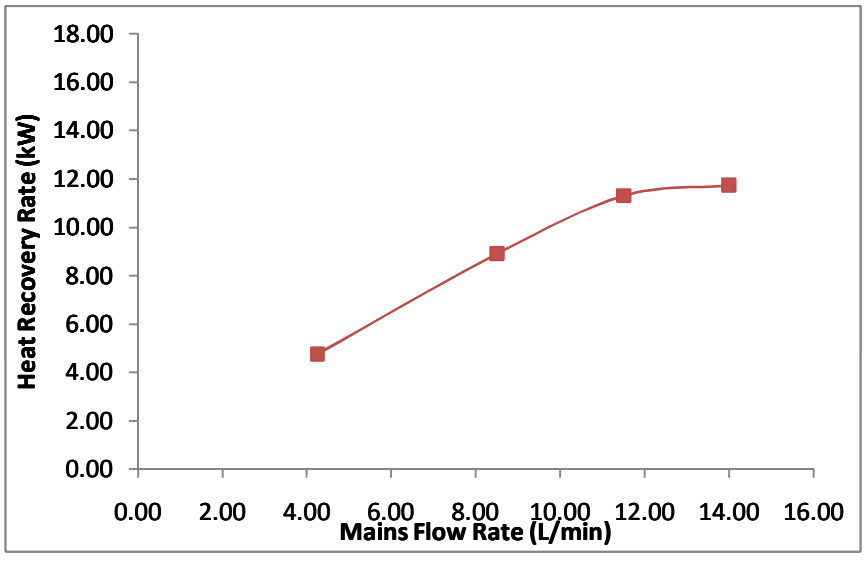
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.12	0.581	16290.40	0.75
2.25	0.541	30429.24	1.34
3.04	0.502	38625.67	2.24
3.70	0.437	40094.20	2.70

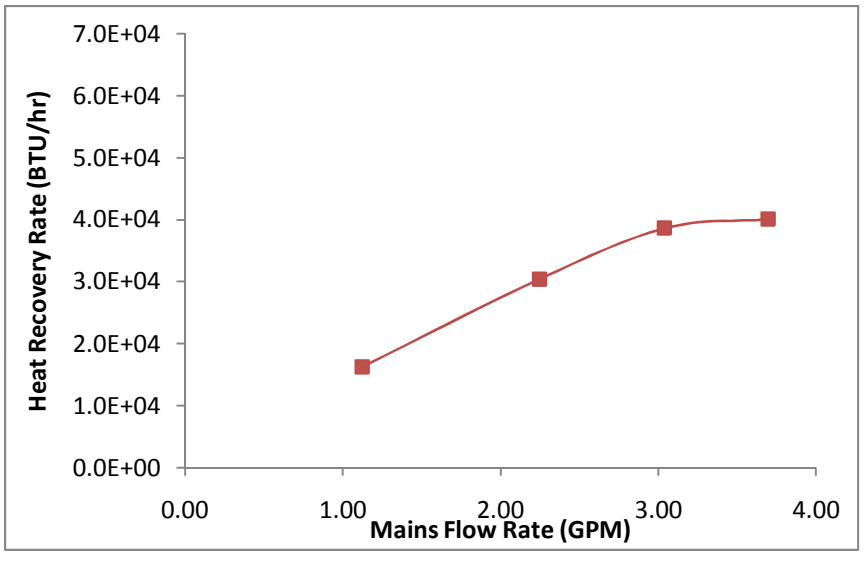
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

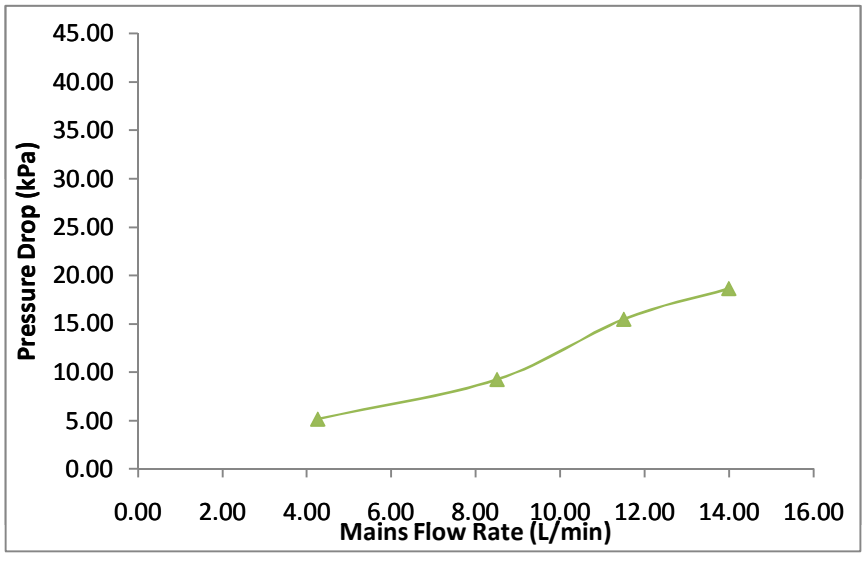
Effectiveness	0.527			
Heat Recovery	9.71	kW	33161.4	BTU/hr
Pressure Drop	11.33	kPa	1.64	PSI

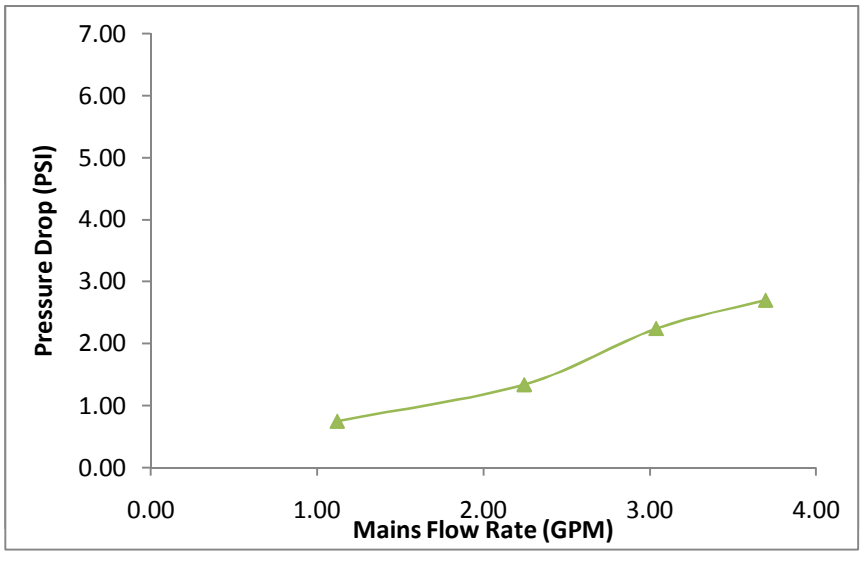












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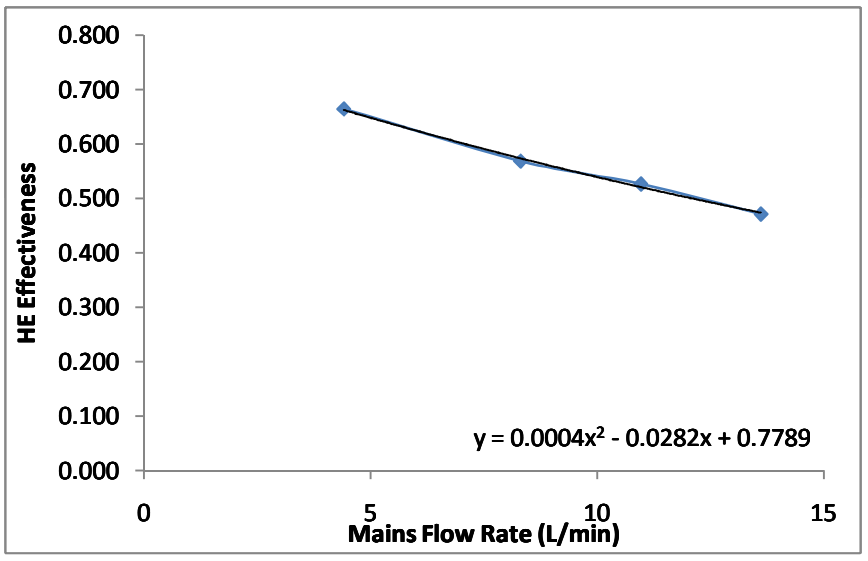
Product: 54in R4in
Manufacturer: Renewability
Test Date: March 3 / 2009

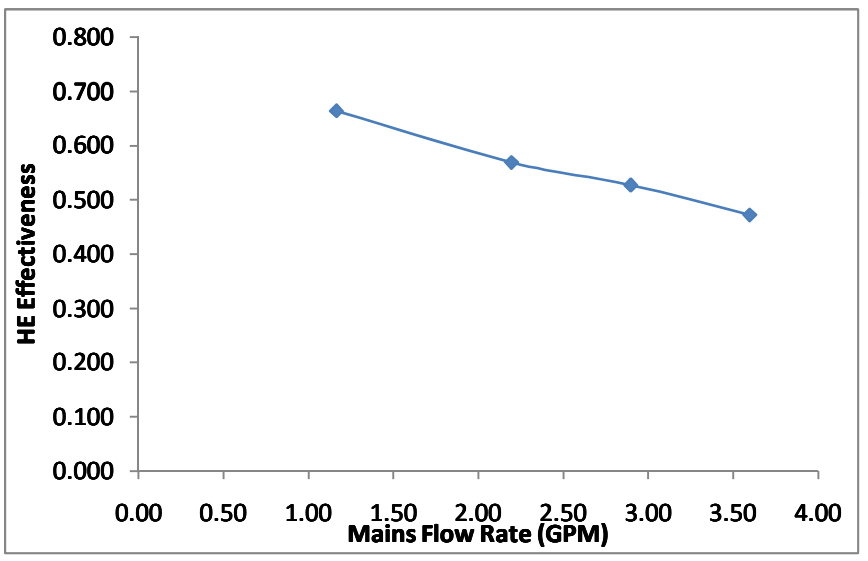
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.41	0.664	5.61	5.06
8.31	0.569	8.97	10.40
10.97	0.527	11.27	16.40
13.62	0.472	12.35	23.95

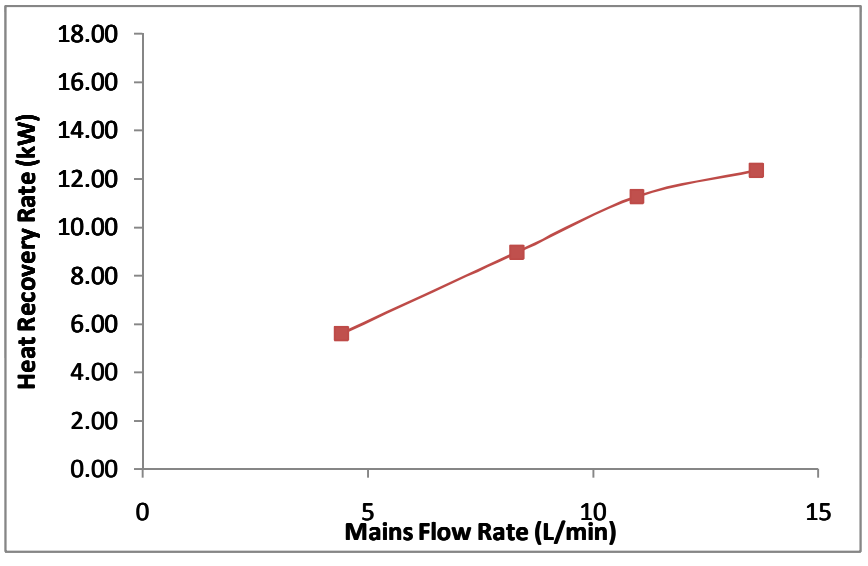
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.16	0.664	19159.15	0.73
2.20	0.569	30634.16	1.51
2.90	0.527	38489.07	2.38
3.60	0.472	42177.46	3.47

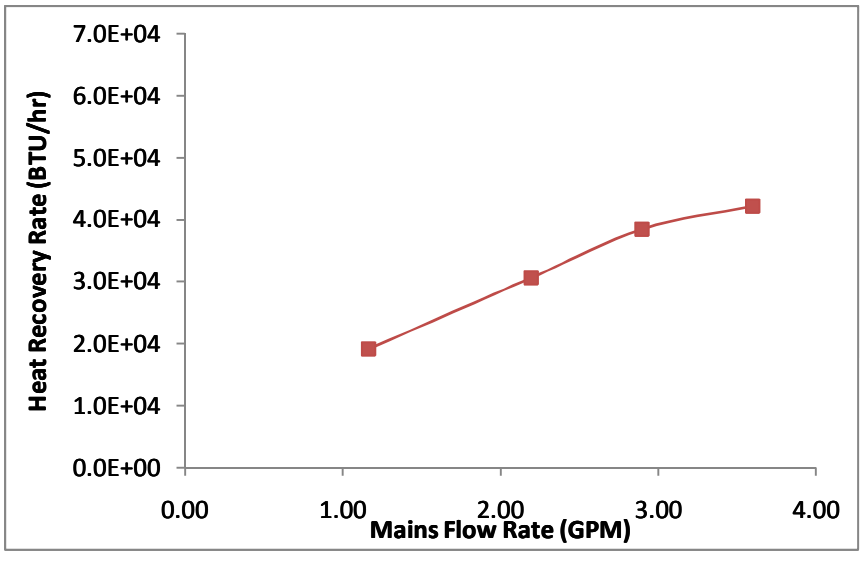
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

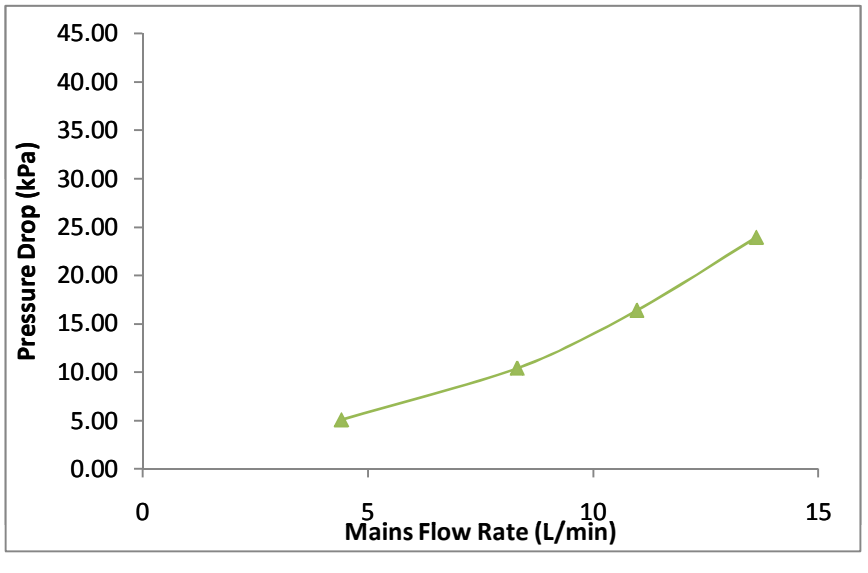
Effectiveness	0.547			
Heat Recovery	10.00	kW	34148.2	BTU/hr
Pressure Drop	13.08	kPa	1.90	PSI

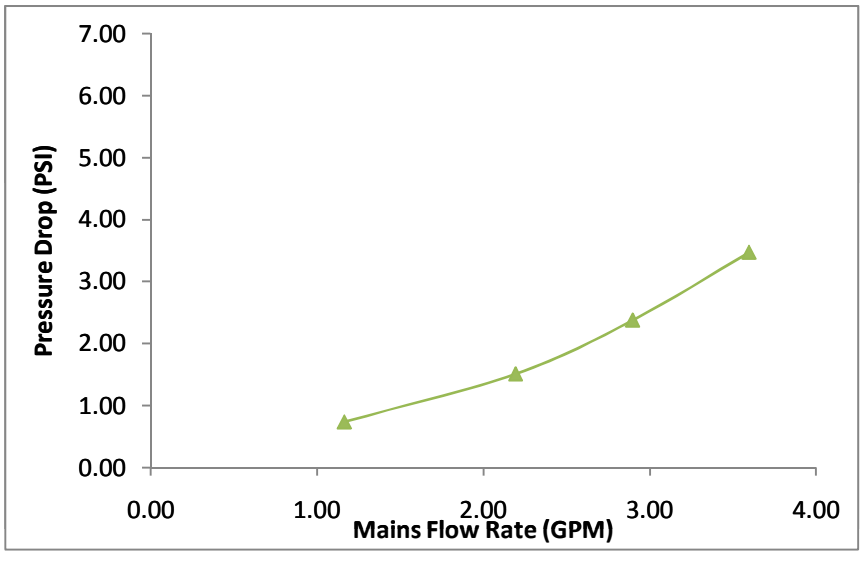












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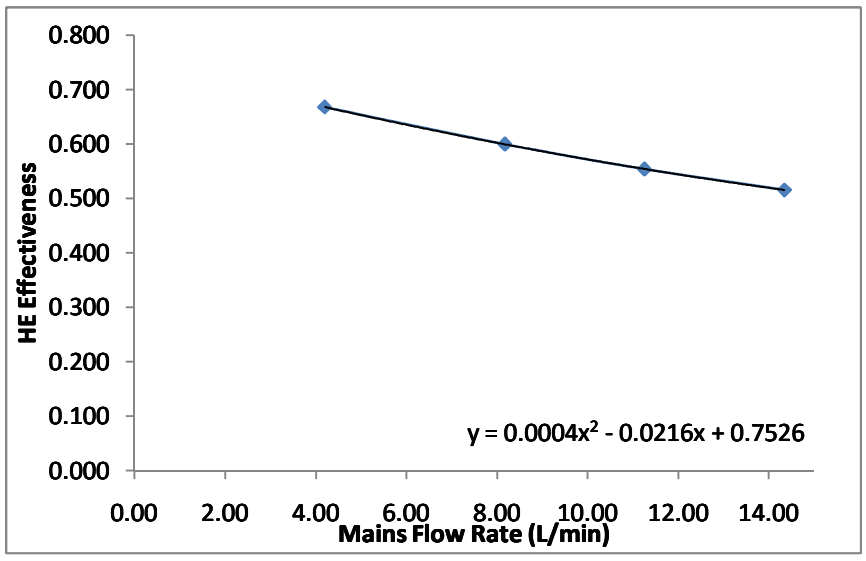
Product: 60in R4in
Manufacturer: Renewability
Test Date: March 2-3 / 2009 (4 L/min - March 26 / 2009 : 14 L/min - March 31 /2009)

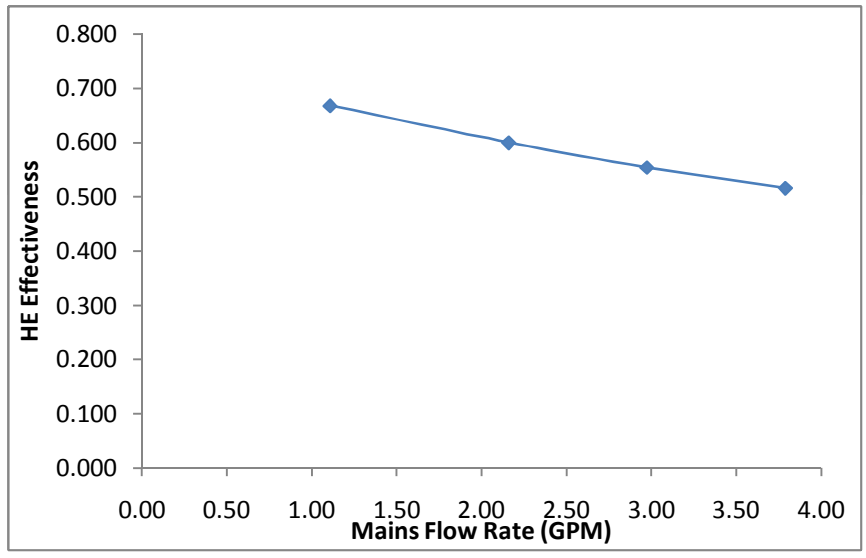
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.20	0.668	5.50	5.08
8.18	0.600	9.60	10.83
11.26	0.554	12.25	17.78
14.35	0.516	14.46	24.79

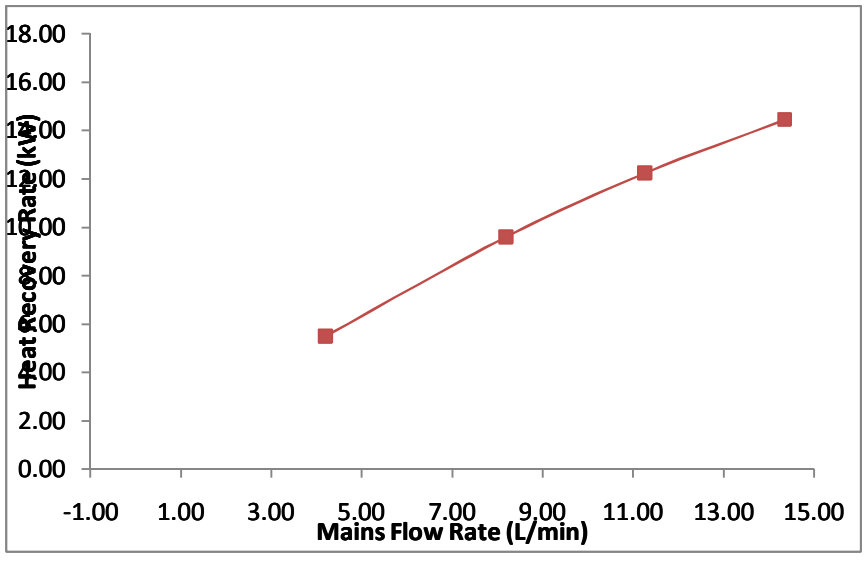
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.11	0.668	18783.48	0.74
2.16	0.600	32785.72	1.57
2.97	0.554	41835.94	2.58
3.79	0.516	49383.49	3.60

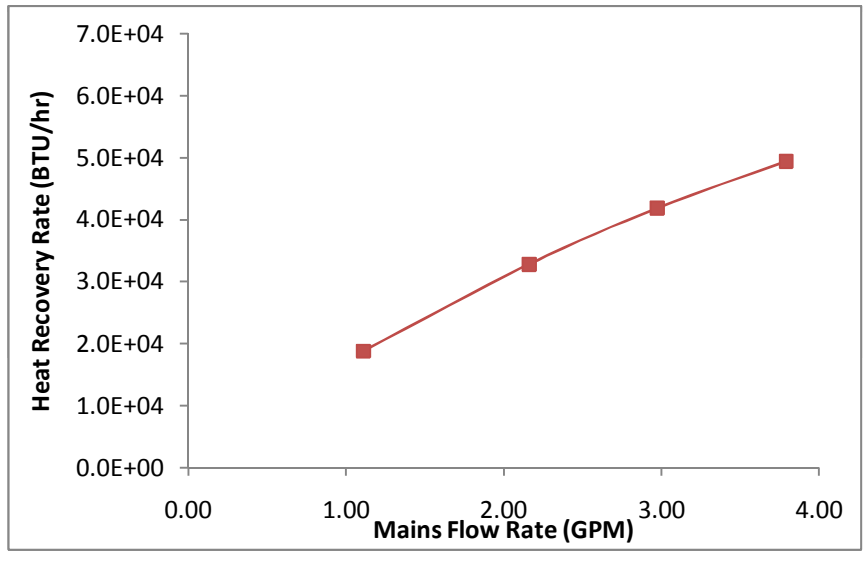
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

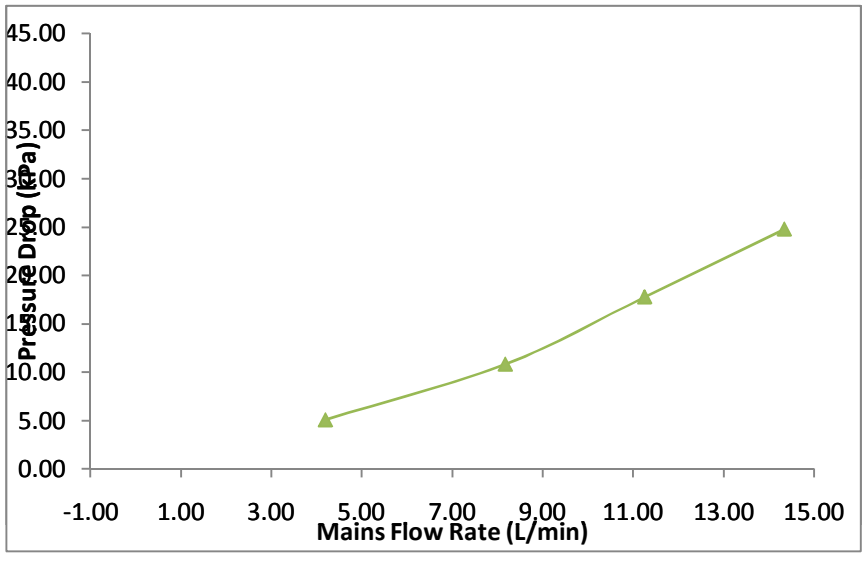
Effectiveness	0.584			
Heat Recovery	10.74	kW	36664.4	BTU/hr
Pressure Drop	13.81	kPa	2.00	PSI

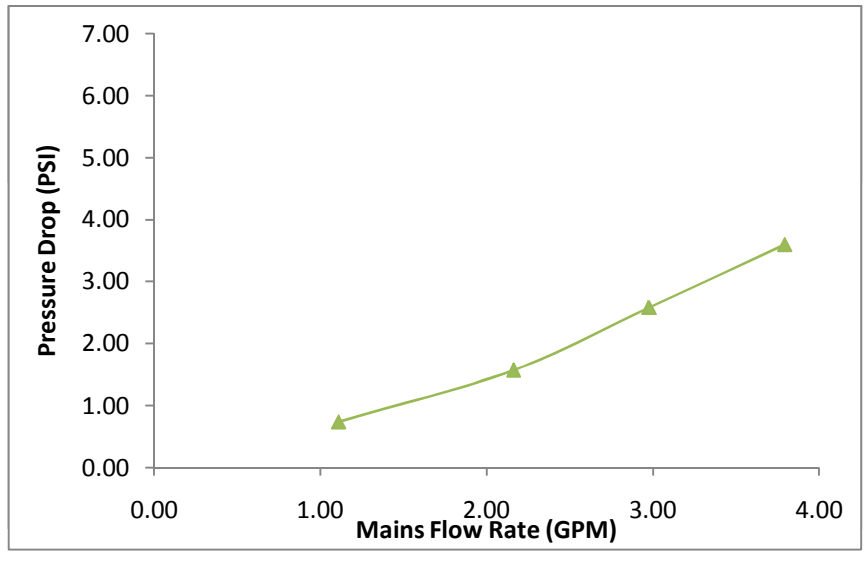












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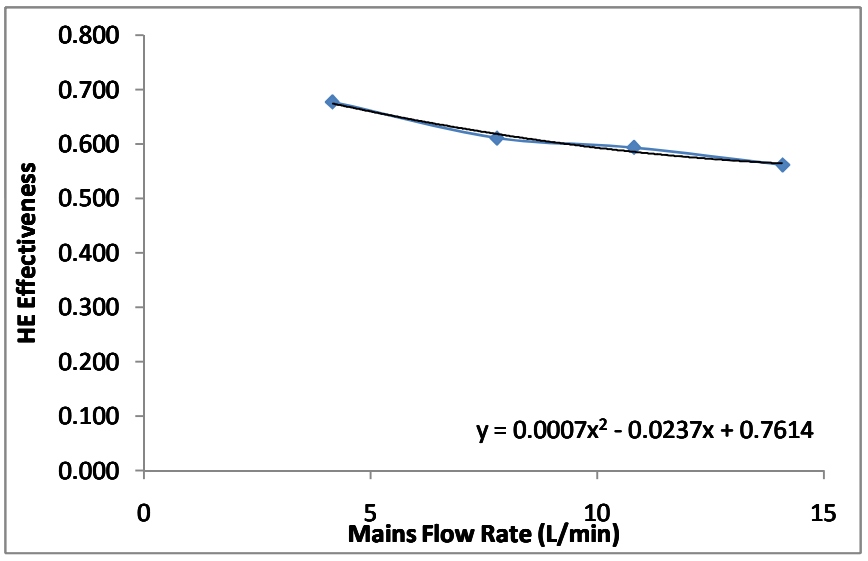
Product: 66in R4in
Manufacturer: Renewability
Test Date: March 10 / 2009 (14 L/min - April 9 / 2009)

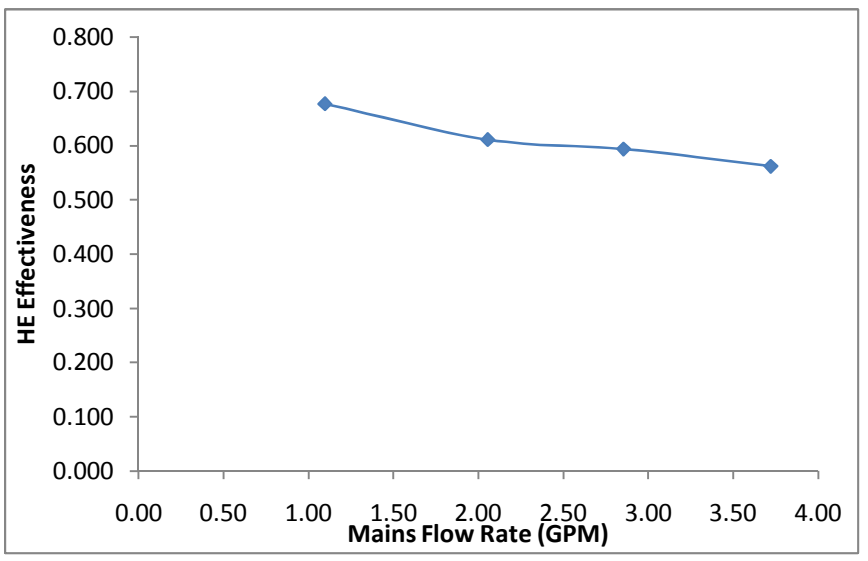
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.16	0.677	5.48	4.26
7.79	0.611	9.28	11.41
10.81	0.594	12.45	20.14
14.09	0.562	15.65	27.59

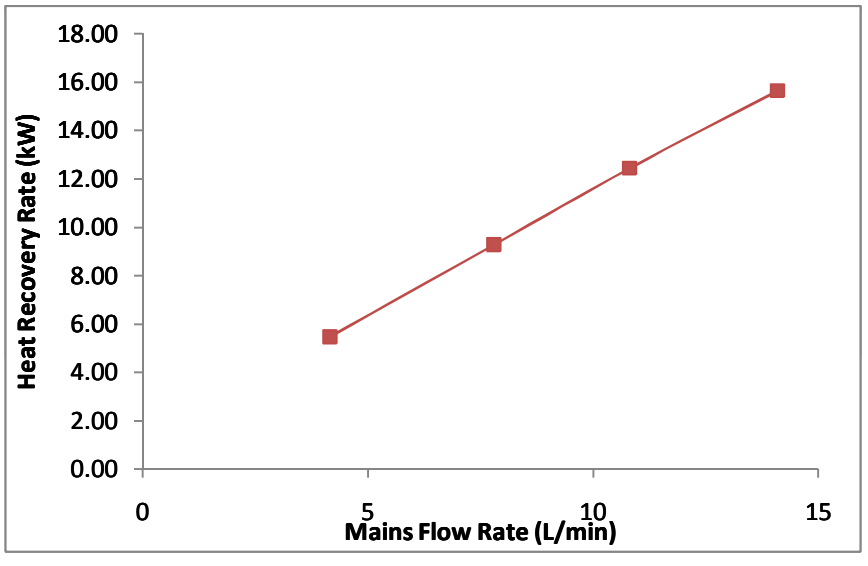
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.10	0.677	18715.18	0.62
2.06	0.611	31692.86	1.65
2.86	0.594	42518.98	2.92
3.72	0.562	53447.55	4.00

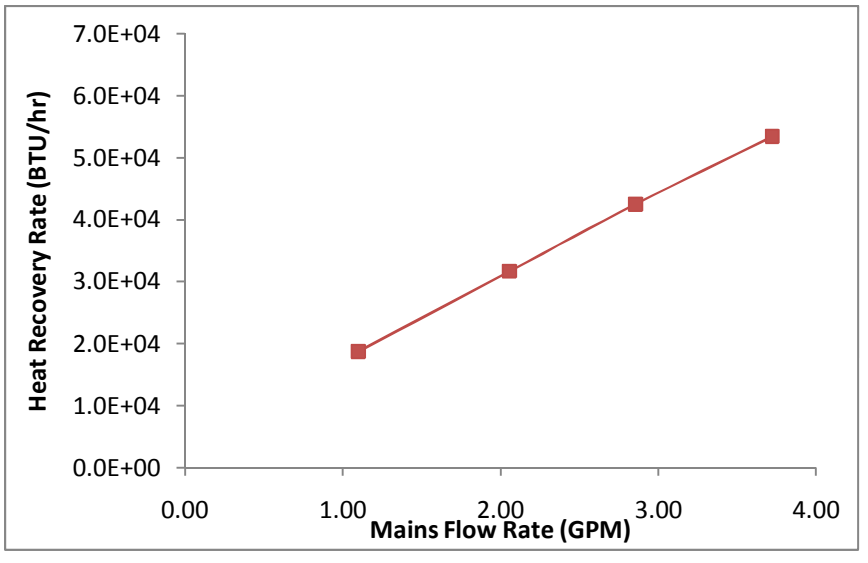
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

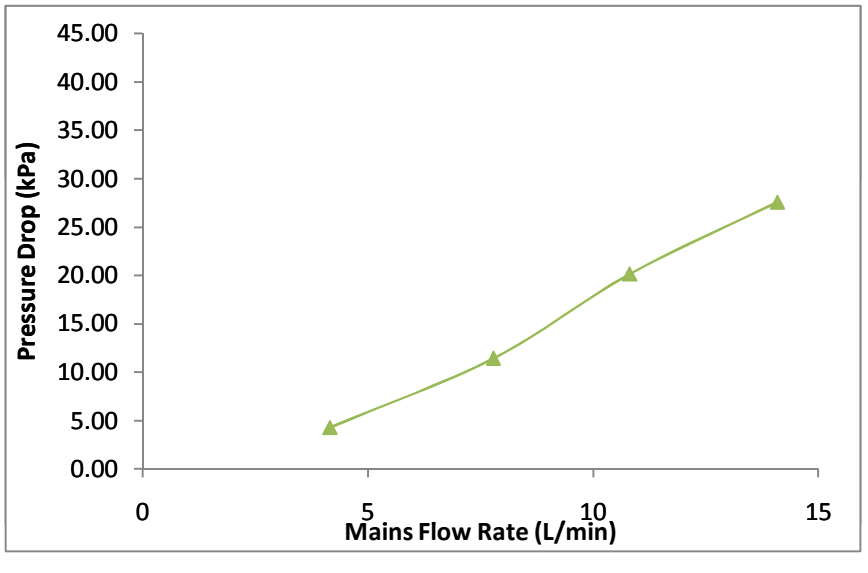
Effectiveness	0.599			
Heat Recovery	11.07	kW	37822.9	BTU/hr
Pressure Drop	16.35	kPa	2.37	PSI

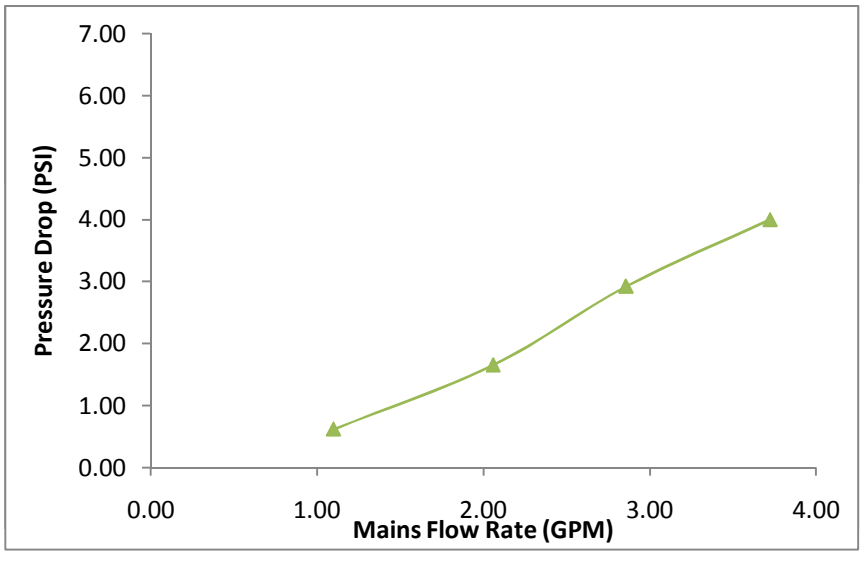












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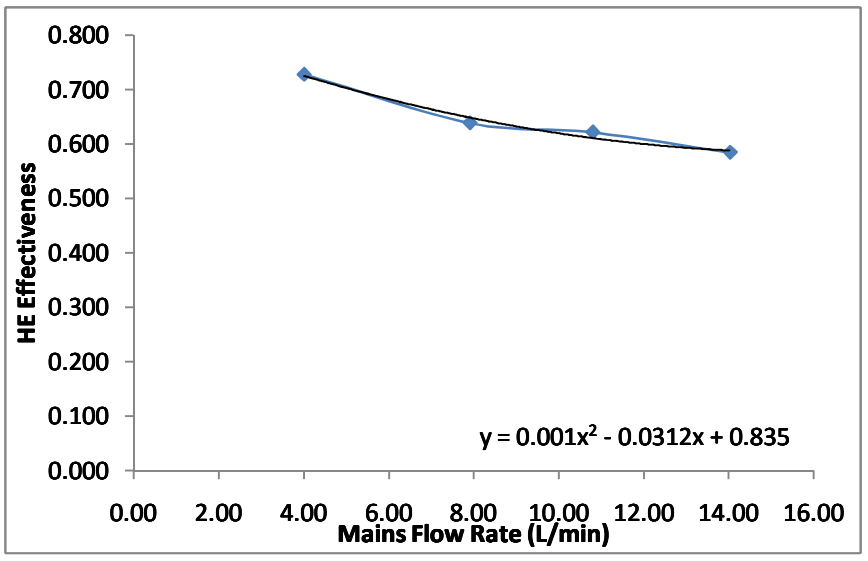
Product: 72in R4in
Manufacturer: Renewability
Test Date: March 9 / 2009 (14 L/min - April 13 / 2009)

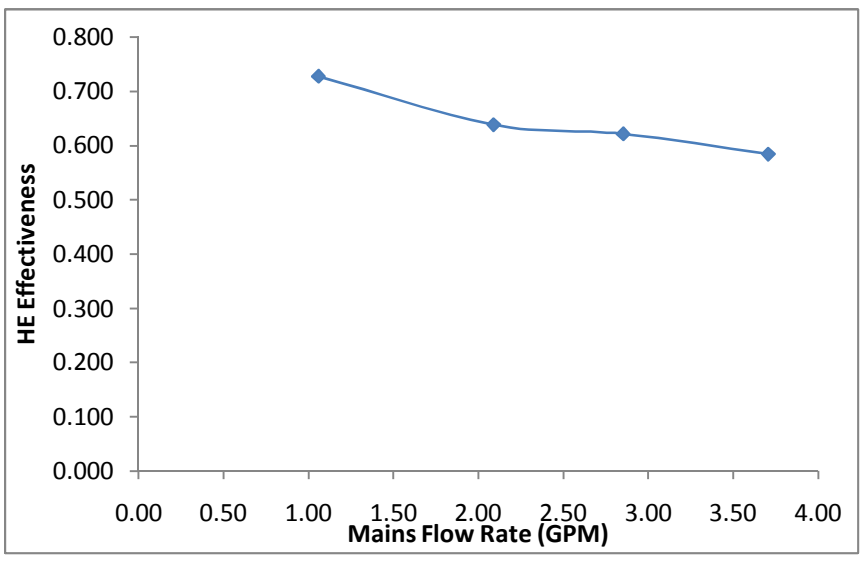
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.01	0.728	5.68	4.80
7.91	0.639	9.85	12.68
10.80	0.622	13.09	20.15
14.03	0.585	16.22	27.33

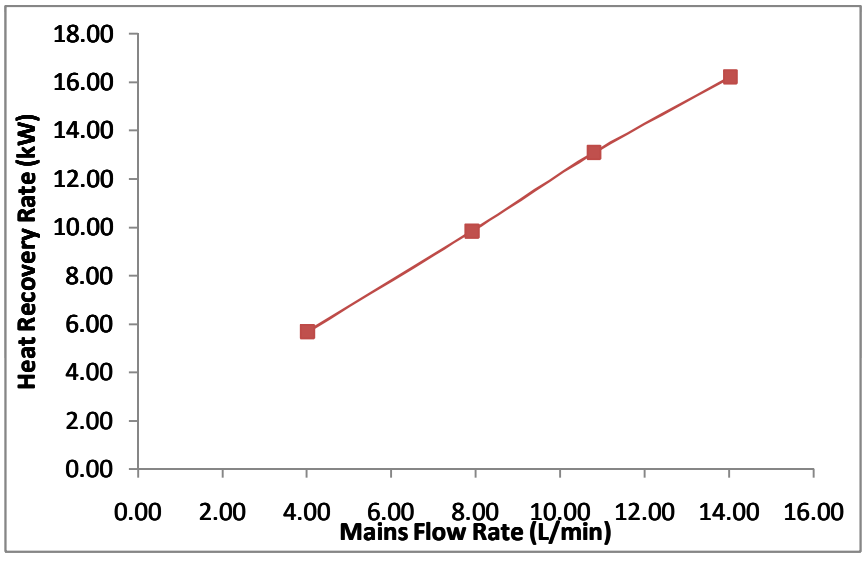
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.728	19398.22	0.70
2.09	0.639	33639.51	1.84
2.85	0.622	44704.69	2.92
3.71	0.585	55394.20	3.96

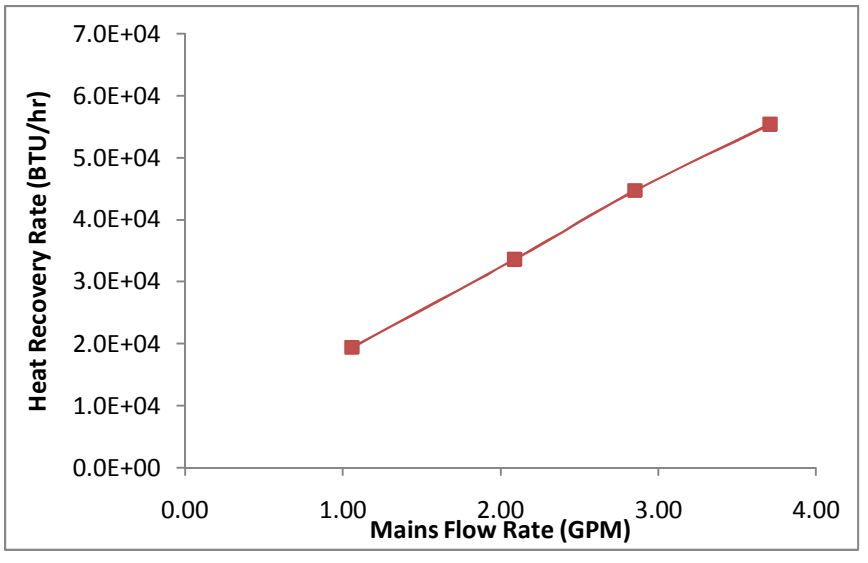
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

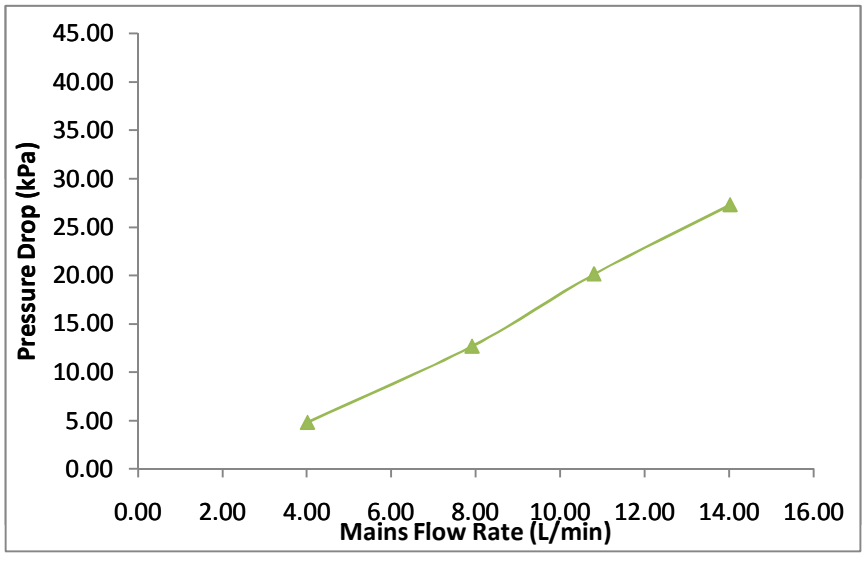
Effectiveness	0.629			
Heat Recovery	11.63	kW	39727.3	BTU/hr
Pressure Drop	16.79	kPa	2.44	PSI

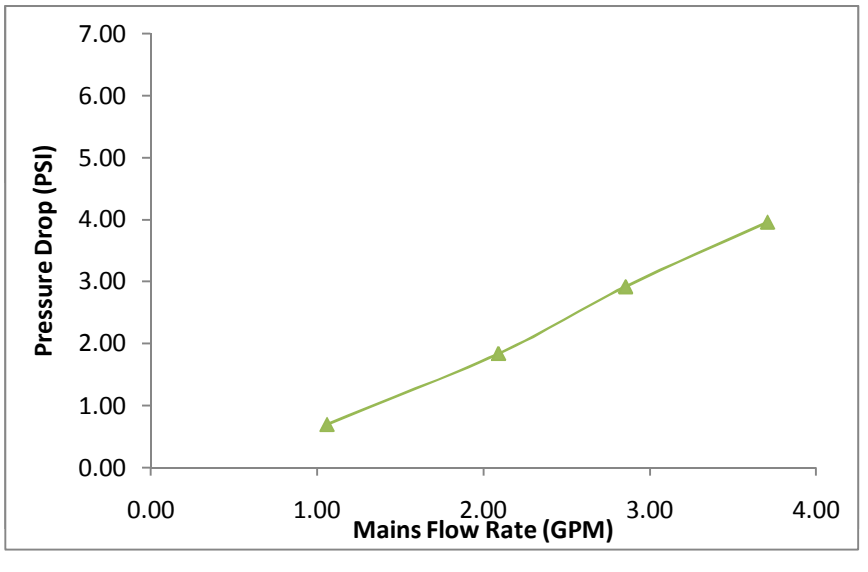












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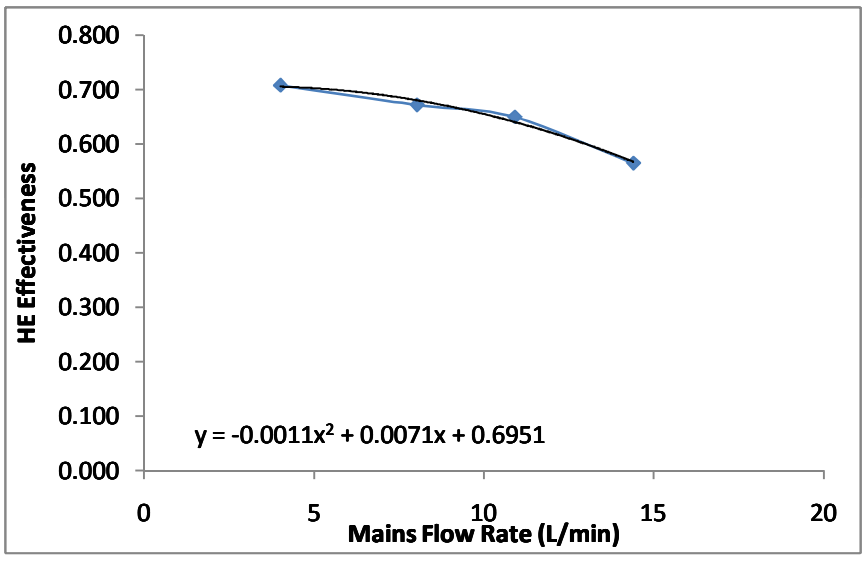
Product: 84in R4in
Manufacturer: Renewability
Test Date: February 14 / 2011

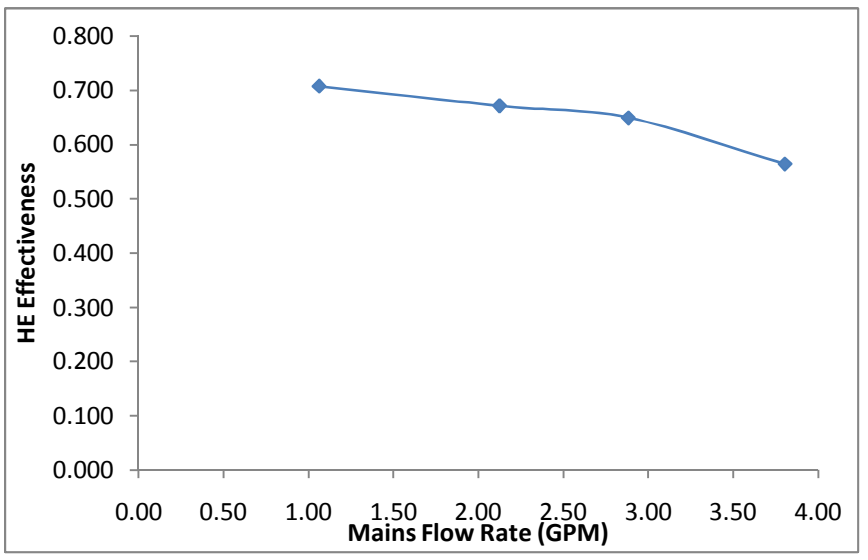
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.02	0.708	5.53	4.57
8.04	0.672	10.45	12.55
10.91	0.650	13.59	20.39
14.4	0.565	16.11	33.22

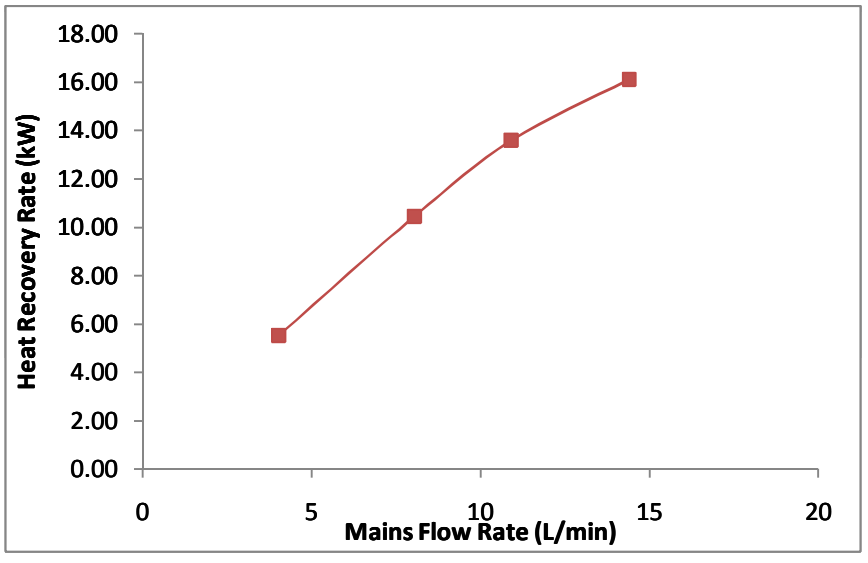
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.06	0.708	18885.94	0.66
2.12	0.672	35688.62	1.82
2.88	0.650	46412.28	2.96
3.80	0.565	55018.53	4.82

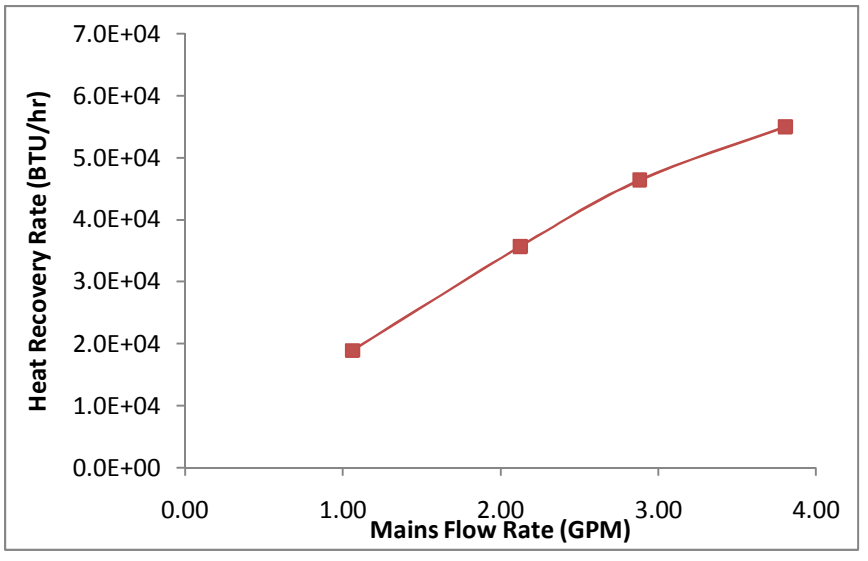
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

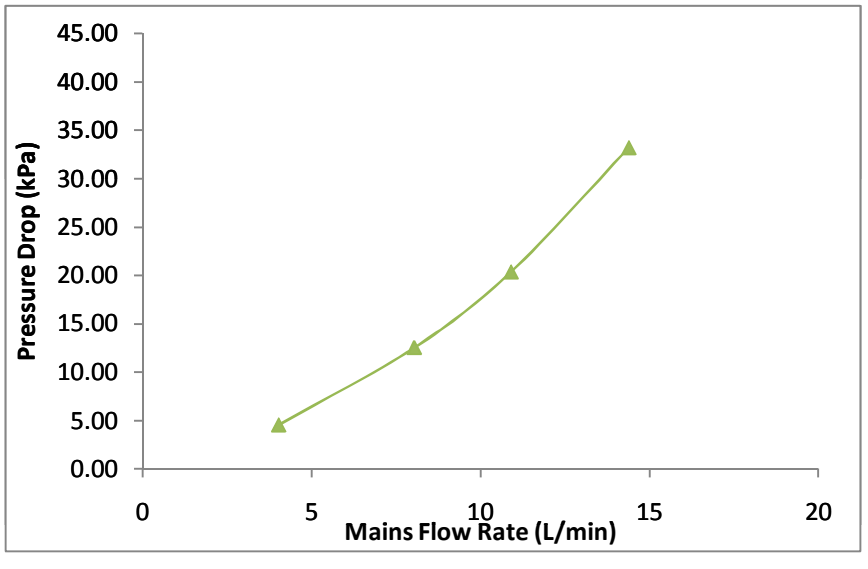
Effectiveness	0.663			
Heat Recovery	12.05	kW	41143.9	BTU/hr
Pressure Drop	16.54	kPa	2.40	PSI

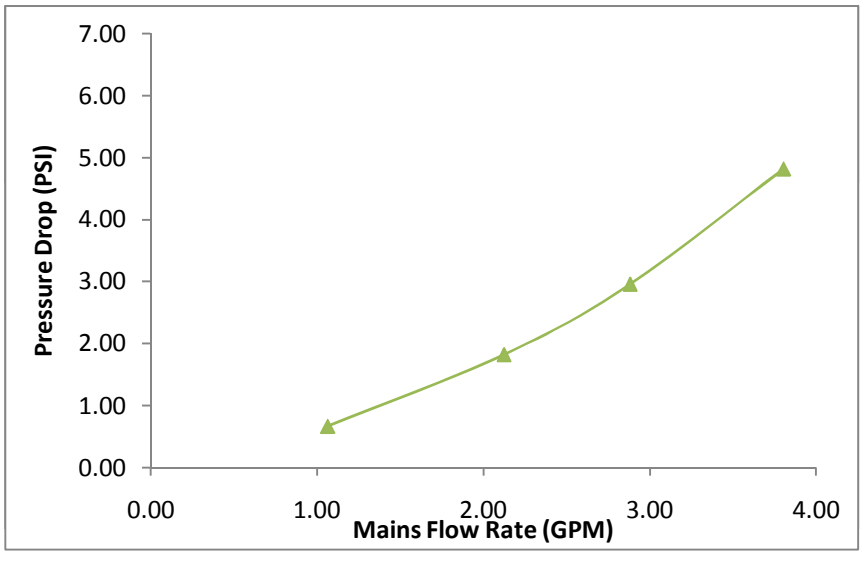












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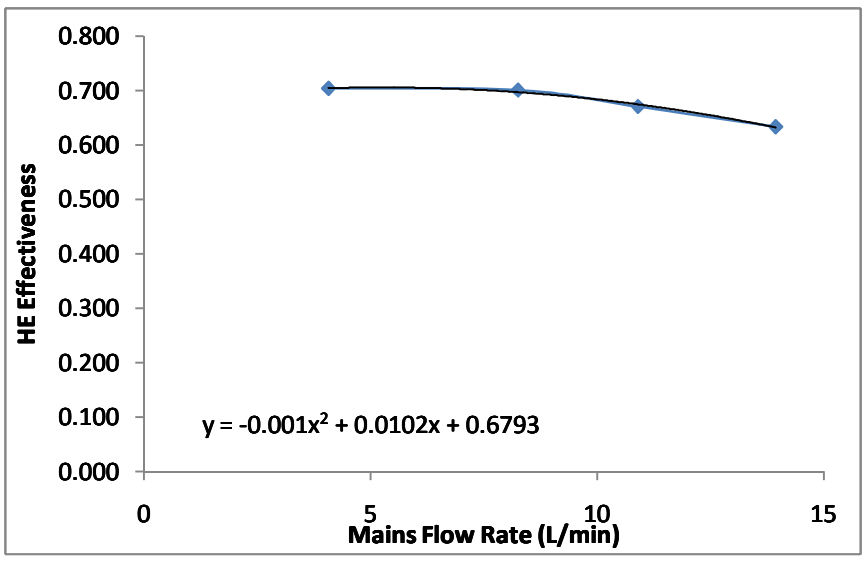
Product: 96in R4in
Manufacturer: Renewability
Test Date: February 10 / 2011

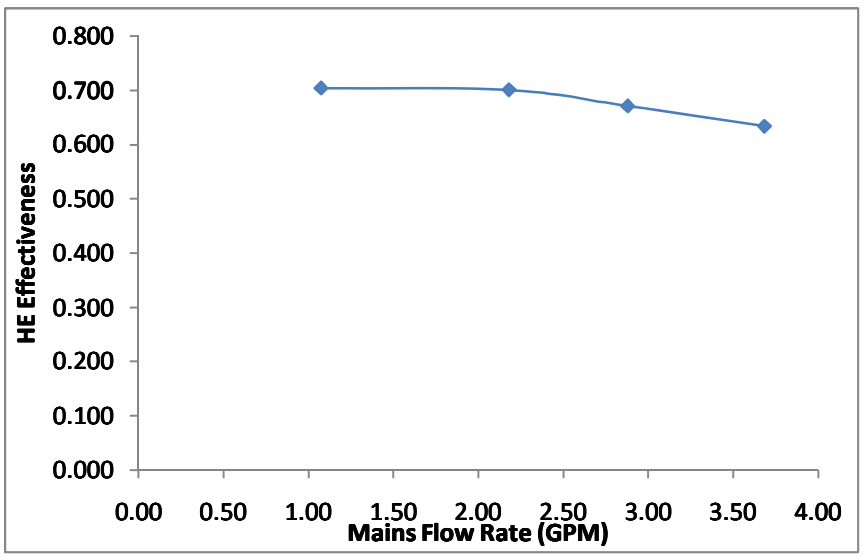
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
4.07	0.704	5.57	5.20
8.25	0.701	11.48	15.09
10.9	0.671	14.37	23.73
13.94	0.634	17.10	33.97

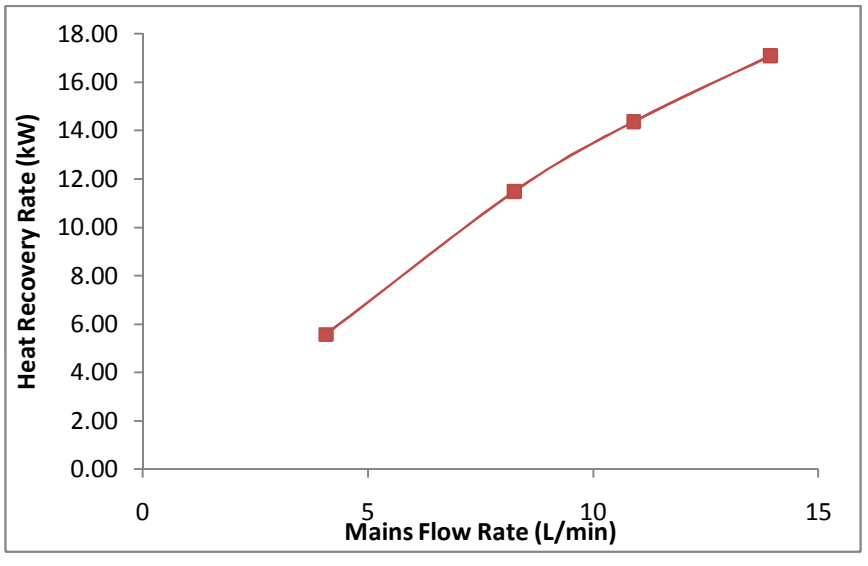
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.08	0.704	19022.55	0.75
2.18	0.701	39206.25	2.19
2.88	0.671	49076.12	3.44
3.68	0.634	58399.56	4.93

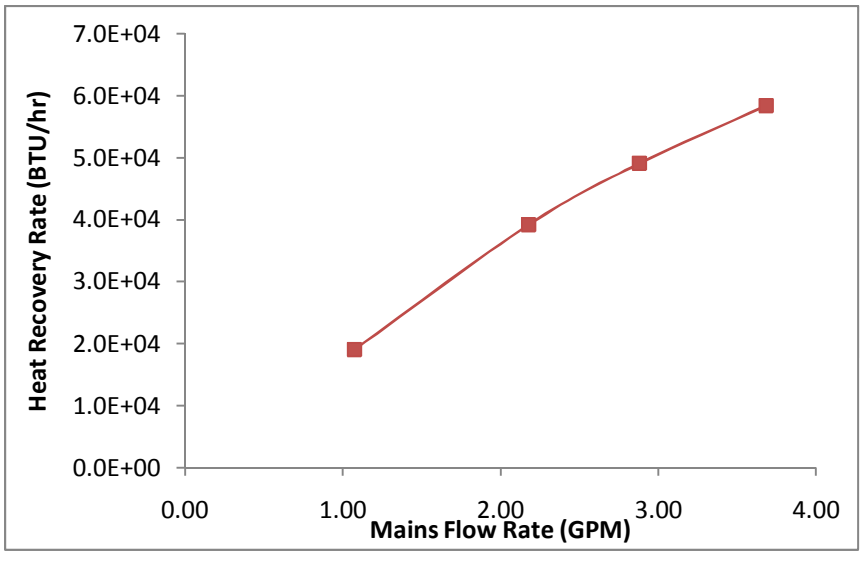
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

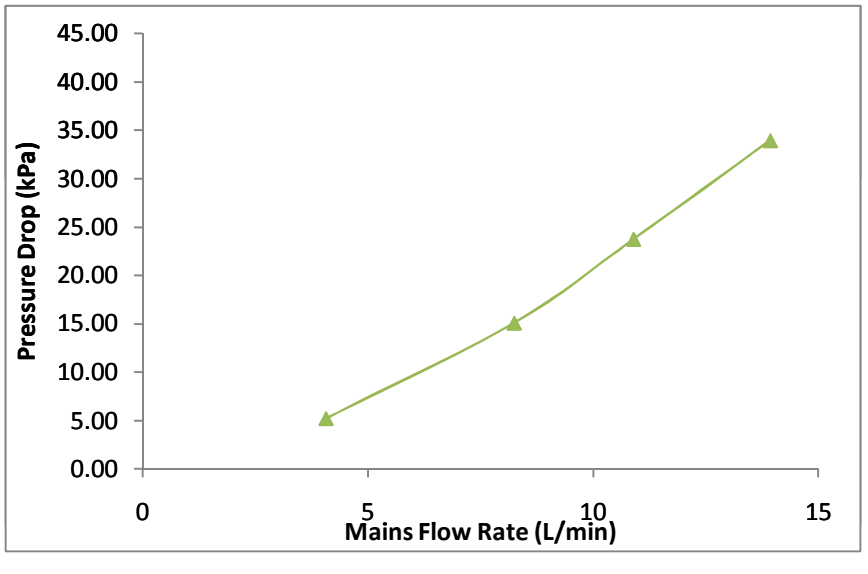
Effectiveness	0.686			
Heat Recovery	12.84	kW	43861.9	BTU/hr
Pressure Drop	19.17	kPa	2.78	PSI

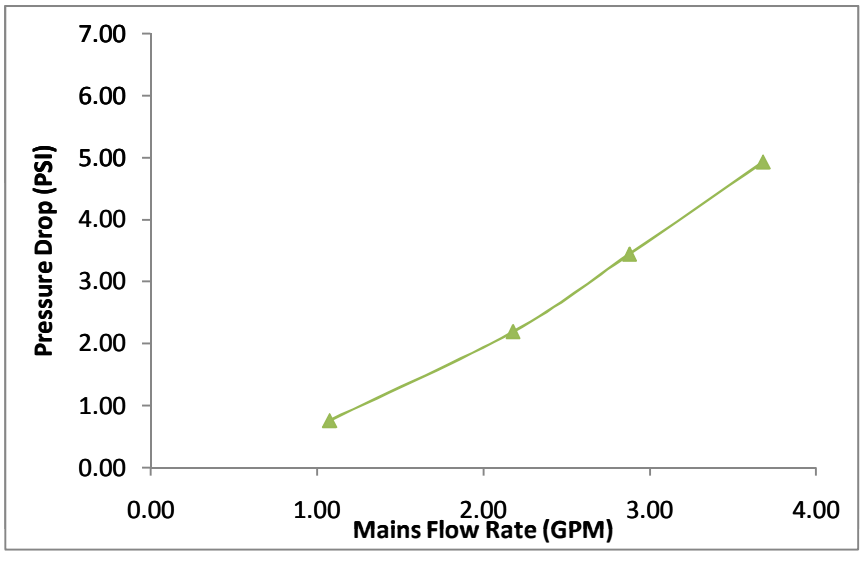












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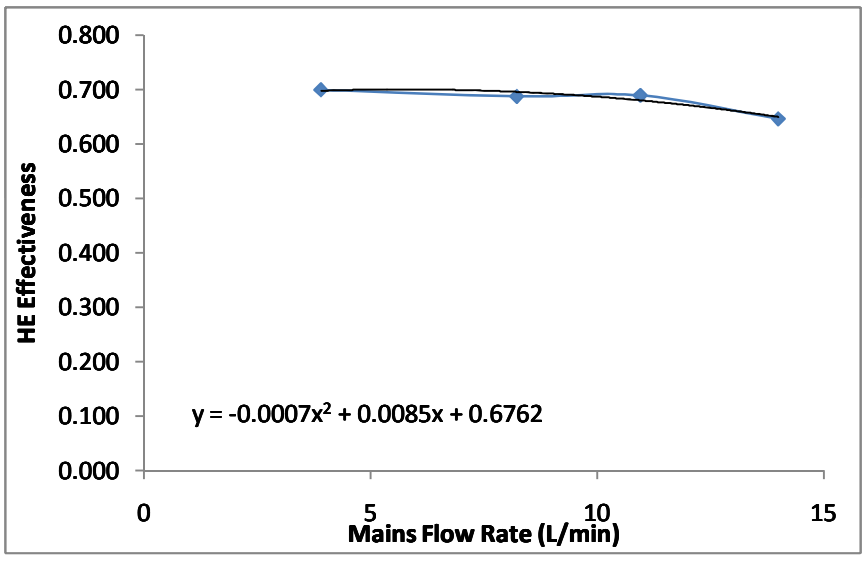
Product: 108in R4in
Manufacturer: Renewability
Test Date: February 10 / 2011

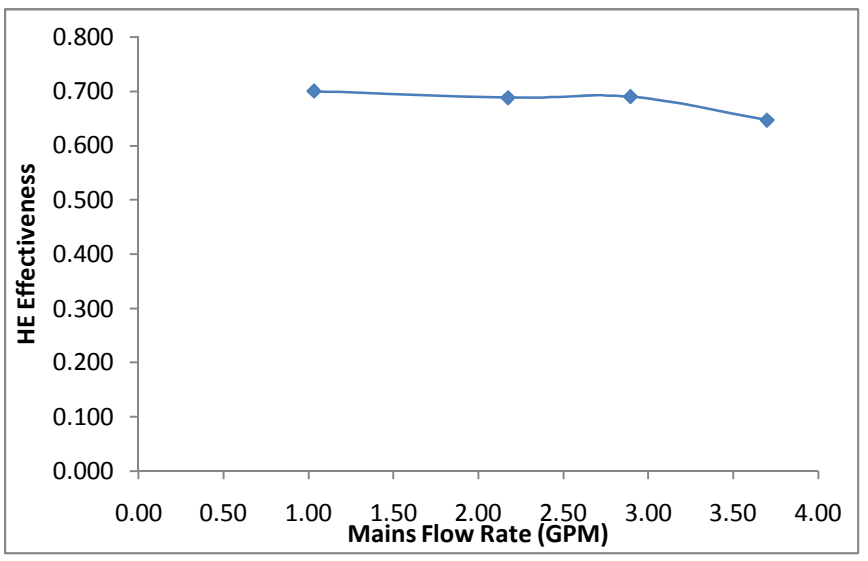
Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.91	0.700	5.46	6.12
8.23	0.688	11.06	18.06
10.96	0.690	14.83	28.12
14	0.647	18.06	39.56

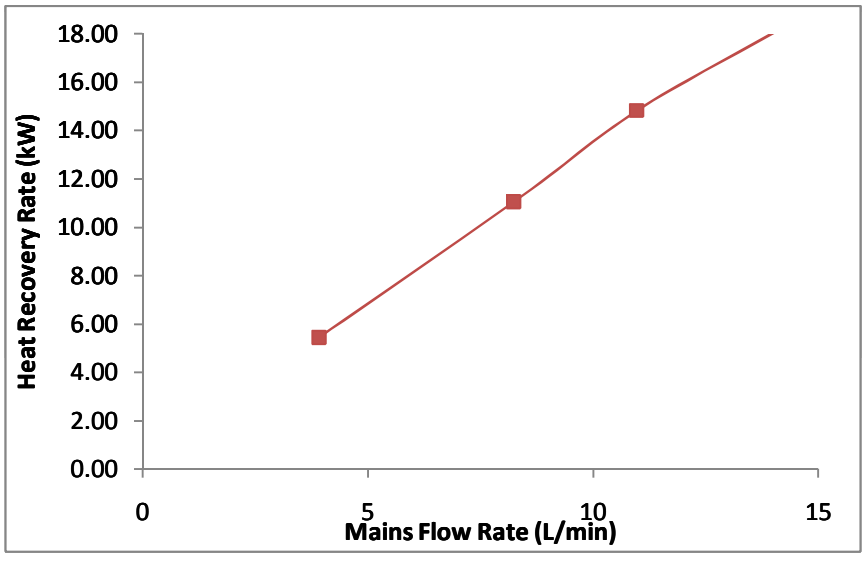
Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.03	0.700	18646.88	0.89
2.17	0.688	37771.88	2.62
2.90	0.690	50647.10	4.08
3.70	0.647	61678.13	5.74

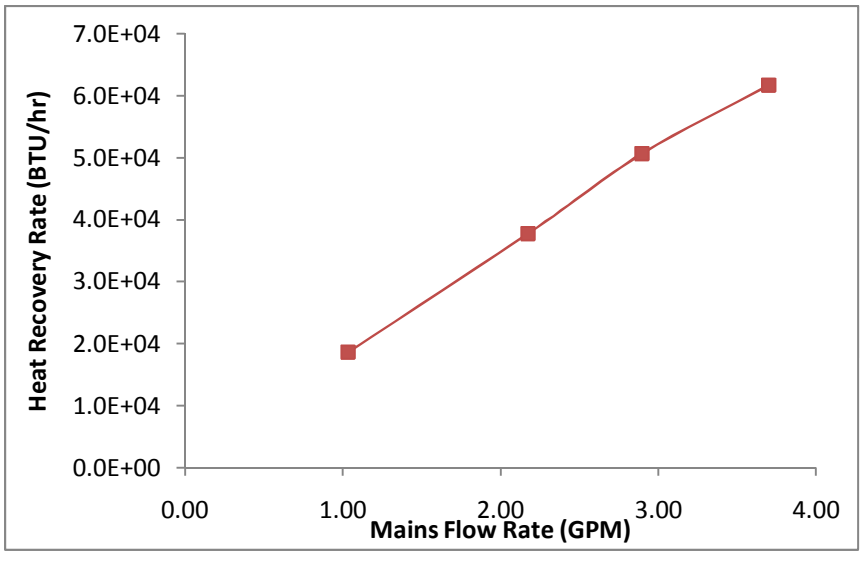
Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

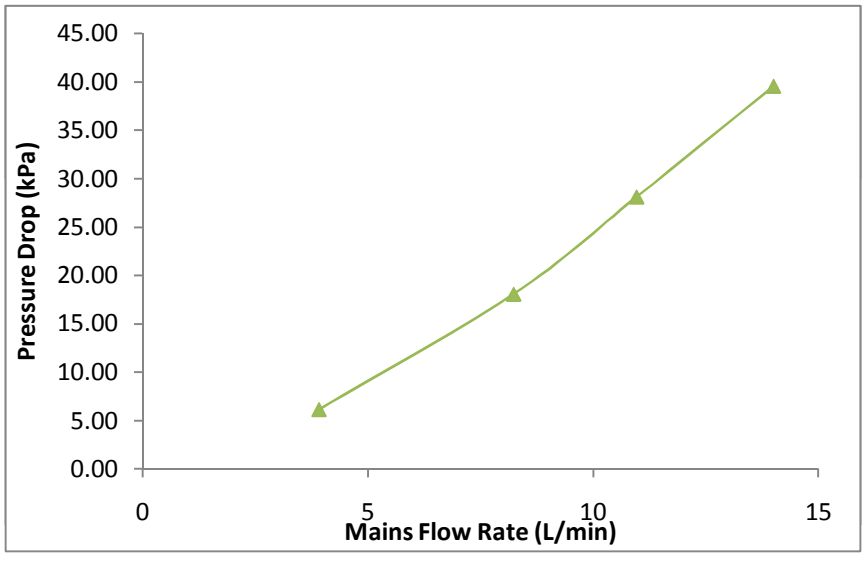
Effectiveness	0.694			
Heat Recovery	12.81	kW	43761.5	BTU/hr
Pressure Drop	22.74	kPa	3.30	PSI

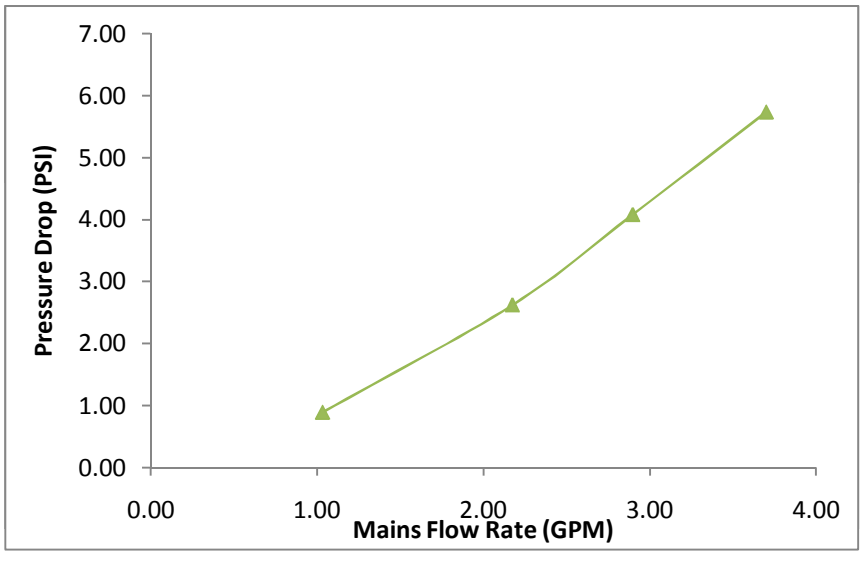












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Product: 120in R4in
Manufacturer: Renewability
Test Date: March 2 / 2009 (14 L/min - April 9 / 2009)

Flow Rate V' (L/min)	Effectivness ε	Heat Recovery Rate q_{DWS} (kW)	Pressure Drop ΔP (kPa)
3.97	0.734	5.64	7.56
8.44	0.732	12.08	22.87
11.23	0.709	15.46	34.98
14.08	0.711	19.40	48.29

Flow Rate V' (GPM)	Effectivness ε	Heat Recovery Rate q_{DWS} (BTU/hr)	Pressure Drop ΔP (PSI)
1.05	0.734	19261.61	1.10
2.23	0.732	41255.36	3.32
2.97	0.709	52798.67	5.07
3.72	0.711	66254.47	7.00

Performance at Standard Conditions (9.5 L/min - 8 °C Mains, 36 °C Shower)

Effectiveness	0.722			
Heat Recovery	13.36	kW	45641.0	BTU/hr
Pressure Drop	27.47	kPa	3.98	PSI