Masonry Stove Residential Heating

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An Analytical & Environmental Study to

Meet the Requirements of MEE Senior Design Capstone

University of Maine

Professor Emeritus Richard Hill

April XX, 2015

Acknowledgements

We would like to thank Professor Richard Hill for his guidance, support and enthusiasm. Without his knowledge and accommodation this project would not have been possible.

Albie Barden and Maine Wood Heat were kind enough to let us spend a day at their shop firing masonry heaters and asking questions.

Jim Rocket and Evergreen Home & Hearth were also kind enough to give us their time knowledge.

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Glossary

Heat pump (air-air) – mini-split: a mechanical device that allows for the transfer of heat from a cold region to a warmer region by means of refrigerant flow and at the cost of electrical energy.

Coefficient of performance (COP): A measure of heat transferred to (electrical) power consumed. Unlike the typical measure of performance, efficiency, the COP may surpass 1, or 100% because energy in the system is not being generated or released from chemical storage, rather it is simply being moved between regions.

Solar Insolation: Radiation released from the sun that is absorbed.

Masonry heater: a site-built or site-assembled, solid-fueled heating device constructed mainly of masonry materials in which the heat from intermittent fires burned rapidly in its firebox is stored in its massive structure for slow release to the building. [1]

Finnish Contraflow: a specific layout of masonry stove whose design originated in Finland.

Introduction

In the 17^{th} and 18^{th} centuries, American homes were heated by mostly by wood fireplaces and stoves. The 19^{th} century saw the introduction of steam and convective air furnaces powered wood and coal. The concept of central heat was born, and quickly replaced the cast iron wood stoves. The 1930s saw the introduction of reliable oil furnaces, which typically provided forced air heating. The most significant advantage of the oil furnace is the automation. Where solid fuel sources such as wood and coal typically must be fed several times per day and often requires adjustment of dampers or other mechanisms, oil furnaces are controlled by electric thermostats. This is still the most common residential heating method today. Baseboard hydronic and resistive heat also became common options in the 20^{th} century. More recently, natural gas, heat pumps, and various forms of hydronic and solar heating have become available.

It seems evident that America is moving away from oil fired forced air or water baseboard for residential heating but what will take its place appear less clear. Maine has seen an increase in heat pumps and natural gas heating recently, but these are not without their problems. Heat pumps will place additional demands on electric power generation systems and infrastructure. Natural gas is a fossil fuel that, like oil, seems likely to increase in price as more complex and expensive extraction methods have to be employed. It will also likely face increasing pressure from environmental groups through social stigmatization or governmental regulation. Another drawback for heating methods like heat pumps and natural gas is that, unlike oil or solid fuel heaters, the fuel energy associated with natural gas systems and heat pumps is not stored in the residence. In the event of a power outage or gas pipeline issue, the homeowner will find himself without a source of heat.

This report investigates the design, performance and regulation of yet another heating method, the masonry heater. Heating with wood has always been familiar for most Maine residents. Maine has traditionally had a high ratio of forested land per resident. This, and its long, sustained periods of cold make it a good candidate for masonry wood heating. Compared to other forms of wood heating, masonry stoves generally offer better performance, in terms of pollution and thermal output, higher cost and are less regulated than a device classified as a wood stove.

Perceived Temperature and Thermal Comfort

An added benefit of Masonry Heaters is thermal comfort they provide. It is known that air temperature is not the only factor in deciding the perceived thermal comfort of a heated space. The other factors that influence this perception are the amount of humidity in the air and its motion, as well as the amount of radiant energy traveling through surrounding spaces.

In general, humid air feels warmer than dry air when the actual temperatures are relatively identical. This phenomenon is related to the evaporation of water through the skin. Since evaporation is a cooling process, the molecules of water need extra energy to become vapor. This causes heat, or energy, to leave the surface of your skin and this is what causes a cooling sensation. When the air is dry, evaporation is enhanced and your skin loses more energy. The opposite also holds true, and as humidity rises, evaporation rates decrease and your skin retains more energy in the form of heat.

Movement of air also influences perceived thermal comfort, and this is where a masonry stove heater benefits the user. Increased air speed, like that of forced air heaters, enhances conduction of heat out of the skin and evaporation. Masonry heaters, however, heat primarily through radiation. We have established that thermal comfort depends on skin temperature. One can be comfortable in cool, dry air despite the skin's loss of energy by conduction to the cool air and evaporation into the dry air. This is possible as long as enough infrared radiation is absorbed by the skin. The masonry heater is able to accomplish this, where other heaters fail. In a house heated only with a fireplace, the radiation propagates in one direction and is subject to drafts. A house snuggly fit with a masonry stove is able to overcome such discomforting temperature contrasts. [2]

Masonry Heater vs. Wood Stove

The masonry wood heater differs from a typical wood stove in its design, performance and use. Masonry type heaters have been used in many cultures in cold climates for centuries. Otherwise known as a masonry stove, ceramic stove, tile stove or Russian fireplace, they traditionally incorporated benches or a flat top surface to serve as a sleeping platform. Rather than iron or steel as the primary construction material, one or more types of masonry stone are used. While masonry stoves tend to take up more space than wood stoves, their thick walls and increased mass allow for much more thermal energy storage. Unlike iron, masonry stone is not a good conductor of heat. At first glance, this may seem to be undesirable, but this actually allows for greater comfort and ease of operation for the residential owner.

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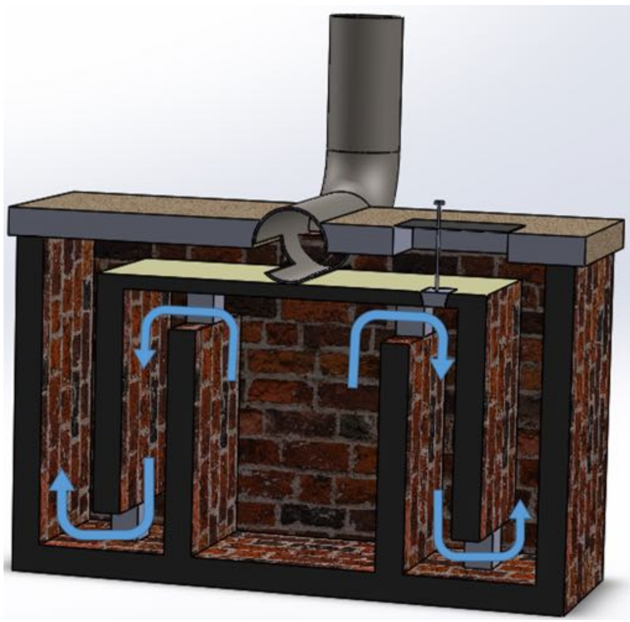
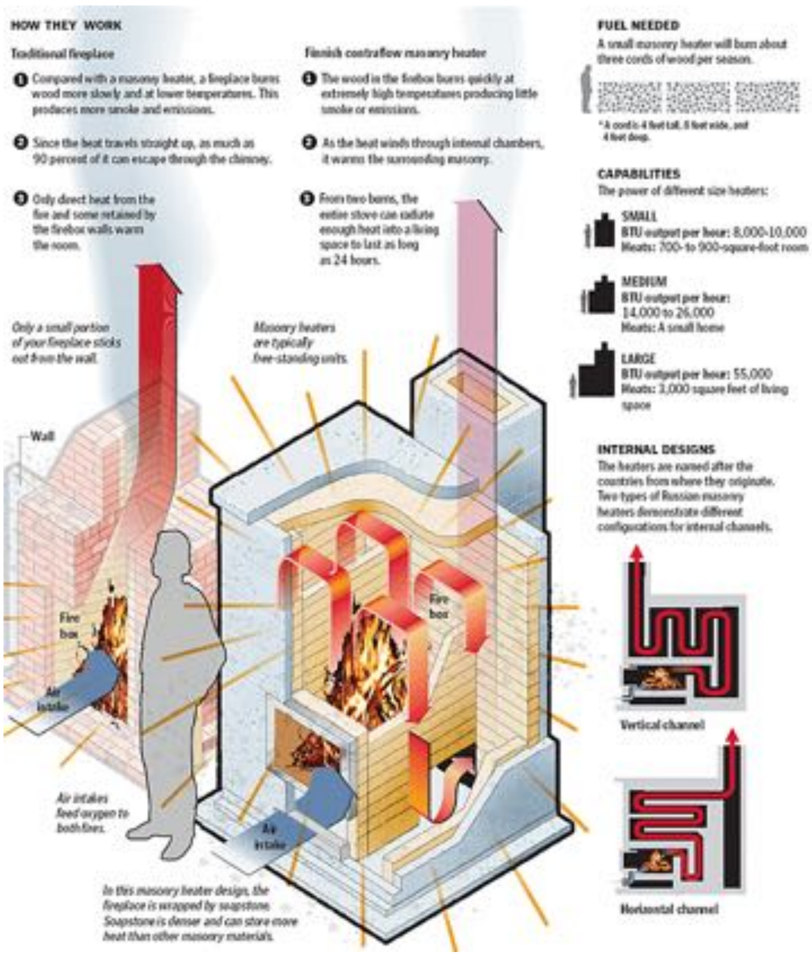


Figure 1 CAD Rendering cutaway of Professor Hill's Stove

During the afternoon into the evening, when the residence is not in particular need for thermal energy, the masonry stove may be loaded with wood and lit. While the wood burns, the masonry will slowly increases in temperature, storing a large amount of energy when compared to the thin iron shell of a traditional wood stove. The peak temperature of the masonry stove is delayed from the start of the burn, which helps prevent overheating during the end of sunlight hours. Similarly, the masonry releases the thermal energy at a much slower rate than an iron shell. This ensures that the resident operating the stove does not need to wake in the middle of the night to

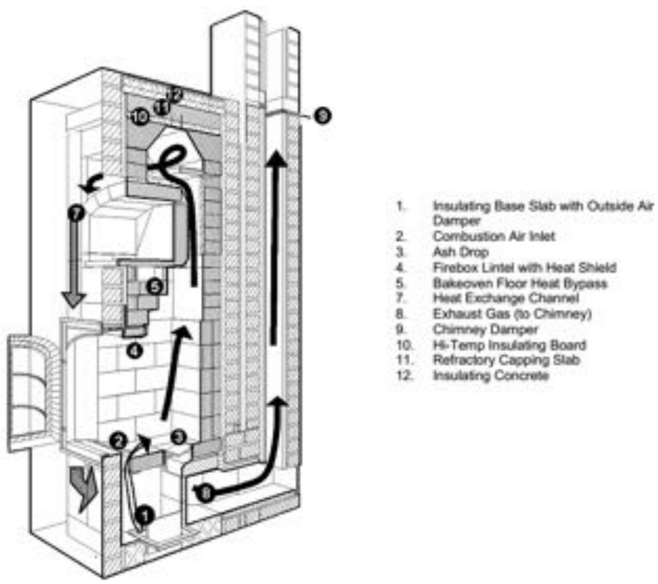


load the furnace and should not wake to a cold home in the morning.

The differences of the masonry stove go beyond the building material to variations in actual design. A typical iron furnace has a small fire chamber and usually a direct exit chimney to the outside. This short burn path tends to allow much heat to escape, unused into the surroundings of the residence. Masonry wood stoves are designed to maximize the length of the flow path that combustion occurs. By allowing more space and time for the combustion gasses to burn, more complete combustion is possible. This means that more of the chemical energy stored in the wood contents is released. Additionally, the elongated flow path works to store as much thermal energy as possible in the surrounding masonry before ejecting the gas into the surroundings. This means lower stack temperature and fewer potentially toxic partial-products from combustion.

In order to minimize thermal stresses that can occur from thermal gradients and material expansion while maximizing heating ability, bricks of varying properties are utilized at different locations in the stove.

Masonry stoves will fit particularly well in the modern home. The rise in the use of the architectural concept of an "open floor plan" compliments the masonry stove. Such a floor plan, which focuses on long lines of sight and minimal interior wall use, is perfect for distributing the radiating heat from the masonry stove, which should be centrally located in the building or space being heated.



The Numbers Behind the Theory

The major property that sets a mason heater apart from a traditional wood stove is the concept of thermal diffusivity. This property is a measure of the ability of a material to conduct thermal energy relative to its ability to store thermal energy. This property is defined by the thermal conductivity, density, and specific heat capacity of a given material. Thermal diffusivity is defined using the mathematical relationship:

$\alpha = k\rho * cp$

Where:

α = the thermal diffusivity

k = the thermal conductivity of a material (the property of a material to conduct heat)

cp = the specific heat capacity of a material (a ratio of heat added to a material compared to the temperature change of that material)

Just as a comparison we can compare the thermal diffusivity of some common mason and woodstove materials at a temperature of 68 ˚F:

Material	Thermal Diffusivity ($ft2$/hr)
Dry Brick	.02015
Steel	.45415
Cast Iron	.8525

From the table above the material with the lowest thermal diffusivity if the brick which means the brick is the material that would take the longest to warm up and would be the material that would take the longest to cool after being heated. This also means that materials with a higher thermal diffusivity will allow heat to move though them more rapidly. Thermal diffusivities are rather arbitrary by themselves but can be used in the world of heat transfer as a variable in some complicated differential transient equations which are used to find heat transfer rates in three dimensional spaces.

Another key aspect of heating with wood is that the heating process is thermal radiation dominated. This means that most of the heat generation from a wood burning device comes from the transfer of heat through the thermal motion of charged particles. This is because the fire itself is separated from the room and the exhaust gases from the fire leave through the chimney without transfering its energy into the room. In this aspect a mason stove also out preforms a woodstove which can be mathematically proven by using Christiansen's Equation of radiation heat transfer which is based upon the mathematical relationship:

$$q= A1*\sigma*(T14-T24)1\epsilon1+A1A21\epsilon2-1$$

Where:

q = to the heat transfer from the stove to the room

σ = Stefan-Boltzmann constant $0.1714*10-8Btu\hbar r*ft2*°R4$

$T1$ = the temperature of the stove

$T2$ = the temperature of the room

$A1$ = the surface area of the stove

$A2$= the surface area of the room

However Christiansen's Equation can be simplified if we say that the surface area of the room is much larger than the stove which simplifies the equation to:

$$q= A1*\epsilon1*\sigma*(T14-T24)$$

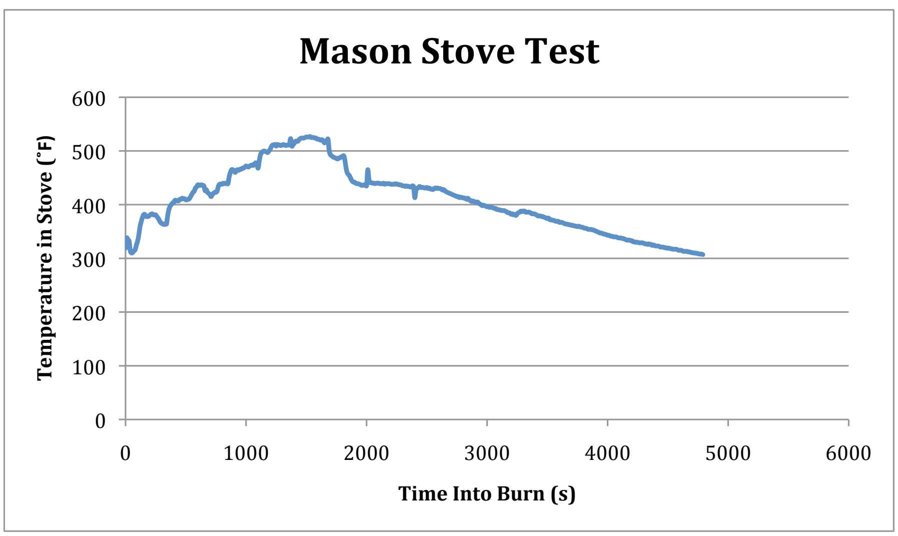
Now that we have equation we can look at the emissivity rates of some different types of stove materials which are shown in the following table:

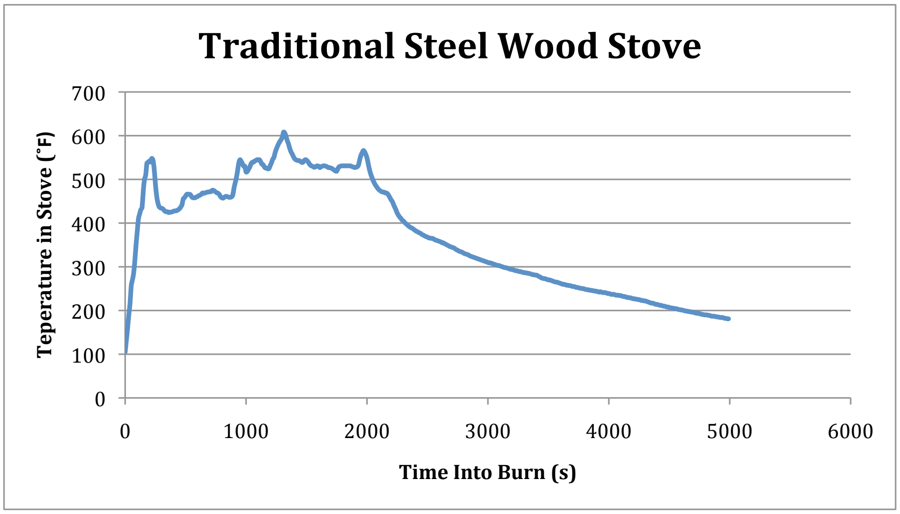
Material	Emissivity
Dry Brick	.835
Cast Iron	.65
Steel	.79

Now by comparing emissivity's of these materials and ignoring the fact that traditional wood stoves have a much smaller surface area compared to mason stoves we can see that for the same given temperatures and dimensions a stove made of brick will generate a greater heat transfer rate to the room (using the heat transfer mode of radiation) over the cast iron or steel wood stove.

The argument can be made that thermal radiation heat transfer is not the only mode of heat transfer for a woodstove but the convection heat transfer rates from air to air through a solid are relatively small unless you can generate huge temperature differences over an extremely large area which would be slightly difficult and awkward to do with a traditional woodstove. However the conduction heat transfer rate for a traditional woodstove greatly out preforms the mason stove but, is also the reason it is very uncomfortable to sit in the vicinity a traditional woodstove. In most cases if the room is large the conduction heat transfer rate of a traditional stove would have a hard time heating the outskirts of the room because the conduction heat transfer rates are just not large enough. If it were possible to generate the rates required to heat the outskirts of the room the temperatures directly next to the stove would be so great it would be difficult for anyone to tend the fire safely.

In order to spare people the from the endless math equations to reinforce this ideas that have been presented we conducted two combustion tests to compare mason heaters vs. a common steel woodstove. These two tests compared the relative air temperature near the outlet of the interior of these stoves over time. These graphs do not show the stove material temperature or the combustion temperatures of the wood being burned. The tests were conducted by using the amount of wood required to make one firing of the stove (which was relatively the same amount of wood in both cases) and then the stove was ran to optimize an efficient burn which is the end goal of anyone who burns wood to heat a space. These tests were not done following any testing standards but were done to give a simple and relative comparison between the two stoves to reinforce the concepts previously described.





Using figures 3 and 4 we can see that temperatures from both tests rapidly increase at the beginning of the tests. This is because there is a rapid temperature climb that was difficult to track because we had to choose a larger sampling time over a larger sampling rate. However for this discussion we do not need the temperature rise within the first couple minutes of firing. From the comparison of these two graphs we can see that steel wood stove reaches a high temperature very early in the test due to the thermal diffusivity of the steel. It does not take a long time for the steel to heat up where as the temperature in the mason stove took a while to reach a high temperature. This is because a mason stove has a larger volume and more mass than a traditional wood stove along with the lower thermal diffusivity. Because of this, the stove is absorbing most of the heat rather than sending it out of the stack. The only downfall to this is that a mason stove (from a cold start) does not immediately start warming the room; it is in a sense “charging” the masonry of the stove. This charging will occur all the way through the burn but once the stove reaches a given temperature it will still charge and heat the room.

The main concept we are trying to show through these tests is what happens once the fire dies out which occurred in both tests slightly before 2000 seconds into the tests. We can see the temperature drop in the traditional stove at a greater rate than that out the mason stove. This is because the high thermal diffusivity of steel allows the heat within the stove to dissipate rapidly.

We can see a more gradual decline in temperature because the brick work has the lower thermal diffusivity allowing it to hold onto its heat for a longer period of time.

This is a key factor when you burn wood and want to wake up to a warm house in the morning without having to put wood into the stove in the middle of the night. A person with a mason stove just needs to thermally "charge" their stove in the evening with enough thermal energy to last until morning.

Standby Losses

Standby losses can have a significant effect on the performance of any fuel burning heating device. The methods of building air infiltration must be considered to obtain a complete picture of heating system performance. The efficiency numbers reported for wood stoves or oil heating systems are almost always for the on-cycle performance only, when the fuel is being combusted. Systems such as resistance heating or heat pumps do not have infiltration losses so care must be taken when trying to develop a clear and complete comparison across types of heating systems. For a typical oil heating system there are 4 sources of building air infiltration:

- Burner on-cycle combustion air: air required for combustion, may be drawn from heated space or directly from outdoors.
- Burner on-cycle draft control air: a barometric regulator is used to maintain a constant draft at the flue outlet. Air is taken from inside the building and must be replace by cold outside air
- Burner off-cycle air flow: Some air flow continues through the chimney because the warm chimney produces a draft effect.
- Burner off-cycle draft control air: the off-cycle chimney draft produces a flow of air through the barometric damper

Similar losses are associated with wood burning devices except that they typically do not have automatically regulated dampers. Combustion air is drawn from inside the building and the draft can be regulated somewhat by the user. Burner off-cycle air is of particular importance for the masonry heater. Because it typically spends a much a higher percentage of time off-cycle than a wood stove it has a much greater potential to lower performance. Ideally, when the burn is complete the damper is 100% closed such that no air is leaving the building through the chimney. The simplicity of this statement is misleading, however, because knowing when the 'burn is complete' is difficult to judge and the penalty for closing the damper too soon is carbon monoxide and other combustion gases. On the other hand, waiting too long to close the damper or not closing it all the way will incur an efficiency loss.

Masonry heaters built by Maine Wood Heat employ a "5% cut out safety slot so that the warm chimney will continue to create a vacuum suction on the heater, thereby drawing off any carbon monoxide gases left in the ash box." [2] Without a system and an operator willing to actively monitor the chimney draft and carbon monoxide production level, a built-in failsafe mechanism like this is advisable, and the small efficiency penalty can be determined and considered for a detailed performance analysis.

To address health concerns such as indoor air quality and mold, a certain amount of air infiltration is desirable. In other words, up to a certain point, the air infiltration incurred by the stove is necessary and therefore can be neglected from a comparison of heating systems. This rate of air exchange must be considered in the context of the heating system if a measure of total building energy efficiency is sought.

Design Description

The original intention of this study was to analyze the articulation of the masonry stove with a heat pump. Ideally, the heat pump would handle moderate heating demands of the shoulder seasons while the masonry stove would be used for the steady cold of the winter months. By using these two heating sources together in an organized fashion, the maximum amount of comfort could be achieved with the least cost of power or fuel (wood).

This was of interest because both heating options provide benefits the other lacks and should provide complementary performance. The heat pump can respond quickly to changes in demand and can be very efficient when operating over moderate temperature differences. The disadvantage of the heat pump is its reliance on the infrastructure and lack of storage in the event of an absence of electricity. Masonry stoves on the other hand, have the capacity to provide long-lasting, steady radiant heat for Maine's coldest days and nights. The nature of wood burning also provides the resident the ability to maintain stores of fuel, that is, a home-owner can keep as much wood on location as is deemed necessary. The function of a masonry stove is not dependent on infrastructure or other external factors.

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Unfortunately, a combination of passive solar gain and resident behavior prevented the use of the masonry wood stove. [See Professor Hill's Note in Appendix D] The aim of the study shifted to assessing the performance of the masonry. In conjunction with a related laboratory experiment for the University of Maine mechanical engineering program's senior laboratory course, we sought to describe the heat storage capacity of the masonry heater and therefore determine how long the stove could maintain a comfortable space temperature between firings. The details of this investigation are presented in the Lab Report section.

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Lab Report

There exist a few different standards for stove testing, but only one ASTM U.S. government approved method for masonry heater assessment. Some methods rely on rapidly cooling flue gasses with a series of iced chambers in order to solidify larger flue components such as partial combustion products. This method requires a rather large assembly and has a very slow turn-over rate for the experiment. The cooling chambers must be removed and washed with acetone to clean them for re-use. The acetone-particulate mixture is then allowed to reduce by acetone evaporation in order to isolate and weight the particulates captured. Without many containers for use as cooling chambers, this process can take upwards of a day to run fully and reset for a subsequent trial.

Another method dilutes a small portion of the flue gas to a specified ratio of flue to ambient air used and passes the now-diluted gas through a particle filter which is weighed to determine the amount of particles captured. This weight of particulates is related to the mass of the fuel (wood), usually on a gram per kilogram basis. The filters can be switched out and should be used for a set time period so the particulate weight can be related to the amount of wood combusted.

Among the standards for flue analysis, there are also standards in the fuel used. Some studies and standards call for small, regular pieces of wood arranged in a standard fashion. These methods of standardizing the fuel tend to call for slender square-rods of wood of a specific species stacked in a predictable way to provide as much similarity from one test-burn to the next. These methods, while perhaps more repeatable, do not accurately model the actual use of a stove.

The actual stove end user usually has irregularly split wood of varying shape and size. The wood in any given resident's supply is not necessarily the same species and depending on the length of time that the fuel has been stored, will have drastically different moisture content, which is a major cause of variability in a test-burn.

The (arguably) more practical standard of wood-fuel calls for a range of sizes of the individual pieces. Acknowledging that the wood is split from a cylinder, usually ending up with a circular sector cross section, not much longer than a foot, one standard calls for wood that may pass through a certain diameter hole, but not a smaller 3 inch hole. Similarly, the moisture content is to be bounded within an acceptable range, rather than held at one specific value. While this standard may have greater variability from one test-burn to another, many trials may be used to describe the behavior with appropriate statistical analysis, and should more accurately reflect actual wood stove use. This is beneficial as the description of performance will describe a performance closer to true operation and can be used for larger study samples of "out of laboratory" stoves. Rather than build a stove in a controlled environment and operating it in a very specific way, the stoves that are in-place at many residences, being operated at different capacities can be better compared to each other.

Typically, for EPA certification of a wood stove or masonry heater, the manufacturer submits their product to a third-party test laboratory which uses and ASTM standard test method to determine performance. Thus far, the EPA has only regulated particulate emissions on a mass/time basis.

Residential Wood Heat Governmental Regulation and Implications

Wood burning devices are subject to two types of government regulation: building codes and emission limits. The focus of this report is emissions regulation. The federal EPA has set a limit for particulate emissions on a mass/time basis since 1988. States are free to adopt stricter regulations; currently only a handful have elected to do so. The federal regulation does not include masonry heaters or wood burning cook stoves, but does specify in detail a wood burning device classification scheme. For a masonry heater to be exempt from regulation in Oregon, it must weigh more than 800 kg, otherwise it is classified as a wood stove regardless of construction type. The federal EPA Most regulation thus far has been targeted specifically at wood stoves, but new regulations released January 2015 will now include wood cook stoves, propose to regulate masonry heaters, and have lowered the allowable particulate emissions effective January 1, 2016 [3]. The EPA does all of its regulation at the front end, through independent testing before the stove is released onto the market. It does not have any method for monitoring owner-built stoves.

Concerning traditional furnaces, there are building codes in place that designate the type of abutment that the furnace must sit on as well as the proper clearance around the fire chamber. Other considerations include proper exhaust handling and chimney height. A major concern for masonry wood stoves, due to their massive nature, is proper foundation support when being introduced to existing buildings. The masonry stoves are so heavy that they often require additional support when located above a basement. Without this, the home-owner risks injury and property damage as well as the loss of the heating source.

Implications for the home owner are usually minor. Any wood stove manufactured before a set of regulations is passed is 'grandfathered' and can be used, bought and sold privately. Insurance rates are a consideration, and vary widely from one insurance carrier to another based presumably on their policies and their case by case assessment. Economically, consumers can expect to bear the cost of research and revised manufacture of stoves that must be altered to meet new regulations, but these up-front costs are typically offset by increased stove efficiency.

As wood stove efficiency has been mandated to increase again and again, their disadvantage compared to masonry heaters narrows. If masonry heaters are subject to governmental regulation, as is proposed, their cost can only be predicted to increase, exacerbating their already overwhelming drawback.

Conclusions

Recommendations for Future Designs

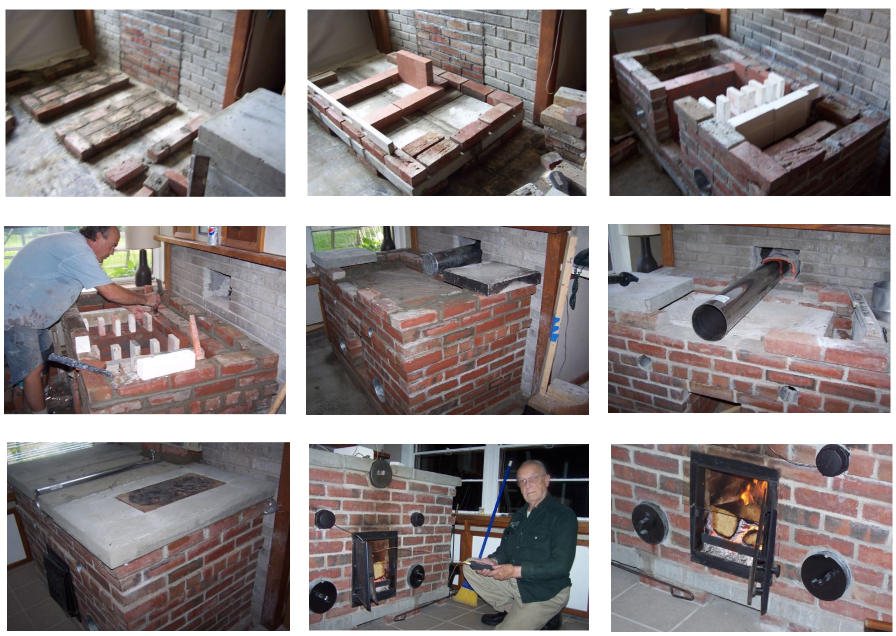
Perhaps one of the most important considerations that were made apparent in the stove at the College Avenue location is proper sealing or material use for the external shell of the stove. Traditional red bricks tend to be porous. This porosity prevented precise monitoring and control of the inlet air for combustion. The benefit of masonry stoves is their elongated burn path, allowing for more complete combustion. When the outer shell of the stove is riddled with tiny holes, cold ambient air is drawn into the stove, mixing with the combustion gasses. This added cooling hinders combustion and shortens the effective burn path, reducing efficiency and total thermal release. This effect should be mitigated as much as possible, providing as air-tight of a combustion chamber as possible.

Appendices

The masonry stove referred to in this report was well documented through the building and testing processes. This section will deal with representing each stage of the project as a whole along with other aspects of this report. All other relevant documents can be found in the following appendices.

Appendix A - Construction

Below are a few images depicting the construction of the masonry stove in Professor Richard Hill's residence.



Appendix B - Air Flow Testing

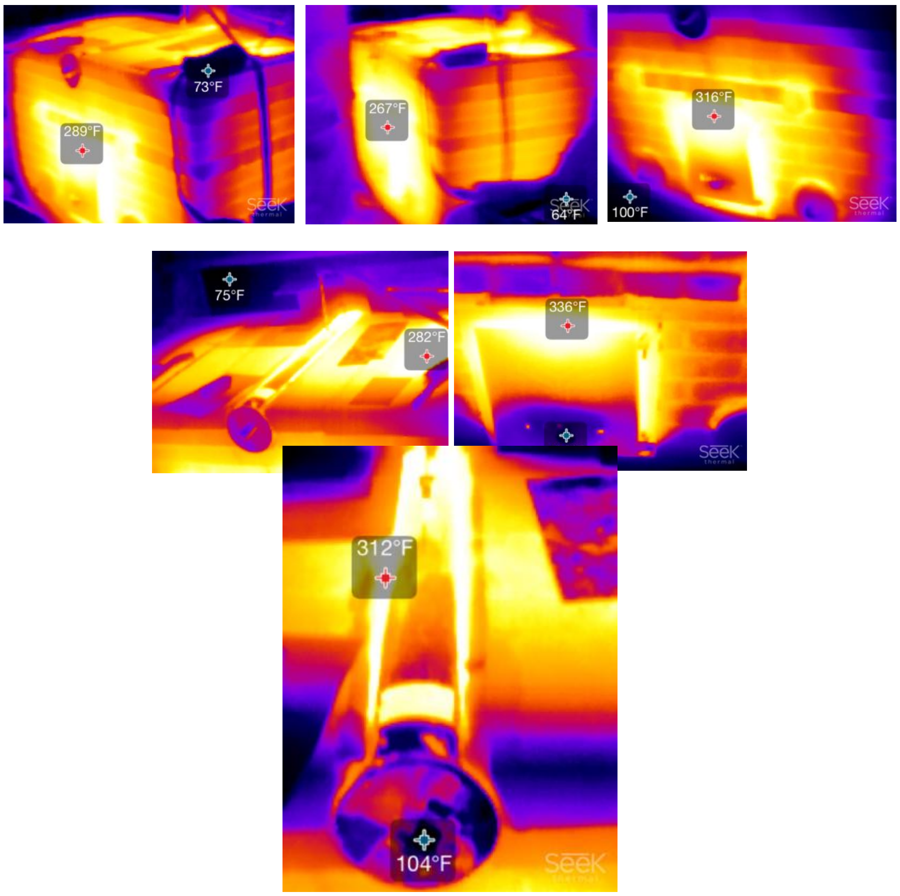
Before any combustion tests could be run, it was necessary to calculate certain qualities relative to the air flow throughout the stove. All orifices were sealed and a vacuum was pulled through a venture. This provided the ideal settings for the measurements needed. The pictures below depict the air flow tests conducted on the masonry stove heater.





Appendix C - Thermal Imaging

A special thermal imaging device was obtained in order to gain a perspective on the temperature variances across the masonry stove. These images allowed a deeper understanding of the heat concentrations throughout the masonry. The images provide a central temperature reading relative to the aim of the device towards the masonry heater.



Appendix D – Letter from Professor Richard Hill

Richard C. Hill
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rchill@maine.edu
207-866-2204

With a l918 birth certificate and having retired from teaching in 1962, it took more courage than wisdom to "take on" the guidance of four students in a capstone project. But thanks to their tolerance and good judgment, we all came out a winner—well—most of the time.

But there was tribulation:

1) **I had hoped that several days of heat-pump operation could be followed with several days of masonry stove operation and a judgment made on pounds of wood per degree day and kWh per degree day in the heat pump. My tenants had no interest in the project and I was unable to cajole them into trying. The heat pump was always able to carry the load, and my tenants so no point in fussing with the masonry stove. The masonry stove was located in an area with strong passive solar gain—another complication.**
2) **Early in the program we found that control of combustion air was nearly impossible. Our instruments were telling us of great quantities of excess air. The mason who constructed the stove (Chris Manlove of Bangor) came in for a half day and fixed the problem. The delay set our program back several weeks.**
3) **Our work shifted focus from 1) the integration of a masonry stove into a scheme of house heating into 2) an analysis if the masonry stove itself.**
4) **Home heating appliances have a social as well as a technical dimension. Appropriate effort was spent on the public reaction to masonry stoves: real-estate agents, insurance underwriters, fire- code officers, air quality people, etc.**

Appendix E – Other Ventures

Whether it is human nature or just plain Mainer ingenuity we decided to find other uses for a masonry stove other than just heating a dwelling. Therefore whether it being a need to reach back into the past or fact that Maine is subjected to frequent power outages which take away the modern conveniences of society we found a procedure in which we could bake bread in our wood fired masonry stove.

Knowing that cooking in the firebox while the fire was active would result in a very burnt and unpleasant product we decided to try and cook using thermal radiation from the stored bricks after the fire had burnt itself out we developed a procedure to convert our stove into a radiation oven.

Procedure

1. Let the fire burn itself out.
2. Remove the reaming coals and ash from the firebox.
3. Place bricks on the bottom of the stove in which a tin cooking sheet can be placed on which acts as a heat shield from the hottest part of the stove (the part of the stove that was in direct contact with the coals.
4. Place a cooking rack over the tin cooking sheet so that it does not come into direct contact with the heat shield.
5. This will be the cooking platform to put the bread tins on.

The end result should give you a configuration that looks like:

Appendix F – Professor Hill's Bean Bread Recipe

Stone Oven Bean Bread

-(Us e of the metric system gives the enterprise a scientific tone)

-Start with 0.300kg red kidney beans

-Add water for a total weight of 1.320kg --- Soak over night

-Place in pressure cooker --- bring to pressure for one hour --- let coast until temperature falls to about 55˚C. Blend with portable mixer.

-Add 0.230 kg molasses --- total weight 1.550 kg

-Add 0.165 kg dry milk --- total weight 1.715 kg

-Add 0.132 kg olive oil --- total weight 1.847 kg

-2 tablespoons dry yeast. By this time, the mix should be about 45˚C (113˚F) *. Blend all of the above with portable mixer. Add rounded tablespoon cinnamon, one tablespoon (level) salt. Set aside for ten minutes --- the mix should swell.

-Add 1.32 kg whole wheat flour --- total weight 3.160 kg

-Add a little water to bring total weight to 3.500 kg

-Turn the crank on the dough mixer; let rise; then divide in 10 loaves (6 by 3 by 2 baking tins) 0.350 kg each; let rise to top of pan; preheat oven to 350˚F (176.7˚C); bake for 50 minutes. Enjoy.

-Store bread, according to the label, includes mono & diglycerides, ethoxylated mono & diglycerides, sodium steroyl lactylate, calcium peroxide, mono-calcium phosphate, ammonium sulphate, calcium sulfate, calcium propionate, ect. Our bread does not have any of that stuff, and we don't want to eat anything we can't spell.

* Temperature above 45˚C (113˚F) will kill the yeast

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