Technical assessment of Hi-mass Masonry Heaters and integrated water loop

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Background

Masonry heaters, though quite popular in Northern Europe, have not gained as much popularity in North America. They distinguish themselves from other wood-burning appliance by storing most of the heat within their high thermal mass envelope, usually stone or brick, by re-circulating the flue gases. Studies have demonstrated their high combustion efficiency and ability to store and release radiant heat over a longer period of time.

A new advancement in this heater technology is the introduction of a hot water generator to provide domestic hot water. Anecdotal reports indicate that 100% of the hot water load can be met by this system. There is currently no data to verify this claim or to characterize the water loop.

With the increasing demand for these systems in R2000 and other “green” homes, we undertook a detailed monitoring program of an installed High Mass Masonry heater. Data collected would allow us to quantify the hot water output of the system in a typical home.

Project Description/Objectives

The Heat-Kit Masonry Heater, supplied by Masonry Stove Builders, was installed in the Ottawa region (January 2005) in an energy efficient home (2-storey, 3100ft^2, including full basement) with a design heat load of 30 000Btu/hr @ -25C. The house is occupied by 2 adults and 2 small children (under 5).

The heater is located centrally on the main floor. Domestic hot water is provided by a 40 US.gal. electric tank. A 60 US.gal. electric tank serves as thermal storage for the masonry heater hot water generator (winter) and the solar collectors (summer). A small Grunfos pump (model xxx) is controlled by a delta-T controller (model USDT 2004B) from Thermo Technologies.

The project objective was to monitor the heat output of the hot water generator of a Hi Mass Masonry heater in a typical home. To do so, thermocouples were installed in the water line as well as a water meter to measure the flow. In addition to this, we collected various surface temperatures on the heater as well as a log of the amount of wood burned. 50lb of wood was burned once-a-day in the masonry heater.

In order to determine the energy contribution of the hot water generator, we calculated the Watt-hours using measured temperatures and water flow. We also compared the hot water tank electrical consumption with and without the masonry heater contribution. As a basis for comparison, a benchmark period before and after the test characterized the electrical consumption as a function of hot water use.

Results and Data Analysis

Hot water generator:

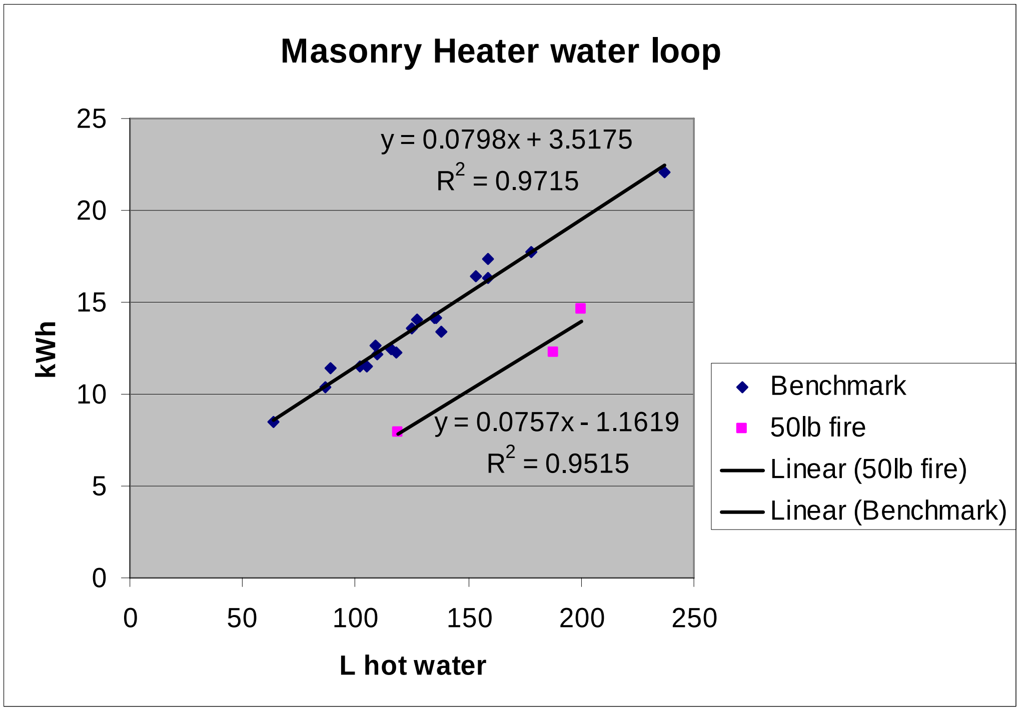
Data was collected at 5-minute intervals. The following equation was used for the energy calculations.

$q = m\ Cp\ (T_{out}-T_{in})/300$ where,
q, kJ/s (kW)
m, water flow (L/5min)
Cp, 4.18 kJ/L-C
Tin, 5-minute average input temperature (Celsius)
Tout, 5-minute average output temperature (Celsius)

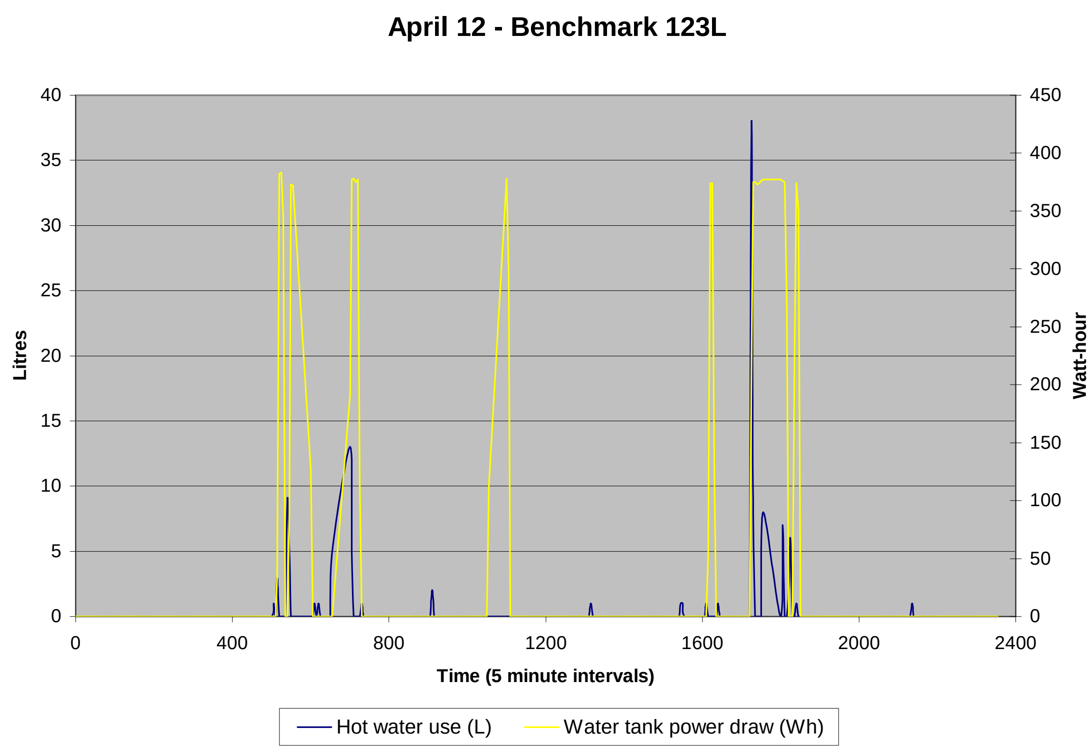
The results of the 4 consecutive test days are presented in the following table. Loop refers to the energy produce by the masonry heater hot water generator. April 6, 2006 data was not used in the analysis since it served as a warm-up day and hot water was used earlier that day.

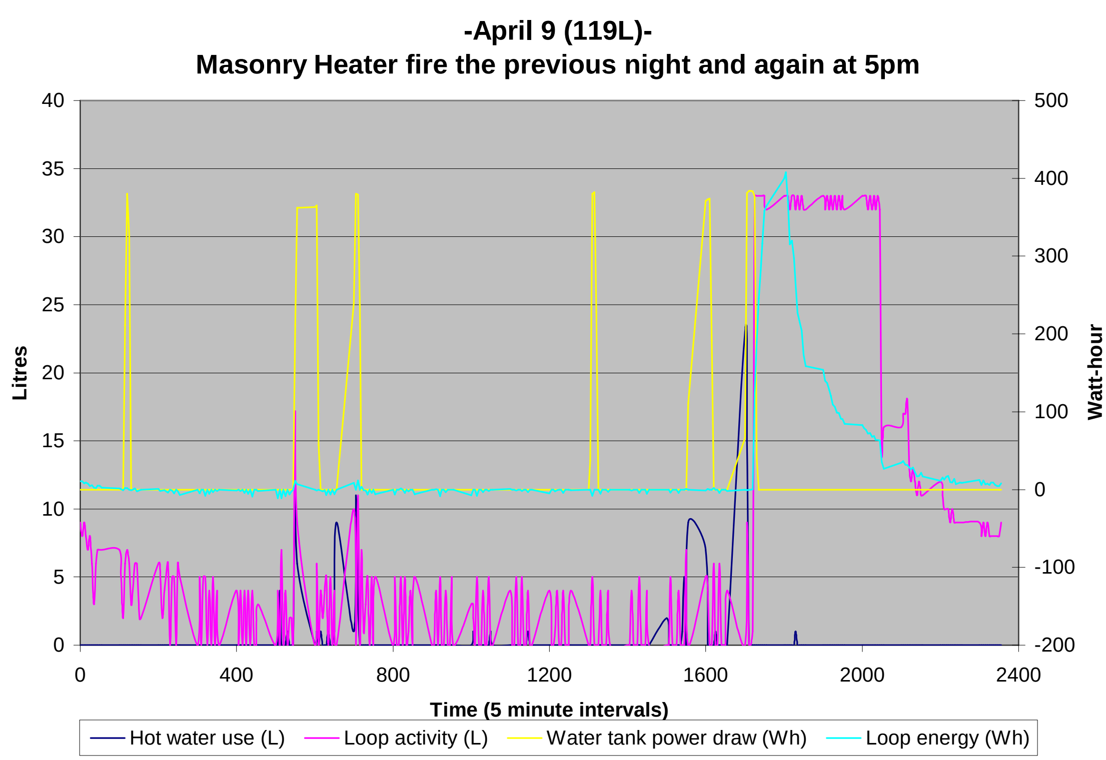
Day	Description	Water (L)	Energy (kWh)	kWh/L	Loop MJ/day	Loop kWh/day	Est. (kWh) (no loop)	Savings (%)
4/6/06	6pm 50lb fire	211	19.269	0.0913	19.40	5.39	NA	NA
4/7/06	5pm 50lb fire	200	14.666	0.0733	22.62	6.28	19.478	25%
4/8/06	8pm 50lb fire	188	12.277	0.0653	23.13	6.43	18.520	34%
4/9/06	5pm 50lb fire	119	7.969	0.0670	27.93	7.76	13.014	39%

The results are plotted below. The graph illustrates the savings compared to benchmark data.


Masonry Heater water loop
y = 0.0798x + 3.5175
R2 = 0.9715
y = 0.0757x - 1.1619
R2 = 0.9515
kWh
L hot water
0
5
10
15
20
25
0
50
100
150
200
250
Benchmark
50lb fire
Linear (50lb fire)
Linear (Benchmark)

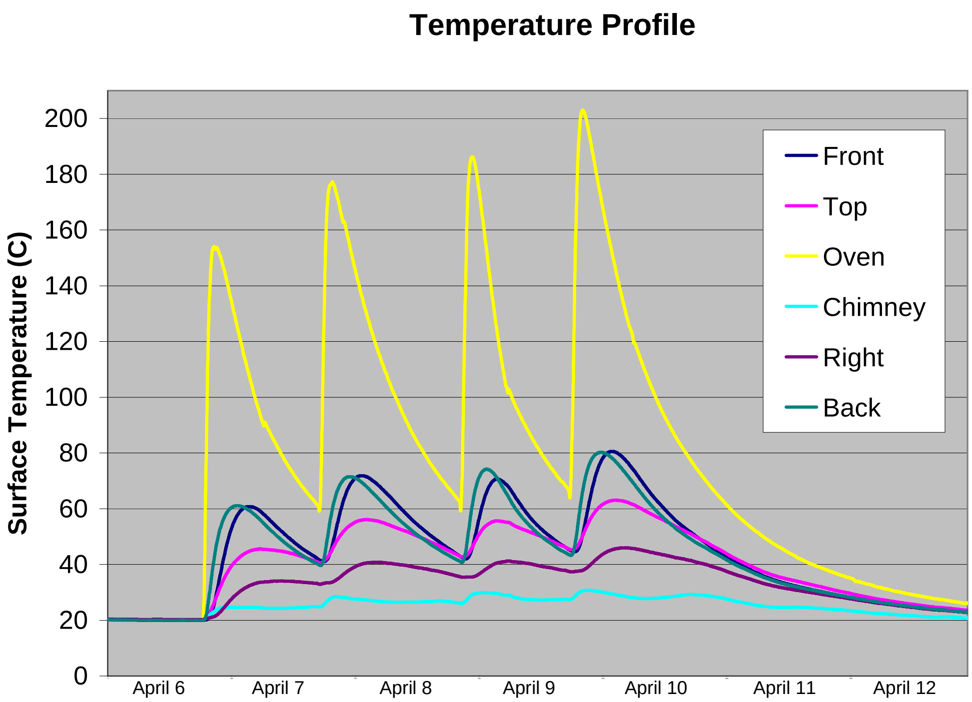
The following graphs show the hot water use pattern on a typical benchmark day followed by a typical day where the masonry heater is fired in the evening.





Surface temperatures

The following graph shows the variation in surface, oven and flue temperatures during 4-day of consecutive 50lb fires.   Additional days were added to show the rate at which the stone cools.



Combustion Analysis

Test Description:

A Testo 330 flue gas analyzer was used to conduct a stack loss test during the burn on May 24, 2006.

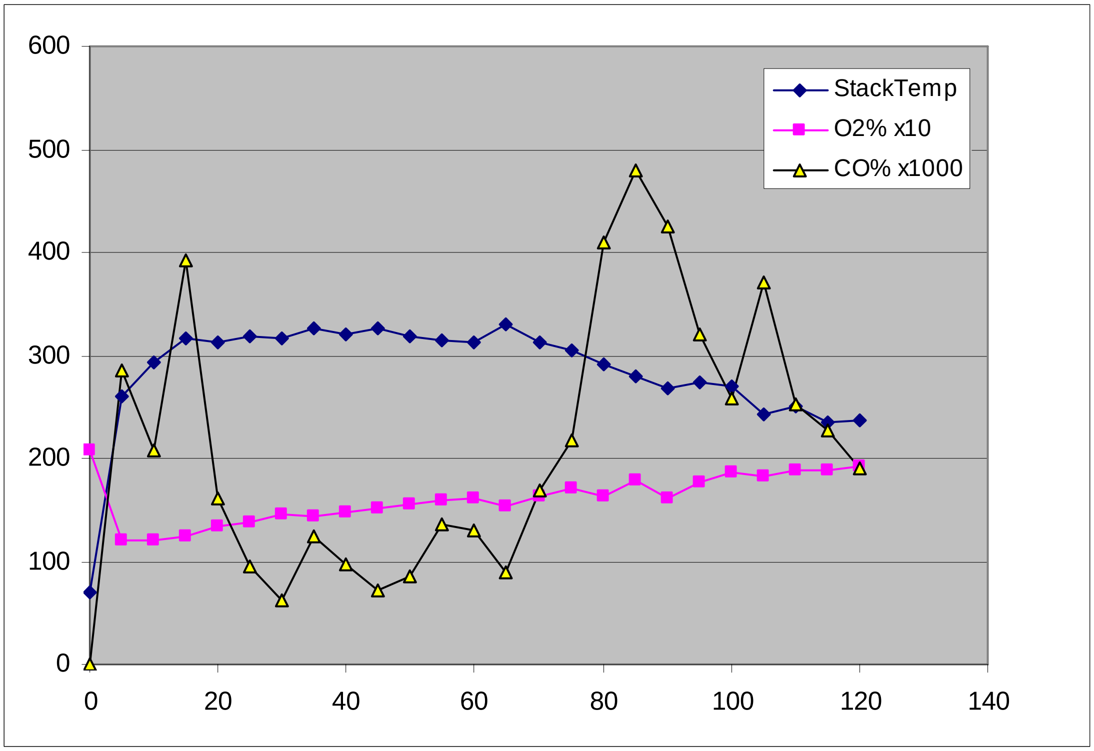
The test probe was inserted through the damper slot in the chimney, approximately 7 ft. above floor level.

The fuel load consisted of 8 pieces of dry split white birch totaling 18.3 kg, plus 0.9 kg kindling. Flue gas readings were taken for two hours from ignition, at which time there was still a bed of coals burning in the heater.

The efficiency calculations are based on “Determination of Condensible Particulate Woodstove Emission Factors Using Condar’s Emissions Sampler”, available at http://heatkit.com/docs/condar.PDF

Test Results

Run Length	2 hours
Total Fuel Weight	19.2 kg
Number of Pieces	8
Kindling Weight	0.9 kg
Wood Moisture	16.1%
Average Stack Temperature	140 C
Average Stack Oxygen	15.87%
Average Stack CO	0.21%
Stack Dilution Factor	4.15
Burn Rate dry kg/hr	8.05
Boiling of Water Loss	11.70%
Dry Gas Loss	15.49%
CO Loss	5.87%
Combustion Efficiency	94.13%
Heat Transfer Efficiency	72.80%
Overall Efficiency	68.53%



Graph of flue gas values over time (minutes). Stack temperature is plotted in degrees Fahrenheit.

Analysis of results

The combustion analysis results are comparable to testing performed on this heater with somewhat larger loads of Douglas Fir fuel. The efficiency was near the middle of the range. Both the CO percentage and the O2 dilution were at the upper end of the range. The CO spike at the start of the burn indicates fuel-rich conditions, which might be due to fuel dryness and species (white birch, which has a very volatile bark).

The CO at the end of the burn is characteristic of the charcoal phase of a batch burn of cordwood. The actual burn rate at this point would be low, which would tend to skew the average CO value compared to one that is based on burn rate. Burn rate is normally measured by putting the appliance on a scale, which is not possible with a high mass appliance such as a masonry heater.

	
Fuel charge and kindling	10 minutes
	
80 minutes	120 minutes

Discussion and Conclusion

Performance of the hot water generator

In this specific installation, the maximum output of the hot water generator was 5 kW, with an average of 2.2 kW over the first 2 hours of the burn period. The average energy savings over the 3-day test period was 33%.

In order to increase the energy savings, the following should be considered; select pre-heat tank to match burn frequency and water use, increase the generators exchanger surface (E-shape instead of C-shape).

In this case, the pre-heat tank was 60 gallons which exceeded the daily consumption of hot water of the house (30-50 gallons). If a smaller tank was used, the temperature of the water after the burn would have been higher, thus requiring less secondary heating to reach 55C. The homeowner subsequently experimented with two burns per day and found that the storage tank water temperature exceeded 55C after the second burn. Had the tank been smaller it might have reached dangerously high temperatures which could cause serious burns if the secondary tank is not fitted with a mixing-valve.

The hot water generator did not seem to affect the masonry heater's combustion performance, though carbon does accumulate on the coil. Recent changes in the combustion air supply (at the back of the burner, http://heatkit.com/html/lopezm.htm) could extend the high temperature burn at the back of the unit, thus increasing the coil's output. MHA also reports that a customer had a E-shaped generator fabricated and found that it would boil-over a 40 gallons hot water tank in a single burn. No data is available to confirm this information, though it stands to reason that a longer pipe would recover more heat. Further testing would be required to confirm this observation.