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Ref 12)

In-Home Evaluation of Emissions from a Grundofen Masonry Heater

Prepared for: **Mutual Materials Company, The Masonry Heater Association, and Dietmeyer, Ward and Stroud**

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

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Executive Summary

Particulate (PM), carbon monoxide (CO), and volatile organic compound (VOC) emissions were measured using OMNI's Automated Woodstove Emissions Sampler (AWES) system on a four-year-old Grundofen masonry heater located in Battle Ground, Washington in December 1991. The heater was operated by the homeowner in his normal fashion using Douglas fir cordwood with 20% moisture. The unit was fired ten times during the week-long test. Average daily burn rate was 1.1 kg/hr with an average output of 12,300 Btu/hr.

PM emissions averaged 1.36 g/kg, 1.5 average daily g/hr, and 1.36 normalized average daily g/hr. These PM values, along with certified pellet stoves, are the lowest that have been recorded for residential biomass burning. Additionally, the soluble organic fraction of the PM was only 0.53 g/kg.

CO emissions averaged 83 g/kg, 92 average daily g/hr, and 83 normalized daily g/hr. These values are comparable to Phase II EPA certified noncatalytic woodstoves.

VOC emissions were 0.4 g/kg and 0.4 average daily g/hr. These values are very low compared to Phase II EPA certified noncatalytic woodstoves.

The average net delivered efficiency was 60%, which is in between conventional and Phase II certified stoves. Down-time stack losses caused by the slow flow of room air past the closed, but not air-tight, baffle have not yet been measured.

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Introduction

There has been an increasing tightening of emissions regulations on residential woodburning devices 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, were exempted from this program by virtue of their large mass.

In more recent years, certain heavy woodburning areas of the west have been declared by the EPA to be in nonattainment for airborne particulate matter of less than 10 microns in diameter (PM_{10}). State Implementation Plans have been written to develop strategies for reducing air pollution to bring these areas into compliance. Measures beyond the EPA woodstove certification process have been needed. Among other things, a need for woodburning devices that are cleaner-burning than certified woodstoves has developed. One such device that has attracted attention has been the masonry heater, a European technology that has existed for several centuries.

The current project has been designed to evaluate the in-home emissions and efficiency performance of a potentially clean-burning heater, the German-designed Grundofen. A Grundofen heater that has been burned for four years in a 3,000-sq.ft home in Battleground, Washington was evaluated over a one-week period in December 1991. The heater was operated by the homeowner as he normally did. Since the heater was the only source of heat, the homeowner burned wood at a loading frequency needed to meet the home's heat demand. The homeowner was supplied with 16-inch long Douglas fir cordwood averaging 20% moisture. During the week the homeowner loaded the heater ten times. Photographs of the Grundofen appear in Figures A-1 through A-4 of Appendix A.

OMNI's Automated Woodstove Emissions Sampler (AWES) and datalogger were used to conduct the sampling. By doing so, a direct comparison can be made to numerous published studies on woodstoves, fireplaces, masonry heaters, and pellet stoves. This system collected samples for PM_{10}, carbon monoxide (CO), and volatile organic compound (VOC) determinations. In addition to producing emissions results, the AWES uniquely collects real-time temperature information on the home's ambient temperature and the stack temperature above the flue damper. Real-time data on stack oxygen content and fuel loading patterns were also collected. Results for the Grundofen are shown in Figures A-5 and A-6 of Appendix A.

The AWES was specially modified for masonry heater sampling. Due to the anticipated low concentration of emissions in masonry heater flue gases, a large volume of these gases had to be sampled in order to collect an adequate amount of particulate catch. In this project, about 900 liters were collected. This meant that the AWES was operated one minute on and two minutes off throughout the sampling period. Additionally, a Tedlar bag was used to collect an integrated flue gas sample for the week-long sample period so that CO, carbon dioxide (CO_2), and VOCs could be measured. More details of how procedures were modified for masonry heaters are provided in the Methodology section.

Two masonry heaters, a Contraflow kit heater and a locally designed and built "Russian" heater, were evaluated by Barnett (1990) in the Western States Clay Products fireplace and masonry heater project. The issue of how to present emissions results for masonry heaters was discussed at length in that report. Because masonry heaters are only burned for short periods, the emissions rate concept used for woodstoves of grams per hour is not appropriate. Instead, the concept of average daily grams per hour was adopted. Emissions values were also normalized to a 1 kg/hr burn rate, the average Phase II EPA woodstove rate, and presented as normalized average daily grams per hour. This procedure is followed in this report.

Methodology

Emissions Sampling

The Modified AWES Emission Sampling System for Masonry Heaters

Automated Woodstove Emissions Samplers (AWES) modified for sampling masonry heater emissions were used in this project. Figure 1 shows a schematic of the modified AWES/data logger system. For the Grundofen, the AWES unit draws flue gases through a 38 cm 15 in.) long, 1.0 cm ($^3/_8$ in.) O.D. stainless steel probe which samples from the center of the flue about 305 cm (10 ft) above the base of the firebox. This location is above the flue damper. The sample then travels through a 1.0 cm O.D. Teflon line, and a heated U.S. EPA Method 5-type filter for collection of particulate matter, followed by a sorbent resin (XAD-2) trap for semi-volatile hydrocarbons. Water vapor is removed by a silica gel trap. Flue gas oxygen concentrations, which are used to determine flue gas volume, were measured by an electrochemical cell. The oxygen cell used in the AWES was manufactured by Lynn Instruments. The AWES uses a critical orifice (Millipore #XX500001) to maintain a nominal sampling rate of 1.0 liters per minute (0.035 cfm). Each AWES critical orifice is calibrated to determine the exact sampling rate.

The AWES unit returns particle-free exhaust gas to the flue via a 0.6 cm ($^1/_4$ in.) Teflon line and a 38 cm (15 in.) stainless steel probe inserted in the flue. Some flue gas exiting the AWES is pumped into a 22-liter Tedlar bag (for later gas analysis) under positive pressure, since the inlet to the bag is on the positive pressure side of the pump. The flow to the bag is controlled by a solenoid valve connected to the pump circuit, a temperature controller, and a rotameter with a flow-controlling orifice. The solenoid valve is open for masonry heaters only when the pump is activated and the flue oxygen is less than 20.6%. The rate of flow into the bag is controlled by the rotameter, which was adjusted to acquire the optimum amount of gas over the entire test without over-pressurizing the bag.

The Data Logger System

The data logger system, known as the CONLOG data logger system, is a second-generation data logging and emission sampler controlling system developed in 1990 by OMNI. The system (Figure 2) consists of a host personal computer (PC) containing a data processing board, a terminal box, and specialized data acquisition software.

The CONLOG software is written in a high-level programming language (C) and can be programmed to control, collect, and store the following software settings and data:

- Establish starting and ending date and length of sampling period
- Establish pump cycle length and thermocouple (TC) cycle recording interval
- Record date and time at pre-selected intervals
- Record three temperatures, including flue gas temperature, averaged over pre-selected intervals
- Record ambient temperature (room temperature), averaged over pre-selected intervals
- Record flue gas oxygen measurements, averaged over pre-selected intervals
- Save file as an ASCII file with PRN suffix on 3.5" disk

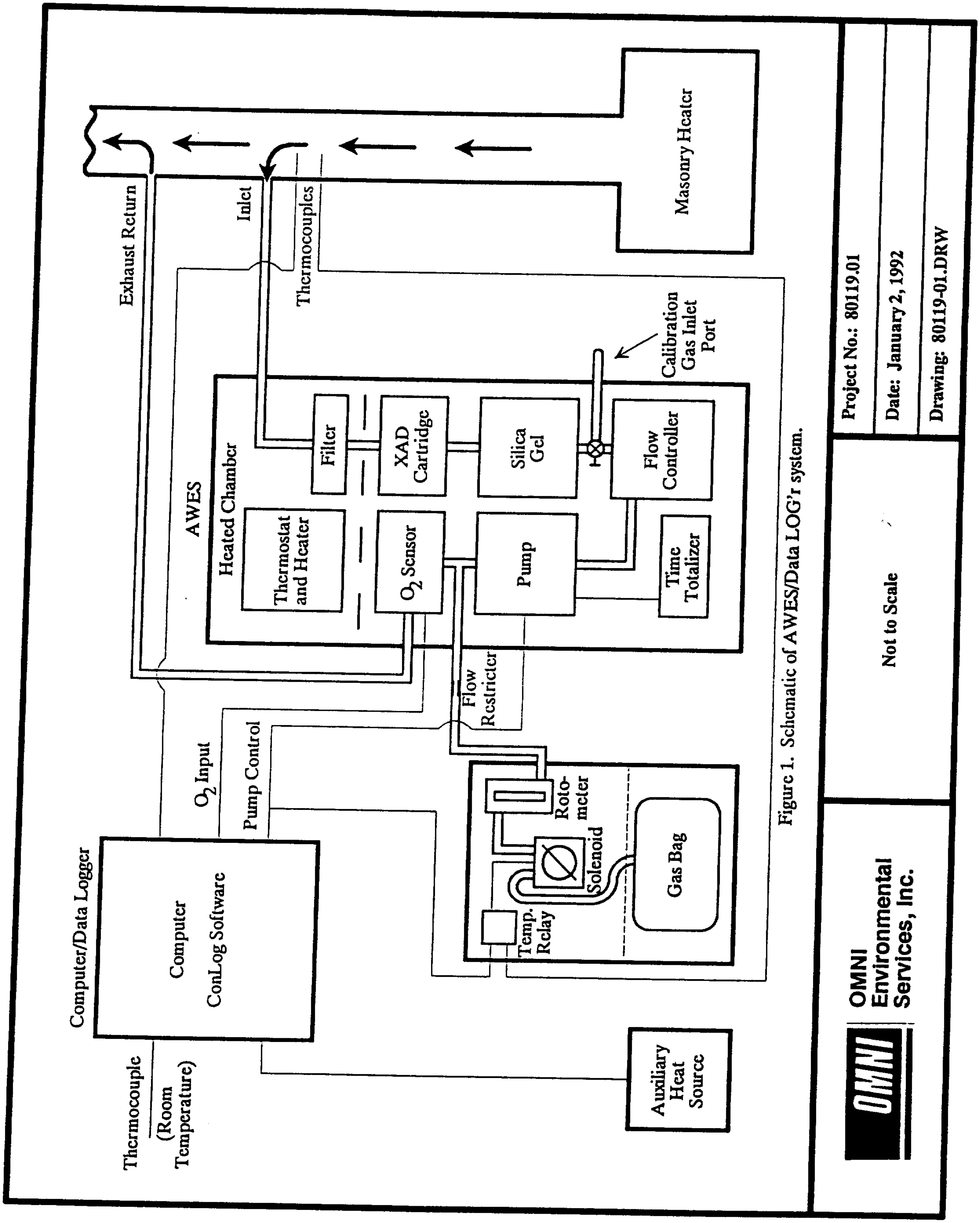

Figure 1. Schematic of AWES/Data LOG'r system.

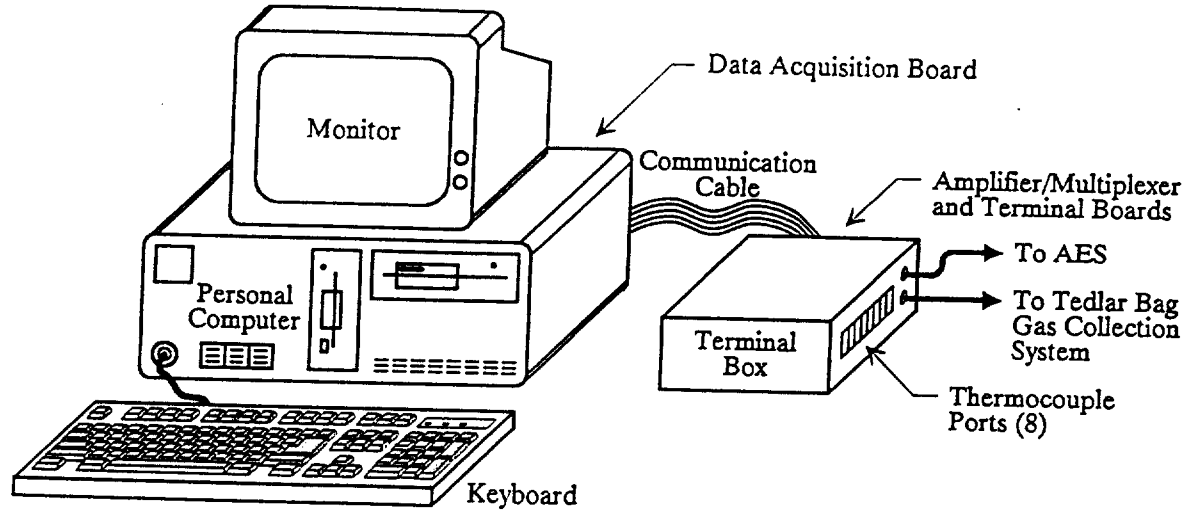

Figure 2. The ConLog data logger system.

Instantaneous readings of real-time data are also displayed on the system status screen of date, time, temperature for TCs 1 through 4, and flue gas oxygen percent. The most recent 15 sets of recorded data are also displayed.

For masonry heaters, temperature, etc. are recorded at five-minute intervals. The sampling pump is operated for one minute on followed by two minutes off. This procedure ensures the sample of about 1,000 liters, which is needed for clean-burning devices.

The CONLOG system uses external sensors which generate analog voltages that are processed by the PC microprocessor's data acquisition board. For this project, a type K ground-isolated, stainless-steel-sheathed TC (Pyrocom 1K-27-5-U) was used to monitor flue gas temperature at 120 cm (4 ft) above the base of the fireplace in the center of the flue gas stream.

The keyboard and screen were left installed in the home during the sample period. The presence of the display screen's real-time data generated considerable interest on the part of the participants in the project and was a positive experience. The CONLOG program was software-locked to prevent possible interference. However, historically, on a few occasions homeowners have been given the password and "walked through" minor program modifications over the telephone to solve a problem that may have occurred during a sampling period. This proved successful and saved considerable field technician time.

Equipment Preparation and Sample Processing Procedures

Prior to emissions testing, the AWES unit was cleaned and prepared with a new fiberglass filter and XAD-2 sorbent resin cartridge. This was done in OMNI's laboratory facility at Beaverton, Oregon. After the sampling period, the stainless steel sampling probe, Teflon sampling line, filter holder, and XAD-2 cartridges were removed from the home and transported to OMNI's laboratory for processing. The components of the AWES sampler were processed as follows:

1. Filters: The glass fiber filter (102 mm in diameter) was removed from the AWES filter housings and placed in a petri dish for desiccation and gravimetric analysis for particulate catch.

2. XAD-2 sorbent resin: The sorbent resin cartridge was extracted in the Soxhlet extractor with dichloromethane for 24 hours. The extraction solvent was transferred to a tared glass beaker. The solvent was evaporated in an ambient air dryer, the beaker and residue were desiccated, and the extractable residue was weighed on a Mettler AE160 balance.

3. AWES hardware: All hardware which was in the sample stream (stainless steel probe, Teflon sampling line, stainless steel filter housing, and all other Teflon and stainless steel fittings) through the base of the sorbent resin cartridge was rinsed with a 50/50 mixture of dichloromethane and methanol solvents. The solvents were placed in tared glass beakers. The solvents were evaporated in an ambient air dryer, desiccated, and weighed to determine the residue fraction weight.

EPA Method 5 procedures for desiccation and the weighing time schedule were followed for 1 through 3 above.

OMNI personnel serviced the sampling equipment at the start and end of the sampling period. At the start of each sampling period, the AWES unit was installed; leak checks were performed; the thermocouples, scale unit, and oxygen cell were calibrated; and the data logger was programmed with the proper sampling interval and start/stop times. The data logger was programmed to activate the AWES units for one minute on and two minutes off for seven consecutive days. At the end of the sampling period, final calibration, and leak-check procedures were performed, and the AWES, sampling line, filter housing, XAD-2 cartridge, and sampling probe were removed and sent to the lab.

Data Processing and Quality Assurance

The data file stored on the data logger's 3.5" computer diskette was sent to OMNI's lab for computer analysis. The data file was reviewed immediately to check for proper equipment operation. The data logger data files, log books, and records maintained by field staff were reviewed to ensure sample integrity, which was excellent for this project.

The data logger file was used in conjunction with the AWES particulate sample to calculate particulate emission rates, daily temperature profiles of the flue temperatures, heater operation time, burn rates, etc. In addition, the computer program output for each file includes graphical representations of parameters and parameter interrelationships (see Figures A-5 and A-6).

Particulate Emissions Calculations

The basic particulate emissions equation produces grams per dry kilogram of fuel burned (g/kg). The basic g/kg equation includes the following components:

1. Particulate mass: The total mass, in grams, of particulate caught on the filter, XAD-2 resin trap, and in the probe rinse. Particulate mass averages about 0.040 grams but varies considerably.

2. Sample time: The number of minutes the sampler operated during the sampling week when the stack oxygen was less than 20.6%.

3. Sampler's flow rate: This is controlled by the critical orifice in the sampler. Flow values vary slightly for the various samplers and average about one liter per minute.

4. Stoichiometric volume: The volume of smoke produced by combusting one dry kilogram of wood. This value is calculated using a carbon balance for each sample but averages about 4,900-5,000 liters at standard temperature and pressure for masonry heaters.

5. Dilution factor: The degree to which the sampled combustion gases have been diluted in the stack by the presence of excess air. The dilution factor is obtained by using the sample period's average oxygen value in the following equation. Dilution factors range from about 2 to 5.

$$\text{Dilution Factor} = ((20.9/(20.9 - \text{Average oxygen}))$$

$$\text{Emissions (g/kg)} = \frac{\text{(Particulates)(Stoich. Vol.)(Dilution Factor)}}{\text{(Sample Time)(Sampler Flow)}}$$

Uncertainty in Emissions Results

Particulate emissions values are presented along with associated uncertainty levels. Each measurement used in the emissions calculations has some degree of uncertainty associated with it, and these uncertainties are propagated to determine the amount of uncertainty attached to each calculated particulate emission rate. Appendix C of the 1991 pellet stove report (Barnett and Fields, 1991) summarizes the criteria, procedures, and calculations used in evaluating uncertainty. Within the low range of emissions values encountered in this project, uncertainty is generally about 20% of the stated value. This was verified independently during the 1990 certified pellet stove project (Barnett and Roholt, 1990) by operating five AWES sampling systems simultaneously while burning a pellet stove.

The issue of sample-blank-induced error was investigated at length by Barnett (1990) in the 1988-1989 Northeast Cooperative Woodstove Study. The values determined in that study have been used here. They include a probable error at the 95% confidence level of ±4.88 mg and an average blank value of 3.9 mg.

Oxygen-cell-induced error was also investigated in the 1988-1989 NCWS study. The 95% confidence level of the probable error contribution to emission values of ±7% is used in this study.

For a detailed treatment of these and other sources of uncertainty and QA procedures utilized, see Appendix C of Barnett and Fields (1991).

Efficiency Calculations

Woodstove efficiency was determined using the "Condar method" described by Barnett (1985). This method uses CO and PM emissions, stack dilution (based on excess air), stack temperature, wood type, and wood moisture to calculate combustion, heat transfer, and overall efficiencies, as well as net output in BTU/hr.

This method has been used in all previous field studies of woodstoves, masonry fireplaces, pellet stoves, and masonry heaters. The stack temperature probe was placed in the Grundofen immediately above the flue damper near the home's exit location for the flue, so the measured efficiency included essentially all of the heat energy that the heater contributed to the home.

AWES Modifications for Masonry Heater Emissions Testing

A modification in data reduction procedures has been made for masonry heaters. All previous AWES sampling of woodstoves used 100 °F stack temperature as the cutoff point to mark the start and end of a combustion cycle. Since masonry heaters maintain high stack temperatures long after combustion ceases, this procedure could not be used. Review of the stack temperature-stack oxygen regression results from computer files of the noncatalytic stoves in the 1988-1989 Northeast Cooperative Woodstove Study (Barnett, 1990) and the 1990 Klamath Falls Pacific Energy Project (Barnett, 1990a) indicated that 100° stack temperature at the end of a burn cycle was associated with 20.6% oxygen in the stack. Therefore, the masonry heater computer program was modified to separate burning from nonburning periods using the 20.6% oxygen criterion rather than 100° stack temperature. A sensitivity analysis using 0.1% increments from 20.5% to 21.5% indicated a low sensitivity to the cutoff setting. All results (g/kg and average daily g/hr) were within a 5% range. Grams per hour were significantly affected, of course, because g/hr = g/kg × burn rate (kg/hr). But, grams per hour is not considered to be a very suitable form for presenting emissions results for masonry heaters (Barnett, 1991).

The sampling period was modified to accommodate the low emissions of masonry heaters. A sampling frequency of one minute of sampling out of every fifteen minutes at a flow rate of one liter per minute has been found to provide optimal sample catches for analysis from clean-burning cordwood stoves during a one-week period. A shorter sampling frequency of one minute out of three minutes at the same flow rate was selected to obtain optimal sample catch from one week of masonry heater sampling. For example, this provided for a particulate catch of 0.038 g from a 900-liter sample for the Grundofen, or only 0.0042 g per 100-liter sample volume.

The final modification was the addition of a flue gas Tedlar bag collection system (Figure 3). Carbon dioxide, carbon monoxide, and oxygen data are generated from this collection system, allowing for calculation of carbon monoxide emission factors. Tedlar bag gases were measured using an NDIR analyzer. Additionally, the Tedlar bag contents were subjected to VOC analysis. VOCs were measured by GC/FID and reported in two ways: total VOCs as methane and methane, following the format of EPA Methods 25 and 25a. The detection limit is 10 ppm.

Emissions Results

PM emissions (see Table 1) averaged 1.36 g/kg and 1.5 average daily g/hr. The 95% confidence limit for the g/kg value is 0.27 g/kg. Normalizing the grams per hour emissions to a 1 kg/hr burn rate as described in Barnett (1991) yields 1.36 average daily g/hr. The average daily burn rate was 1.1 dry kg/hr.

Average CO emissions were 83 g/kg, 92 average daily g/hr, and 83 normalized average daily g/hr.

All of the VOC emissions were methane. They averaged 0.4 g/kg, average daily g/hr and normalized average daily g/hr.

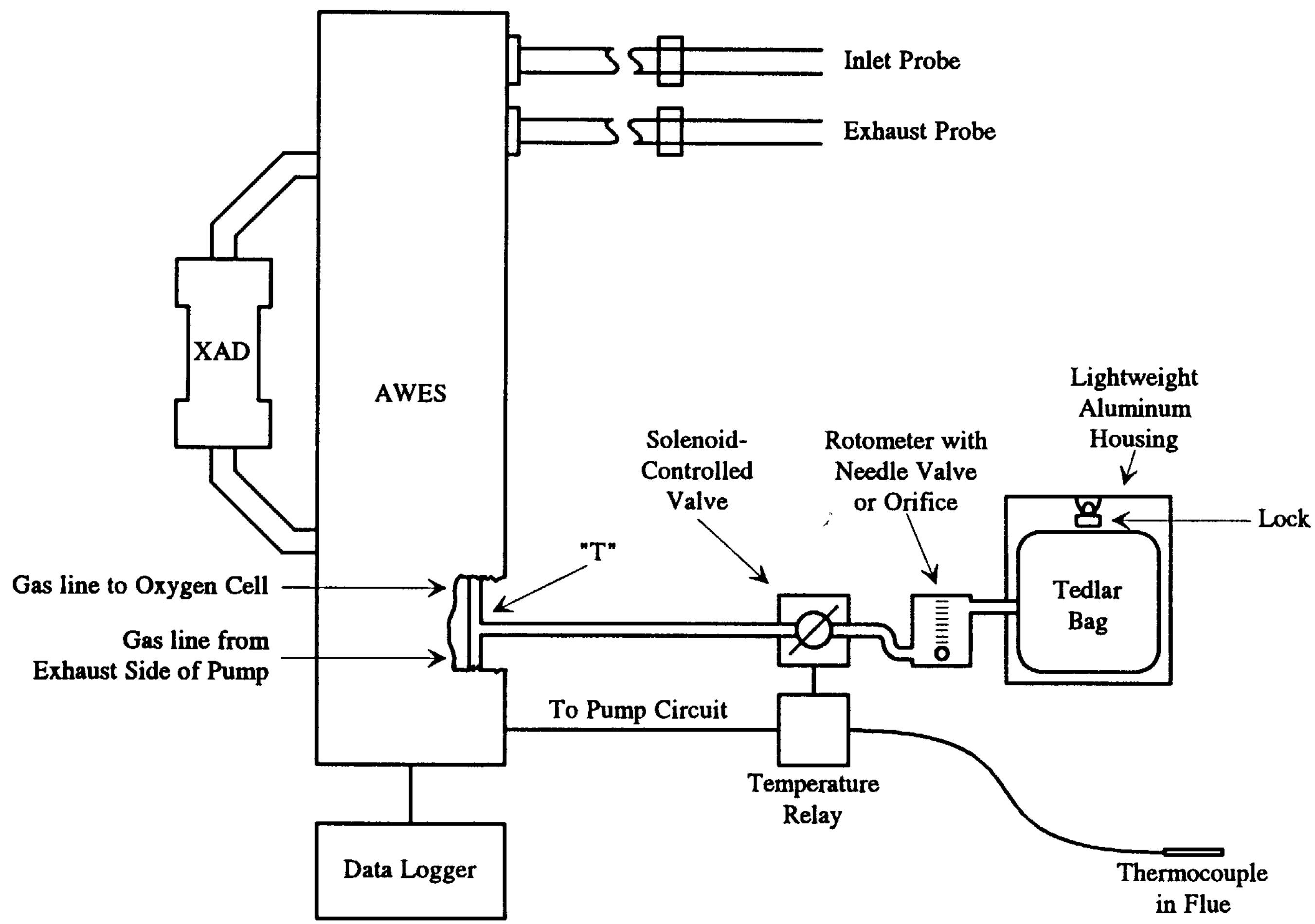

Figure 3. Schematic of AWES system modified for masonry heater application.

MASONRY HEATER EMISSIONS RESULTS

HOUSE AND RUN:	MORRISON
SAMPLE DATES:	DECEMBER 6–12, 1991
HEATER TYPE:	GRUNDOFEN
FUEL TYPE:	DOUGLAS FIR

TOTAL STOVE BURNING HOURS=		44.42 HOURS	
% OF TIME FIREPLACE BURNED=		27.03 PERCENT	
AVE. STACK TEMP=		286.36 DEGREES F.	
* AVE OXYGEN (STACK)=		17.74 PERCENT	
* AVE. OXYGEN (BAG)=		18.1	*****
TOTAL WOOD USED, WET LBS.=		478.0	
WOOD MOISTURE (DRY BASIS %)=		20.0	*****
AWES FLOW RATE(L./MIN)=		0.944	*****
LENGTH OF SAMPLE CYCLE (MIN.)=		3	*****
AVERAGE CO % (BAG)=		0.19	*****
AVERAGE CO2 % (BAG)=		2.6	*****
VOC, PPM (BAG)=		15	*****
TOTAL PARTICULATES IN MG.			
RINSE=	26.2 ****		
XAD=	6 ****		
FILTER=	6.4 ****		
MINUS AVE BLANK	3.9		
TOTAL PARTICULATES=		0.035 GM.	
TOTAL DRY WOOD USED=		181.06 KG.	
* BURN RT (DRY KG/H) DURING BURN=		4.08 KG/HR	
AVE DAILY BURN RT (DRY KG/H)=		1.10 KG/HR	
AIR TO FUEL RATIO=		45.36	

* PARTICULATE EMISSIONS:

* GM/KG=	1.36
GM/KG UNCERTAINTY=	0.27
* GM/HR=	5.53
Ave. daily g/hr=	1.50

* CO EMISSIONS:

GM/KG=	83.06
GM/HR=	338.57
Ave. daily g/hr=	91.51

* VOC EMISSIONS:

GM/KG=	0.37
GM/HR=	1.52
Ave. daily g/hr=	0.41

ADDITIONAL ITEMS:

AVE WOOD LOAD (WET LB.)=	47.80
AVE. WOOD USAGE/DAY (WET LB.)=	69.81
# TIMES LOADED/DAY=	1.46
AVE. AMBIENT TEMP=	70.55

NET EFFICIENCY:

COMBUSTION EFFIC.=	95.0
HEAT TRANS. EFFIC=	62.8
NET EFFICIENCY=	59.7
NET OUTPUT (BTU/HR)=	12291

Table 1

Comparatively, the PM emissions were very low. Figure 4 indicates that Grundofen emissions are about 91% lower than conventional woodstoves.[a] They are also much lower than Phase II EPA-certified woodstoves, lower than exempt pellet stoves, and nearly as low as certified pellet stoves. All of the above comparisons involve field evaluations.

Another significant aspect of the Grundofen's PM emissions is that the soluble organic fraction (extracted with methylene chloride) of this PM is only 39% or 0.53 g/kg (Figure 5). The majority of the PM (0.83 g/kg, or 61%) is ash and carbon, which is considered less harmful to human health than the organic fraction.

CO emissions are comparatively not as low as PM emissions. They are about the same as Phase II certified noncatalytic woodstoves and half those of conventional stoves.

There is little in-home data on VOCs. A single test on a certified pellet stove had no detectable VOC, but the detection limit was considerably higher than the Grundofen value. In-home evaluations of five Phase II and four conventional stoves were conducted in Klamath Falls, Oregon in 1992 using cordwood and densified logs. Results are preliminary at this time. Conventional stoves averaged about 20-25 g/hr and the Phase II stoves about 10 g/hr. By comparison, the VOCs from the Grundofen are very low.

Efficiency

The average net delivered efficiency of the Grundofen was 60%. This efficiency is about midway between the 50-55% average of conventional woodstoves and the 65-70% average for Phase II woodstoves as measured in homes.[3,8,9,10,11]

The design of the heat transfer system is moderately effective (Figure 6). Improvement could be made by reducing the excess air so that stack oxygen averaged about 16%. Stack temperature currently appears to be sufficienctly low.

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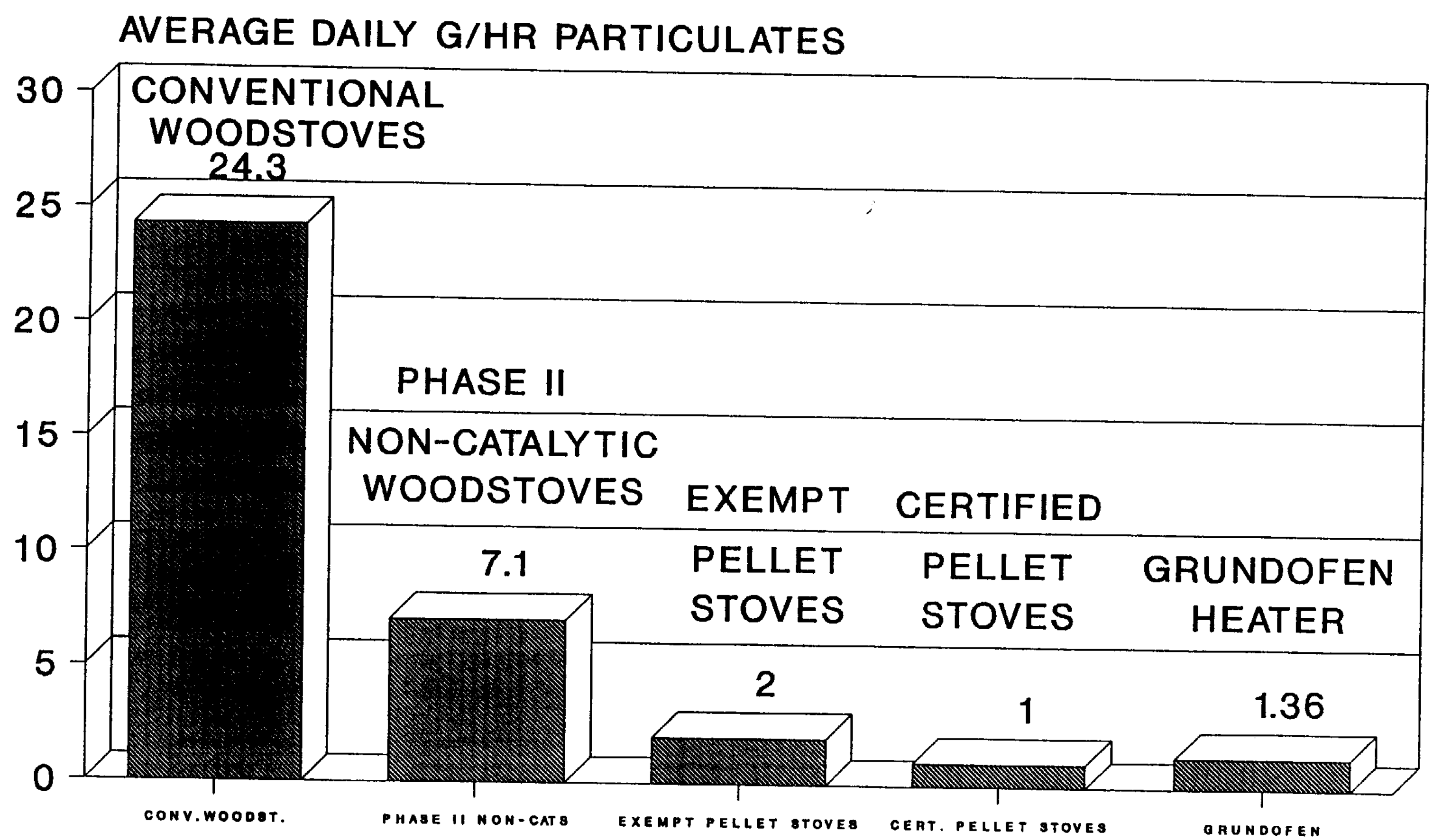
[a] The woodstove values in this figure are from the summary paper by McCrillis and Jaasma, 1991. The Certified pellet stove values are from Barnett and Roholt, 1990, and the exempt pellet stove values are from Barnett and Fields, 1991.

AVERAGE DAILY G/HR PARTICULATES FOR WOODSTOVES, PELLET STOVES AND THE GRUNDOFEN MASONRY HEATER.



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

Figure 4

Soluble vs Insoluble Fraction of PM, Grundofen Masonry Heater

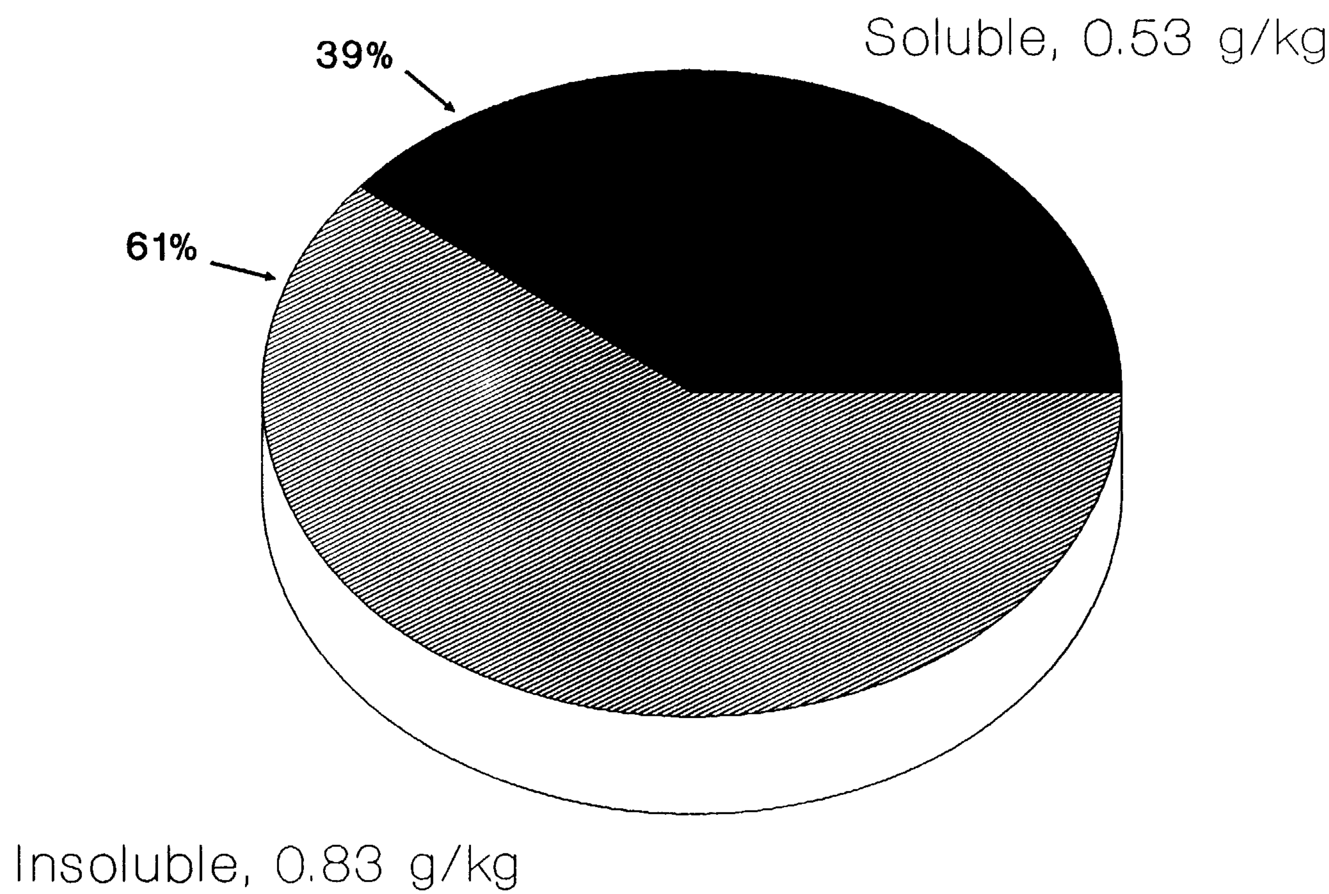
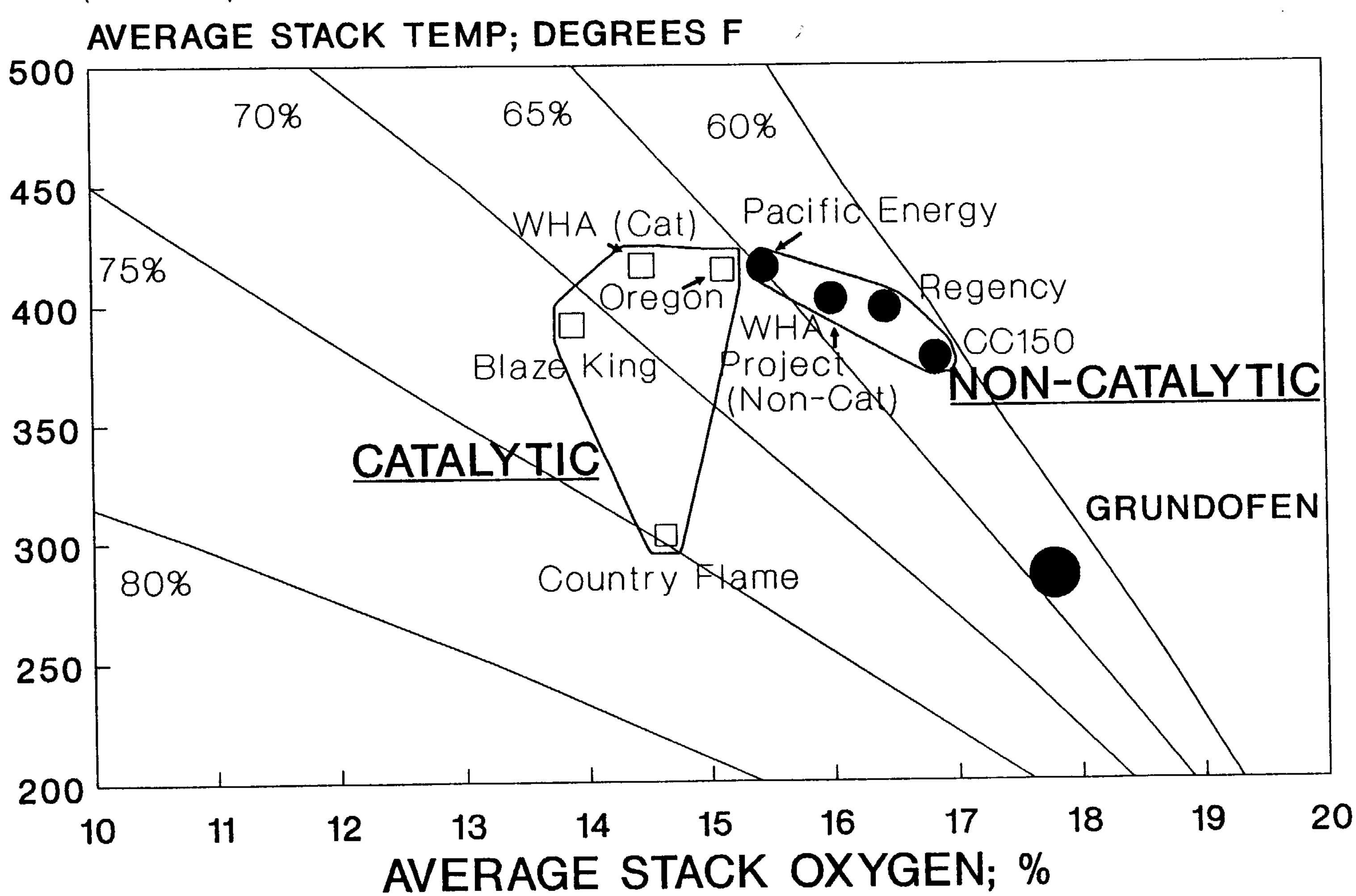


Figure 5

HEAT TRANSFER EFFICIENCY DIAGRAM: FIELD STUDIES: CAT, NON-CAT STOVES & GRUNDOFEN

(Stack temp for woodstoves measured 1' above stove. Stack temp is lower at top of pipe.)



Woodstove studies: 1989 NCWS, 1990 WHA.

Figure 6

References

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11. OMNI Environmental Services, Inc., 1992, In-Home Evaluation Comparing the Performances of Five Phase II and Four Conventional Woodstoves in Klamath Falls, Oregon using Cordwood and Densified Logs, in progress.

Appendix A

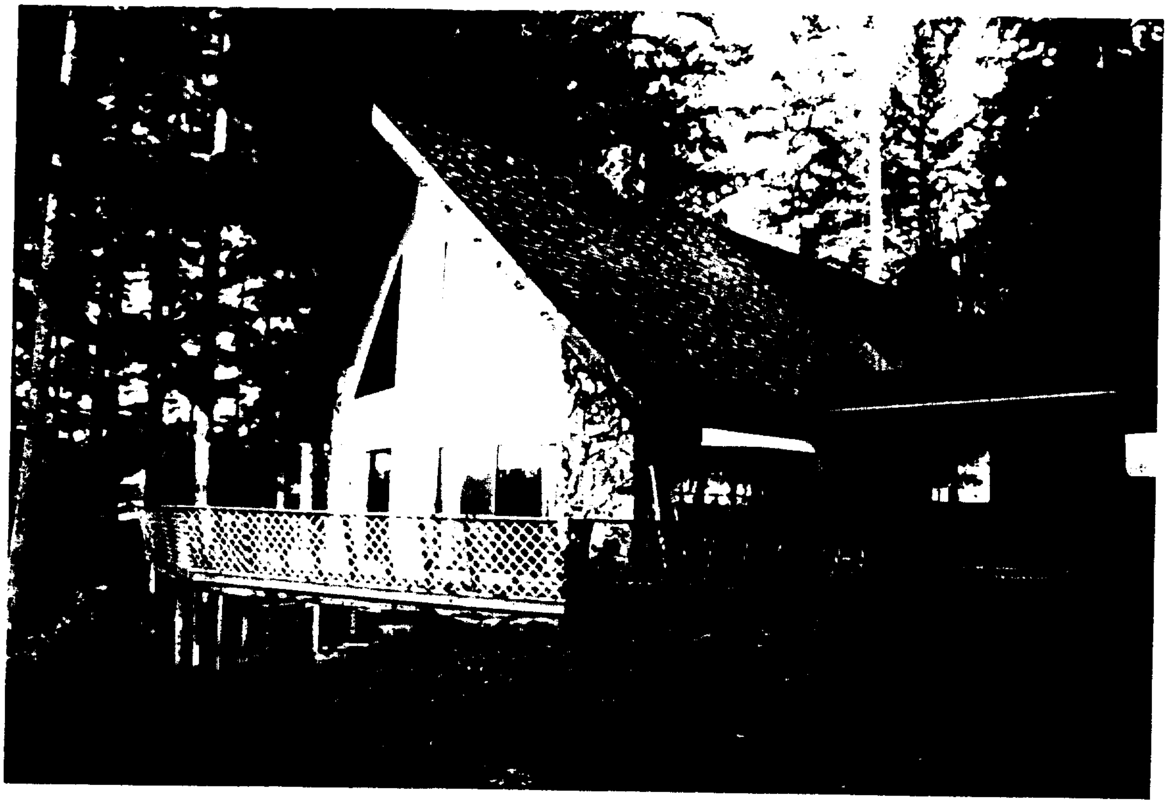


Figure A-1. View of the Battle Ground, Washington home with the Grundofen heater chimney in center of roof.

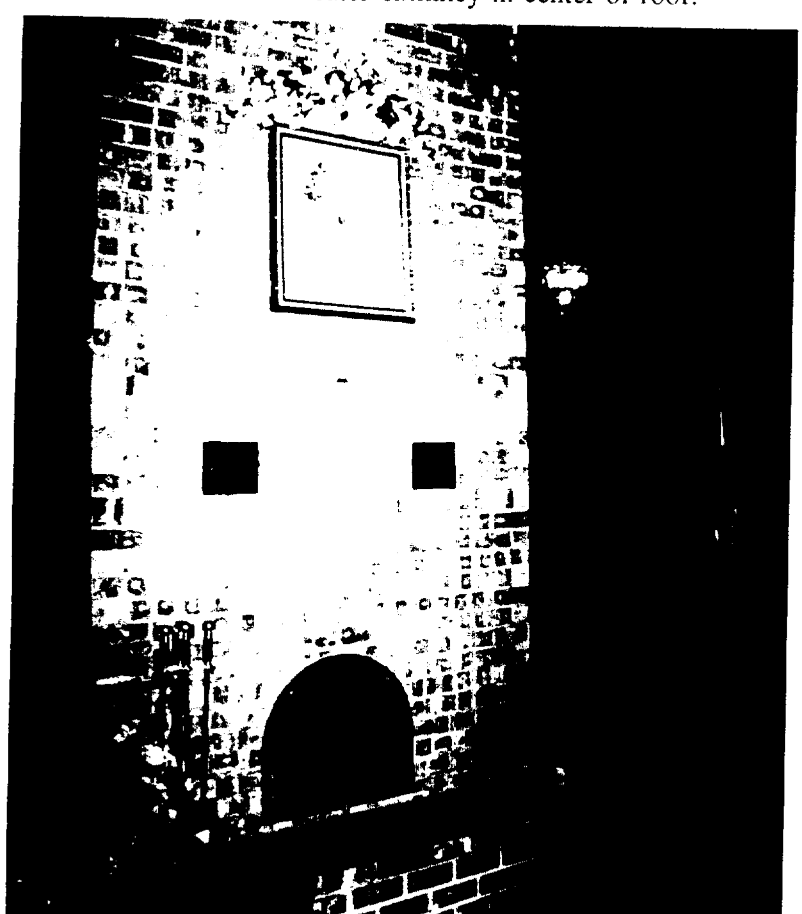


Figure A-2. View of front of Grundofen heater.

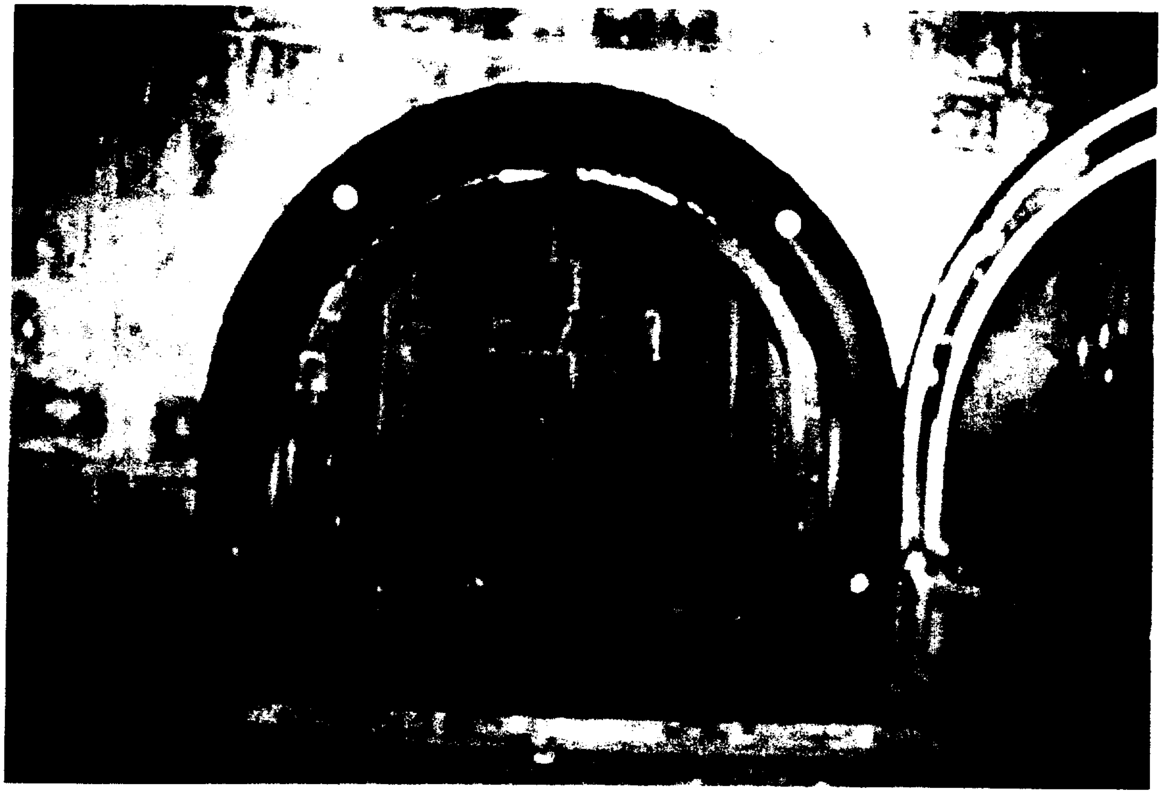


Figure A-3. View of Grundofen firebox.

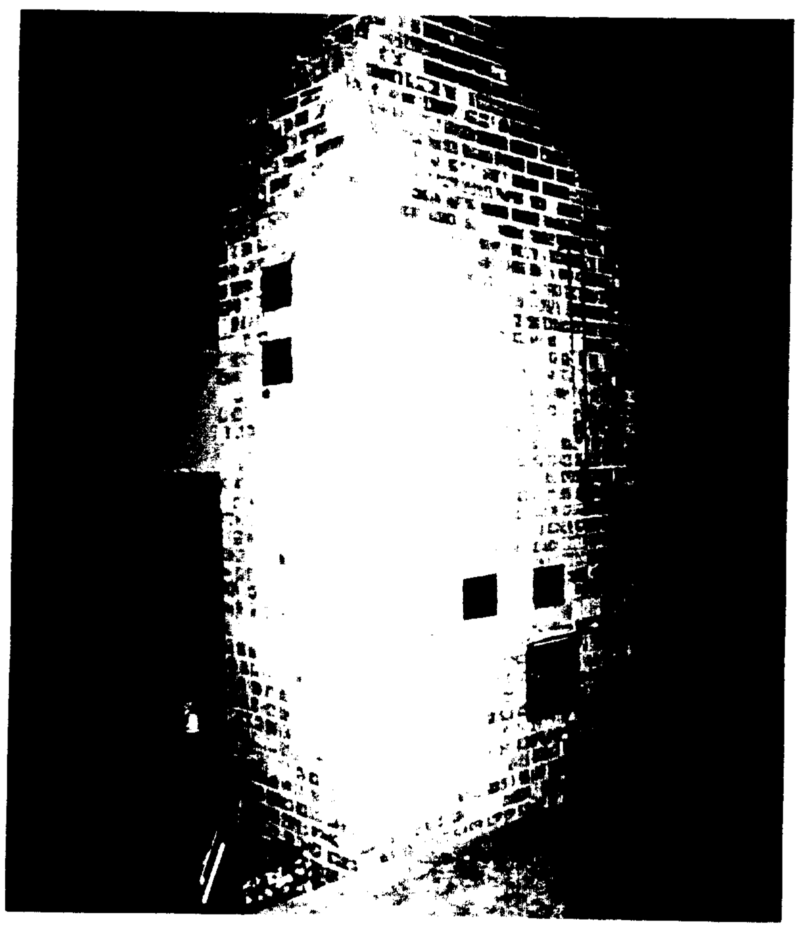
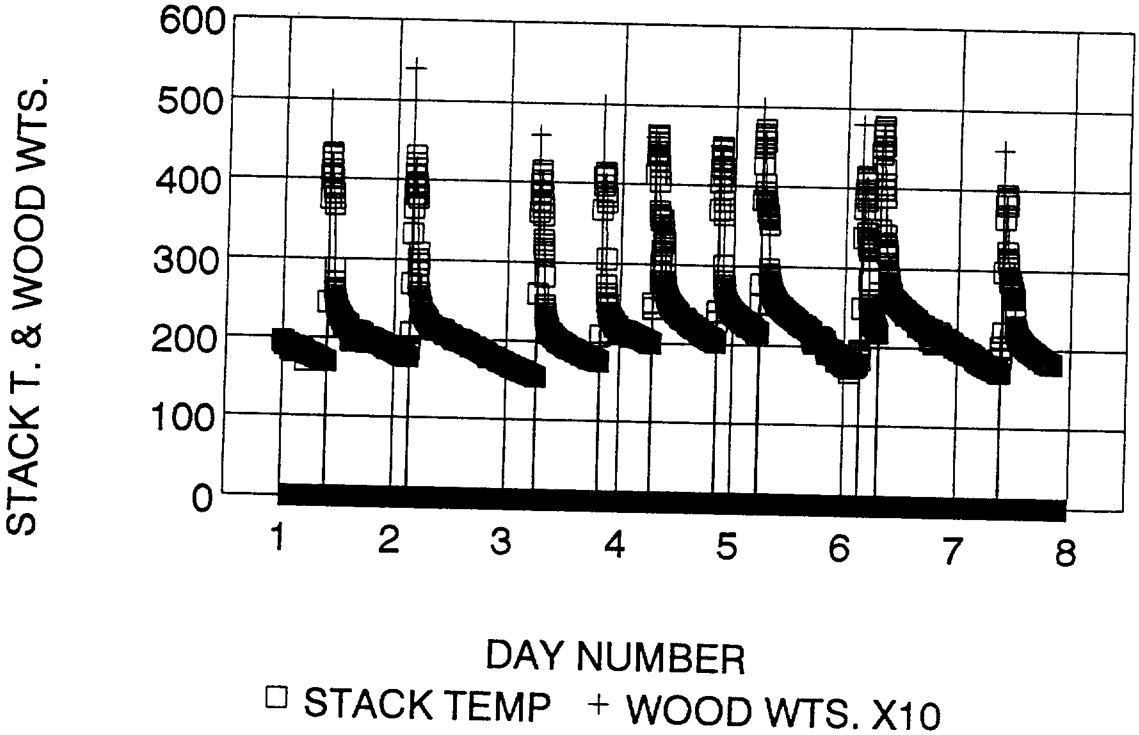


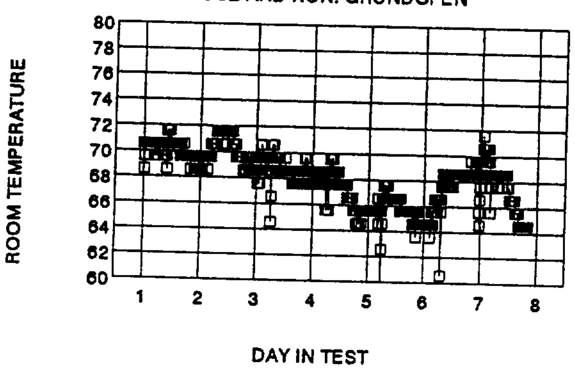
Figure A-4. View of back of Grundofen heater.

GRUNDOFEN FIELD TEST; 12/91

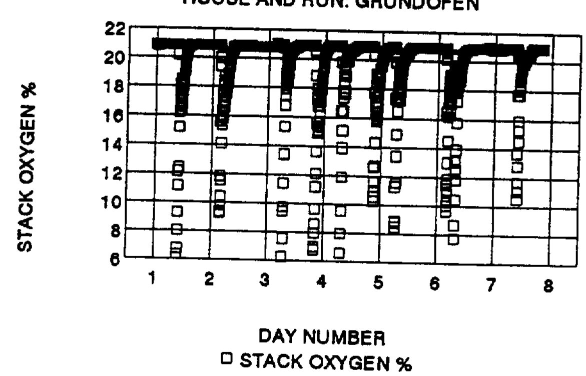
STACK TEMP AND WOOD WEIGHTS
ALL 7 DAYS. HOUSE AND RUN: GRUNDOFEN



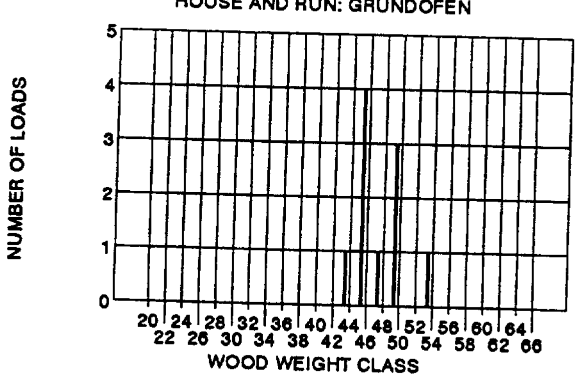
HOUSE AMBIENT TEMPERATURE
HOUSE AND RUN: GRUNDOFEN



STACK OXYGEN % FOR ALL 7 DAYS
HOUSE AND RUN: GRUNDOFEN



HISTOGRAM OF WOOD LOADS
HOUSE AND RUN: GRUNDOFEN



STACK T. VS OXYGEN; CALIB. DATA
HOUSE AND RUN:

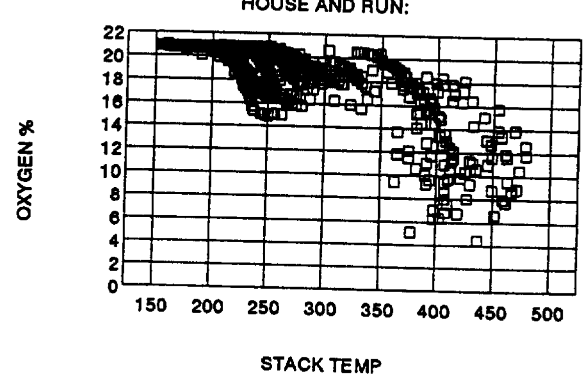


Figure A-5

GRUNDOFEN FIELD TEST; 12/91

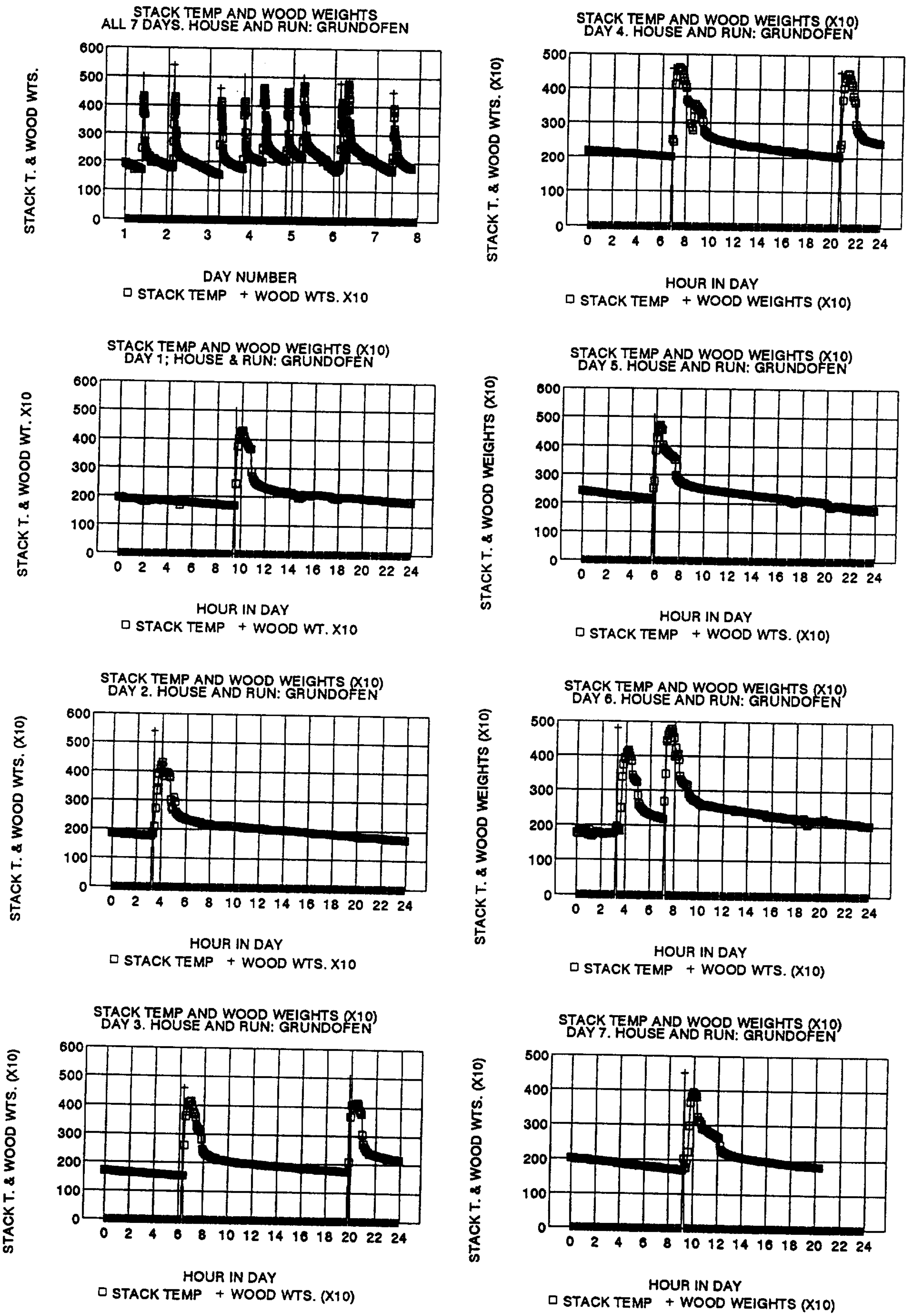


Figure A-6

In-Home Masonry Heater Follow-up Questionnaire

Your Name: Gary and Jolene Morrison

Heater Brand and Model: Dietmier/Ward & Stroud - Masonry Heater

1. It is important to us to know how your burning differed during the test from your *usual* burning. Please comment on the following: indicate your normal situation and then note the difference from during the test.

   a. Length of your burns in hours. N = $1^1/_2$ hrs
      T = $1^1/_2$ hrs

   b. Number of times you load wood during a burn.
      N = one
      T = one

   c. The pounds of wood per load. T = 40-50 lb
      N = ?

   d. Number of pieces of wood per load at startup.
      cut plywood = 10 pcs
      mill ends = 35 pcs - 2×4s, 16" long

   e. Number of pieces of wood per load when reloading. Does not apply - 1 load only

   f. The length and diameter of wood you use. T = 2×4 mill ends, 16" long
      N = split fir, supplied to us, 16"

   g. How do you orient the wood in the fireplace? For example: side to side, front to back, inclined against fireplace back or not, tightly packed or not, large logs on bottom or on top.
      N = alternate log cabin style, side to side, front to back (vice versa)
      T = front to back

   h. The species of the wood.
      N = fir/hemlock (2×4 mill ends)
      T = fir/hemlock (split wood supplied for test)

   i. How did you read our scale, in pounds or kilograms? pounds

   j. Moisture of the wood (dry, wet?). Do you keep your wood covered?
      N = seasoned - covered with tarp
      T = 15% - 20%

Legend:

N = Normal operation.
T = Operation during test.

General

1. How many cords of wood per winter do you burn (account for leftover wood)?
3 cords

2. Do you burn this amount every year? How does it vary?
varied depending on how cold it gets etc. - $2^1/_2$ - 3 cords each year

3. What percentage of each day of the week do you usually burn per winter season?
For example: I burn 25% of all Mondays, etc. 2 (fire) × $1^1/_2$ = 3 hrs

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
3 hrs/12%	3 hrs/12%	3 hrs/12%	3 hrs/12%	3 hrs/12%	3 hrs/12%	3 hrs/12%

4. How many hours do you burn each time you burn?

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
$1^1/_2$ hrs	$1^1/_2$ hrs	$1^1/_2$ hrs	$1^1/_2$ hrs	$1^1/_2$ hrs	$1^1/_2$ hrs	$1^1/_2$ hrs

5. How long is your burning season in months? Sept. - March

6. Number of fires per year? Approx. 350

7. Do you use a grate? No

8. Do you use doors (how often?)? Yes. Loading door - always

10. What is your normal startup technique?
newspaper/stack wood/light match - etc.

11. What is the area of your house? 3,000 sq ft

12. Approximately what area of is heated by the heater? Entire house

13. Where do you normally get your wood? from a truss manufacturing plant

14. When was your heater installed? February - 88?