A REPORT ON THE PARTICULATE EMISSIONS PERFORMANCE OF MASONRY HEATERS – DEFINTION, DATA, ANALYSIS AND RECOMMENDATIONS

Prepared for: The Masonry Heater Caucus of the Hearth, Patio and Barbecue Association

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Date: February 5, 2008

The scope of this report is to provide the U. S. Environmental Protection Agency with chronologically organized information about the particulate emissions performance of masonry heaters as a defined product class and to provide conclusions and recommendations based on that information.

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Introduction

This White Paper is submitted by the Masonry Heater Caucus of the Hearth, Patio and Barbecue Association to support its request that the Office of Air Quality Planning and Standards (OAQPS) recognize that Masonry Heaters are a class of solid fuel heating devices that are inherently clean-burning and can be a viable emissions control option in PM-impacted areas. The White Paper has five parts:

- Background
    - Provides relevant background information on regulatory status, numbers installed annually, data sources, etc.
- Definition
    - Defines what comprises a clean-burning masonry heater including a list of critical features.
- Data
    - Summarizes the available North American emissions performance data.
- Conclusions
    - Summarizes our conclusions on emissions performance.
- Recommendations
    - A section containing our recommendations that includes procedures that can be used to provide assurances that masonry heaters built in the field include the critical elements identified in the definition of clean-burning masonry heater.

Background

Modern masonry heater designs originated in Europe and those designs have been in use for many decades, if not centuries. While masonry heaters are installed in relatively large numbers across Europe, they represent only a small niche in the solid-fuel burning market in the United States. Masonry heaters are site-built, often by individual masons, making it hard to provide a precise number of installed units. The Masonry Heater Caucus estimates that between 600 and 1,000 masonry heaters are installed in North America each year. This represents only a fractional percentage of all solid-fuel burning appliance sales and installations.

EPA's wood stove New Source Performance Standard (NSPS), 40 CFR Part 60, Subpart AAA, specifically exempts masonry heaters because the Regulatory Negotiation Committee recognized that they are inherently clean-burning due to their high burn rates and air-rich characteristics. This is explained in the preamble to the proposed regulations[1] as follows: "*The 800 kg cutoff was established as an easy means of excluding*

[1] Federal Register/Vol. 53, No. 38/February 26, 1988/Rules and Regulations/Page 5864. See Attachment 1.

high mass fast-burn wood-burning appliances known as "Russian stoves" or "European tile stoves." These devices typically operate at hot, fast burn rates and cannot be damped. It is also likely that they are incapable of meeting the 5 kg/hr minimum burn rate. The intent of the committee was to exempt from the standards these appliances which rely on clean-burning air-rich conditions and which have high combustion efficiencies."

Notwithstanding EPA's clear determination in the NSPS rulemaking that masonry heaters are inherently clean-burning, because of their high burn rates and air-rich characteristics, masonry heaters have had a difficult time getting accepted by SIP planners as viable control options for PM-impacted areas. In some jurisdictions, only NSPS-certified wood stoves have been allowed. While the intent may have been to eliminate "loop-hole" products as a means of improving air quality, the result for some product classes, including masonry heaters, has been to effectively ban a clean-burning alternative. Other areas have followed EPA's RACM/BACM guidance[2] and allowed NSPS-certified appliances, along with other appliances that have been shown to be "equivalent." [See also Renner memo[3].] However, these equivalency provisions, although written with good intent, are flawed in concept. The NSPS emission limits were based on Best Demonstrated Technology (BDT) for traditional wood-burning stoves and inserts and were supported with significant data from the Oregon woodstove certification program. These levels do not translate to appliances employing different technologies and, therefore, with different BDT. Masonry heaters are not designed nor do they operate like NSPS certified stoves or inserts. Moreover, the very different operating profiles for masonry heaters compared to woodstoves present difficult issues when attempting to make "equivalency" findings. The fuel load in a masonry heater is fully-consumed in a short period of time. This heats a large mass of refractory, which in turn discharges the stored heat over many hours. Woodstoves are also batch loaded, but the heat is delivered as the fuel load is consumed. The length of the burn depends on how the operator sets the air controls. When comparing emissions performance on a gram/hr basis, the masonry heater emissions must be averaged over the period of time that useful heat is being provided to the home in order to compare them with woodstoves on an "apples to apples" basis. Finally, the fact that air quality planning agencies frequently require costly case-by-case showings of "equivalency" has been an additional, significant obstacle to masonry heater builders.

We are presenting the results of masonry heater testing that has been conducted in North America, but it is important to recognize that considerable testing has also been conducted in Europe and that testing corroborates the clean-burning performance of masonry heaters as a class of products.

[2] Technical Information Document for Residential Wood Combustion Best Available Control Measures, U. S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1992. See Attachment 2.

[3] Memo: F. H. Renner to Chief, Air Branch, Regions I – X, September 23, 1991, Interpretation of EPA's Guidance for Residential Wood Combustion Emission Control Measures. See Attachment 3.

Definition

It is also necessary to establish a way to determine what masonry heater designs should qualify for recognition in that class and for that the following definition is proposed.

"A masonry heater is a site-built or site-assembled, solid-fueled heating device constructed mainly of masonry materials or soapstone in which the heat from intermittent fires burned rapidly in its firebox is stored in its massive structure for slow release to the building. It has an interior construction consisting of a firebox and heat exchange channels built from refractory components."

Specifically, a masonry heater has the following characteristics:

- Site-built or site-assembled.
- A mass of at least 800 kg. (1760 lbs.).
- Tight-fitting fuel loading doors that are closed during the burn cycle,
- An overall average wall thickness not exceeding 250 mm (10 in.).
- Under normal operating conditions, the external surface of the masonry heater, except immediately surrounding the fuel loading door(s), does not exceed 110 C. (230 F.).
- The gas path through the internal heat exchange channels downstream of the firebox includes at least one 180-degree change in flow direction, usually downward, before entering the chimney.
- The length of the shortest single path from the firebox exit to the chimney entrance is at least twice the largest firebox dimension.
- A combustion air control that is designed to provide a high-fire burn rate only.
- A combustion air introduction system that directs the majority of the combustion air to the area in the firebox that is at or above the level of the fire.
- Constructed or installed by qualified masonry heater builders.

ASTM E-1602 "Standard Guide for Construction of Solid Fuel Burning Masonry Heaters" provides design and construction information for the range of masonry heaters most commonly built in the United States and can be used as the basis for determining whether a particular design qualifies for recognition as a masonry heater. A copy for reference purposes only is included as Attachment 5.

Data

A table showing the reports from testing in North America that provides data relevant to types of masonry heaters that meet the above definition is included as Attachment 6. The table includes a brief description of the test parameters and the average emission results. The data comprises the results from research studies, test method development efforts, and testing for certification to state masonry heater rules. The average particulate performance is presented as emission factors (grams of particulate per kilogram of fuel burned). This format provides the best way to compare emissions from high-burn-rate, high-combustion-efficiency, intermittently-fired appliances. Emission rates, when available in the reports, have also been provided. However, as was briefly discussed in the Background section, emission rates (grams of particulate per hour) can be deceiving when evaluating intermittently fired high-mass appliances. One or two fires that last only a few hours can provide heat for a full twenty-four hour period. Emission rates should therefore be normalized over the period of time that heat is being provided by the masonry heater if they are to be used to compare different appliance types. The emission rates we are reporting here may not have been calculated using the same procedures in each case. Some values have been normalized, some have not. These differences should be taken into consideration when comparing individual values. We have also included ranges for data, as well as results from individual heaters when available in the reports.

The data that we are presenting represents all data from masonry heater testing in North America that we have been able to obtain with the exception of data from a test series conducted on four products from one manufacturer[4]. Please note that some additional reports have been issued that address sub-sets of testing results from the reports we have cited. Those reports have not been included if their data are contained within the cited reports. The table also includes a reference to the AP-42 emission factor for masonry heaters. Full references for each cited report are included in Attachment 7.

Report cover pages and extracted summaries or excerpts from the reports, when available, are included in Attachments 8 - 21. Copies of the full reports can be made available upon request.

Reference C (Attachment 10) is the report on the field testing of five heaters that represent a cross-section of the masonry heater designs that were being built across the country. This study from 1991-1992 was funded by Masonry Heater Association members. Ultimately, EPA was approached and agreed to monitor and audit this test program. In an EPA memorandum[5], Dr. Robert C. McCrillis presents his evaluation of the test results from the masonry heater test program. These results (which covered a broad range of heater designs) were used by EPA to calculate the 2.8 g/kg emission factor for masonry heaters that is listed in EPA's AP-42 document "Emission Factors from Residential Wood Combustion".

[4] These data were excluded because the tests were not conducted following a masonry heater test protocol but were instead generated using a fueling and operating protocol for factory-built fireplaces.
[5] Memo: R. C. McCrillis to D. Mobley, May 8, 1992, Masonry Heater Field Performance Data. See Attachment 4.

Conclusions

The test data support previous conclusions regarding the particulate emission performance of masonry heaters as a class and further defined as those designs that meet the criteria outlined earlier in this paper. Using a variety of test procedures, fueling protocols and fuel types, emission measurement methodologies, laboratory and in-situ measurements, the resultant average particulate emissions have ranged from 1.4 to 5.8 grams of particulate per kilogram of fuel burned. The average of the averages for this data is 2.9 g/kg. Again, the current AP-42 emission factor for masonry heaters is 2.8 g/kg. Note: We have not included the emission results for the Russian Heater cited in Reference B (Attachment 9). This heater was constructed by a mason inexperienced and untrained in masonry heater construction and the emission performance is considered as an outlier when compared to all other available data.

The low average particulate emissions from masonry heaters combined with the small number of annual installations justifies allowing masonry heater installations to continue without imposing undue burdens on the installers of these appliances. The cost associated with testing individual masonry heaters is simply prohibitive and does not represent a needed expenditure to protect air quality. Another means of satisfying air quality regulators is appropriate in this case.

Recommendations

Masonry heaters as a class should be accepted by EPA as clean-burning and EPA should give the appropriate guidance, in the form of a letter from the Office of Air Quality Planning and Standards, to state, local and tribal air quality regulators. That letter should recommend allowance of the installation and operation of qualified masonry heaters in PM-impacted areas as a viable strategy for PM reduction from Residential Wood Combustion (RWC). We suggest that the current AP-42 emission factor of 2.8 g/kg continues to be representative of the expected performance of masonry heaters as a class.

Qualified masonry heaters are defined as those in conformance with the masonry heater definition included in this paper.

Conformance with the specified masonry heater design parameters should be confirmed and documented by an independent third party laboratory for each masonry heater design. This would be an engineering evaluation based on design drawings provided by the masonry heater builder or manufacturer. The conformance report would be applicable to each heater that is installed in accordance with the conforming design. Additional affirmations by the masonry heater installer or builder that the design as built in the field is in conformance with the design drawings could be considered if needed.

Attachment 1: Reference 1 – Excerpt from Federal Register

5864 Federal Register / Vol. 53, No. 38 / Friday, February 26, 1988 / Rules and Regulations

firebox, EPA believes that it may still be possible for circumvention to occur. In such cases, however, it would be the consumer rather than the fireplace manufacturer who would be held accountable for making an affected facility. For example, if a homeowner installs an enclosure on his new fireplace and if this enclosure results in the facility meeting the four criteria that define a "wood heater," this homeowner has "manufactured" an affected facility. As noted below, homemade or hand-built wood heaters are not exempt from this regulation.

As explained on page 4959 of the proposal preamble, the standards would apply to homemade woodstoves. One commenter stated that homemade woodstoves should be exempt from this regulation because homemade woodstoves are used primarily by the poor to provide inexpensive heat. Several other commenters favored the regulation of these appliances because of the relatively large number of such stoves, their impact on the environment, the potential for future circumvention if they are not controlled, and the potential sales that will be lost by manufacturers of wood heaters who have incurred the additional expense of complying with the regulation.

In response to the comment that homemade stoves should be exempt because they provide inexpensive heat for the poor, EPA believes that although the initial cost of a homemade stove may be less than a mass-produced manufactured woodstove, because it is assembled by the homeowner with some homeowner-supplied parts, it may likely be less durable, less efficient, and less safe—all of which may make it more expensive in the long run. Even if homemade stoves were to have lower life cycle costs, the lowered costs would not outweigh the environmental costs of exempting them from the standards. Finally, it should be noted that for those who cannot afford the initial costs of a new certified wood heater, this regulation does not restrict the sale of second hand stoves. The second hand stove market is a major source of inexpensive wood heating appliances.

The EPA agrees with the commenters affirming that kit stoves be regulated. One estimate indicates that homemade wood heaters comprise 5 percent of the market. Most of these are believed to be kit stoves. A kit stove is a type of wood heater that someone other than the commercial manufacturer completes or alters in a way as suggested by the manufacturer. A kit stove may or may not include all of the components necessary to construct the appliance, but does include plans, designs, and assorted hardware (e.g., door, legs, flue pipe fittings). Often, the consumer supplies a steel drum which becomes the firebox for the stove.

The EPA believes that manufacturers of kit stoves should be subject to the certification requirements as are the manufacturers of fully assembled wood heaters. Therefore, EPA is requiring that kit stove manufacturers have their designs certified. For those designs that are certified, the kit stove manufacturer would include in the kit any necessary hardware for assembling the emission controls (e.g., a catalytic combustor and associated equipment such as flame impingement shields and a temperature monitoring port), appropriate temporary and permanent labels, and the owner's manual.

Because some of the fabrication of the wood heater occurs at the retail or consumer level, EPA requires that kit stove manufacturers submit a kit, rather than a fully assembled wood heater, to the accredited laboratory for certification testing. To approximate more closely the quality of fabrication that occurs among consumers, a laboratory technician, using only the instructions and designs available in the kit, would construct a wood heater using the materials in the kit and the type of firebox (e.g., size and quality of steel drum) specified in the instructions. If the instructions allow the consumer to substitute different components (e.g., different sized steel drums), each variation that could affect emissions would constitute a different model and require separate certification.

The EPA is aware of at least one manufacturer of wood heater kits who sells catalytic combustors as an accessory. This same manufacturer has his stove designs safety tested and provides labels indicating compliance with the U.S. Consumer Product Safety Commission safety testing requirements. Therefore, the approach described above would not represent a significant departure from existing practice. As suggested in the proposal preamble, in view of the emissions impact and the potential for circumvention if kit stoves are exempt from this regulation, EPA believes it is reasonable that kit stoves be covered by the regulation and that the manufacturers of the kits be responsible for having their designs certified.

A commenter asked for clarification of the applicability of the standards to so-called "Russian stoves" or "European tile stoves."

The 800 kg cutoff was established as an easy means of excluding the high-mass fast-burn wood-burning appliances known as "Russian stoves" or "European tile stoves." These devices typically operate at hot, fast burn rates and cannot be damped. It is also likely that they are incapable of meeting the 5 kg/hr minimum burn rate. The intent of the committee was to exempt from the standards these appliances which rely on clean-burning air-rich conditions and which have high combustion efficiencies. It should be noted, however, the exclusion does not apply to appliances which exceed the 800 kg threshold only because of masonry or other materials which are not sold by the manufacturer as integral parts of the appliance.

Two manufacturers of wood-fired cookstoves requested an exemption from the standards for these appliance types because the design principles for room heaters and cookstoves were significantly different and because cookstoves comprise a very small fraction of the wood heater market.

The EPA agrees with the commenters who recommend excluding cookstoves. The operational characteristics of cookstoves have not been shown to be compatible with the demonstrated technologies analyzed in this rulemaking. Also, the number of cookstoves is very small relative to all other wood heaters. Therefore, the promulgated standards exempt cookstoves and include the definition of "cookstove" recommended by the WHA, with one modification as noted below. The design features necessary to be defined as a cookstove include: (1) An oven with an oven rack; (2) a mechanism for measuring the temperature in the oven; (3) a flame path which is routed around the oven; (4) a shaker grate; (5) an ash pan; (6) an ash clean-out door below the oven; and (7) the absence of a fan and/or heat channels to dissipate heat from the appliance. The final standards include one modification not recommended by industry. To qualify, the appliance must have a minimum oven size of 0.028 cubic meters (1.0 cubic foot). This is smaller than the oven sizes of bona fide cookstoves currently on the market, but large enough to discourage circumvention of the standards by simply adding a small cavity and calling it an oven.

One commenter asked whether a company that produced fewer than 2,000 stoves per year could purchase and produce a stove design from a large manufacturer and still be entitled to the 1-year exemption as a small manufacturer. This same commenter asked whether a qualifying small

Attachment 2: Reference 2 – Cover page

Houck

EPA-450/2-92-002

TECHNICAL INFORMATION DOCUMENT
FOR RESIDENTIAL WOOD COMBUSTION
BEST AVAILABLE CONTROL MEASURES

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

September 1992

Attachment 2: Reference 2 – Excerpt

2.4 ALL NEW WOOD STOVE INSTALLATIONS[3] EPA-CERTIFIED, PHASE II STOVES OR EQUIVALENT

This integral measure recommends that stoves not be allowed to be installed which are (1) not certified by EPA to Phase II emission limits or (2) cannot document (through "in-home" field testing data) emissions equivalent to or less than "in-home" field test emissions of EPA-certified Phase II stoves.[4] The intent of this requirement is to prevent the sale or resale and installation of non-EPA-certified stoves and the resale and installation of used EPA-certified Phase I stoves. The program should require that when homeowners intend to install a new or used wood stove, they file a form with the implementing or lead planning agency and swear in an affidavit that the stove is EPA-certified to Phase II emission limits. The implementing or lead planning agency should be responsible for processing the forms and affidavits and checking the brand name of the proposed stove installation against a list of EPA-certified, Phase II stoves (and their equivalents). Properly trained and qualified inspection personnel should conduct random surveys of stoves in homes to confirm compliance.

The implementing or lead planning agency should make the public aware of the requirement for stove certification, the

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[3]New installations should include both "brand-new" stoves and fireplaces and "new-used" units (i.e., newly purchased units that are not "brand-new").

[4]See memorandum clarifying nature of RWC guidance and describing procedure for entities seeking emission reduction credit for RWC devices not certified by EPA but which can demonstrate comparable or lower emissions through field testing. Process includes consultation with EPA's Office of Research and Development on appropriate in-use testing methods and procedures (Ref. 1). For example, EPA has recently reviewed in-home field data for certain masonry stoves tested during the 1991/92 heating season and has accepted the resultant emissions data for use in SIP-related activities (Ref. 2).

Attachment 3: Reference 3 – Renner Memo

12/18/1991 12:53 OMNI Environmental Svcs. 503 526 2085 P.02
DEC 17 '91 13:23 WHA JOHN CROUCH 208-278-3865 0 P.1/3

UNITED STATES ENVIRONMEN
Office of Air Quality Plar
Research Triangle Park, N

Post-it™ brand fax transmittal memo 7671 | # of pages ▸ 3
To Skip | From John
Co. | Co.
Dept. | Phone #
Fax # | Fax #

September 23, 1991

MEMORANDUM

SUBJECT: Interpretation of EPA's Guidance for Residential Wood Combustion Emission Control Measures

FROM: Fred H. Renner, Jr., Acting Chief Fred Renner
SO_2/Particulate Matter Programs Branch, AQMD (MD-15)

TO: Chief, Air Branch
Regions I-X

In September 1989, the U.S. Environmental Protection Agency (EPA) issued guidance for controlling wood smoke emissions from residential wood combustion (RWC) in a document entitled Guidance Document for Residential Wood Combustion Emission Control Measures (EPA-450/2-89-015). The document was issued as a recommendation to State and local agencies developing wood smoke control programs and not to prevent such agencies from considering other wood smoke control devices or measures not discussed in the document. However, it has been brought to EPA's attention that, despite its purpose, the guidance has in some cases been construed as restrictive and exclusionary in nature. The purpose of this memorandum is to clarify EPA's intent behind issuing this guidance and explain what documentation EPA expects in evaluating control measures discussed and not discussed in the guidance.

The nonexclusionary nature of the guidance document is embodied in EPA's policy regarding RWC emission reduction credits as explained in Chapter 1.0 of the guidance document. To reiterate, the emission reduction credits recommended in Appendix F of the document are only suggested and should thus be considered starting points in assessing the effectiveness of RWC control programs and regulations. Any application for credit in a State implementation plan (SIP) must be accompanied by a justification in the implementing agency's specific program or regulation. For instance, for a mandatory curtailment program to receive a 50 percent wood stove credit, it should contain documentation in the SIP that the implementing agency has addressed each of the elements described in Table 5-9 of the document. All credit applications in SIP's are, of course, subject to EPA review to ensure the credit level is justified.

In their SIP's, State and local agencies can also request credit greater than that recommended in the document, as well as credit for measures not included in the document. Contrary to how the RWC guidance document may, in some cases, be interpreted, EPA will consider well-supported requests for credit for wood-burning devices not listed in Table 3-1 and Appendix F of the document. Merely because a wood-burning device is not EPA-certified does not mean it does not merit emission reduction credit and, hence, status as a device that burns more cleanly than a conventional wood stove. To obtain credit, however, proponents for such devices must provide justification for credit to be granted in the same manner as the devices currently listed in the guidance document (e.g., EPA-certified Phase II cordwood and pellet stoves), as described below.

The suggested credits currently in the guidance document for the conversion of conventional wood stoves to EPA-certified catalytic, noncatalytic, and pellet stoves are based on field test data documenting the emissions reductions associated with the different advanced wood-burning technologies. Therefore, if SIP credit is sought for conversion to wood heaters not listed in the guidance document [including wood heaters determined to be "not affected" by EPA's wood heater new source performance standard definition (see 53 Federal Register February 26, 1988) and hence exempt], the request should be accompanied by a justification based on emission reductions documented through "in-home" field testing (versus laboratory testing). The EPA recommends that the field testing employ an emissions sampling and data-gathering technique that is reviewed by EPA prior to the start of testing.

If EPA finds that field test data indicate a wood-burning device not currently listed in the guidance document is clean burning relative to conventional stoves and, therefore, warrants emission reduction credit, depending on its emissions performance, that stove may be afforded status similar to that of an EPA-certified stove with demonstrated emissions significantly lower than that of conventional stoves. That is, EPA will approve control strategies under SIP's to the extent of demonstrated emission reduction credits for such devices.

In-use testing to establish emission reduction potential should be conducted in accordance with valid procedures established in consultation with EPA's Air and Energy Engineering Research Laboratory within the Office of Research and Development. Should you be contacted by an air pollution control agency or by any other entity seeking credit for devices that have not already been subject to in-use testing, please refer them to Robert McCrillis at 919/541-2733.

12/18/1991 12:55 OMNI Environmental Svcs. 503 526 2085 P.04

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If you have any questions regarding this clarification, please contact Chris Stoneman (FTS 629-0823).

Attachment

cc: Bob Lebens, SSCD
Vickie Patton, OGC
Bob McCrillis, ORD
Gwen Jacobs, AQMD
Chris Stoneman, AQMD
Eric Ginsburg, AQMD
PM-10 Contacts, Regions I-X

Attachment 4: Reference 4 – McCrillis Memo Excerpts

OPTIONAL FORM 99 (7-90) FAX TRANSMITTAL # of pages ► 2
To Dean Neely | From Bob McCrillis
Dept./Agency Co Dept of Health | Phone # 919-541-2233
Fax # 303-782-5493 | Fax # 919-541-2157
NSN 7540-01-317-7368 5099-101 GENERAL SERVICES ADMINISTRATION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

DATE: May 8, 1992

SUBJECT: Masonry Wood Heater Field Performance Data

FROM: Robert C. McCrillis
Organics Control Branch (MD-61)

TO: David Mobley
Chief, Emission Inventory Branch (MD-14)
OAQPS

THRU: Wade Ponder
Chief, Organics Control Branch (MD-61)

This memo transmits to you my evaluation of the test results obtained during the 1991-92 winter on masonry wood heaters. Masonry wood heaters are exempt from EPA regulation under the wood heater NSPS because their weight exceeds 800 kg. Some are also exempt because their air to fuel ratio exceeds 35:1. EPA established a procedure[1] wherein manufacturers of exempt wood burning devices could have their products tested in the field using methods acceptable to EPA. EPA then would publish the results for the state and local regulatory agencies' use in preparing SIPs.

Four masonry heater manufacturers and one factory built fireplace manufacturer decided to take advantage of this opportunity and contracted to have their devices field tested this past winter. I was asked by OAQPS to review the test procedures used and determine if they were, in my judgement, acceptable to EPA. The masonry heaters were tested by OMNI Environmental Services, Inc. and the fireplace by Virginia Polytechnic Institute and State University.

In my judgement, the procedures used by OMNI were acceptable to EPA. To provide an independent review of their procedures, I asked Judy Ford to provide QA oversight as if this were an AEERL-funded project. Three audits were performed by Research Triangle Institute (RTI): Laboratory Technical Systems, Laboratory Performance Evaluation, and Field Technical Systems and Performance Evaluation. All three audits received the rating "acceptable with qualifications". This rating is next to the highest (best)

1. Memo, F.H. Renner to Chief, Air Branch, Regions I-X, September 23, 1991.

possible rating. This rating means[2]:

"Minimum criteria are satisfied and good data quality seems likely; qualifications on the possible limitations of the data are noted and some corrective actions may be recommended. The recommendations may be implemented at the Project Officer's discretion."

Several of the more significant recommendations were implemented and are reflected in the results in the following table.

Masonry heater field test data - 1991-92 heating season.

Heater Brand	PM10 M5H g/kg	Burnrate kg/hr	CO g/kg	VOC g/kg	Efficiency %	Wood Species/ % moisture
Grundofen	1.62	1.10	83.00	0.37	59.70	DF/20%
Crown Royal 2000	2.06	0.21	69.10		65.40	Alder/20%
BioFire 4X3	2.20	0.95	72.00		54.00	DF/19%
Tulikivi KTU2100	6.39	0.41	107.00		59.00	DF/20%

The PM10 values have been converted to EPA Method 5H (M5H) equivalents. Under wood species, DF means douglas fir.

The procedures used by VPI were also acceptable to EPA, in my judgement. RTI is in the process of reviewing VPI's input. AEERL performed extensive audits of VPI during the 1989-90 heating season tests in Crested Butte and found their procedures acceptable. Since VPI used basically the same procedures and the same field personnel this winter, I feel confident in their results. As far as the fireplace results are concerned, however, all this is mute since the emission rates were much higher than hoped so the manufacturer (Majestic) has asked that they not be disclosed. AEERL is currently testing one of Majestic's "low emission" fireplaces in our laboratory. To date, results look quite good. I do not know why the field data came out high except that Majestic told me the homeowner operated it at a very low burnrate. This fireplace incorporates the secondary combustion technology in the better noncatalytic woodstoves; if not operated hot enough, however, they produce high emissions. At the appropriate burnrate, the fireplace consumes wood at a rate in the range of 4-6 kg/hr. Perhaps the homeowner did not want to use wood at that rate.

I am attaching copies of the individual masonry heater test reports. I received these from the manufacturers and there was no mention of the reports being confidential.

cc (with attachments): Chris Stoneman (MD-15)
Michael Hamlin (MD-14)

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2. AEERL Quality Assurance Procedures Manual for Project Officers.

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92-118.06

Table 1. Summary of conventional fireplace data.

HOUSE AND RUN: SAMPLE DATES: FIREPLACE TYPE: FUEL TYPE: FUEL MOISTURE:	ZAG. #1 12/17–12/20/91 CON-VENTIONAL D. FIR 20% MOIST	F0101 2/06–2/13/91 CON-VENTIONAL D. FIR 19% MOIST	F0301 2/28–3/07/91 CON-VENTIONAL D. FIR 20% MOIST	F0401 2/22–2/28/91 MODIFIED RUMFORD D. FIR 20% MOIST	F0701 3/02–3/10/91 CONV., HIGH ALT. D. FIR 21% MOIST	AVERAGES	
TOTAL STOVE BURNING HOURS=	28.17	30.25	24.67	24.75	28.92	27.3	TOTAL STOVE BURNING HOURS=
% OF TIME FIREPLACE BURNED=	31.07	18.16	14.83	21.46	46.69	26.5	% OF TIME FIREPLACE BURNED=
AVE. STACK TEMP(DEGREES C)=	91	95	70	66	150	95	AVE. STACK TEMP(DEGREES C)=
AVE. OXYGEN %(STACK>38 DEG.C)=	20.15	20.44	20.50	20.45	19.98	20.30	AVE. OXYGEN %(STACK>38 DEG.C)=
AVE. OXYGEN % (BAG)=	20.2	20.4	20.3	20.4	19.7	20.20	AVE. OXYGEN % (BAG)=
TOTAL WOOD USED (WET kg)=	Not determined	39.2	52.7	34.2	68.9	38.5	TOTAL WOOD USED (WET kg)=
WOOD MOISTURE (DRY BASIS %)=	19.5	18.9	19.9	19.7	20.8	19.6	WOOD MOISTURE (DRY BASIS %)=
AWES FLOW RATE (L/min)=	1.089	0.944	1.025	0.944	0.987	0.99	AWES FLOW RATE (L/min)=
LENGTH OF SAMPLING CYCLE (min)=	2	2	3	3	3	2.50	LENGTH OF SAMPLING CYCLE (min)=
AVERAGE CO % (BAG)=	0.070	0.050	0.040	0.050	0.070	0.056	AVERAGE CO % (BAG)=
AVERAGE CO2 % (BAG)=	0.7	0.49	0.47	0.46	0.98	0.62	AVERAGE CO2 % (BAG)=
NUMBER OF BURN CYCLES IN TEST=	7	7	7	10	4	7.0	NUMBER OF BURN CYCLES IN TEST=
TOTAL PARTICULATES (mg)							TOTAL PARTICULATES (mg)
RINSE =	55.3	37.9	39.1	51.5	52.9	49.3	RINSE =
XAD =	39.9	76.7	14.8	3.2	7.3	28.8	XAD =
FILTER =	35.0	6.0	21.7	20.9	28.4	22.4	FILTER =
MINUS AVE BLANK	3.9	3.9	3.9	3.9	3.9	3.9	MINUS AVE BLANK
TOTAL PARTICULATES (g)=	0.136	0.107	0.072	0.072	0.085	0.0943	TOTAL PARTICULATES (g)=
TOTAL DRY WOOD USED (kg)=	Not determined	72.5	95.6	62.9	121.5	70.8	TOTAL DRY WOOD USED (kg)=
BURN RATE (DRY kg/hr)=	4.17	2.40	3.92	2.54	4.21	3.45	BURN RATE (DRY kg/hr)=
AIR/FUEL RATIO=	177	263	279	289	125	223	AIR/FUEL RATIO=
PARTICULATE EMISSIONS:							PARTICULATE EMISSIONS:
g/kg=	20.5	25.7	31.0	32.2	15.0	24.9	g/kg=
g/hr=	85.4	61.6	121.5	81.7	63.1	82.7	g/hr=
AVE. DAILY g/hr=	14.3	11.1	17.9	8.4	19.0	14.1	AVE. DAILY g/hr=
CO EMISSIONS:							CO EMISSIONS:
g/kg=	112.4	119.2	101.6	121.8	80.5	107.1	g/kg=
g/hr=	459	286	399	309	339	360	g/hr=
AVE. DAILY g/hr=	75.6	51.5	58.5	31.9	102.1	64.5	AVE. DAILY g/hr=
ADDITIONAL ITEMS:							ADDITIONAL ITEMS:
AVE. BURN CYCLE LENGTH (hr)=	4.02	4.32	3.52	2.46	7.23	4.31	AVE. BURN CYCLE LENGTH (hr)=
WET kg USED/ BURN CYCLE=	Not determined	12.3	16.6	7.5	36.8	18.3	WET kg USED/ BURN CYCLE=
# WOOD LOADS/BURN CYCLE=	Not determined	4.6	3.0	4.4	5.8	4.44	# WOOD LOADS/BURN CYCLE=
AVE WOOD LOAD (WET kg)=	Not determined	2.7	5.5	2.4	6.4	4.3	AVE WOOD LOAD (WET kg)=
AVE. WOOD USAGE/DAY (WET kg)=	Not determined	12.4	16.7	15.7	57.3	25.5	AVE. WOOD USAGE/DAY (WET kg)=
AVE. AMBIENT TEMP (DEGREES C)=	Not determined	21.1	18.9	18.1	17.2	18.9	AVE. AMBIENT TEMP (DEGREES C)=

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Table 2. Summary of Rosin, masonry heater and moisture analysis data.

	ROSINS				MOISTURE ANALYSIS (CONVENTIONAL FIREPLACE)			MASONRY HEATERS			
HOUSE AND RUN: SAMPLE DATES: FIREPLACE TYPE: FUEL TYPE: FUEL MOISTURE:	F0001 2/22/– 3/02/91 ROSIN OR. EQUIP D. FIR 20% MOIST	F0002 6/13– 6/24/91 ROSIN OR. EQUIP D. FIR 20% MOIST	ZAG. #2 1/00– 1/06/91 ROSIN RETRO D. FIR 17% MOIST	ROSIN AVERAGE	F0102 2/13– 2/20/91 CON-VENTIONAL D. FIR 15 % MOIST	F0101 2/06– 2/13/91 CON-VENTIONAL D. FIR 20% MOIST	F0103 2/20– 2/27/91 CON-VENTIONAL D. FIR 24% MOIST	F0201 12/06– 12/12/91 GRUNDOFEN HEATER D. FIR 20% MOIST	F0501 2/27– 3/06/91 CONTRA-FLOW D. FIR 18% MOIST	MASONRY HEATER AVERAGE	
TOTAL STOVE BURNING HOURS=	50.83	39.50	37.75	41.5	27.67	30.25	25.58	44.24	14.25	29.24	TOTAL STOVE BURNING HOURS=
% OF TIME FIREPLACE BURNED=	32.85	23.52	33.07	30.5	15.47	18.16	15.33	27.03	8.49	17.76	% OF TIME FIREPLACE BURNED=
AVE. STACK TEMP(DEGREES C)=	98	88	104	98	97	95	61	141	223	182	AVE. STACK TEMP(DEGREES C)=
AVE. OXYGEN %(STACK>38 DEG.C)=	20.00	20.17	20.22	20.16	20.32	20.44	20.45	17.74	16.72	17.23	AVE. OXYGEN %(STACK>38 DEG.C)=
AVE. OXYGEN % (BAG)=	20.1	20.5	20.2	20.3	20.5	20.4	20.3	18.1	16.7	17.4	AVE. OXYGEN % (BAG)=
TOTAL WOOD USED (WET kg)=	135.5	98.7	184.2	150.7	43.7	39.2	36.4	217.3	149.5	183.4	TOTAL WOOD USED (WET kg)=
WOOD MOISTURE (DRY BASIS %)=	20.3	20.0	16.9	18.5	15.0	19.9	24.2	20.0	17.9	18.9	WOOD MOISTURE (DRY BASIS %)=
AWES FLOW RATE (L/min)=	1.054	1.067	1.044	1.1	0.944	0.944	0.967	0.944	1.084	1.014	AWES FLOW RATE (L/min)=
LENGTH OF SAMPLING CYCLE (min)=	3	3	2	2.5	2	2	3	3	3	3	LENGTH OF SAMPLING CYCLE (min)=
AVERAGE CO % (BAG)=	0.050	0.017	0.030	0.032	0.060	0.050	0.070	0.190	0.140	0.165	AVERAGE CO % (BAG)=
AVERAGE CO2 % (BAG)=	0.80	0.43	0.80	0.71	0.63	0.49	0.56	2.50	4.00	3.30	AVERAGE CO2 % (BAG)=
NUMBER OF BURN CYCLES IN TEST=	7	7	5	6.00	7	7	7	10	7	8.5	NUMBER OF BURN CYCLES IN TEST=
TOTAL PARTICULATES (mg)											TOTAL PARTICULATES (mg)
RINSE =	40.5	41.7	84.4	52.8	30.7	37.9	75.7	26.2	47.0	36.6	RINSE =
XAD =	38.3	12.5	10.6	20.5	33.5	78.7	6.0	6.0	20.2	13.1	XAD =
FILTER =	7.9	15.0	23.0	17.2	50.9	6.0	37.8	6.4	8.1	7.3	FILTER =
MINUS AVE BLANK	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	MINUS AVE BLANK
TOTAL PARTICULATES (g)=	0.081	0.065	0.109	0.0865	0.111	0.107	0.1191	0.035	0.071	0.053	TOTAL PARTICULATES (g)=
TOTAL DRY WOOD USED (kg) =	112.6	82.2	157.6	127.5	53.7	72.5	68.1	181.1	126.8	153.9	TOTAL DRY WOOD USED (kg)=
BURN RATE (DRY kg/hr)=	2.22	2.08	4.17	3.2	3.03	2.40	2.66	4.06	8.90	6.49	BURN RATE (DRY kg/hr)=
AIR/FUEL RATIO=	157	171	159	162	109	263	223	39	30	35	AIR/FUEL RATIO=
PARTICULATE EMISSIONS:											PARTICULATE EMISSIONS:
g/kg=	9.37	10.58	10.8	10.4	22.1	25.7	41.4	1.4	5.8	3.6	g/kg=
g/hr=	20.76	22.04	45.0	33.2	58.9	61.6	110.1	5.5	51.7	28.6	g/hr=
AVE. DAILY g/hr=	6.3	5.2	14.2	9.9	11.0	11.1	16.8	1.5	4.4	2.9	AVE. DAILY g/hr=
CO EMISSIONS:											CO EMISSIONS:
g/kg=	72.12	49.25	44.4	52.5	108.7	119.2	140.3	83.1	41.09	62.0	g/kg=
g/hr=	160	100	185	158	329	286	373	339	364	351	g/hr=
AVE. DAILY g/hr=	48.4	24.1	58.3	47.3	54.2	51.5	56.8	91.5	31.0	61.2	AVE. DAILY g/hr=
ADDITIONAL ITEMS:											ADDITIONAL ITEMS:
AVE. BURN CYCLE LENGTH (hr)=	7.26	5.64	7.55	7.0	3.95	4.32	3.65	4.40	2.21	3.30	AVE. BURN CYCLE LENGTH (hr)=
WET kg USED/ BURN CYCLE=	42.6	31.0	81.1	59	13.7	12.3	12.1	21.7	21.4	21.5	WET kg USED/ BURN CYCLE=
# WOOD LOADS/BURN CYCLE=	5.1	3.0	7.7	5.4	3.8	4.6	3.3	1.0	1.0	1.0	# WOOD LOADS/BURN CYCLE=
AVE WOOD LOAD (WET kg)=	8.2	4.7	3.4	4.4	3.5	2.7	3.7	21.7	21.4	21.5	AVE WOOD LOAD (WET kg)=
AVE. WOOD USAGE/DAY (WET kg)=	19.4	14.1	38.7	27.7	13.7	12.4	12.2	31.7	21.4	26.5	AVE. WOOD USAGE/DAY (WET kg)=
AVE. AMBIENT TEMP (DEGREES C)=	20.3	20.7	19.8	20.1	21.1	21.5	20.6	21.8	20.3	21.8	AVE. AMBIENT TEMP (DEGREES C)=

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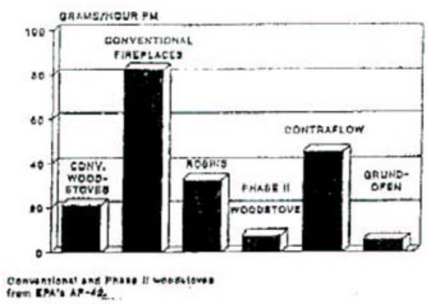


Figure 2. Comparison of PM grams per hour for woodstoves, fireplaces, and masonry heaters.

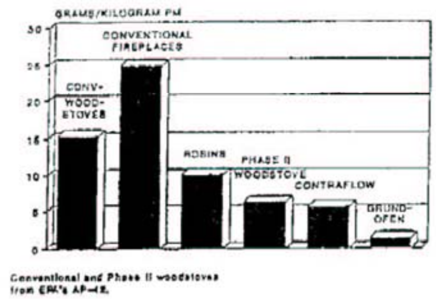
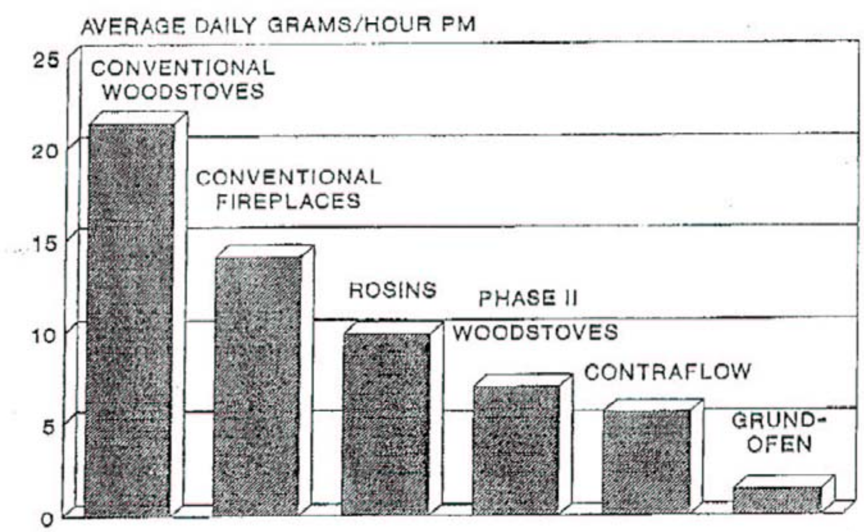


Figure 3. Comparison of PM grams per kilogram for woodstoves, fireplaces, and masonry heaters.



Masonry heater values normalized to a 1.0 kg/hr burn rate, the Phase II woodstove field average.

Figure 4. Comparison of PM average daily grams per hour for woodstoves, fireplaces, and masonry heaters.

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Attachment 5: ASTM E1602-03

Designation: E 1602 – 03

An American National Standard

Standard Guide for Construction of Solid Fuel Burning Masonry Heaters[1]

This standard is issued under the fixed designation E 1602; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the design and construction of solid fuel burning masonry heaters. It provides dimensions for site constructed masonry heater components and clearances that have been derived by experience and found to be consistent with the safe installation of those masonry heaters.

1.2 Values given in SI units are to be regarded as standard. Inch/pound units may be rounded (see IEEE/ASTM SI-10). All dimensions are nominal unless specifically stated otherwise. All clearances listed in this guide are actual dimensions.

1.3 This guide applies to the design and construction of masonry heaters built on-site with the components and materials specified herein. It does not apply to the construction/installation requirements for component systems that have been safety tested and listed. The requirements for listed masonry heater systems are specified in the manufacturer's installation instructions.

1.4 The design and construction of solid fuel burning masonry heaters shall comply with applicable building codes.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

C 11 Terminology Relating to Gypsum and Related Building Materials and Systems

C 43 Terminology of Structural Clay Products

C 71 Terminology Relating to Refractories

C 270 Specification for Mortar for Unit Masonry

C 401 Classification of Alumina and Alumina-Silicate Castable Refractories

E 136 Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C

IEEE/ASTM SI-10 Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *UL Standards:*

UL 103 Chimneys, Factory Built Residential Type and Building Heating Appliances[3]

3. Terminology

3.1 Terms used in this guide are as defined in Terminology C 11, Definitions C 43, Terminology C 71, and Classification C 401.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *approved*—acceptable to the authority having jurisdiction.

3.2.2 *authority having jurisdiction*—the organization, office, individual, or agent thereof, who is responsible for approving construction, materials, equipment, installation, procedure, and so forth. In most cases in which a building permit is required, the authority is typically the building official or his agent. Where a building permit is not required, the authority is typically the owner or his agent.

3.2.3 *bypass damper*—a valve or plate that provides a direct path to the chimney flue for the flue gases or portion thereof.

3.2.4 *capping slab*—a horizontal refractory barrier covering the top of the masonry heater.

3.2.5 *cleanout opening*—an access opening in a flue passageway of the masonry heater or chimney that is designed to allow access to the flue for purposes of inspecting for and removal of ash, soot, and other extraneous matter that may become trapped.

3.2.6 *damper*—an adjustable valve or plate for controlling draft or the flow of gases, including air.

3.2.7 *firebox (firechamber)*—that portion of the masonry heater that is designed for containing and burning the fuel charge.

3.2.8 *gas slot*—a small fixed opening that provides a bypass for unburned flue gases, and is a critical safety feature in certain masonry heater designs (namely those of the Grundofen type with vertical flue runs) (see Fig. 1, Fig. 2, Fig. 3, and Fig. 6).

3.2.9 *hearth extension*—the noncombustible surfacing applied to the floor area extending in front of and beyond each side of the fuel loading door of the masonry heater; also applies

[1] This guide is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning Applications.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Underwriter's Laboratories, 333 Pfingsten Road, Northbrook, IL 60062.

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FIG. 1 Vertical Channel Masonry Heater (Russian)

1. Ashbox
2. Ash Drop
3. Capping Slab
4. Chimney
5. Clean-Out
6. Combustion Air
7. Downdraft Channel
8. Exhaust Gas
9. Expansion Joint
10. Exterior Wall
11. Firebox
12. Fuel-Loading Door
13. Gas Slot
14. Hearth Extension
15. Heater Base
16. Insulation
17. Shut-Off Damper
18. Updraft Channel

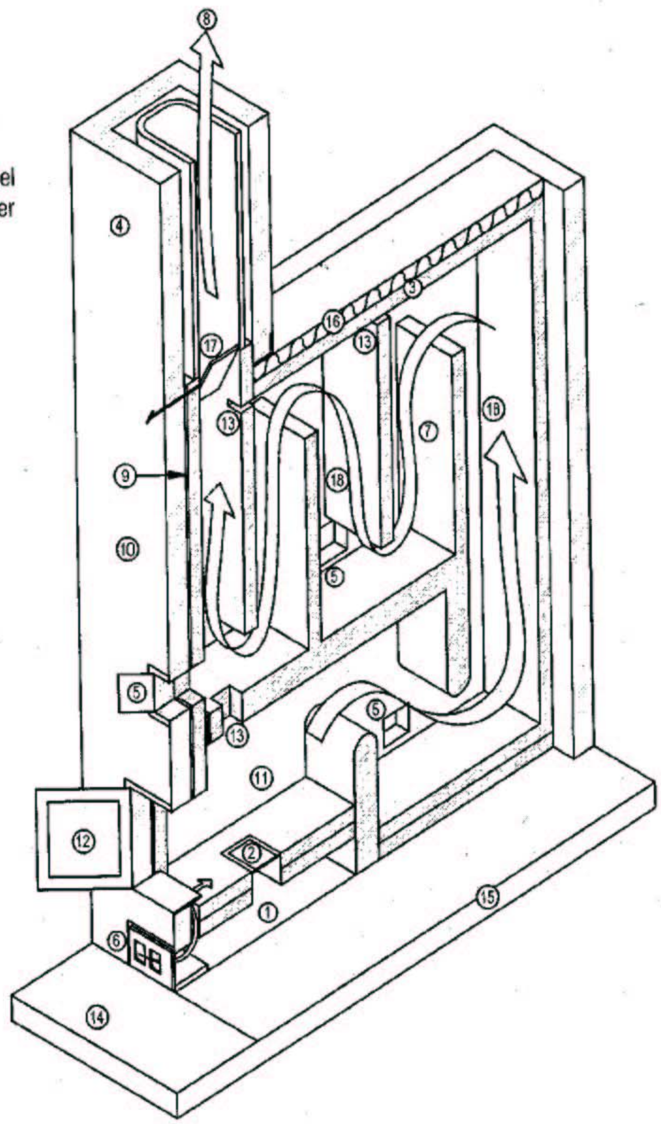

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FIG. 2 Horizontal Channel Masonry Heater (Russian)

1. Ashbox
2. Ash Drop
3. Capping Slab
4. Chimney
5. Clean-Out
6. Combustion Air
7. Exhaust Gas
8. Expansion Joint
9. Exterior Wall
10. Firebox
11. Fuel-Loading Door
12. Gas Slot
13. Hearth Extension
14. Heater Base
15. Horizontal Channel
16. Insulation
17. Shut-Off Damper

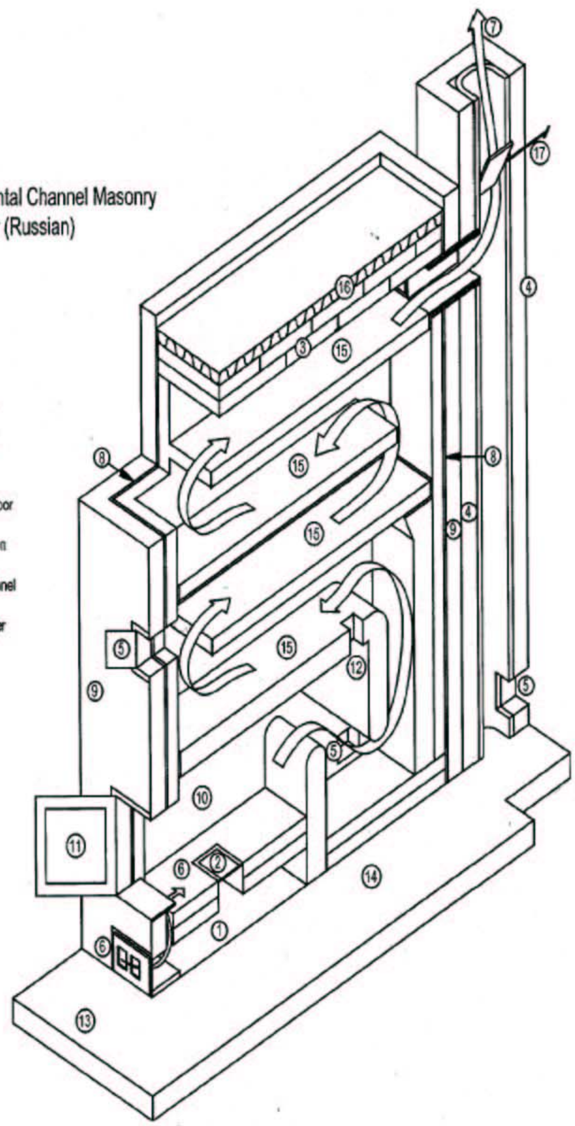
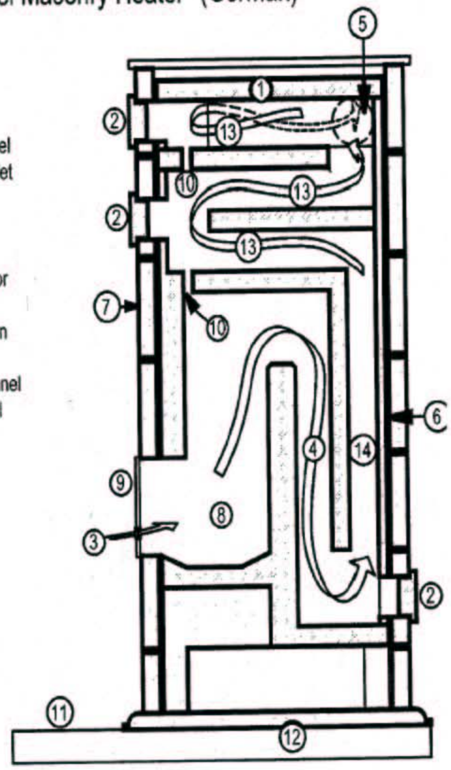


FIG. 3 Combination Vertical and Horizontal Channel Masonry Heater (German)

1. Capping Slab
2. Clean-Out
3. Combustion Air
4. Downdraft Channel
5. Exhaust Gas Outlet
6. Expansion Joint
7. Exterior Wall
8. Firebox
9. Fuel-Loading Door
10. Gas Slot
11. Hearth Extension
12. Heater Base
13. Horizontal Channel
14. Updraft Channel



to the floor beneath a masonry heater or beneath an elevated overhanging masonry heater hearth.

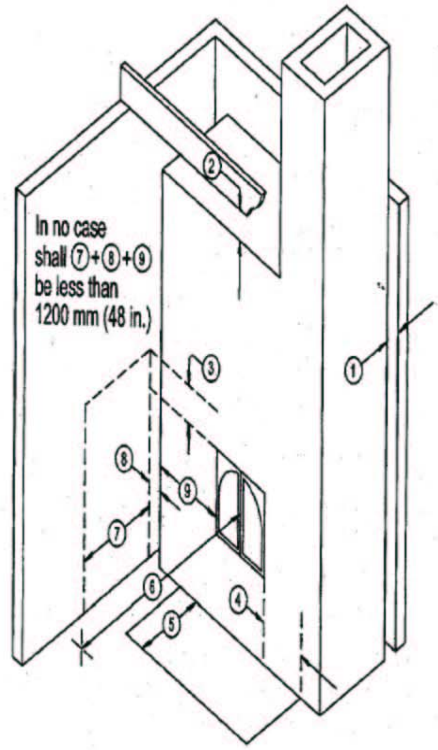
3.2.10 *masonry heater base*—that portion of the support for the masonry heater, between the masonry heater and the foundation, that is below the firebox or the heat exchange areas.

3.2.11 *heat-exchange flue channel*—a chamber or passageway between the firebox and the chimney flue in which heat resulting directly from combustion of fuel is transferred to the surrounding masonry.

3.2.12 *kachel*—a European term used to describe a masonry heater tile; a refractory ceramic tile intended for the outer wall of a masonry heater that is designed specifically to store and transfer heat.

3.2.13 *listed*—equipment or materials included in a list published by an organization concerned with product evaluation acceptable to the authority having jurisdiction to conduct periodic inspection of production of listed equipment or materials and whole listing states either that the equipment or materials meet appropriate standards or have been tested and found suitable for use in a specified manner.

3.2.14 *masonry heater*—a vented heating system of predominantly masonry construction having a mass of at least 800 kg (1760 lbs), excluding the chimney and masonry heater base. In particular, a masonry heater is designed specifically to capture and store a substantial portion of the heat energy from a solid fuel fire in the mass of the masonry heater through internal heat exchange flue channels, enable a charge of solid fuel mixed with an adequate amount of air to burn rapidly and more completely at high temperatures in order to reduce emission of unburned hydrocarbons, and be constructed of sufficient mass and surface area such that under normal operating conditions, the external surface temperature of the



NOTE—Clearances form combustible walls or framing may be reduced with an engineered protection system, other than in front of fuel-loading doors.

FIG. 4 Clearances to Combustibles

(1) 100 mm (4 in.) to combustible framing from masonry heater.
(2) 200 mm (8 in.) to ceiling.
(3) 200 mm (8 in.) minimum extent of side wall heat shield above firebox door.
(4) 300 mm (12 in.) hearth extension (sides).
(5) 500 mm (20 in.) hearth extension (front).
(6) 1200 mm (48 in.) in front of fuel-loading doors to combustible framing.
(7) extent of mandatory heat shield in front of masonry heater, required only when clearance to combustible material from fuel loading door ((8) + (9)) is less than 1200 mm (48 in.).
(8) 100 mm (4 in.) minimum clearance from side wall of masonry heater to heat shield (if used) or combustible framing.
(9) distance from fuel-loading doors to side wall of masonry heater.
(7) + (8) + (9) The sum of these must be greater than or equal to 1200 mm (48 in.).

masonry heater (except in the region immediately surrounding the fuel loading door(s)), does not exceed 110°C (230°F).

3.2.15 *mortar, masonry*—a mixture of cementitious materials (consisting of Portland or blended cement and hydrated lime, masonry cement, masonry cement and Portland cement, or masonry cement and blended cement), fine aggregate, and sufficient water to produce a workable consistency (see Specification C 270).

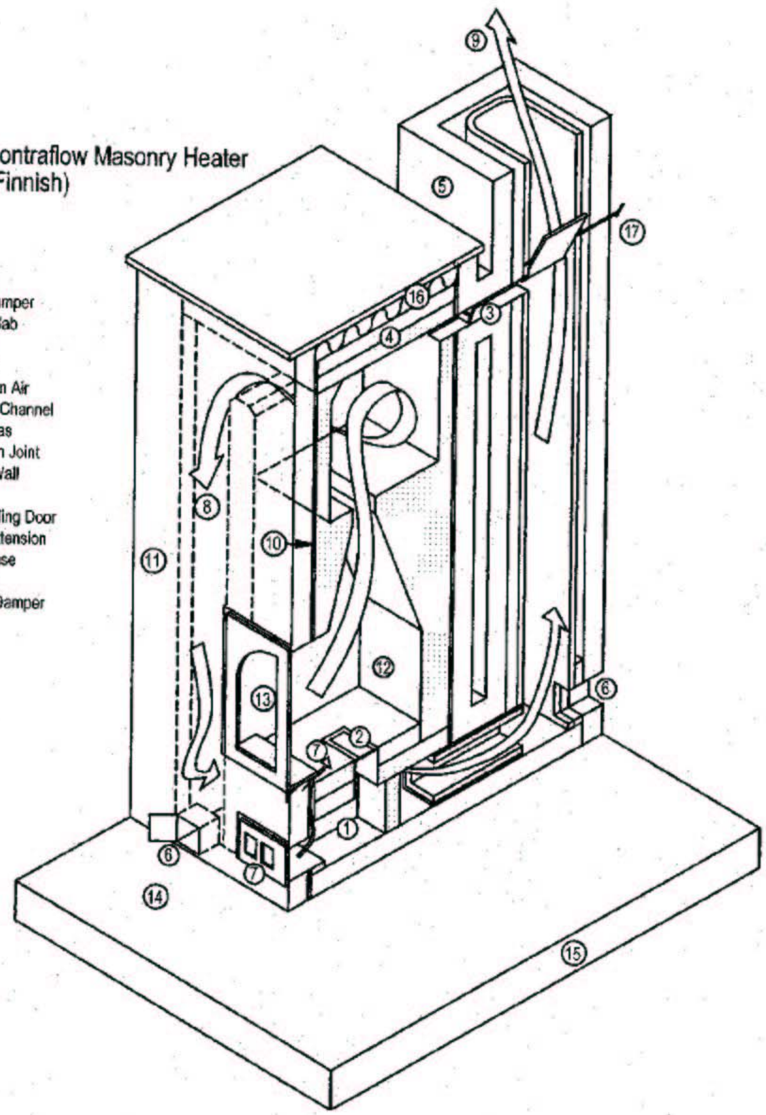
3.2.16 *mortar, fire clay*—mortar consisting of fine aggregate and fire clay as a binding agent.

3.2.17 *mortar, soapstone refractory*—a mixture of powdered soapstone and sodium silicate.

3.2.18 *noncombustible material*—a material that, in the form in which it is used and under the conditions anticipated, does not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Materials reported

FIG. 5 Contraflow Masonry Heater (Finnish)

1. Ashbox
2. Ash Drop
3. Bypass Damper
4. Capping Slab
5. Chimney
6. Clean-Out
7. Combustion Air
8. Downdraft Channel
9. Exhaust Gas
10. Expansion Joint
11. Exterior Wall
12. Firebox
13. Fuel-Loading Door
14. Hearth Extension
15. Heater Base
16. Insulation
17. Shut-Off Damper



as passing the requirements of Test Method E 136 are, for the purpose of this guide, considered noncombustible.

3.2.19 *soapstone*—a variety of natural stone (hydrated silica of magnesium) that is suitable for high-temperature applications in masonry heaters.

3.2.20 *wing wall*—a noncombustible lateral projection from the exterior wall of a masonry heater for use in bridging the space between a masonry heater and a combustible partition wall.

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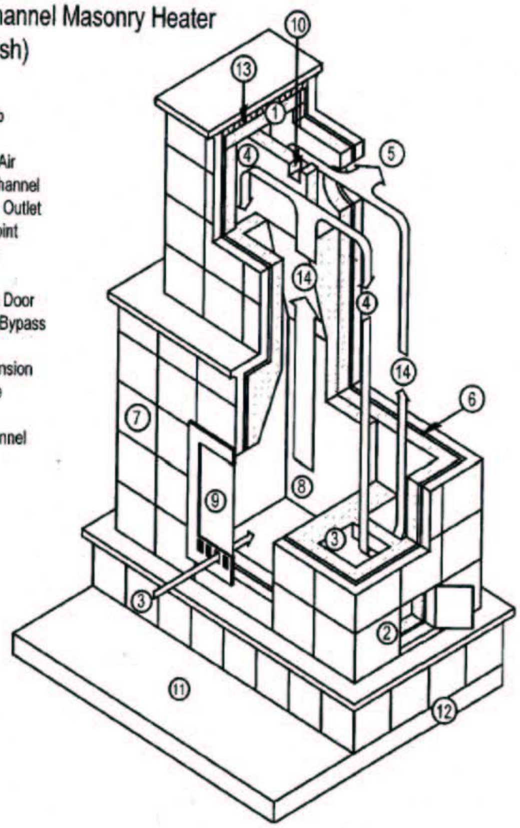
FIG. 6 Five Channel Masonry Heater (Swedish)

1. Capping Slab
2. Clean-Out
3. Combustion Air
4. Downdraft Channel
5. Exhaust Gas Outlet
6. Expansion Joint
7. Exterior Wall
8. Firebox
9. Fuel-Loading Door
10. Gas Slot or Bypass Damper
11. Hearth Extension
12. Heater Base
13. Insulation
14. Updraft Channel



4. Significance and Use

4.1 This guide can be used by code officials, architects, and other interested parties to evaluate the design and construction of masonry heaters. It is not restricted to a specific method of construction, nor does it provide all specific details of construction of a masonry heater. This guide does provide the principles to be followed for the safe construction of masonry heaters.

4.2 This guide is not intended as a complete set of directions for construction of masonry heaters.

4.3 Construction of masonry heaters is complex, and in order to ensure their safety and performance, construction shall be done by or under the supervision of a skilled and experienced masonry heater builder.[4]

5. Requirements

5.1 *Foundation*—Masonry heater foundations and foundation walls shall meet local building codes for standard masonry fireplaces and shall be designed with consideration given to the mass and size of the masonry heater.

5.2 *Clearance from Combustibles*—Clearances shall be in conformance with this section, as illustrated in Fig. 4.

[4] The Masonry Heater Association of North America, 1252 Stock Farm Road, Randolph, VT 05060, web site: http://www.mha-net.org, is one organization that represents a body of knowledge on masonry heater construction and qualified builders.

The Masonry Products Caucus of the Hearth Products Association, 1601 N. Kent Street, Suite 1001, Arlington, VA 22209, web site: http://www.hearthassoc.org, is another organization that represents both manufacturers and qualified builders of masonry heaters.

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5.2.1 *Clearance from Foundation*—All combustible structural framing members shall have a clearance of not less than 50 mm (2 in.) from the masonry heater foundation.

5.2.2 *Clearance from Fuel-Loading Door*—Maintain a minimum clearance of 1200 mm (48 in.) from combustible materials to fuel-loading doors, unless an engineered protection system as specified in 5.2.2.1 is provided, except for clearance directly in front of fuel-loading doors. A minimum clearance of 1200 mm (48 in.) shall be maintained in front of fuel-loading doors. This dimension shall not be reduced for any reason.

5.2.2.1 Clearance from fuel-loading doors to combustible materials may be reduced, other than in front of fuel-loading doors, if the combustible material is protected by an engineered protection system acceptable to the authority having jurisdiction. Engineered systems installed for the protection of combustible material shall limit the temperature of the combustible material to 50°C (90°F) above ambient temperature. Systems shall be designed upon applicable heat transfer principles, taking into account the geometry of the system, the heat loss characteristics of the structure behind the combustible material, and possible abnormal operating conditions of the masonry heater.

5.2.2.1.1 When an engineered protection system is used to reduce the perpendicular clearance from fuel-loading doors, it must extend a minimum of 200 mm (8 in.) above the fuel-loading doors or firebox opening. In addition, the sum of the dimensions from the fuel-loading doors, the distance from the heater to combustible material, and the length of the protection system in front of the heater face shall be no less than 1200 mm (48 in.).

5.2.3 *Clearance from Rear, Side, and Front Walls*—Clearance from a masonry heater to combustible structural framing and other combustible materials shall be not less than 100 mm (4 in.), unless an engineered protection system is provided, or a protection system accepted by the authority having jurisdiction is provided.

5.2.3.1 Clearance from a masonry heater to combustible materials may be reduced by the use of materials or products listed for protection purposes. Materials and products listed for the purpose of reducing clearance to combustibles shall be installed in accordance with the conditions of the listing and the manufacturer's instructions and shall meet the criteria of Section 5.2.2.1.

5.2.4 *Clearance from the Ceiling*—The clearance from the masonry heater capping slab to the ceiling shall be a minimum of 200 mm (8 in.).

5.2.4.1 *Extensions of Exterior Wythes to Ceiling*—When exterior masonry wythes of the masonry heater are carried to the ceiling, insulate and vent the top of the masonry heater above the heat exchange channels to reduce possible static heat buildup.

5.2.5 *Wing Walls*—Wing walls may be added to a masonry heater and used as room partitions. Wing walls located at the corners of a masonry heater for the purpose of forming a room divider shall be a minimum of 100 mm (4 in.) in length and a maximum of 100 mm (4 in.) in thickness and be constructed with noncombustible materials. Wing walls located more than 200 mm (8 in.) from a corner of the masonry heater shall be a minimum of 200 mm (8 in.) in length and a maximum of 100 mm (4 in.) in thickness and be constructed with noncombustible materials.

5.3 *Firebox Floor*—The firebox floor shall be a minimum thickness of 100 mm (4 in.) of noncombustible material and at least the top 50 mm (2 in.) shall be refractory material. The firebox floor or a portion thereof may also contain a cast iron grating.

5.4 *Hearth Extension*:

5.4.1 Masonry heaters shall have hearth extensions of brick, concrete, stone, tile, or other approved noncombustible material properly supported. Remove wooden forms used during the construction of hearth and hearth extension once construction is completed.

5.4.2 *Closed Door Fireboxes*—With a masonry heater designed to be fired with a closed door of glass or metal, the hearth extension shall be at least 500 mm (20 in.) in front of the facing materials and at least 300 mm (12 in.) beyond each side of the masonry heater opening. When a raised hearth of at least 200 mm (8 in.) in height is used and the hearth extension is located at the base of the door, the hearth extension can be reduced to 400 mm (16 in.) in front of the facing materials.

5.4.3 *Open Fireboxes*:

5.4.3.1 Where the firebox opening is less than 0.6 m^2 (6 ft^2), the hearth extension shall extend at least 400 mm (16 in.) in front of the facing materials and at least 200 mm (8 in.) beyond each side of the firebox opening.

5.4.3.2 Where the firebox opening is 0.6 m^2 (6 ft^2) or larger, the hearth extension shall extend at least 500 mm (20 in.) in front of the facing materials and at least 300 mm (12 in.) beyond each side of the firebox opening.

5.4.4 Where a firebox opening overhangs a floor, the hearth extension shall also cover the area beneath the overhang and extend beyond the firebox opening as specified in 5.4.2.

5.5 *Cleanout Openings*:

5.5.1 Chimney flues shall have a cleanout access at their base.

5.5.2 *Heat Exchange Channels*—If the design limits natural access, install cleanout openings or a means for cleaning all chimney flues and heat exchange areas. If an ash dump or grate is provided in the firebox, provide a tight-fitting cover of noncombustible material, 3 mm (⅛ in.) minimum thickness, at the base of the ash pit. Cleanout doors for the foundation shall have a minimum size of 200 by 200 mm (8 by 8 in.). Situate the opening to facilitate inspection, cleaning, and maintenance of the masonry heater.

5.6 *Outside Combustion Air*—When required by the local building code, provide a duct with a minimum cross-sectional area of 7700 mm^2 (12 $in.^2$) or equivalent. When outside combustion air is required by the authority having jurisdiction the duct shall have a damper that can be fully closed when not in use. Materials shall be non-combustible and methods of construction shall comply with the requirements of the authority having jurisdiction.

5.6.1 In applications in which outside air is introduced directly into the firebox, the air duct must enter the building at a level below the firebox.

5.6.2 Design and position the air inlet to prevent live coals from entering the air duct. To prevent rodents from entering the air duct, cover the outside entry opening of the duct with a 6 mm (¼ in.) corrosion resistant wire mesh.

5.6.3 *Ash Pit Located in Foundation*—When outside air is introduced into the firebox via the ash pit, introduce the air duct through the upper region of the ash pit wall.

5.6.4 When outside air is introduced into the firebox, construct the air duct from noncombustible materials.

5.7 *Heat exchange channels*:

5.7.1 Heat exchange channels shall be built with firebrick, soapstone, or other refractory materials laid in refractory mortar, fire clay mortar, or soapstone refractory mortar. Masonry units shall be laid with full mortar joints.

5.7.2 *Capping Slab*—A capping slab shall be of at least 57 mm (2¼ in.) in actual thickness above the uppermost heat exchange channels.

5.7.3 *Gas Slot*—When required, a gas slot shall have a cross-sectional area of at least 1⁄30 of the firebox floor area and a height of 30 mm (1¼ in.). Refer to Fig. 1, Fig. 2, Fig. 3, and Fig. 6 for typical locations.

5.8 *Shut-off Damper(s)*—One or more shut-off dampers may be installed near the juncture of the masonry heater and chimney or in the chimney. Each damper shall have external controls and be constructed of cast iron or steel of at least 12 gauge, 2.5 mm (0.10 in.) in thickness. To reduce the possibility of toxic gases escaping into the room, the cross-sectional area of the damper's opening shall be not less than 5 % of the interior cross sectional area of the flue.

5.9 *Chimney*—Vent masonry heaters with a low-heat type masonry chimney approved by the authority having jurisdiction or with a factory-built residential type chimney that meets the requirements of UL 103 HT.

5.9.1 The chimney shall not be supported by the interior walls of the masonry heater unless specifically designed to do so. The chimney can be built integrally with an exterior wythe of the masonry heater, provided the exterior wythe is constructed of solid masonry and has a minimum thickness of 100 mm (4 in.).

5.9.2 Flue sizes shall be in accordance with the design specification of the builder or the designer of the masonry heater.

5.10 *Chimney Connector*—The chimney connector shall be accessible for inspection and cleaning. Chimney connectors shall be airtight and fitted with airtight joints. Where differential movement can take place between a masonry heater and chimney, make provision for this movement in such a way as to maintain the integrity of the connector joints. Materials and methods of construction shall comply with the requirements of the authority having jurisdiction.

6. Typical Masonry Heater Types

6.1 There are several different masonry heater types. Fig. 1, Fig. 2, Fig. 3, Fig. 5, and Fig. 6 show the names and schematic sections of typical masonry heater designs.

7. Keywords

7.1 brick; Contraflow; firebrick; fire clay mortar; Grundofen; Kachelofen; Kakelugn; masonry heater; mortar; refractory mortar; Russian; soapstone refractory mortar

Attachment 6: Summary of Emission Test Reports for Masonry Heaters

Reference	Report Name	Date of Test Report	Wood Type	Sampling Method	Fueling Protocol	Heater Identification	Burn Rate Range (kg/hour)	PM Emissions Range (g/kg)	Average Burn Rate (kg/hour) (While Burning)	Average PM Emissions (g/kg)	Average PM Emissions (g/hour) See Note 1
A	Masonry Heater Emissions Test Method Development (VPI)	1990	Douglas fir 4x4's	Based on method 5G	VPI Proposed Protocol	Grundofen Contraflow Average		0.2 - 1.6 0.8 - 6.2		1.4	0.8 - 1.1 1.3 - 2.8
B	In-Home Evaluation of Emissions from Masonry Fireplaces and Heaters (OMNI)	1991	Douglas fir cordwood	AWES	Homeowner operated	Contraflow Russian (See Note 2)			8.2 2.5	5.6 9.6	5.6 9.6
C	Summary Report of In-Home Emissions and Efficiency Performance of Five Commercially Available Masonry Heaters (OMNI)	1991-1992	Douglas fir cordwood and Alder cordwood	AWES	Homeowner operated	Biofire Grundofen Heat-Kit Royal Crown Tulikivi Average				1.9 1.4 5.8 1.4 5.7 3.2	1.8 1.5 4.4 0.3 2.3
D	Evaluation of Emissions from Masonry Heaters and Masonry Fireplaces in Homes (OMNI)	1992	Douglas fir cordwood	AWES	Homeowner operated	Grundofen Contraflow			4.1 8.9	1.4 5.6	1.4 5.6
E	In-Home Evaluation of Emissions from a Temp-Cast 2001 Masonry Heater	1992	Poplar cordwood	AWES	Homeowner operated				1.78	2.96	1.26 (Daily)
F	Mastercraft Swedish Heater Kit	1993	Douglas fir	AWES					7.7	1.9	0.42 (Daily)
G	Moberg/Royal Crown MRC-3036 (OMNI)	1994	??	AWES	??					3.9	3.4
H1	Moberg 3042 (OMNI)	1996	??	ESS	Colorado					1.95	5.5
H2	Moberg 3042 (OMNI)	1996	Douglas fir	ESS	Washington State					1.79	4.7
I	U.S.E.P.A. AP-42	1996								2.8	2.8
J1	Report on Finnish-style masonry heater KTU2100 (OMNI) Test 1	1997	Douglas fir dimensional cribs (3 cribs)	ESS Washington State	Washington State					2.5	3.0
J2	Report on Finnish-style masonry heater KTU2100 (OMNI) Test 2	1997	Douglas fir dimensional crib (1 crib)	ESS Washington State	Colorado				6.1	3.1	3.8
K	Report on Finnish-style masonry heater TU1000 (OMNI)	1999	Cordwood	AWES	Colorado				10.4	2.6	
L	Report on Finnish-style masonry heater TU2200 (OMNI)	1999	Cordwood	AWES	Colorado					3.5	
M	Report on Finnish-style masonry heater TU2450 (OMNI)	1999	Cordwood	AWES	Colorado					2.0	
N1	Test Report on Swedish style masonry heater built by Jerry Frisch (OMNI)	2006	Douglas fir cordwood	proposed ASTM (Now ASTM E2515) & ESS	Colorado	Swedish Style	3.8 - 4.1	2.4 - 2.9	4.0	2.7 (2.0 using ESS)	
N2	Test Report on Swedish style masonry heater built by Jerry Frisch (OMNI)	2006	Douglas fir dimensional cribs	proposed ASTM (Now ASTM E2515) & ESS	Colorado	Swedish Style	3.0 - 3.3	2.3 - 5.0	3.1	3.3 (2.0 using ESS)	

Note 1: The emission rates in grams/hour are calculated differently in different test reports. Some are the 24 hour average, some are EPA NSPS weighted averages while others have efficiency factored in. Use these values with caution and see the individual reports for more information on how they were calculated.

Note 2: The Russian heater used in this study was constructed by a mason with no previous training or experience building masonry heaters. The emission performance may be the result of design errors.

Attachment 7: Reference Reports

A. Stern, C. H, Jaasma, D. R. and J. W. Shelton, Masonry Heater Emissions Test Method Development, Wood Heating Alliance, March 1990.
B. Barnett, S. G., In-Home Evaluation of Emissions from Masonry Fireplaces and Heaters, Western Clay Products Association, Prepared by: OMNI Environmental Services, Beaverton, OR, Report # 80-10201, September 6, 1991
C. Barnett, S. G., Summary Report of the In-Home Emissions and Efficiency Performance of Five Commercially Available Masonry Heaters, Masonry Heater Association, Prepared by: OMNI Environmental Services, Beaverton, OR, Report # 80-13301, May 22, 1992 (Revised June 1, 1993).
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H. H1: Moberg 3042 Masonry Heater Emissions Testing Report (Compliance with Colorado Regulation No. 4), FireSpaces, Inc., Portland, OR, Prepared by: OMNI Environmental Services, Beaverton, OR, Report No. 001-S-02-3-B, January 1996.
H2: Moberg 3042 Masonry Heater Emissions Testing Report (Compliance with Washington State UBC Section 31-2), FireSpaces, Inc., Portland, OR, Prepared by: OMNI Environmental Services, Beaverton, OR, Report No. 001-S-02-3-A, January 1996.
I. Report on Revisions to 5TH Edition AP-42 Section 1.10 Residential Wood Stoves, Contract No. 68-D2-0160, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 29, 1996.

J. J1: Test Report: Masonry Heater Particulate Emissions and Overall Efficiency. Tulikivi Oy Model KTU-2100, Tulikivi Oy, Juuka, Finland, Prepared by: OMNI-Test Laboratories, Inc., Beaverton, OR, Project # 020-S-01-03, May 1997.
J2: Test Report: Masonry Heater Particulate Emissions and Overall Efficiency. Tulikivi Oy Model KTU-2100, Tulikivi Oy, Juuka, Finland, Prepared by: OMNI-Test Laboratories, Inc., Beaverton, OR, Project # 020-S-01-03, May 1997.
K. Tulikivi Oy; Model TU 1000 Emission Testing Report (Protocol Conformance with Colorado Regulation No. 4), Tulikivi Oy, Juuka, Finland Prepared by: OMNI Environmental Services, Beaverton, OR, Report No. 020-S-06-3, April 29, 1999.
L. Tulikivi Oy; Model TU 2200 Emission Testing Report (Protocol Conformance with Colorado Regulation No. 4), Tulikivi Oy, Juuka, Finland Prepared by: OMNI Environmental Services, Beaverton, OR, Report No. 020-S-06-3, April 29, 1999.
M. Tulikivi Oy; Model TU 2450 Emission Testing Report (Protocol Conformance with Colorado Regulation No. 4), Tulikivi Oy, Juuka, Finland Prepared by: OMNI Environmental Services, Beaverton, OR, Report No. 020-S-06-3, April 29, 1999
N. N1: Emissions Report, Swedish Kakelugn Style Masonry Heater, Built by Jerry Frisch, Prepared by: OMNI-Test Laboratories, Inc., Beaverton, OR, 2006.
N2: Emissions Report, Swedish Kakelugn Style Masonry Heater, Built by Jerry Frisch, Prepared by: OMNI-Test Laboratories, Inc., Beaverton, OR, 2006.

Attachment 8: Reference A - Report Cover Page

Final Report on

MASONRY HEATER EMISSIONS
TEST METHOD DEVELOPMENT

Submitted to

Wood Heating Alliance
1101 Connecticut Ave. Suite 700
Washington, D.C. 20036

and

Fireplace Emissions Research Coalition

Submitted by

Curtis H. Stern and Dennis R. Jaasma

Department of Mechanical Engineering
Virginia Polytechnic Institute & State University
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and

Jay W. Shelton
Shelton Research, Inc.
P. O. Box 5235
Santa Fe, NM 87502

March, 1990

Attachment 8: Reference A - Executive Summary

EXECUTIVE SUMMARY

A standard test method for determining carbon monoxide (CO) and particulate matter (PM) emissions from masonry heaters has been developed. The method specifies the fueling protocol and laboratory measurement procedures for determination of both emission rates (g/hr) and factors (g/kg). The fuel load size and fueling intervals are dependent upon the firebox volume of the masonry heater.

The test starts with the heater at ambient temperature and involves five firings to achieve burn rates in two ranges. The low burn rate range, used for the first two firings, is 0.70-1.10 dry kg/hr. The high burn rate range, used for the last three firings, is 2.10-3.30 dry kg/hr. Emission samples are extracted from a dilution tunnel with a set flow rate and configuration. PM sampling is similar to EPA Method 5G for wood stoves. CO concentration is measured by a nondispersive infrared (NDIR) gas analyzer. The emissions results for each firing are burn-rate weighted according to EPA Method 28 to obtain the overall emission totals for the test cycle.

The emissions were measured for a Grundofen and a Contraflow type masonry heater. The averages for the two heaters of the EPA weighted average emission rates were 67 g/hr CO and 1.4 g/hr PM. In a parallel effort, a field sampler for masonry heaters was developed and tested in the laboratory. The field sampler shows acceptable agreement with the standard test method for CO emissions, but the PM emissions results are consistently high for reasons as yet unknown.

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Attachment 9: Reference B – Cover Report Page

In-Home Evaluation of Emissions From Masonry Fireplaces and Heaters

Prepared for: Western States Clay Products Association
3130 La Selva, Suite 302
San Mateo, California 94403

Prepared by: Stockton G. Barnett
OMNI Environmental Services, Inc.
10950 SW Fifth Street, Suite 160
Beaverton, Oregon 97005-3400

September 6, 1991

80102-01

Attachment 9: Reference B – Executive Summary

Executive Summary

While woodstoves have undergone extensive regulation for almost ten years, fireplaces have only recently begun to be regulated. Capitalizing on the woodstove regulatory experience, this project was commissioned by Western States Clay Products to be the first research project to obtain basic baseline emissions data on masonry fireplaces and masonry heaters under real-world conditions in homes. Direct comparison of results with previous field studies of woodstoves and pellet stoves can be made.

The main objective of the current project was to measure particulate and carbon monoxide emissions from a baseline of conventional fireplaces and a group of potentially cleaner-burning fireplace designs and masonry heaters. Additional objectives were to evaluate the effects of wood moisture and altitude on conventional fireplace emissions.

To ensure widespread applicability for the Pacific Northwest and tight scientific control, the Portland, Oregon area was chosen as the field area, Douglas fir was used as the fuel, and fuel moisture content was held constant at 20%. All homeowners burned as they normally did and no instructions on burning techniques were given. Five conventional fireplaces, two Rosin fireplaces, one modified Rumford design, and two masonry heaters were evaluated.

The Automated Woodstove Emissions Sampler (AWES), which has been used extensively in field studies of woodstoves and pellet stoves, was used to measure emissions. The samplers were operated for seven days in each home. Typically each home burned their fireplace once a day. Tests were conducted from December 1990 through March 1991. An additional test on one of the Rosins was conducted in June 1991.

The tests provided information on how homeowners burn their fireplaces. For the conventional fireplaces, the average burn rate was 3.45 dry kg/hr, the average burn cycle length was 4.3 hours, the average number of wood loads per burn cycle was 4.4, and the average wood load weight was 9.4 wet pounds. Of these variables, the only one with a large amount of variation was the average wood load weight, which varied over a range of 3:1.

Masonry heater burn patterns were quite different. Average burn rate for the combustion period was 8.2 kg/hr for the Contraflow and 2.5 kg/hr for the locally built Russian unit.[1] Average burn lengths were 2.2 and 2.3 hours, respectively, and wood loads averaged 47 and 15 wet pounds, respectively. Both heaters were burned only once or twice per day as needed to heat the homes.

Particulate emissions[2] from the conventional fireplaces averaged 24.9 g/kg, 82.7 g/hr, and 14.1 average daily g/hr. These values are near the upper end of the range of results in the literature, which comprises mostly laboratory tests. CO emissions from the conventional fireplaces averaged 107 g/kg, 360 g/hr, and 64.5 average daily g/hr.

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[1] This heater was built by a local mason who had no prior experience in masonry heater design.

[2] Particulate emissions in this report are expressed in AWES units which are directly comparable to all previous field woodstove results. Values for EPA Method 5H, the lab certification method, would be 10-20% lower.

Attachment 9: Reference B – Executive Summary (cont.)

Emissions from the Rosin fireplaces were generally less than 50% of those from the conventional fireplaces. A *t-test* indicated that the g/kg difference was significant at the 98% probability level. Particulate emissions averaged 10.4 g/kg, 33.2 g/hr, and 9.9 average daily g/hr. CO emissions averaged 52.5 g/kg, 158 g/hr, and 47.3 average daily g/hr.

Emissions from the Contraflow masonry heater were about half those of the locally designed and built Russian heater. Contraflow particulate emissions were 5.6 g/kg, 45.7 g/hr, and 5.6 normalized average daily g/hr. CO emissions were 41.0 g/kg, 336.8 g/hr, and 31.0 normalized average daily g/hr. Emissions from the locally designed Russian unit were about twice as high.

The format in which emissions results are presented is of great importance. For example, use of different formats can result in as much as an 8:1 difference in comparative emissions results. Grams per hour (which is used for woodstoves) is considered the poorest representation of fireplace/masonry heater emissions because these types of devices are only burned for a few hours each day. Thus, use of g/hr greatly exaggerates emissions contributions to airsheds. A new term, **average daily g/hr**, is introduced which appears to be more appropriate. This format portrays the total amount of pollution that a given combustion device contributes to an airshed on a daily basis. Average daily g/hr is used rather than grams per day to facilitate a direct and easy comparison with the body of woodstove data which is expressed in grams per hour. Grams per kilogram produces somewhat similar rankings for fireplaces, but is less appropriate to meet the objective of quantifying the amount of pollution per day. It is, however, valuable in calculating the total emissions contribution per burning season for any residential biomass combustion device.

To facilitate direct comparison of masonry heater results with those of woodstoves, the term normalized average daily g/hr is used. This term refers to average daily g/hr at a burn rate of 1.0 kg/hr, the field average for certified woodstoves. This term is equal to g/kg.

The effects of wood moisture (range 15% to 24%) on emissions from a conventional fireplace were significant above 20% moisture. Emissions ranged from 22.1 at 15% moisture to 41.4 g/kg at 24% moisture. The effect of altitude on emissions could not be measured because a second variable—long burns associated with the fireplace being burned only on weekends—was present.

The real-world data collected in this project can be used to negotiate with regulators to develop fair and equitable regulations for all stakeholders. Efforts should be made to ensure that the relatively clean-burning Rosin be acceptable for burning within any of the new regulations.

The data from this project should be used as the foundation for the development of a realistic emissions laboratory standard for masonry fireplaces and heaters[3] and to evaluate candidate laboratory test methods. Considering the large mass and lack of portability of masonry fireplaces and heaters, in-home testing (as conducted in this project) must be considered an acceptable certification procedure.

The Fireplace Emissions Research Coalition (FERC) laboratory test procedure of Virginia Polytechnic Institute (VPI) should be evaluated for applicability to masonry fireplaces by comparing the Brick Institute of America (BIA) results with those of the current project. The VPI masonry heater laboratory procedure

[3] This development process would philosophically follow closely the system currently being used to develop the stress test protocol for woodstoves which will be used to evaluate potential product durability problems.

Attachment 9: Reference B – Emission Comparison

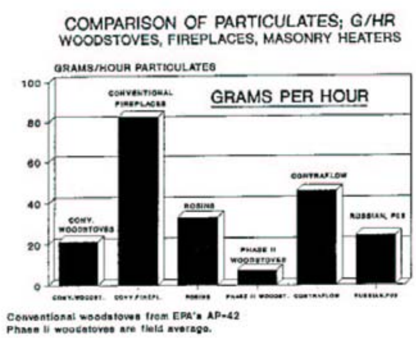


Figure 10

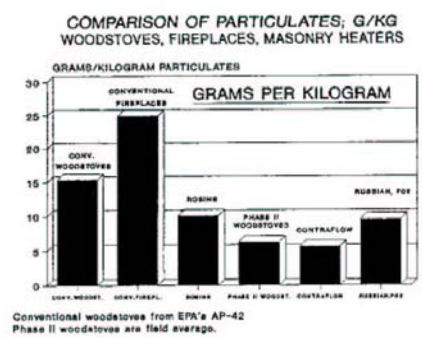
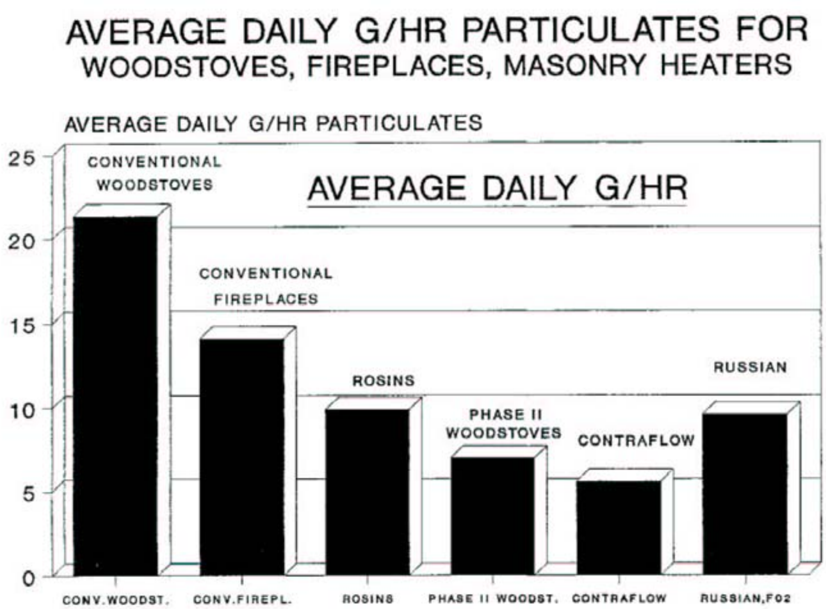


Figure 12



Masonry heater values normalized to a 1.0 kg/hr burn rate, the Phase II woodstove field average.

Figure 11

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Attachment 10: Reference C - Report Cover Page

Summary Report of the In-Home Emissions and Efficiency Performance of Five Commercially Available Masonry Heaters

Prepared for: The Masonry Heater Association

Prepared by: Stockton G. Barnett
OMNI Environmental Services, Inc.
10074 SW Arctic Drive
Beaverton, Oregon 97005

May 22, 1992

(Revised June 1, 1993)

80133-01

Attachment 10: Reference C - Executive Summary

Executive Summary

General

Emissions regulations for residential woodburning devices have become tighter in recent years. In 1986, the EPA established a woodstove certification program that went into effect in two stages in 1988 and 1990. Masonry heaters, which essentially function as high-mass, rapidly burning woodstoves with a large heat storage capacity, were exempted from this program by virtue of their large mass.

More recently, certain airsheds in the west, with extensive residential woodburning, have been declared in nonattainment by the EPA for airborne particulate matter of less than 10 microns in diameter (PM_{10}). State Implementation Plans (SIPs) have been written to develop air pollution reduction strategies to bring these areas into compliance. Unfortunately, masonry heaters have not been included in this process because they cannot qualify for EPA emissions certification due to their large mass. Hence, they have not been placed on the EPA's Reasonably Available Control Measure (RACM) Emissions Reduction Credit list. Accordingly, state and local governments have excluded masonry heaters from their own lists of emissions reduction control strategies. Recently the EPA, in recognition of this problem, instituted an "in-home" emissions test option for "non-affected" residential wood combustion RWC devices such as masonry heaters. These tests provide more realistic emissions and efficiency information than lab tests and their results can be used to obtain emissions reduction credits.

Objectives and Methodology

This project's main objective has been to sample a representative population of commercially available masonry heaters in homes. The data will be used by EPA to produce a masonry heater AP-42 emissions value which will be used to calculate an emissions reduction credit. An additional objective has been to explore these heaters as potentially very clean burning technologies that can qualify as low-emitting Best Available Control Measures (BACM).

Particulate (PM) and carbon monoxide (CO) emissions and net efficiency were measured on five masonry heaters in western Oregon and Washington in 1991 and 1992 using OMNI's Automated Woodstove Emissions Sampler (AWES). Each heater was operated by the homeowner in his normal fashion and was fired seven to ten times during the week-long test. In four of the five houses the heater was the only source of heat.

Results

PM emissions for the five heaters averaged 3.2 g/kg, 1.8 average daily g/hr, and 3.2 normalized[1] average daily g/hr. These PM values are higher than field values from certified pellet stoves and lower than from Phase II EPA certified noncatalytic woodstoves.

[1] Emissions values are "normalized" for easy comparison to 1 dry kg/hr burn rate, the average in-home burn rate for certified noncatalytic woodstoves.

Attachment 10: Reference C - Executive Summary (Continued)

CO emissions averaged 74 g/kg, 50 average daily g/hr, and 74 normalized daily g/hr. These values are comparable to Phase II EPA certified noncatalytic woodstoves.

The average net delivered efficiency was 58%, which is midway between conventional and EPA certified Phase II woodstoves. Average heat output was 7425 BTU/hr and average daily burn rate was 0.68 dry kg/hr.

Following EPA procedures and using the most recent field data, the average masonry heater emissions reduction credit is 81% compared to 91% for certified pellet stoves and 64% for certified noncatalytic woodstoves. Because the final version of the BACM guidance document is not yet available, masonry heaters will have to be evaluated for BACM status at a later date.

Attachment 10: Reference C – Emission Results

Emissions Results

PM emissions for the five masonry heaters averaged 3.2 g/kg and 2.1 average daily g/hr (Table 1). The average daily burn rate was 0.69 dry kg/hr. The 95% confidence limit for each test is generally about ±20% of the emissions value. The 95% confidence limit for the five heater average is ±2.8 g/kg. Tables 1 through 7 in Appendix A contain the results from each heater's emissions test.

Table 1. Summary of emissions and efficiency results for the five masonry heaters.

Heater Model	PM		CO		Burn Rate	Net Efficiency
	g/kg	Ave. Daily g/hr	g/kg	Ave. Daily g/hr	Ave. Daily kg/hr	Ave. %
Biofire	1.9	1.8	72	69	0.95	54
Grundofen	1.4	1.5	83	92	1.10	60
Heat-kit	5.8	4.4	41	31	0.76	54
Royal Crown	1.4	0.3	69	15	0.21	65
Tulikivi	5.7	2.3	107	44	0.41	59
Averages	3.2	2.1	74	50	0.69	58

Average CO emissions were 74 g/kg with an average daily g/hr of 50.

Comparatively, the average PM emissions (Figure 5) were somewhat higher than emissions from certified pellet stoves (1.7 g/kg) as tested in homes (Barnett and Roholt, 1990) and considerably lower than EPA 1990-certified Phase II noncatalytic woodstoves (AP-42 value of 7.0 g/kg). The average masonry heater emissions are 79% lower than the EPA's AP-42 emissions value of 14.9 g/kg for conventional woodstoves (Table 2).

CO emissions are comparatively not as low as PM emissions. They are comparable to Phase II certified noncatalytic woodstoves but significantly lower than conventional stoves (McCrillis and Jaasma, 1991 and Reference 15).

Efficiency

The average net delivered efficiency of the five masonry heaters was 58%. This efficiency is about midway between the 50-55% average for conventional woodstoves and the 65-70% average for Phase II woodstoves as measured in homes (References 1,10,14,15). The average heat output was 7248 BTU/hr.

The design of the heat transfer systems is generally not quite as effective as Phase II noncatalytic stoves (Figure 6). Improvement could be made by reducing the excess air so that stack oxygen averages about 15-16% and aiming for an average stack temperature of 300 to 350°.

Attachment 11: Reference D – Cover Page

92-118.06

Evaluation of Emissions from Masonry Heaters and Masonry Fireplaces in Homes

Stockton G. Barnett
OMNI Environmental Services, Inc.
Beaverton, Oregon

Robert C. McCrillis
U.S. Environmental Protection Agency
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina

Richard B. Crooks
Mutual Materials Company
Bellevue, Washington

Attachment 11: Reference D – Excerpt from Summary

PM emissions from the conventional masonry fireplaces averaged 24.9 g/kg, 82.7 g/hr, and 14.1 average daily g/hr (Table 1 and Figures 2,3,4 and 5). These values are near the upper end of the range of results in the literature,[5-16] which comprises mostly laboratory tests and some field tests with the fireplaces being operated by laboratory technicians. The EPA recently revised their fireplace AP-42[17] downward from 14.0 to 10.8 g/kg. CO emissions from the conventional masonry fireplaces averaged 10 g/kg, 36 g/hr, and 64.5 average daily g/hr (Figure 6), significantly higher than the EPA AP-42 value of 61.1 g/kg.

PM emissions from the Rosin masonry fireplaces were generally less than half of those from the conventional masonry fireplaces (Figure 2, 3, 4, and 5). A *t*-test indicated that the grams-per-kilogram difference was significant at the 98% probability level. Particulate emissions averaged 10.4 g/kg, 33.2 g/hr, and 9.9 average daily g/hr. CO emissions averaged 52.5 g/kg, 158 g/hr, and 47.3 average daily g/hr (Figure 6). The retrofit Rosin reduced emissions by 47% compared to its conventional predecessor.

The effects of wood moisture (range, 15 to 24%) on emissions from a conventional masonry fireplace were significant above 20% moisture. Particulate emissions ranged from 22.1 g/kg at 15% moisture to 41.4 g/kg at 24% moisture (Figure 7) and CO emissions ranged from 109 to 140 g/kg (Figure 8).

Masonry Heater Emissions

The underfire air Contraflow masonry heater particulate emissions were 5.6 g/kg, 45.7 g/hr, and 5.6 normalized average daily g/hr (Table 2 and Figures 2, 3, and 4). CO emissions were 41.0 g/kg, 336.8 g/hr, and 31.0 normalized average daily g/hr. Particulate emissions from the non-underfire air Grundofen were only 1.4 g/kg, 5.5 g/hr, and 1.4 normalized average daily g/hr. CO emissions were 83 g/kg, 339 g/hr, and 83 normalized average daily g/hr. The Grundofen's particulate emissions are among the lowest measured for an RWC device, about the same as the cleanest-burning pellet stoves.[4]

Three other potentially promising masonry heater designs are currently being evaluated in the field. Improvements in masonry heater design, in particular the abandonment of underfire air, are currently being undertaken. It appears that masonry heater technology holds promise for meeting the strictest of emissions standards.

Field Versus Laboratory Results

It is important to compare field and laboratory results since the validity of laboratory tests hinges on their ability to faithfully reflect and predict field performance. Because laboratory certification tests for woodstoves do not correlate well with field performance[2,18] there is additional need to closely examine such relationships for each type of RWC device. There are now comparative data for masonry fireplaces, and masonry heater data will be available soon.

A project was conducted by Virginia Polytechnic Institute[16] (VPI) for the Hearth Products Association (HPA) which used a newly developed laboratory test protocol for fireplaces to measure emissions from both conventional and Rosin masonry fireplaces. The conventional baseline included one fireplace, and the same Rosin models which were evaluated in the current project were tested at VPI. The results (Figures 9 and 10) show that the conventional fireplace PM emissions were only about 20% of the field average and 30% of the cleanest-burning field fireplace in the current study. The Rosins were about the same in the laboratory as in the field. The net result is that the relative ranking of the conventional and advanced-technology fireplaces is reversed. As a result of this problem and the gross understatement of the conventional fireplace emissions, it

Attachment 11: Reference D – Data Summary

92-118.06

Table 2. Summary of Rosin, masonry heater and moisture analysis data.

	ROSINS				MOISTURE ANALYSIS (CONVENTIONAL FIREPLACE)			MASONRY HEATERS			
HOUSE AND RUN:	F0301	F0302	ZAG. #2		F0102	F0101	F0103	F0201	F0501		
SAMPLE DATES:	2/22/– 3/02/91	6/13– 6/24/91	1/03– 1/06/91		2/13– 2/20/91	2/06– 2/13/91	2/20– 2/27/91	12/06– 12/12/91	2/27– 3/06/91		
FIREPLACE TYPE:	ROSIN OR. EQUIP	ROSIN OR. EQUIP	ROSIN RETRO	ROSIN AVERAGE	CON-VENTIONAL	CON-VENTIONAL	CON-VENTIONAL	GRUNDOFEN HEATER	CONTRA-FLOW	MASONRY HEATER AVERAGE	
FUEL TYPE:	D. FIR	D. FIR	D. FIR		D. FIR	D. FIR	D. FIR	D. FIR	D. FIR		
FUEL MOISTURE:	20% MOIST	20% MOIST	17% MOIST		15 % MOIST	20% MOIST	24% MOIST	20% MOIST	18% MOIST		
TOTAL STOVE BURNING HOURS=	50.63	39.50	37.75	41.5	27.67	30.25	25.58	44.24	14.25	29.24	TOTAL STOVE BURNING HOURS=
% OF TIME FIREPLACE BURNED=	32.85	23.52	33.07	30.6	16.47	18.16	15.33	27.03	8.49	17.76	% OF TIME FIREPLACE BURNED=
AVE. STACK TEMP (DEGREES F.)=	209	190	216	209	206	203	142	286	434	360	AVE. STACK TEMP (DEGREES F.)=
AVE OXYGEN %(STACK> 100 DEG. F)=	20.03	20.17	20.22	20.16	20.32	20.44	20.45	17.74	16.72	17.23	AVE OXYGEN %(STACK> 100 DEG. F)=
AVE. OXYGEN % (BAG)=	20.1	20.5	20.2	20.3	20.5	20.4	20.3	18.1	16.7	17.4	AVE. OXYGEN % (BAG)=
TOTAL WOOD USED (WET kg)=	135.5	98.7	184.2	150.7	43.7	39.2	38.4	217.3	149.5	183.4	TOTAL WOOD USED (WET kg)=
WOOD MOISTURE (DRY BASIS %)=	20.3	20.0	16.9	18.5	15.0	18.9	24.2	20.0	17.9	18.9	WOOD MOISTURE (DRY BASIS %)=
AWES FLOW RATE (L/min)=	1.054	1.067	1.044	1.1	0.944	0.944	0.967	0.944	1.084	1.014	AWES FLOW RATE (L/min)=
LENGTH OF SAMPLING CYCLE (min)=	3	3	2	2.5	2	2	3	3	3	3	LENGTH OF SAMPLING CYCLE (min)=
AVERAGE CO % (BAG)=	0.050	0.017	0.030	0.032	0.060	0.050	0.070	0.190	0.140	0.165	AVERAGE CO % (BAG)=
AVERAGE CO2 % (BAG)=	0.80	0.43	0.80	0.71	0.63	0.49	0.56	2.60	4.00	3.30	AVERAGE CO2 % (BAG)=
NUMBER OF BURN CYCLES IN TEST=	7	7	5	6.00	7	7	7	10	7	8.5	NUMBER OF BURN CYCLES IN TEST=
TOTAL PARTICULATES (mg)											TOTAL PARTICULATES (mg)
RINSE (mg)=	40.5	41.7	64.4	52.8	30.7	37.9	78.7	26.2	47.0	36.6	RINSE (mg)=
XAD (mg)=	36.3	12.5	16.6	20.5	33.5	78.7	6.0	6.0	20.2	13.1	XAD (mg)=
FILTER (mg)=	7.9	15.0	23.0	17.2	50.9	6.0	37.6	6.4	8.1	7.3	FILTER (mg)=
MINUS AVE BLANK	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	MINUS AVE BLANK
TOTAL PARTICULATES (g)=	0.081	0.065	0.100	0.0665	0.111	0.107	0.119	0.035	0.071	0.053	TOTAL PARTICULATES (g)=
TOTAL DRY WOOD USED (kg)=	112.6	82.2	157.6	127.5	83.7	72.5	68.1	181.1	126.8	153.9	TOTAL DRY WOOD USED (kg)=
BURN RATE (DRY kg/hr)=	2.22	2.08	4.17	3.2	3.03	2.40	2.66	4.08	8.90	6.49	BURN RATE (DRY kg/hr)=
AIR/FUEL RATIO=	157	171	159	162	199	203	223	39	30	35	AIR/FUEL RATIO=
PARTICULATE EMISSIONS:											PARTICULATE EMISSIONS:
g/kg=	9.37	10.58	10.8	10.4	22.1	25.7	41.4	1.4	5.8	3.6	g/kg=
g/hr=	20.76	22.04	45.0	33.2	66.9	61.6	110.1	5.5	51.7	28.6	g/hr=
AVE. DAILY g/hr=	6.3	5.2	14.2	9.9	11.0	11.1	16.8	1.5	4.4	2.9	AVE. DAILY g/hr=
CO EMISSIONS:											CO EMISSIONS:
g/kg=	72.12	49.26	44.4	52.5	106.7	119.2	140.3	83.1	41.0	62.0	g/kg=
g/hr=	160	103	185	158	329	286	373	339	364	351	g/hr=
AVE. DAILY g/hr=	48.4	24.1	58.3	47.3	54.2	51.5	56.8	91.5	31.0	61.2	AVE. DAILY g/hr=
ADDITIONAL ITEMS:											ADDITIONAL ITEMS:
AVE. BURN CYCLE LENGTH (hr)=	7.26	5.64	7.55	7.0	3.95	4.32	3.65	4.40	2.21	3.30	AVE. BURN CYCLE LENGTH (hr)=
WET kg USED/ BURN CYCLE=	42.6	31.0	81.1	59	13.7	12.3	12.1	21.7	21.4	21.5	WET kg USED/ BURN CYCLE=
# WOOD LOADS/BURN CYCLE=	3.1	3.0	7.7	5.4	3.6	4.6	3.3	1.0	1.0	1.0	# WOOD LOADS/BURN CYCLE=
AVE WOOD LOAD (WET kg)=	6.2	4.7	3.4	4.4	3.8	2.7	3.7	21.7	21.4	21.5	AVE WOOD LOAD (WET kg)=
AVE. WOOD USAGE/DAY (WET kg)=	19.4	14.1	38.7	27.7	13.7	12.4	12.2	31.7	21.4	26.5	AVE. WOOD USAGE/DAY (WET kg)=
AVE. AMBIENT TEMP (DEGREES F.)=	67.9	68.7	67.0	67.6	69.3	70.1	68.4	70.6	67.9	69.2	AVE. AMBIENT TEMP (DEGREES F.)=

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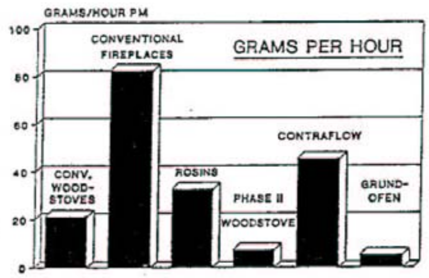
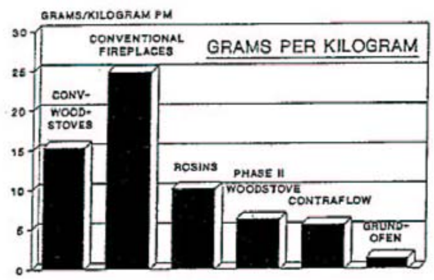
Attachment 11: Reference D – Emission Comparison Chart

92-118.06



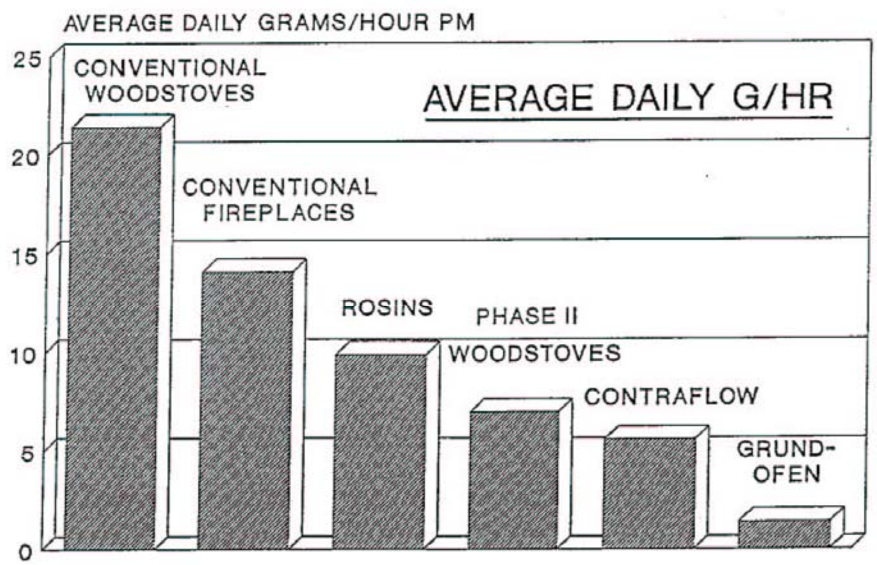
Conventional and Phase II woodstoves from EPA's AP-42.

Figure 2. Comparison of PM grams per hour for woodstoves, fireplaces and masonry heaters.



Conventional and Phase II woodstoves from EPA's AP-42.

Figure 3. Comparison of PM grams per kilogram for woodstoves, fireplaces and masonry heaters.



Masonry heater values normalized to a 1.0 kg/hr burn rate, the Phase II woodstove field average.

Figure 4. Comparison of PM average daily grams per hour for woodstoves, fireplaces and masonry heaters.

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Attachment 12: Reference E – Report Cover Page

In-Home Evaluation of Emissions from a Temp-Cast 2001 Masonry Heater

Prepared for: Temp-Cast 2000 Masonry Heater Manufacturing, Inc.

Prepared by: Roger Bighouse
Stockton G. Barnett
OMNI Environmental Services, Inc.
10074 SW Arctic Drive
Beaverton, Oregon 97005

May 8, 1992

80131-01

Attachment 12: Reference E – Excerpt from Report

Every three minutes it operated for one minute. This causes the collected gases to be more dilute than those emitted during just the combustion phase. Thus, in Table 1, the O_2 values are artificially high and the CO and CO_2 values low. This method of gas collection does not affect the calculated CO emissions values at all, however.

Emissions Results

PM emissions averaged 2.96 g/kg and 1.26 average daily g/hr. Table 1 shows the results from each emissions test. The 95% confidence limit for the g/kg value is ±0.6 g/kg. Normalizing the grams per hour emissions to a 1 kg/hr burn rate as described in Barnett (1991) yields 2.96 normalized daily g/hr. The average daily burn rate was 0.43 dry kg/hr.

Average CO emissions were 82.7 g/kg, 35.2 average daily g/hr, and 82.7 normalized average daily g/hr.

Comparatively, the PM emissions (Figure 4)[a] were between the emissions of certified pellet stoves as tested in homes (Barnett and Roholt, 1990) and EPA 1990-certified Phase II noncatalytic woodstoves. The Temp-Cast 2001 emissions are about 80% lower than the EPA's AP-42 emissions value of 14.9 g/kg for conventional woodstoves.

CO emissions are comparatively not as low as PM emissions. They are comparable to Phase II certified noncatalytic woodstoves but significantly lower than conventional stoves (McCrillis and Jaasma, 1991 and Reference 11).

Efficiency

The average net delivered efficiency of the Temp-Cast 2001 was 61.8%. This efficiency is in between the 65-70% average for Phase II woodstoves and 50-55% average for conventional stoves as measured in homes (References 1,6,10,11). The average heat output was 4915 BTU/hr.

The net delivered efficiency is average for masonry heaters (Table 1 and Figure 5). The design of the heat transfer system could perhaps be improved somewhat by reducing the average stack oxygen to 15-16%.

[a] The woodstove values in this figure are from the summary paper by McCrillis and Jaasma, 1991. The Certified pellet stove values are from Barnett and Roholt, 1990, and the exempt pellet stove values are from Barnett and Fields, 1991.

Attachment 12: Reference E – Data Summary

MASONRY HEATER EMISSIONS RESULTS

HOUSE AND RUN:	TEMP–CAST	
SAMPLE DATES:	4/22–29/92	
HEATER TYPE:	TEMP–CAST 2001	
FUEL TYPE:	POPLAR	
TOTAL STOVE BURNING HOURS=	40.05 HOURS	
% OF TIME HEATER BURNED=	23.84 PERCENT	
AVE. STACK TEMP=	199.81 DEGREES F.	
* AVE OXYGEN (STACK)=	18.68 PERCENT	
* AVE. OXYGEN (BAG)=		*****
TOTAL WOOD USED, WET LBS.=	199.0	
WOOD MOISTURE (DRY BASIS %)=	26.6	*****
AWES FLOW RATE(L./MIN)=	1.08	*****
LENGTH OF SAMPLE CYCLE (MIN.)=	3	*****
AVERAGE CO % (BAG)=	0.0347	*****
AVERAGE CO2 % (BAG)=	0.53	*****
VOC, PPM (BAG)=		*****
TOTAL PARTICULATES IN MG.		
RINSE=	37 ****	
XAD=	9.6 ****	
FILTER=	12.3 ****	
MINUS AVE BLANK	3.9	
TOTAL PARTICULATES=	0.055 GM.	
TOTAL DRY WOOD USED=	71.45 KG.	
* BURN RT (DRY KG/H) DURING BURN=	1.78 KG/HR	
AVE DAILY BURN RT (DRY KG/H)=	0.43 KG/HR	
AIR TO FUEL RATIO=	56.42	
* PARTICULATE EMISSIONS:		
* GM/KG=	2.96	
GM/KG UNCERTAINTY=	0.60	
* GM/HR=	5.29	
Ave. daily g/hr=	1.26	
* CO EMISSIONS:		
GM/KG=	82.72	
GM/HR=	147.57	
Ave. daily g/hr=	35.18	
* VOC EMISSIONS:		
GM/KG=	0.00	
GM/HR=	0.00	
Ave. daily g/hr=	0.00	
ADDITIONAL ITEMS:		
AVE WOOD LOAD (WET LB.)=	24.88	
AVE. WOOD USAGE/DAY (WET LB.)=	28.43	
# TIMES LOADED/DAY=	1.14	
AVE. AMBIENT TEMP=	70.89	
NET EFFICIENCY:		
COMBUSTION EFFIC.=	94.4	
HEAT TRANS. EFFIC=	65.4	
NET EFFICIENCY=	61.8	
NET OUTPUT (BTU/HR)=	4915	

Table 1 10

Attachment 12: Reference E – Graphical Presentation

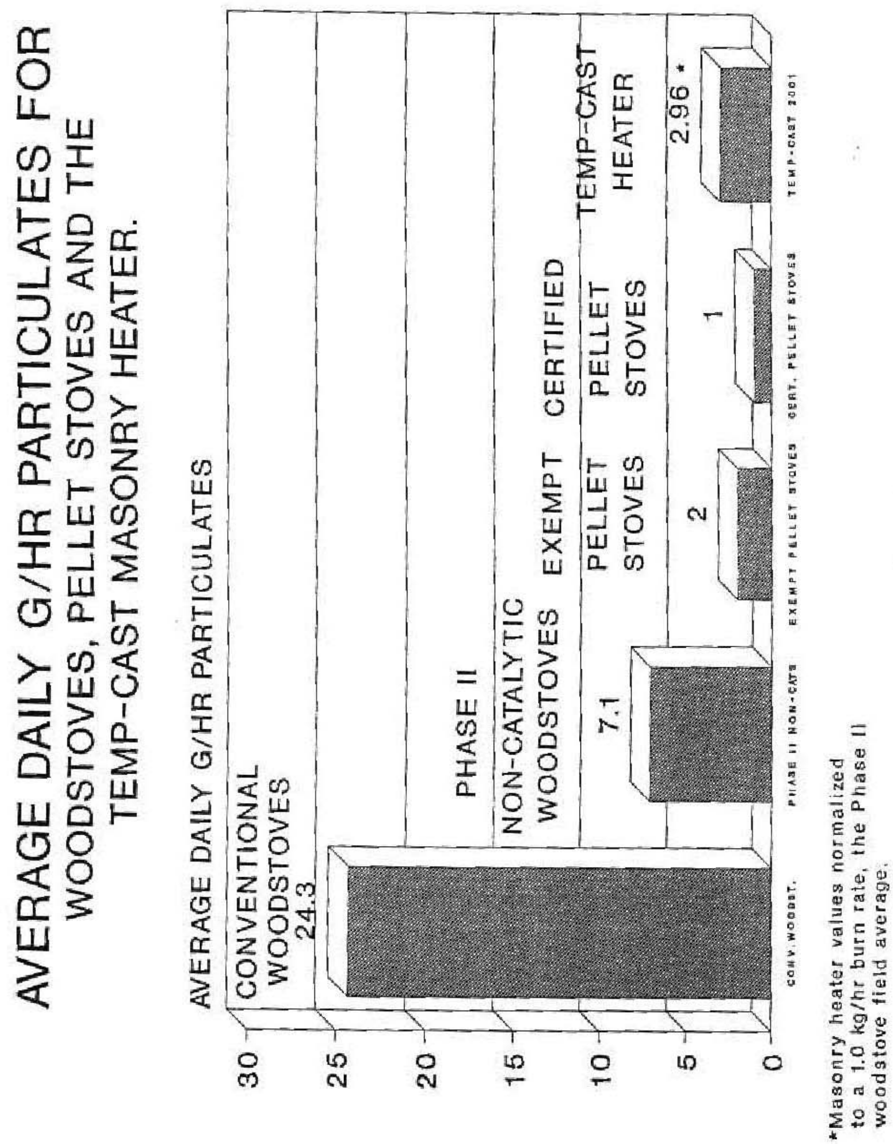

Figure 4

11

Attachment 13: Reference F – Report Cover Page

In-Home Evaluation of Emissions from a Mastercraft Swedish Heater Kit Masonry Heater

Prepared for: Mastercraft Masonry
PO Box 73
Brush Prairie, WA 98606

Prepared by: Science Applications International Corporation
10074 SW Arctic Drive
Beaverton, Oregon 97005

March 23, 1993

Attachment 13: Reference F – Executive Summary

Executive Summary

Particulate (PM), carbon monoxide (CO), and volatile organic compounds (VOC) emissions were measured using SAIC's Automated Woodstove Emissions Sampler (AWES) systems on a first-year Mastercraft Swedish Heater Kit masonry heater located near Battle Ground, Washington in March 1993. The heater was operated by the homeowner in his normal fashion using douglas fir cordwood with 13.5% average moisture (dry basis). The unit was fired seven times during the week-long test. The AWES was operated for the entire test and its results are reported herein.

PM emissions averaged 1.90 g/kg, 1.32 average daily g/hr, and 1.90 normalized average daily g/hr. These PM values are between those obtained from certified pellet stoves and EPA certified Phase II woodstoves in the field.

CO emissions averaged 95.7 g/kg, 66.3 average daily g/hr, and 95.7 normalized daily g/hr. These values are comparable to Phase II EPA certified noncatalytic woodstoves.

VOC emissions averaged 9.57 g/kg, 6.63 average daily g/hr, and 9.57 normalized daily g/hr.

The average net delivered efficiency was 62.5%, which is in between EPA certified Phase II woodstoves and conventional stoves. Average heat output was 8105 BTU/hr and daily burn rate averaged 0.69 dry kg/hr.

Attachment 14: Reference F – Data Summary

Table 1. Masonry Heater Emissions Results: Mastercraft Swedish Heater Kit.

SAMPLE DATES:	3/12/93 – 3/19/93			
HEATER TYPE:	MasterCraft – Swedish Heater Kit			
FUEL TYPE:	Douglas Fir			
Total Burning Period =		15.09	hours	
Percent of Time Heater Burned =		8.98	%	
Average Stack Temp. during burn =		270.14	°F	
Average Oxygen during burn (Stack) =		17.76	%	
Average Oxygen (Bag) =		20.43	%	
Total Wood Used =		290.8	wet lb	
Wood Moisture =		13.5	% dry basis	
AWES Flow Rate =		0.9714	l/min	
Length of Sample Cycle =		3.0	min	
Average CO (Bag) =		0.052	%	
Average CO2 (Bag) =		0.59	%	
Average VOC (Bag) =		91	ppm	
TOTAL PARTICULATES:				
Rinse =	45.0 mg			
XAD–2 =	6.3 mg			
Filter =	−30.4 mg			
Average Blank =	−3.9 mg			
Total Particulates =		0.017	g	
Total Dry Wood Used =		116.46	dry kg	
Burn Rate during burn =		7.72	dry kg/hr	
Average Daily Burn Rate =		0.69	dry kg/hr	
Air to Fuel Ratio =		45.57	to 1	
PARTICULATE EMISSIONS:				
g/kg	1.90	±		0.61
g/hr	14.65	±		4.67
Ave. daily g/hr=	1.32	±		0.42
CO EMISSIONS:				
g/kg	95.69			
g/hr	738.51			
Ave. daily g/hr=	66.33			
VOC EMISSIONS:				
g/kg	9.57			
g/hr	73.85			
Ave. daily g/hr=	6.63			
ADDITIONAL ITEMS:				
Average Wood Load =		41.54	wet lb	
Average Wood Usage =		41.54	wet lb/day	
Number of times Loaded per Day =		1.00		
Average Ambient Temperature =		75.42	°F	
NET EFFICIENCY:				
Combustion Efficiency =		94.13	%	
Heat Transfer Efficiency =		66.42	%	
NET EFFICIENCY=		62.53	%	
Net Heat Output =		8105	BTU/hr	

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Science Applications International Corporation 10

Attachment 13: Reference F – Graphical Presentation

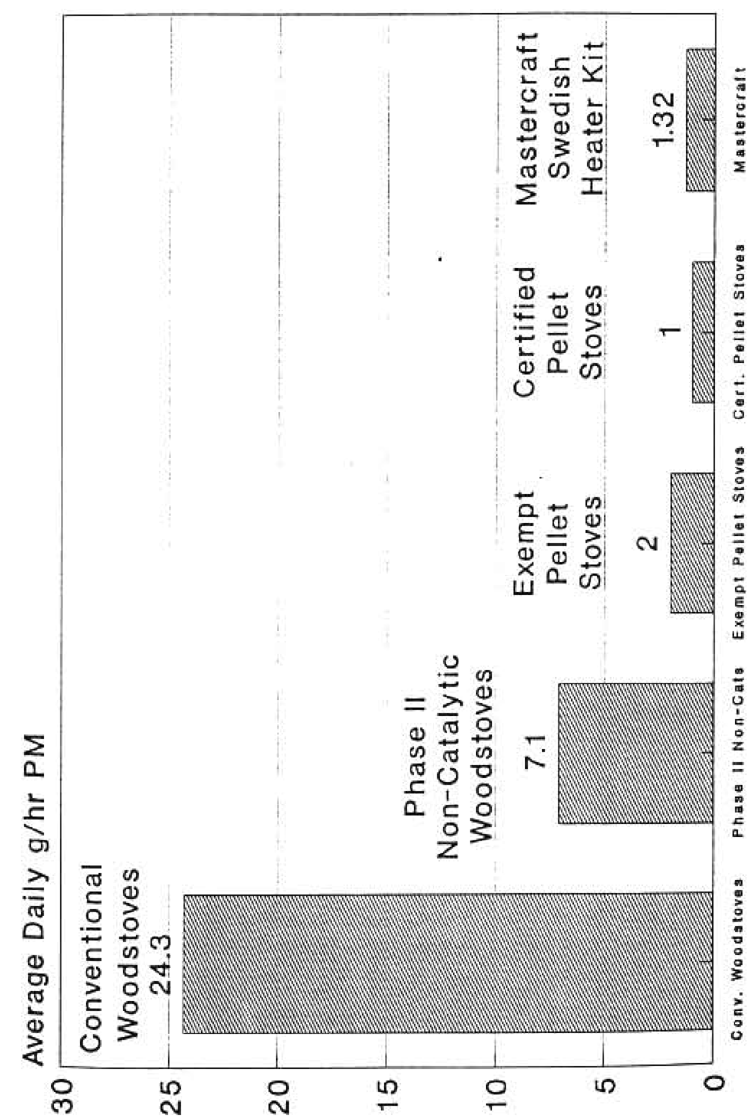

Figure 3. Average daily g/hr particulates for woodstoves, pellet stoves, and the Mastercraft Swedish Heater Kit masonry heater.

Science Applications International Corporation 12

Attachment 14: Reference G – Report Cover Page

Evaluation of Efficiency and Emissions from a Moberg/Royal Crown MRC-3036 Masonry Heater

SUMMARY REPORT. Complete report with Appendices available by request to:
FireSpaces, Inc.
921 S.W. Morrison St., Suite 440
Portland, Oregon 97205
tel. (503) 227-0547

Prepared for: **Fire Spaces, Inc.**
Walter Moberg Design
921 SW Morrison, Suite 440
Portland, Oregon 97205
(503)227-0547

Prepared by: **OMNI Environmental Services, Inc.**
5465 SW Western Avenue, Suite M
Beaverton, Oregon 97005
(503)643-3788

May 28, 1994
OMNI REPORT
#001S-013

Attachment 14: Reference G – Summary Page

Emissions Results

Table 1 shows the results of AES measurements and sampling over the test period. Total particulate (TP) emissions averaged 3.9 g/kg and 3.4 g per hour. The 95% confidence limit for the g/kg value is ±0.90 g/kg. The average burn rate was 0.88 dry kg/hr.

Average CO emissions were 20.3 g/kg, 17.8 g per hour.

Comparatively, the particulate emissions (Figure 3) were between the emissions of certified pellet stoves as tested in homes[5] and EPA 1990-certified Phase II noncatalytic woodstoves. The Moberg/Royal Crown Model MRC-3036 Masonry Heater emissions are 30% of the EPA's AP-42 emissions value of 14.9 g/kg for conventional woodstoves.

CO emissions are very low as compared to EPA certified catalytic and noncatalytic woodstoves as well as other masonry heaters.

Efficiency Results

The average net delivered efficiency of the Moberg/Royal Crown Model MRC-3036 Masonry Heater was 53.8%. The average heat output was 9372 BTU/hr.

Attachment 15: Reference H1 – Report Cover Page

OMNI

Moberg 3042 Masonry Heater Emissions Testing Report

(Compliance with Colorado Regulation No. 4)

Prepared for: FIRESPACES, INC.
223 NW NINTH AVENUE
PORTLAND, OREGON 97209-3305
(503) 227-0547

Prepared by: OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite M
Beaverton, Oregon 97005
(503)643-3788

Test Date: November, 1995

January, 1996

OMNI REPORT
#001-S-02-3-B

Attachment 15: Reference H1 – Summary Page

Masonry Heater EmissionsTesting Report
Moberg 3042

Demonstration of Compliance with Colorado Regulation 4 Standards

Summary of Testing:

Starting on November 16, 1995, OMNI Environmental Services, Inc. conducted a two-day emissions test at a private residence in Portland, Oregon for the purpose of obtaining "approved" designation from the Colorado Department of Health for the MRC 3042 masonry heater design. Testing was conducted using an automated sampling system (an OMNI ESS) to determine particulate and carbon monoxide emission factors and to record flue temperature and oxygen concentration data.

Test Results and Discussion:

The test results show an **average particulate emission factor of 1.95 grams per kilogram (g/kg)**, at an emission rate of 4.70 grams per hour (g/hour). Carbon Monoxide (CO) emissions were measured at 14 g/kg and 33 g/hour. Testing was conducted as an abbreviated test series in support of Section IV.B.3 of Regulation 4 of the Colorado Air Quality Control Commission (1994). The MRC 3042 fireplace design has substantially the same core construction as the MRC 3036 fireplace (Masonry Heater Approval letter from Gary Finiol; CAQCC, dated August 23, 1994) with modifications only in proportional dimension. The MRC 3042 fireplace design demonstrated particulate emissions that are within the **Colorado Regulation 4 requirement of 6.0 g/kg.**

Drawings providing dimensions for Regulation 4 Masonry-heater specifications are contained in Appendix G to this report. The following provides a listing of Appendices and their contents:

Attachment 15: Reference H2 – Report Cover Page

OMNI

Moberg 3042 Fireplace Heater Emissions Testing Report

(Compliance with Washington State UBC Section 31-2)

SUMMARY REPORT. Complete report with Appendices available by request to:

FireSpaces, Inc.
223 NW Ninth Avenue
Portland, Oregon 97209-
(503) 227-0547 tel or 227-0548 fax
www.firespaces.com

Prepared for: FireSpaces, Inc.
223 NW Ninth Avenue
Portland, Oregon 97209-

Prepared by: OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite M
Beaverton, Oregon 97005
(503)643-3788

Test Date: November, 1995

January, 1996
001-S-02-3-A

Attachment 15: Reference H2 – Summary Page

Fireplace Heater EmissionsTesting Report
Moberg 3042

For Demonstrating Compliance with the Washington State Building Code Standard for Fireplace Emissions Requirements (UBC Section 31-2)

Summary of Testing:

On November 30, 1995, OMNI Environmental Services, Inc. conducted emissions testing on the MRC 3042 fireplace design in conformance with the Washington State test and operating protocol. The testing reported here was conducted at the Moberg R&D facility in Portland, Oregon. OMNI used the Washington emissions sampling system (an OMNI ESS) to sample particulate emissions. OMNI technician Jacob Tiegs conducted all testing including set-up, take-down, and the laboratory analysis of ESS samples.

Testing was conducted with the **doors closed and a hearth grate in place**. The fuel loading schedule, load weight, and fuel moisture were determined in accordance with the Washington required protocol. Three fuel charges were loaded during the test period and the unburned ashes were weighed and subtracted at the end of the test period for a total "fuel burned" weight.

Test Results and Discussion:

The test results show an **average particulate emission factor of 1.79 grams per kilogram (g/kg)**, at an average emission rate of 5.53 grams per hour (g/hour). Carbon Monoxide emissions were measured at 48 g/kg and 148 g/hr. The MRC 3042 fireplace design exhibited emissions that are within the **Washington State requirement of 7.3 g/kg**.

Table 1 presents a complete summary of test measurements and sample analyses. Figure 1 presents a time-base graph of flue-gas temperatures and oxygen concentrations and indications of when and how much fuel was added during the test period.

Attachment 16: Reference I - AP-42 Revision Report Excerpts

REPORT ON REVISIONS TO
5TH EDITION AP-42
Section 1.10
Residential Wood Stoves

Prepared for:

Contract No. 68-D2-0160, Work Assignment 50
EPA Work Assignment Officer: Roy Huntley
Office of Air Quality Planning and Standards
Office of Air and Radiation
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Prepared by:

Eastern Research Group
Post Office Box 2010
Morrisville, North Carolina 27560

July 29, 1996

Attachment 16: Reference I - AP-42 Revision Report Excerpts

4.2.3 References 9 and 10 - Preliminary Data on Wood Stoves

During the winter of 1991-1992, two separate series of in-home emissions tests were conducted on wood stoves in Crested Butte (two noncatalytic Phase II stoves, six catalytic Phase I and two catalytic Phase II stoves) and Klamath Falls (four conventional stoves, three noncatalytic Phase II stoves and two catalytic Phase II stoves). The results of these tests are important in that these stoves have been tested in prior years (excluding the Klamath Falls conventional wood stoves) and the results should provide some insight into the effect of stove degradation on emissions. Degradation mainly affects catalytic components. However, over time, warpage of other internal parts can cause leaks which contribute to increased emissions. Results of these two tests are summarized in Table 4-2, even though the data cannot be included in emission factor development pending evaluation of the test reports. A preferred approach for tracking degradation might be to extract from the existing data base any emissions data for stoves with test results from multiple years, and add in the most recent year's data to form a separate "degradation" data base. In fact, work has already begun to develop this type of data base.

4.2.4 References 11, 13, 13, 14, 15 - Masonry Heaters

References 11 through 15 reported emissions from five types of masonry heaters under in-home burning conditions. All five references reported PM, CO and CO_2 emissions. These data were rated "A." A summary of the test data from all five test series is shown in Table 4-3.

Reference 11 also reported emissions for a "Russian" style masonry heater which was constructed by a mason from a plan that was later changed. Emissions from this unit were not included in the emission factor development since this unit is not commercially available and is probably not representative of the general masonry heater population in terms of construction or emissions.

Attachment 16: Reference I - AP-42 Revision Report Excerpts

TABLE 4-3. SUMMARY OF NEW IN-HOME EMISSIONS DATA FOR MASONRY HEATERS[11-15]

Sample Dates	1991 - 1992
Fuels	Douglas Fir, Alder
Average Fuel Moisture	19%
Total Burn Time	135.1 hours
Total Burn Cycles	41
Average Burn Rate	4.73 dry kg/hr
Average Emissions:[a]	
PM	2.8 g/kg
CO	74.5 g/kg
CO_2	1,924.7 g/kg

a. These data were collected using an AWES unit, and have been converted to M5H equivalent values. See section 4.3.1.1 of this report for an explanation of the conversion calculations, and Appendix A for a sample calculation.

4.3 EMISSION FACTOR METHODOLOGY

A Lotus1-2-3™ spreadsheet was used to compile PM and CO emissions data and calculate emission factors as part of the 1991 revision to the AP-42 section on residential wood stoves. The 1991 spreadsheets were updated during the current revision to include new correlation equations used to calculate equivalent EPA Method 5H values for PM from field-test data. (See section 4.3.1.1 for details of these calculations). New spreadsheets were developed to calculate PM, CO and speciated organic compound emission factors from new references. Also, new spreadsheets were developed to calculate emission factors for noncriteria pollutants (i.e., CO_2 and PAH).

4.3.1 Criteria Pollutant Emission Factor Development

Emission factors for NO_x (rated "E"), SO_x (rated "B"), were not changed from the 1991 emission factors. Emission factors for CO and PM were revised using existing emission factors (rated "B") and new data (rated "A") resulting in new composite CO and PM emission factors,

4-7

Attachment 16: Reference I - AP-42 Revision Report Excerpts

TABLE 1.10-2. (METRIC UNITS) EMISSION FACTORS FOR RESIDENTIAL WOOD COMBUSTION[a]

Pollutant/ EPA Certification[b]	Emission Factor Rating	Wood Stove Type[c]			Pellet Stove Type[d]		Masonry Heater
		Conv. g/kg	Non-Cat g/kg	Cat g/kg	Certified g/kg	Exempt g/kg	Exempt[e] g/kg
PM-10[f,g]							
Pre-Phase I	B	15.3	12.9	12.1			
Phase I	B		10.0	9.8			
Phase II	B		7.3	8.1	2.1		
All	B	15.3	9.8	10.2	2.1	4.4	2.8
Carbon Monoxide[f]							
Pre-Phase I	B	115.4					
Phase I	B			52.2			
Phase II	B		70.4	53.5	19.7		
All	B	115.4	70.4	52.4	19.7	26.1	74.5
Nitrogen Oxides[f]		1.4[h]		1.0[i]	6.9[i]		
Sulfur Oxides[f]	B	0.2	0.2	0.2	0.2		
Carbon Dioxide[j]	C				1,475.8	1,835.6	1,924.7
Total Organic Compounds[k]							
Methane	E	32.0		13.0			
Non-Methane	E	14.0		8.6			

a. Units are in (grams of pollutant/kg of dry wood burned).
b. Pre-Phase I = not certified to 1988 EPA emission standards; Phase I = certified to 1988 EPA emission standards; Phase II = certified to 1990 EPA emission standards; All = average of emission factors for all devices.
c. Conv = Conventional; Non-Cat = Noncatalytic; Cat = Catalytic.
d. Certified = Certified pursuant to 1988 NSPS; Exempt = Exempt from 1988 NSPS (i.e., air:fuel ratio >35:1).
e. Exempt = Exempt from 1988 NSPS (i.e., weight >800 kg).
f. References 5-13, 22-26, 28.
g. Defined as equivalent to total catch by EPA method 5H train.
h. Rating = C.
i. Rating = E.
j. References 12, 22-26, 28.
k. References 14, 15, 18. The data used to develop the emission factors showed a high degree of variability within the source population. The use of these emission factors on specific sources may not be appropriate.

10/92 1.10-5

Attachment 17: Reference J1 and J2 – Report Cover Page

Possession Record	
Copy Number:	
Name	Date

Test Report: Masonry Heater Particulate Emissions and Overall Thermal Efficiency. Tulikivi Oy Model KTU-2100 May 1997

Prepared for: **Tulikivi Oy**
FIN-83900 Juuka
FINLAND

Prepared by: ***OMNI-Test* Laboratories, Inc.**
5465 SW Western Avenue, Suite G
Beaverton, Oregon 97005 USA
(503)643-3788

May 1997
Project # 020-S-01-3

Attachment 17: Reference J1 and J2 – Summary Page

Tulikivi Oy. Model KTU-2100
FINLAND
020-S-01-3

Test Report
Test Dates: May 20 and 21, 1997

SUMMARY

The Tulikivi Model KTU-2100 masonry heater was tested for particulate emissions and overall thermal efficiency by *OMNI-Test* Laboratories, Inc. (OMNI) of Beaverton, Oregon, USA. Two tests were conducted in accordance with the emissions and thermal efficiency sampling and analysis specifications of the *Model Performance Standard for Fireplaces and Masonry Heater Emissions*: the first one was conducted on May 20, 1997 and the second on May 21, 1997.

Test-Burn Number 1 was conducted using three successive fuel loads of the size and weight stipulated by the Model Standard and the Washington State Method. Test-Burn Number 2 however, was conducted using only one, large fuel load simulating Colorado Regulation-4's in-home user defined fuel loading protocol. The tested masonry heater configuration and test results are presented in the following Summary Table:

Summary Table. Test Configuration and emissions results for the Tulikivi KTU-2100 Masonry Heater.

Test-Burn	Test Configuration	Particulate Emissions		Overall Thermal Efficiency
Number 1 (Three fuel load test)	Door Closed, With Hearth Grate, No Draft Inducer, and No Catalyst	**2.5 grams/kilogram** (U.S. EPA Method 5H equivalents calculated in accordance with Washington State UBC Chapter 31-2)	**3.0 grams/hour (per kilogram/hour)** (U.S. EPA 5H equivalents calculated in accordance with The Model Standard)	52.5%
Number 2 (Single, large fuel load test)	Door Closed, With Hearth Grate, No Draft Inducer, and No Catalyst	**3.1 grams/kilogram** (U.S. EPA Method 5H equivalents calculated in accordance with Washington State UBC Chapter 31-2)	**3.8 grams/hour (per kilogram/hour)** (U.S. EPA 5H equivalents calculated in accordance with The Model Standard)	51.2%

OMNI-Test Laboratories Inc. -i-

Attachment 18: Reference K – Report Cover Page

Tulikivi Oy; Model TU 1000
Emissions Testing Report

(Protocol Conformance with Colorado Regulation No. 4)

Prepared for: Tulikivi Oy
FIN-83900
Juuka, Finland

Prepared by: OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite G
Beaverton, Oregon 97005
(503) 643-3788

April 29, 1999
020-S-06-3

Attachment 18: Reference K – Summary Page

Fireplace Heater Emissions Testing Report
Tulikivi TU 1000

For Demonstrating Compliance with the Colorado Regulation 4 Standards

Summary of Testing:

Beginning on April 5 and ending on April 12, 1999, OMNI Environmental Services, Inc. conducted "in field" emissions testing on the Tulikivi TU 1000 fireplace design in conformance with the Colorado Regulation 4 Standards and operating protocol. All testing reported here was conducted at the Bullard residence in the rural area east of Livingston, Montana. OMNI used an EPA audited procedure which requires the use of an EPA audited automated wood emissions sampler (an OMNI AWES) to sample particulate emissions. OMNI technician Chuck Fisher conducted all testing including set-up, take-down, data reduction, and the laboratory analysis of samples.

Testing was conducted with the **doors closed and a hearth grate in place**. The fuel loading schedule for the testing was determined by the home owner . Fuel loading weight was approximately 80% of the manufacturer's recommendations and measured by an OMNI technician. Fuel moisture content was measured by an OMNI technician. One load of fuel was burned per day.

Test Results and Discussion:

The test results show an **average particulate emission factor of 2.6 grams per kilogram** (g/kg). The Tulikivi; Model TU 1000 design exhibited emissions that meet the emission standards set forth in Federal Regulations 40CFR Part 60, Subpart AAA, Subsection 60.532(b)(1) or (2). The resulting average particulate emission factor is below the **Colorado State requirement of 6.0 g/kg**.

Table 1 presents a summary of test measurements and sample analyses for the test. Plot 1 presents a time-base graph of flue-gas temperatures, flue-gas oxygen concentrations, and indications of when and how fuel was added during the test period.

Attachment 19: Reference L – Report Cover Page

Tulikivi Oy; Model TU 2200
Emissions Testing Report

(Protocol Conformance with Colorado Regulation No. 4)

Prepared for: Tulikivi Oy
FIN-83900
Juuka, Finland

Prepared by: OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite G
Beaverton, Oregon 97005
(503) 643-3788

April 29, 1999
020-S-06-3

Attachment 19: Reference L – Summary Page

Fireplace Heater Emissions Testing Report
Tulikivi TU 2200

For Demonstrating Compliance with the Colorado Regulation 4 Standards

Summary of Testing:

Beginning on April 5 and ending on April 12, 1999, OMNI Environmental Services, Inc. conducted "in field" emissions testing on the Tulikivi TU 2200 fireplace design in conformance with the Colorado Regulation 4 Standards and operating protocol. All testing reported here was conducted at the McGee residence within the city limits of Livingston, Montana. OMNI used an EPA audited procedure which requires the use of an EPA audited automated wood emissions sampler (an OMNI AWES) to sample particulate emissions. OMNI technician Chuck Fisher conducted all testing including set-up, take-down, data reduction, and the laboratory analysis of samples.

Testing was conducted with the **doors closed and a hearth grate in place**. The fuel loading schedule for the testing was determined by the home owner . Fuel loading weight was approximately 80% of the manufacturer's recommendations and measured by an OMNI technician. Fuel moisture content was measured by an OMNI technician. One load of fuel was burned per day.

Test Results and Discussion:

The test results show an **average particulate emission factor of 3.5 grams per kilogram (g/kg)**. The Tulikivi; Model TU 2200 design exhibited emissions that meet the emission standards set forth in Federal Regulations 40CFR Part 60, Subpart AAA, Subsection 60.532(b)(1) or (2). The resulting average particulate emission factor is below the **Colorado State requirement of 6.0 g/kg**.

Table 1 presents a summary of test measurements and sample analyses for the test. Plot 1 presents a time-base graph of flue-gas temperatures and the flue-gas oxygen concentrations.

Attachment 20: Reference M – Report Cover Page

Tulikivi Oy; Model TLU 2450
Emissions Testing Report

(Protocol Conformance with Colorado Regulation No. 4)

Prepared for: Tulikivi Oy
FIN-83900
Juuka, Finland

Prepared by: OMNI Environmental Services, Inc.
5465 SW Western Avenue, Suite G
Beaverton, Oregon 97005
(503) 643-3788

April 29, 1999
020-S-06-3

Attachment 20: Reference M – Summary Page

Fireplace Heater Emissions Testing Report
Tulikivi TLU 2450

For Demonstrating Compliance with the Colorado Regulation 4 Standards

Summary of Testing:

Beginning on April 5 and ending on April 12, 1999, OMNI Environmental Services, Inc. conducted "in field" emissions testing on the Tulikivi TLU 2450 fireplace design in conformance with the Colorado Regulation 4 Standards and operating protocol. All testing reported here was conducted at the residence Dr. Sirr in the rural are north of Gardiner, Montana. OMNI used an EPA audited procedure which requires the use of an EPA audited automated wood emissions sampler (an OMNI AWES) to sample particulate emissions. OMNI technician Chuck Fisher conducted all testing including set-up, take-down, data reduction, and the laboratory analysis of samples.

Testing was conducted with the **doors closed and a hearth grate in place**. The fuel loading schedule for the testing was determined by the home owner . Fuel loading weight was approximately 80% of the manufacturer's recommendations and measured by an OMNI technician. Fuel moisture content was measured by an OMNI technician. One load of fuel was burned per day.

Test Results and Discussion:

The test results show an **average particulate emission factor of 2.0 grams per kilogram (g/kg)**. The Tulikivi; Model TLU 2450 design exhibited emissions that meet the emission standards set forth in Federal Regulations 40CFR Part 60, Subpart AAA, Subsection 60.532(b)(1) or (2). The resulting average particulate emission factor is below the **Colorado State requirement of 6.0 g/kg**.

Table 1 presents a summary of test measurements and sample analyses for the test. Plot 1 presents a time-base graph of flue-gas temperatures and the flue-gas oxygen concentrations.

Attachment 21: Reference N1 and N2 – Report Cover Page

Emissions Report

Swedish Kakelugn Style Masonry Heater

Built by: Jerry Frisch

OMNI-Test Laboratories, Inc.
Product Testing & Certification

Mailing: Post Office Box 743
Street: 5465 SW Western Avenue • Suite G
Beaverton, Oregon 97075 USA

Phone: (503) 643-3788
Fax: (503) 643-3799

OMNI-Test Laboratories, Inc.
Test Report dated October 2007: omni-rs users Testing Masonry Heater new report

1 of 4

Attachment 21: Reference N1 and N2 – Summary Page

OMNI-Test Laboratories, Inc has completed a series of emissions tests on the Swedish Kakelugn style masonry heater built by Jerry Frisch. The appliance cured for 20 days before testing was initiated.

OMNI performed a total of 8 tests on the masonry heater, 4 with dimensional lumber and 4 with cordwood. Testing began on July 12, 2006 and concluded on August 14, 2006. The fueling protocol used was the Colorado Masonry Heater Standard using dimensional lumber. The emissions were sampled using 3 different sampling systems:

1. The proposed ASTM dilution tunnel sampling system that uses dual 47mm filter trains. This system is very similar to the U.S. Environmental Protection Agency Method 5G-3.
2. Samples were also taken using the Emission Sampling System (ESS) developed by *OMNI* in the late 1980's for the U.S. EPA for performing *in situ*, in-home testing of wood-fired fireplace and home heating appliances.
3. On tests 5 & 6, the Condar emissions sampling system was also used.

The results of all of the tests performed are shown in Table 1.

Table 1

Run	Fuel Moisture (dry basis)	Fuel Weight (dry kg)	Test Duration (hours)	Burn Rate (dry kg/hr)	Emissions Factor (g/kg) ASTM	Emissions Factor (g/kg) ESS	Emissions Factor (g/kg) Condar	Fuel Type
1	20.9	16.3	5.3	3.1	3.3	2.1	Not tested	Dimensional
2	11.7	18.8	5.0	3.8	2.7	1.9	Not tested	Cordwood
3	23.0	17.0	5.2	3.3	5.0	2.3	Not tested	Dimensional
4	10.9	19.0	4.7	4.1	2.7	2	2.5	Cordwood
5	20.9	18.0	6.0	3.0	2.7	2	2.5	Dimensional
6	22.3	16.7	5.3	3.1	2.3	1.7	Not tested	Dimensional
7	11.9	21.5	5.3	4.0	2.4	2	Not tested	Cordwood
8	10.9	19.3	5.0	3.9	2.9	2	Not tested	Cordwood