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The Hearth as an Element of the Sustainable House - A Comparison of Emission Test Methods for New Clean Burning Wood Fired Masonry Fireplaces

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INTRODUCTION

Residential scale biomass combustion can contribute to the sustainability aspect of housing. Wood fuel does not result in the introduction into the atmosphere of otherwise permanently sequestered carbon, as the use of fossil fuel does. Solutions such as residential wood heating (RWH) should not be ignored by the scientific community. Although difficult to do on a large scale, it is nevertheless much easier to replace home heating fossil fuel use with renewables than to replace transportation fuel use, due to the lower energy quality requirements for home heating. It can be argued that using low entropy fossil fuel merely to produce low grade (high entropy) heat is unsustainable by definition.

However, ambient air quality degradation from RWH emissions is the main obstacle to the increased use of this technology, and is equally unsustainable on a large scale. Research into RWH emissions is relatively recent, and efforts are ongoing to develop better tools. This paper describes a recent project to compare three different particulate matter (PM) emissions measuring methods. An attempt is made to establish a context for this work beyond that of simple regulatory requirements by examining some broader RWH issues.

History of the Hearth

The first controlled use of fire by man predates our own species, and is now believed to have occurred 1.4 million years ago by Homo erectus. Agriculture, in contrast, is only about 10,000 years old. Although chimneys were known in Han China 2,000 years ago, they only came into general use among our British forebears around the sixteenth century.

The open fireplace was brought to this continent by our British ancestors. In our colder North American climate, it was replaced for primary heating by the closed combustion iron stove in the eighteenth century. Even to this day, it is still commonly used as a main heat source in the British Isles[1]. This ancient relationship with fire continues to this day even though few people still carry the awareness that the words “hearth” and “heart” share a common origin.

Other European cultures had parallel developments, but with different technological outcomes. Of particular interest recently has been the masonry heater, which differs from the fireplace in having the ability to store large amounts of heat in a thermal mass. Recent North American research into masonry heater performance has been reported previously[2,3]. Although there is now an overlap between masonry fireplaces and masonry heaters, data for this report was obtained from tests done on two variations of the traditional masonry fireplace, the Rumford and the Rosin.

DEFINING SUSTAINABILITY

It is useful to examine fireplace performance issues from the viewpoint of sustainability. Woodburning has the potential to be a sustainable technology, but it must be done with high efficiency and low emissions. Traditional masonry fireplaces are receiving increasing scrutiny from air quality regulators. Washington state, a bellwether jurisdiction for progressive environmental regulation, is implementing state Clean Air Act requirements with state Building Code regulations requiring particulate emissions certification for new masonry fireplaces as well as factory-built fireplaces as of January 1, 1997.[4]

Sustainability has an intuitive appeal, but a precise definition has not yet had the opportunity to stand the test of time. Gas fireplaces, for example, are currently enjoying the favor of consumers and some environmental advocates. This is based partially, no doubt, on an industry advertising campaign offering reassurances that burning natural gas is "the right thing for the environment". What, then, is sustainability? And how do we define a "sustainable" fireplace?

The First International Conference on Sustainable Construction took place in 1994[5], and defining sustainability occupied two of the fifteen sessions. Conference coordinator Charles Kibert noted that the concept of sustainability is not a new one. It became part of the environmental vernacular in 1987 when the Brundtland Report described sustainability as "leaving sufficient resources for future generations to have a quality of life similar to ours."

Dr. Kibert makes a comparison of the traditional building construction criteria of performance, quality and cost with sustainability criteria of resource depletion, environmental degradation, and a healthy environment. This is summarized in Table 1.

This suggests a context for fireplace emissions research. If we start by attempting to define a generalized set of sustainability criteria, we may then use these criteria to identify specific research tasks that may inform regulation.

Table 2 uses Kibert's traditional criteria to compare a conventional wood burning masonry fireplace with an advanced combustion wood burning masonry fireplace and with a zero clearance gas fireplace. Table 3 uses Kibert's sustainability criteria for the same comparison.

We note that the conventional criterion of installed cost is currently perhaps the overiding factor in fireplace specification by the housebuilding industry. Convenient "push button" operation is perhaps a secondary, performance, criterion.

Examining the sustainability criteria, we note that obvious masonry fireplace advantages such as long lifecycle and the potential for reusability of materials are not recognized by current housing cost accounting methods. Discounted cash flow accounting places a premium on capital cost and has little regard for lifecycle costs, let alone environmental impacts. By the same token, the standard high emissions, low efficiency fireplace pays no penalty. Neither does the fossil fueled gas fireplace.

This is admittedly a tentative analysis and reflects the fact that explicit regard for sustainability criteria is a new and evolving trend in the housing field.

Moving Towards Sustainability

The ability to use minimally processed, locally grown fuel for domestic heating is a realistic option in many locales on this continent. There is a caveat attached to firewood use, however. Grown, harvested or burned improperly, it can also become an environmental liability.

Research into fireplace emissions is surprisingly recent[6,7,8,9].

Table 4 compares US-EPA field test data for masonry fireplaces with other residential wood heating (RWH) appliance types. Emissions for conventional open fireplaces are high compared to current woodstoves[10] due to poor combustion conditions associated with cooling from excessive dilution air. Stack losses are high, efficiency is low, and integration into "system" approaches to mechanically ventilated airtight housing is difficult at best[11].

In the transition to a more sustainable economy, the masonry fireplace must move from its current position as a symbol of wealth and leisure to reclaiming its role as an active and central part of a household that makes frugal and appropriately targeted energy use a main pathway towards sustainability

Early results from a fireplace emissions testing program conducted at Lopez Labs by the author and colleague J. Frsich indicate that there may be several avenues towards reduced emissions. One result, described in more detail below and in Table 5, has been the development of a simple new combustion air supply that, in conjunction with the use of an airtight glass door, is able to reduce the emissions from a masonry fireplace to below US-EPA limits for woodstoves.

RESIDENTIAL WOOD HEATING EMISSIONS

Sulfur

It is interesting to note that wood is essentially a clean fuel, with almost no sulfur content to speak of.

Carbon monoxide

Carbon monoxide (CO), like all woodburning emissions except fly ash, is a product of incomplete combustion. Because CO is relatively easy to measure, CO emissions have been used as a surrogate measure of overall woodburning emissions in Europe, where regulations have until recently focused exclusively on CO.

Particulates

This is not the case in North America, however. American data indicates that woodsmoke-caused wintertime violations of National Ambient Air Quality Standards (NAAQS) tend to occur earlier and more often from particulate matter (PM) than CO.

PM has become the focus of emissions research and regulation in the United States[12] and Canada[13]. The greatest public health concern is from particulate matter that is smaller than 10 microns (PM10). Particles of this size can pass directly into the bloodstream through the lung walls.

PM is a complex and variable mixture of incomplete combustion products. At the low toxicity end of the scale are non soluble inorganic compounds. These include soot, which is pure carbon, and ash, which consists of mineral salts. A 1992 American study[14] of in-home emissions from a masonry heater found a PM non soluble fraction of 61%.

The semi-volatile soluble organic compounds cool upon exposure to the atmosphere and condense into a very fine mist of chemically complex tar droplets, with 90% of the particles smaller than 1 micron. Of the soluble organic compounds, of most concern are the polycyclic aromatic hydrocarbons (PAH's), many of which are Class A carcinogens[15].

Volatile organic compounds

Little data is available on volatile organic compounds (VOC's). The American study cited above found VOC emissions of 0.4 g/kg from a masonry heater.

A COMPARISON OF PM EMISSIONS MEASURING METHODS

The McNear Brick Tests

In 1995, Western States Clay Products Association (WSCPA) sponsored a series of field tests of 2 masonry fireplaces. Three separate emissions measuring methods were used simultaneously–a modified EPA-M5G, an AES and OM41 as modified for use at Lopez Labs. Testing was conducted at the McNear brickyard in San Rafael, CA.

Methods used in this study

Fueling protocol. A fueling protocol developed by the author and colleague J. Frisch at Lopez Labs was used in most of this study. The Lopez protocol differs from EPA-M28 in that it uses real world fuel. Limited earlier testing[16,17] on two masonry heaters indicated that use of dimensioned lumber could reduce PM emissions by approximately 50%.

The Lopez Labs fueling protocol uses cordwood. Instead of sizing, it is a specification for describing the fuel load in enough detail to allow the original initial condition in the firebox to be reconstructed at a later date.

Three separate PM measurement methods were run simultaneously in this study.

Modified EPA-M5G. This method was conducted by S. McNear from McNear Brick, the site of the testing, and Dr. D. Jaasma from Virginia Polytechnic. It consisted of a Method 5G dilution tunnel and filter train. Two filter trains were run in parallel to provide data redundancy. Flow rate through the tunnel was measured with a pitot tube and held constant by means of a variable speed fan. A sample was drawn from the tunnel at a constant rate, and therefore at a fixed proportion to the total tunnel flow.

Automated Emissions Sampler (AES). This method was conducted by P. Tiegs and J. Tiegs from OMNI Environmental (Beaverton, Oregon). The AES unit is a portable emissions sampling system. Flue gas is drawn from the stack and the sample travels through a heated filter for collection of particulate matter. The filter is followed by a cartridge containing a sorbent resin for collecting semi-volatile hydrocarbons. Flue gas oxygen concentration is measured by an electrochemical cell.

A constant sample flow is maintained and a subsample of this flow is pumped into a bag for later laboratory analysis of average carbon dioxide and carbon monoxide concentration.

The system operates automatically for the duration of the test period (typically one week) except for daily input of fuel weight data. For this study, the AES was run in a daily mode in order to yield discrete data on individual burns.

Oregon Method 41 (OM41). An appliance developer has different criteria in selecting a testing method than a regulator. The regulator's criteria are more rigorous and are based on legalistic requirements. The developer's main requirements are simplicity and cost. Until recently, almost no woodstove research and development programs used Method 5 dilution tunnels in the development of cleaner burning appliances. They used the Condar dilution tunnel, which was developed by the late Dr. Stockton Barnett, one of the pioneers of modern woodstove performance testing. This method became an official method in Oregon, the state that originated woodstove regulation, and is known as Oregon Method 41 (OM41).

Fireplaces Tested

Frisch Rosin. The Frisch Rosin fireplace is based on the Rosin firebox, developed in 1939 by Professor P.O. Rosin at the Institute of Fuel in Great Britain. Using the principles of dimensional analysis, Rosin applied findings from fluid model studies to full scale masonry fireplaces. It consists of a curved precast refractory firebox and a refractory hood. It has no smoke shelf. In the Frisch-Rosin design, an airtight ceramic glass door is added to the basic Rosin. The main feature is the combustion air supply, which does not have an adjustable control. It is very simple, consisting of a 1" i.d. air tube on either side that is aimed directly at the fire.

Buckley Rumford. The Buckley Rumford uses the traditional Rumford fireplace design. Initially designed as a retrofit for the huge fireboxes of the day, it gained wide popularity. It reduced the depth of the firebox considerably and added splayed sides. This increased the radiation of heat into the room considerably. It also added a throat and a smoke shelf.

An important feature is the curved chimney breast. This is the trailing edge of the top of the fireplace opening. Rosin's aerodynamic models clearly show eddies at this point for a standard fireplace with a square edge. A 30" Buckley Rumford with 18' of 8x12 flue was used for the McNear tests.

Test Description

Frisch Rosin. Prior to the tests at McNear Brick, 26 tests spread over two years were performed on the Rosin fireplace at Lopez Labs using OM41. Four of these tests were with the same combustion air configuration (Frisch) that was used for the California tests and have been reported previously[18]. A total of 10 tests were performed at McNear Brick. There is OM41 data for all 10 tests, M5 data for 5 tests, and data from all three methods for 2 tests. In addition, a second AES system was run in normal (non-discrete) mode for a 7 day certification run. Subsequent to the McNear tests an additional 9 tests were conducted at Lopez Labs on a standard site-built fireplace using the Frisch air supply. All tests with the Frisch air supply were run with the airtight glass doors closed and with identical fuel configurations, with the fuel load kindled from the top ("top down" burn).

Buckley Rumford. A total of 7 test runs were done at McNear Brick. All runs were in the open fireplace mode. All three test methods were used for three tests, dilution tunnel only was used for three tests, and for one test there is tunnel and OMNI data. Fueling for the tests was variable, and on some tests included the use of a gas log lighter.

TEST RESULTS

Data used for this report

Data for this report is taken from summaries provided by the participants as well as copies of the original laboratory notes for the M5 and OM41 data. Nine test runs used two or more test methods simultaneously. Data from the last 6 of these 9 tests is used for this report due to various problems during initial tests. In addition, data from the 7 day AES certification test on the Frisch Rosin is reported.

Test Results

Test results for the 6 comparison tests are summarized in Figure 1. Tests 1 – 4 are on the open Buckley Rumford and tests 5 – 6 are on the closed Frisch Rosin. The difference between open and closed combustion is readily apparent on the chart from the larger error bars on the AES open fireplace data due to higher dilution. For the closed tests, clustering of the data points is noticeably tighter.

Test results for the AES certification run on the Frisch Rosin are summarized in Table 5.

CONCLUSIONS

A number of data resolution and accuracy issues were seen with all three test methods. Considering that this was the first ever attempt to run these three methods simultaneously under field conditions, this is not unexpected and highlights some of the difficulties involved in establishing real world fireplace performance. OM 41, the simplest method, did not emerge with any clear disadvantages over the other methods.

The AES certification test results for the Frisch Rosin with the Frisch air supply are noteworthy. It is the first demonstration of a clean burning masonry fireplace using simple technology. While it is only a single data point due to the cumulative nature of the AES method, it is in good agreement with both the discrete McNear Brick data as well as prior Lopez Labs data[19] and subsequent Lopez Labs data. This data allows us to predict with more confidence the possibility of a clean burning site built masonry fireplace. A likely path will be to provide a trained fireplace builder with a specification for airtight ceramic glass doors and combustion air inlet configuration. For the end user, it may require a specification for fuel sizing, moisture, stacking, and batch burning of a single charge using top ignition.

DISCUSSION

Wood is a complex fuel in its natural state. The extraordinary process of solar energy storage through atmospheric carbon reduction by photosynthesis is an undervalued option as a power source for domestic heating. Using wood fuel properly will place a requirement on the user. He must move beyond his present role as simply an energy consumer and become an active participant in a closed energy cycle. This may well serve as a template for awareness of sustainability issues on a larger scale. It is not unreasonable to place a burden of environmental awareness on the fireplace user if we are to reduce our unsustainable dependence on fossil fuel.

Our journey to sustainability will no doubt be a long one, and we will need the sense of connection that the ancient act of watching a fire can give us. It appears surprisingly easy to make substantial improvements to the conventional site built masonry fireplace, and we can use this as a transition technology that is acceptable in the current homebuilding marketplace. As in all natural systems, more pathways to sustainability will start at the bottom than at the top.

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Table 1. Comparison of traditional criteria with sustainability criteria (Kibert)

Traditional Criteria	Sustainability Criteria
Performance	Resource depletion
Quality	Environmental degradation
Cost	Healthy Environment

Table 2. Fireplace comparison using traditional criteria

Traditional Criteria	Conventional Woodburning Masonry Fireplace	Advanced Combustion Woodburning Masonry Fireplace	Direct Vent Gas Fireplace
Performance	low efficiency	medium efficiency	low to medium efficiency
	high emissions	low emissions	low emissions
	open fire	closed fire	closed fire
	renewable fuel, minimally processed	renewable fuel, minimally processed	premium non-renewable fossil fuel
Quality	Hand built locally by skilled craftsperson	Hand built locally by skilled and educated craftsperson	Factory made, simulated masonry finish
Cost	Higher	Higher	Lower

Table 3. Fireplace comparison using sustainability criteria

Sustainability Criteria	Conventional Masonry Fireplace	Advanced Combustion Masonry Fireplace	Direct Vent Gas Fireplace
Resource depletion	natural materials (clay)	natural materials (clay)	highly processed materials (steel)
	embodied energy:	embodied energy:	embodied energy:
	low (adobe) to high (hard clay bricks)	low (adobe) to high (hard clay bricks)	high
	long lifecycle (100 years)	long lifecycle (100 years)	short lifecycle (20 years)
	reusable materials (using appropriate mortars)	reusable materials (using appropriate mortars)	some recyclable materials
	burns renewable fuel	burns renewable fuel	burns non renewable fuel
Environmental degradation	high toxic emissions	low toxic emissions	low toxic emissions
	low greenhouse emissions	low greenhouse emissions	high greenhouse emissions
Healthy environment	"heart" of the home, psychological well-being	"heart" of the home, psychological well-being	artificial fire, simulated well-being

Table 4. Comparison of US-EPA (AP41) field tested emissions by RWC appliance type

RWC Appliance Type	PM emission factor, g/kg
Masonry fireplaces	17.3
Masonry heaters	2.8
Woodstoves (non-catalytic)	
Pre-EPA	15.3
EPA Phase II certified	7.3
Pellet Stoves	
Uncertified	4.4
EPA Phase II certified	2.1

Table 5. Test results for the 7 day AES certification field test of the Frisch Rosin fireplace

Parameter	Value
PM Emission Factor, g/kg	2.2
PM Emission Rate, g/hr	2.9
CO Emission Factor, g/kg	44
CO Emission Rate, g/hr	59.7
Net Delivered Efficiency, %	57.9
Average Heat Output, BTU/hr	15,184
Average Burn Rate, dry kg/hr	1.33

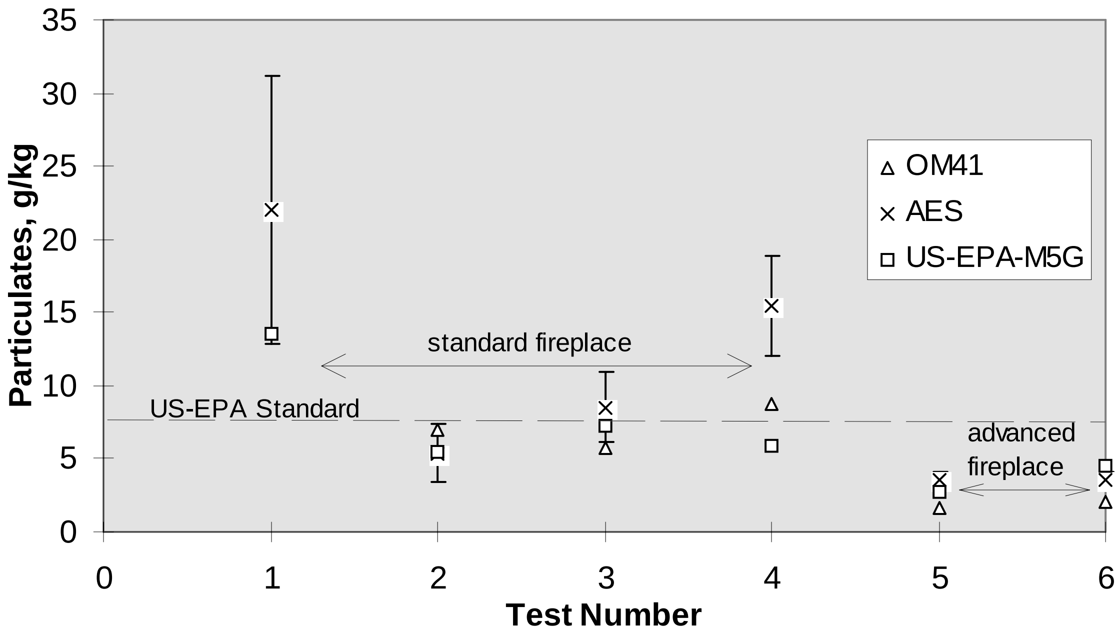

Figure 1. Comparison of masonry fireplace PM emission factors as measured by three different test methods