EFFICIENCY STUDY OF A CONTRAFLOW MASONRY WOOD-BURNING HEATER

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ABSTRACT

This study determines the efficiency of a Finnish contraflow masonry wood-burning heater in a residential setting in Pleasant Hill, Oregon.

Data concerning the thermal properties of the home were collected between February 15th and February 23rd of 2009. This data was used in conjunction with calculations of heat gain and loss to determine an operating efficiency of 79.5 % for the contraflow masonry wood-burning heater.

1. INTRODUCTION

Contraflow masonry stoves are thermally massive wood-burning stoves specifically designed to increase the efficiency of wood combustion for the purposes of residential heating. Contraflow masonry wood stoves were first produced in Finland and other regions of Northern Europe in the 17th and 18th centuries as a response to a declining supply of wood resources (Tulikivi, 2008). Contraflow masonry stoves are large wood-burning stoves with several specially designed efficiency increasing thermal characteristics used for residential heating and baking. They were designed in an attempt to provide superior efficiency compared to traditional woodstoves or simple fires.

Contraflow masonry stoves increase the heating efficiency of wood combustion through the employment of several key strategies. First, through a controlled air intake, the stoves create an internal draft, constantly stoking the fire, producing higher burning temperatures than traditional woodstoves. A higher burning temperature increases combustion efficiency by more thoroughly consuming small particulates and combustible gasses. Secondly, after the combustion process, contraflow masonry stoves increase efficiency by sending the heat-bearing exhaust gas on a circuitous route through channels within the masonry structure surrounding the combustion chamber before exiting out the chimney.

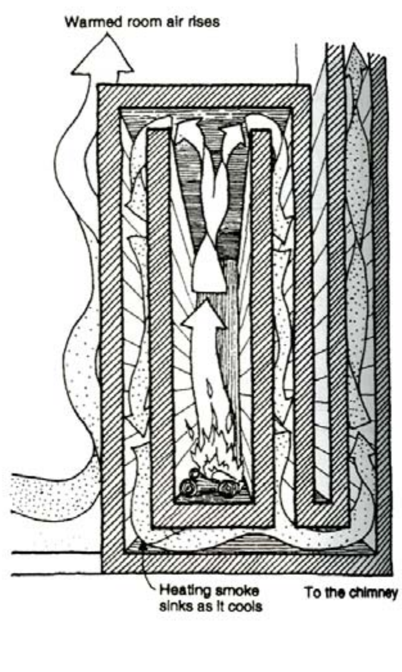

Figure 1. Section of a contraflow masonry stove, showing the circuitous route taken by the exhaust gasses within the masonry structure. (Modified from Stein, et al. 2005 p. 334)

Through this process heat is transferred to and stored in the thermal-mass of the fireplace structure itself. This heat is then slowly radiated out into the surrounding area over the course of several hours, or even days (Tulikivi, 2008).

This study will focus on determining the efficiency of a contraflow masonry stove in a typical, active, single-family home context.

The Barkman family of Pleasant Hill Oregon allowed the use of their home and their Tulikivi contraflow masonry stove for the study. The home has a mostly open floor plan on the first floor, making it a good candidate for efficient wood heating as the heat easily spreads from the fireplace through the rest of the space. The stove faces a kitchen island and, according to the homeowner, becomes a social hub around the time of lighting fires. Typically, a single fire is lit every evening in the winter. On the coldest of days a second fire in the morning is required. The fires burn for roughly one hour.

Figure 2. Photograph of Barkman family contraflow masonry heater. Pleasant Hill, Oregon.

2. HYPOTHESIS

The contraflow masonry stove operates at 90% efficiency.

3. METHODOLOGY

To accurately calculate the stove's efficiency, the available energy from the fuel consumed by the stove was compared to the net heat loss of the home.

For the duration of a 7-day observation period, 5 HOBO H8 Pro Series data loggers were placed in the study area as well as outside to measure internal and external temperature. The average internal and external temperatures were used to calculate an average Δt for this study. Heat loss though the envelope was calculated using this Δt, areas derived from architectural drawings of the house, and published R and U values of pertinent envelope assemblies.

Figure 3. First floor plan of the Barkman residence showing the location of the contaflow masonry stove and data loggers.

To isolate the heat produced by the stove, other internal heat sources (solar gain, occupant and appliance heat) were calculated and subtracted from the net heat loss of the building. The remaining figure represents the net heat loss and therefore the total heat released into the home by the stove.

The energy consumed by the stove was calculated by applying an assumed constant energy content in BTUs per pound of quarter split Douglas fir to the amount of wood used during the observation period. The homeowners weighed and recorded the amount of wood burned each day and at what times the burns occurred on a data sheet.

The ratio between the energy consumed by the stove and the net heat loss of the home was then calculated. This difference is presumably due to a combination of inefficient combustion and heat loss up the chimney. The ratio of net heat loss of the home to energy available from the fuel represents the efficiency of the stove.

4. RESULTS

Results are broken into four sections: temperature data collected, heat loss, heat gains and measured fuel.

4.1 Temperature Data Collected

Temperature recorded by the data loggers shows a distinct day and night swing as well as small peaks in inside temperature after each fire.

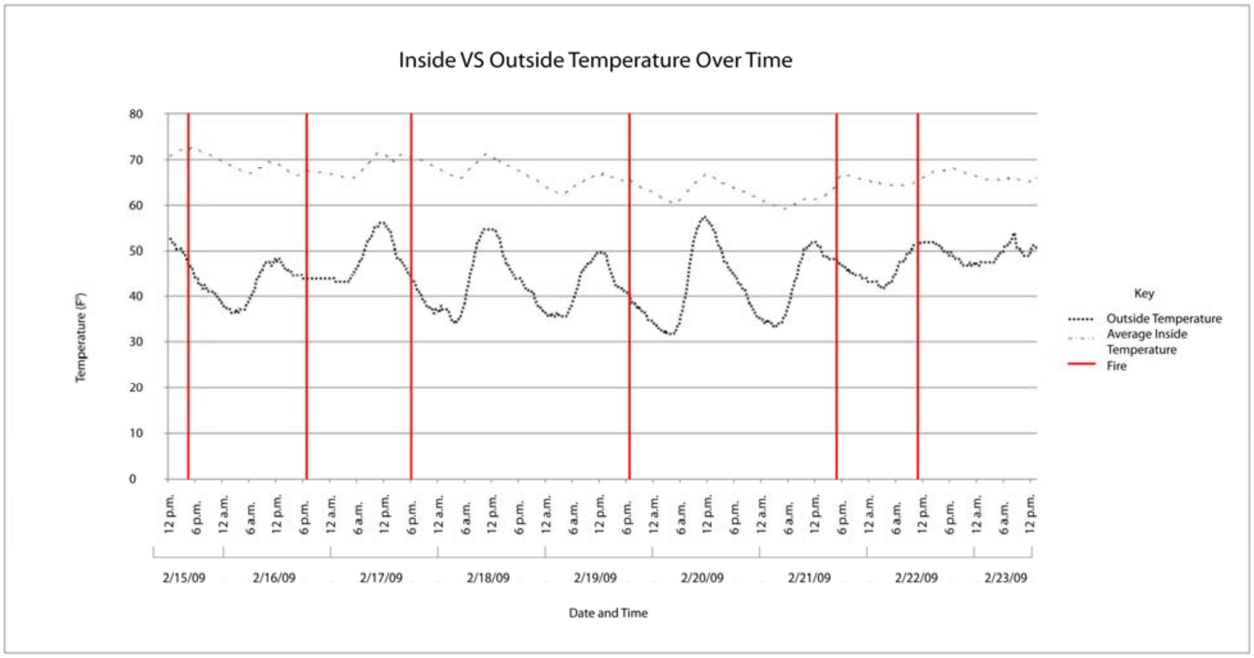

Figure 4. Inside VS Outside Temperature over time graph with fire burning events.

4.2 <u>Heat Loss</u>

4.2.1 <u>Indoor/Outdoor Temperature</u>

The interior design temperature selected for this analysis was 65.91^{0}F. This temperature was chosen because this was the found average indoor temperature. The exterior average temperature was 44.64^{0}F, that gives 65.9 – 44.6 = **21.27^{0}F = Δt.**

4.2.2 <u>Opaque Above-Ground Walls</u>

<u>TABLE 1</u>

Component	**R-Value** ^{o}F ft^2 h / Btu
Exterior Moving Air Film (winter)	.17
Wood Shingles	.87
Vapor Permeable Felt	.06
1/2" Plywood Sheathing	.62
5 ½" Fiberglass Batt R-21	21
1/2" Gypsum Board	.32
Interior Still Air Film	.68
Total	**23.72** ^{o}F ft^2 h / Btu U = 1/R = 0.0422

(Source: Stein, et al. 2005 pp. 1549-1567)

Total wall area from design drawings (minus doors and windows) = **2101 ft^2**.

U A Δt = 0.0422 x 2101 x 21.27 = **1885 Btu/hr.**

4.2.3 <u>Doors</u>

Total door area from design drawings = 179.9 ft^2
U Value of Door (wood door with light) = 0.39 BTU/^{0}F ft^2 hr.

U A Δt = 0.39 x 179.9 x 21.27 = **1492 Btu/hr.**

4.2.4 <u>Windows</u>

Total window area from design drawings = 515 ft^2
U Value of window (double glaze, ½") = .51 BTU/^{0}F ft^2 hr.

U A Δt = 0.51 x 400 x 21.27 = **5587 Btu/hr.**

4.2.5 <u>Roof</u>

Insulated Ceiling area: 1707 ft^2
U Value of roof system with R-30 batt from Stein, et al. = .034 BTU/^{0}F ft^2 hr.

U A Δt = 0.034 x 1707 x 21.27 = **1235 Btu/hr.**

4.2.6 <u>Floor</u>

Total floor area from design drawings = 1707 ft^2
U Value of floor system from Stein, et. al. = .074 BTU/^{0}F ft^2 hr.

U A Δt = 0.074 x 1707 x 21.27 = **2687 Btu/hr.**

4.2.7 Infiltration

This construction falls into the medium category (Stein et al. 2005 p.1602) Since we are working with a winter outdoor design temperature of 44.6^{0}F, the table gives us a design infiltration rate (ACH) of .73 cfm.

Volume of interior space from design drawings = 20243 ft^3.

$$V = \frac{(ACH)(volume, ft^3)}{60\,\min/hr} = \frac{.73x27670}{60} = 246.29 \text{ cfm.}$$

Heat loss is calculated as

q = cfm x 1.1 x Δt = 336.7 x 1.1 x 21.27
= **5762 Btu/hr.**

4.2.8 Latent Heat Loss

The relative humidity in the house is not intentionally controlled (which allows latent heat loss to be "ignored.")

4.2.9 Total Heat Loss

The sum of above mentioned heat losses is17400 Btu/hr. The occupants heat 76.8% of their home with this system (the rest of the rooms are closed off) which gives:

17400 Btu/hr X .768 = 14608 Btu/hr

Total Calculated Heat Loss = 14608 Btu/hr

4.3 Heat Gains

4.3.1 Solar Heat Gain

The Solar heat gain was calculated using the Window Heat Gain Calculator (Gronbeck, 2005). Clearness factor for Eugene was determined to be 42% (Kusterer, 2009). The outside surface was variable, so the default reflectance of 0.2 was used. The SHGC for double glazed clear wood windows is 0.58. Window areas were determined from design drawings.

Solar Heat Gain By Window Orientation:
South: $398 Btu/ft^2/day \times 226 ft^2 \times \frac{1 day}{24 hr}$ = 3748 Btu/hr
North: $37 Btu/ft^2/day \times 82 ft^2 \times \frac{1 day}{24 hr}$ = 126 Btu/hr
East: $163 Btu/ft^2/day \times 76 ft^2 \times \frac{1 day}{24 hr}$ = 516 Btu/hr
West: $163 Btu/ft^2/day \times 207 ft^2 \times \frac{1 day}{24 hr}$ = 890 Btu/hr
Total: = **5308 Btu/hr**

4.3.2 Internal Heat Sources

230 Btu/hr per occupant for 4 occupants was used to determine total heat gain from occupants as **920 Btu/hr** (Stein, et al, 2005 p 1611).

Heat gain from equipment was estimated as **1400 Btu/hr** (Stein, et al, 2005 p 1611).

Total Heat Gain = 7628 Btu/hr

4.4 Measured Fuel

The study was conducted over 7 days starting at 3:30 pm on February 15, 2009 until 5:30 pm on February 23, 2009. Over that period of time, 239 pounds of douglas fir were loaded into the masonry heater and burned to heat the house.

TABLE 2

Date	Time of Burn	Amount of Fuel
2.15.09	3:25 pm – 5:53pm	54 lbs
2.16.09	8:40 pm – 9:35pm	27 lbs
2.17.09	6:17 pm – 8:40 pm	35lbs
2.18.09	NO BURN	NO BURN
2.19.09	7:50 am – 10:30 am	56 lbs
2.20.09	NO BURN	NO BURN
2.21.09	4:20 pm – 7:00 pm	43 lbs
2.22.09	11:30 am – 1:15pm	24 lbs

Douglas fir has 18.1 MBtu/cord and weighs 2900 lbs/cord (Sweep's Library, 2009).

$\frac{18.1 MBtu/cord}{2900 lbs/cord}$ = 6241 Btu/lb.

6241 Btu/hr X 239 = 1,492,000 Btu

239 lbs of wood therefore gives 1,492,000 Btu total for the 7 days, two hours.

$\frac{1492000 Btu}{170 hrs}$ = **8776 Btu/hr.**

4.5 Total Heat Losses and Gains

Net heat loss is calculated by subtracting the total internal heat gains due to solar, occupant and equipment sources from the heat loss of the building:

14608 Btu/hr – 7628 Btu/hr = **6980 Btu/hr**

Potential Heat from Masonry Heater = **8776 Btu/hr**

Stove efficiency = (6980 Btu/hr) / (8776 Btu/hr) x 100 = **79.5% efficiency**

5. ANALYSIS

The masonry heater in conjunction with other sources of heat gain supplied sufficient heat to overcome the home's heat loss. It kept the home at an average temperature of 65.9^{0}F despite relatively cold temperatures outside. Heat loss through the thermal envelope accounted for 14608 Btu/hr. The single largest source of heat loss was predictably through the windows, which accounted for 38% of the total heat loss. Heat gains from sources other than the masonry heater produced 7628 Btu/hr. By subtracting the heat gains (7628 Btu/hr) from the total heat loss through the envelope (14608 Btu/hr), the net heat loss of the building is determined (6980 Btu/hr). This value represents the heat produced by the masonry heater. Comparing this number to the potential available energy from the wood (8776 Btu/hr) provides the efficiency of the stove. The stove was found to be 79.5% efficient.

6. CONCLUSIONS

The initial hypothesis that the masonry heater would operate at 90% efficiency proved incorrect. The heater in fact operated at 79.5% efficiency. This is most likely due to the process of burning wood, which can only operate at a limited efficiency level.

Further study of the stove's efficiency would benefit from testing in a closed environment. The variables of internal heat gain from occupants and appliances and the passive solar heat gain were estimated in this study but could be eliminated entirely in a closed laboratory experiment.

In 'A Pattern Language', Christopher Alexander highlights the importance of fire in human existence: "There is no substitute for fire…build the fire in a common space – perhaps in the kitchen – where it provides a natural focus for talk and dreams and thought" ('Pattern Language', #181). The data obtained from the data loggers suggests that heating a home with fire provides a feeling of thermal comfort at lower temperatures, as the temperatures in the space fell below American Society of Heating Refrigeration and Air-conditioning Engineers (A.S.H.R.A.E) standard 55-2004 (Stein et. al. 2005 p.88) on a few different occasions. Conversations with the homeowner revealed that the stove was not lit on two of the seven days because they considered the space "warm". The data loggers indicate that on these days the outdoor temperature was higher than the other days, but interior temperatures went well below the temperatures experienced on the days when the stove was used. This suggests that heating with such a stove allows occupants to customize how often and to what temperature they heat their space on a more intimate level than a traditional system and, since the owners are in such close contact with the method of heating, they realize its significance and importance and are able to live with and appreciate the variations in temperature.

7. ACKNOWLEDGEMENTS

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