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A ONE-CHANNEL MONITOR FOR WOOD STOVE HEAT OUTPUT: Project Report for the Hood River Conservation Program

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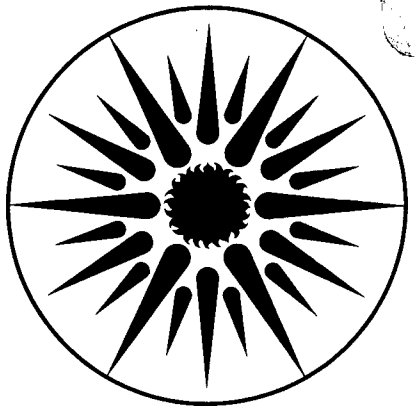

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A ONE-CHANNEL MONITOR FOR WOOD STOVE HEAT OUTPUT:
Project Report for the Hood River Conservation Program

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Energy Efficient Buildings Program
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*Jay Shelton is the Director of Shelton Energy Research in Santa Fe, New Mexico

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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ABSTRACT

A major problem associated with monitoring the overall energy performance of single family residences is to determine the energy contribution of wood-burning appliances. Because the heat content of wood is variable and the efficiency of a stove changes with operating conditions, the energy contribution cannot be accurately determined by monitoring the amount of wood burned. The goal of the research presented in this report was to find a single-channel sensor whose output could be correlated with the heat output of a wood stove. To accomplish this, five wood stoves were monitored with thermocouples and radiometers while being operated in a calorimeter room. Using several physical models to describe the heat transfer, sensor readings were compared with the heat output measured by the calorimeter room. It was found that radiometers and surface temperature probes are suitable for monitoring the heat output of a wood stove, both providing consistent results for separate tests on a given stove. The radiometers, however, provide accurate results using an average correlation parameter for all stoves. Using this average parameter value, the radiometers predict the full-cycle (start-up to cool-down) heat output to within 20% of the measured value. This report describes the experimentation and data analysis, presents the correlation parameters for the radiometers and temperature sensors, and provides detailed installation instructions for one of the radiometers.

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* Jay Shelton is the director of Shelton Energy Research in Santa Fe, New Mexico.

INTRODUCTION

Many attempts have been made to monitor the overall energy performance of energy-efficient homes, retrofitted homes, and large statistical samples of single-family residences. The Hood River Conservation Project in Portland, Oregon, shares many of the problems associated with these efforts, one of which is to determine the energy contribution of wood-burning appliances. Even when the manufacturer's efficiency rating is available, the heat output of a stove cannot be accurately determined by monitoring the amount of wood burned. The heat content of the wood varies within a large range, and the efficiency of a stove varies with different operating conditions. This report describes the research and results of a study by Lawrence Berkeley Laboratory and Shelton Energy Research to develop a single-channel monitor for wood stoves.

The goal of this research is to find a single-channel sensor that provides an output that can be correlated with the heat output of a wood stove. Such a sensor could then be used to monitor the heat output of stoves in the Hood River Conservation district. To accomplish this, we tested five wood stoves typical of those found in the Hood River district*. Each stove was monitored simultaneously with thermocouples and radiometers while being operated in a calorimeter room. The sensor readings were then compared with the heat output measured by the calorimeter room, using several physical models to describe the heat transfer from the stove. The five stoves tested were: the Fisher Grandma Bear, the Fisher Baby Bear, the Jotul Model 602C, the Earthstove, and the Blaze Princess stove. The stoves are of different sizes and shapes and of the radiant type, except for the Blaze Princess, which is fitted with a convective blower.

EXPERIMENTAL DESIGN

Our experimental procedure was to correlate the output of various sensors to the heat output of a stove as measured in a calorimeter room. To test different monitoring strategies, each stove was fitted with five surface-mounted temperature sensors (thermocouples), and was monitored by radiometers in three locations. The measured heat input to the calorimeter room served as the basis of comparison for all of the monitoring strategies.

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* The stoves were selected by contacting the major wood stove distributors and retailers in the district to determine which stoves were the most popular.

The heat generated by a stove is removed from the 2.4 m by 3.6 m (8 ft by 12 ft) calorimeter room by circulating air at a temperature slightly below that of the room surrounding the calorimeter (see figure 1). The high air flow maintains the calorimeter room at a relatively constant temperature, close to that of the surrounding room. The air is blown vertically between two metal meshes along all four walls of the room. Blowing the air along the walls allows the heat output of the stove to be removed without changing the convective heat transfer at the stove surface. The mesh isolates the walls from direct radiation from the stove and augments the convective heat transfer with the cooling air. This reduces the required wall insulation and improves the room's time response to changes in wood stove heat output. The result is a room with a short response time, which enables us to track changes in wood stove heat output (i.e. the instantaneous output of the stove).

Two types of sensors were chosen as possible candidates for a single-channel wood stove monitor: surface temperature sensors and infrared radiometers. By measuring surface temperature we expect to determine the heat output, knowing that heat is transferred from the stove by radiation and natural convection. The radiometers measure a representative sample of the radiative flux leaving the stove and thus should correlate with the heat output.

For the temperature sensors, five locations on the surface of the stove were chosen: the top, the two sides, the front and the back of the stove. The temperature at each location was monitored continuously during all tests. By using multiple locations, we can look for differences in correlation and possibly find an optimal location. In addition, tests were performed to map the variations in temperature on a given face of the stove.

All our tests were performed with three radiometers in place, one pointed toward a front corner of the stove, the others pointed toward a rear corner from different distances. Data from the three locations were used to determine an optimal location and the variation between locations. The sensitivity of the radiometer reading to angular or radial displacement was also checked by rotating the sensor and changing the distance between sensor and stove.

For each stove, at least two tests were performed, including one when the stove was operating at high output and one at low output. By examining both high power and low power operation, we can look for a systematic change in sensor/output correlation with power. For some stoves, additional tests were performed to help us measure the

fluctuation between tests. All tests were between 11 and 22 hours long, including start-up, a period of reasonably steady burning, and the tail of the dying fire and cooling stove.

DATA INTERPRETATION AND RESULTS

For the purposes of the Hood River Conservation project, this study sought to provide a means of determining the total heat gain from a wood stove by monitoring a single sensor. We are primarily interested in long-term (weekly or monthly) energy balances, rather than tracking the instantaneous heat output of a stove. The simplest way to obtain such a result is to find a relationship between the average heat output of the stove and the average reading of the sensor in question. The results presented in this report are based on the simplest relationship between the two variables - a single multiplicative constant determined from the ratio of the average heat flux to the average sensor reading. Mathematically, this correlation is referred to as a single-parameter fit, because the relationship between the two variables is represented by a single constant (parameter).

Having determined the correlation parameter for a particular stove, we would like to estimate the accuracy of this relationship when it is used for field measurements. There are many techniques for quantifying the accuracy of a correlation, such as the summation of residuals squared, or R^2, or the standard error of each parameter. We chose the standard deviation of parameter values determined in separate laboratory tests. This measure of accuracy is consistent with the primary goal of this project, to predict the overall energy gain from a wood stove. The percentage fluctuations in the parameter for laboratory tests is a measure of the percentage error in overall energy gain to be expected in the field. Our secondary measure of accuracy is the standard deviation of instantaneous heat output predictions when compared with measured heat outputs. This is a measure of how well our model (correlation) tracks changes in heat output. Although this comparison is most important for short-term energy balances, it also provides a measure of how well our single-parameter correlation describes the heat transfer from the stove.

When making a single-parameter fit of measured heat output to sensor measurements, we use an equation of the form:

$$Q = \alpha X \qquad (1)$$

where

Q is the dependent variable (e.g. the measured heat output),
X is the independent variable (e.g. the sensor reading), and
α is the correlation parameter.

The value of the correlation parameter (α) is determined by dividing the sum of heat output measurements by the sum of corresponding sensor readings.

The independent variable (X) in equation 1, can have many different functional forms. That is to say, it need not be the exact sensor reading, but rather can be some function of the sensor reading. This is especially important for surface temperature measurements. If we assume that the rate of heat input to the calorimeter room is proportional to the net radiation of heat from the stove, X will have the form $T^4 - T_a^4$, where T is the measured surface temperature and T_a is the interior temperature of the calorimeter room. If we assume that the heat is input to the room by natural convection, X will have the form $(T - T_a)^{1.25}$. We could also assume that the heat loss is directly proportional to the temperature difference, in which case X is $T - T_a$.

For the five stoves tested, the correlation parameter (α) in equation 1 was determined for the three radiometers using the measured heat flux as the independent variable. Correlations were also determined for the stove-top temperature sensor using radiative, natural convection, and linear heat transfer models (i.e., the three independent variables described above).

Table 1 presents the complete set of correlation parameters determined for the three radiometers. All three are Linear Laboratories Model EM-200. The first and third radiometers (LL1 and LL3) are directed toward the left rear corner of the stove from 183 cm (72 in.) above the ground. They are both 36 cm (14 in.) behind the rear of the stove, the first being 61 cm (24 in.) to the left, and the third 122 cm (48 in.) to the left. The second radiometer (LL2) is on the diagonal from the front left corner, 71 cm (28 in.) to the left, 71 cm (28 in.) in front of the stove, and 71 cm (28 in.) higher than the top of the stove.

TABLE 1
Correlation Parameters for Radiometers

Stove/Test	Test Length [h]	Average Heat Output [W]	Correlation Parameter, α [m^2]		
			LL1	LL2	LL3
Fisher Grandma					
1	13.33	6170	78.5	44.9	79.4
2	20.00	2160	90.8	37.3	82.8
Fisher Baby					
1	18.33	1250	70.8	35.6	74.3
2	20.00	1020	84.7	30.4	80.0
3	20.00	1250	82.4	37.1	73.7
4	20.00	1240	68.6	33.2	71.7
Jotul 602c					
1	22.00	2390	80.8	42.3	59.7
2	19.00	740	101.5	31.3	75.1
Earthstove					
1	12.00	5330	n/a	n/a	n/a
2	12.00	5070	n/a	n/a	n/a
3	11.00	3310	n/a	n/a	n/a
4	19.83	1650	89.9	48.3	86.9
5	20.00	2030	92.4	47.6	89.3
Blaze Princess					
1	11.00	4830	100.3	84.1	104.8
2	11.00	2620	109.2	84.1	113.9
3	19.33	1500	154.6	51.6	134.8
4	16.67	2260	105.8	53.8	108.2

The correlation parameters in Table 1 have the units of area [m^2]. The parameters are derived from the radiometer outputs in units of W/m^2 and the heat output in Watts [W]. Substituting the heat output [W] for Q, and the radiometer output [W/m^2] for X in equation 1, the correlation parameter, α, must have the units of m^2. To use these correlations to predict the heat output of a wood stove from radiometer measurements, the calibration of the radiometer is also required. This calibration refers to the relationship between voltage and radiant flux supplied by the manufacturer. Using the calibration to get the radiant flux in W/m^2, multiplying by the correlation parameters in Table 1 gives the heat output of the stove in Watts [W].

A quick review of Table 1 shows that for each radiometer location, the correlations are reasonably consistent for separate tests of each stove. We also note that the correlation for each radiometer location does not differ very much between stoves. The exception to both these observations is the Blaze Princess stove. Its correlation parameters vary significantly between tests and differ considerably from those of the other stoves. The behavior of the Blaze Princess stove can be understood to result from the forced convection blower it uses to remove heat from the stove. Because the heat is removed by convection, the radiative heat transfer being measured by the radiometer represents a much smaller fraction of the total heat transfer.

Excluding the Blaze Princess, the average and standard deviations of the correlation parameter for the three radiometers are 84.0 ± 10.0 for LL1, 38.7 ± 6.7 for LL2, and 77.3 ± 8.5 for LL3. The standard deviation is thus between 11 and 17% of the average value, indicating that a single correlation parameter can provide reasonable predictions of heat output. If we use an individual correlation for each stove, the standard deviations of the correlation parameters drop to between 2 and 16% for LL1, between 1 and 21% for LL2, and between 2 and 16% for LL3; our accuracy improves. These standard deviations indicate the errors to be expected in heat output measurements in the field.

A closer examination of Table 1 shows that the correlation parameters for radiometers LL1 and LL3 increase with decreasing heat output, and that the correlation parameters for LL2 decrease with decreasing heat output. The results for LL1 and LL3 are as we expect, because at lower heat outputs a smaller fraction of the heat leaves the stove by

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* If we exclude the Jotul 602c, the standard deviations of the individual stove correlations are all lower than those of the average correlations: 2-11% for LL1, 1-13% for LL2, and 2-12% for LL3.

radiation. Because the radiometer measures only the radiant portion of the heat leaving the stove, its correlation parameter must increase as the fraction of convective heat input to the calorimeter room increases. Explaining the behavior of LL2 is less straightforward. One possible explanation is that more of the heat leaves the stove from the front because of changes in burn pattern at lower heat outputs.

Table 2 presents the heat output correlations for the temperature probe (thermocouple) on top of each stove. Three correlations with heat output were made for each sensor. The first correlation uses $T^4 - T^4_{room}$, where T is the measured stove-top temperature and T_{room} is the average temperature of the calorimeter room. (For computational purposes, the independent variable was multiplied by T^4_{room}, where T_{room} was assumed to be constant at 300°K, making the independent variable $((T/T_{room})^4 - 1)$, thereby giving the correlation parameter the units of Watts.) This correlation attempts to scale the total heat output of the stove to the radiative heat output of the stove top. The second correlation scales the total heat output to the heat output by natural convection $(T - T_{room})^{1.25}$. The third correlation scales the heat output directly to the temperature difference between the surface and the room air. Although this last correlation could be interpreted as corresponding to heat transfer by forced convection, it is simply an empirical correlation because the actual heat transfer by forced convection is insignificant.

We can make several observations from the results presented in Table 2. The first is that the radiative correlation parameters are the most consistent within each stove's set of tests. Both the natural-convection and linear correlation parameters change considerably with average heat output*. The radiative parameters do not change between tests at low output and high output, indicating that the radiative heat transfer model may be a better approximation of total heat transfer. We also observe that the variation in correlation parameters between stoves is much larger for all the temperature sensor correlations than for the radiometers (see Table 1). This is to be expected because the radiometer correlations should be less affected by stove surface area.

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* The only exception to this is Earthstove, for which the convective and linear correlations are at least as consistent as the radiative correlations.

TABLE 2

Correlation Parameters for Stove-top Temperature Probe

Stove/Test	Test Length [h]	Average Heat Output [W]	Correlation Parameter $((\frac{T}{T_{room}})^4-1)$ [W]	Correlation Parameter $(\Delta T)^{1.25}$ [W/K$^{1.25}$]	Correlation Parameter ΔT [W/K]
Fisher Grandma					
1	13.33	6170	1040	10.5	39.5
2	20.00	2160	1210	8.71	28.0
Fisher Baby					
1	18.33	1250	748	6.85	23.5
2	20.00	1020	776	5.17	15.5
3	20.00	1250	815	7.46	25.8
4	20.00	1240	833	7.99	28.4
Jotul 602c					
1	22.00	2390	499	5.90	23.3
2	19.00	740	518	3.58	11.3
Earthstove					
1	12.00	5330	1150	9.63	34.7
2	12.00	5070	1110	8.97	32.1
3	11.00	3310	1400	9.67	31.3
4	19.83	1650	1110	8.44	27.5
5	20.00	2030	1070	8.30	27.7
Blaze Princess					
1	11.00	4830	n/a	n/a	n/a
2	11.00	2620	1640	11.0	33.5
3	19.33	1500	1160	7.68	23.2
4	16.67	2260	1290	11.0	37.9

To sum up our presentation of the test results, we examined the summations of residuals obtained by comparing instantaneous correlation predictions with the measured heat outputs. By examining these summations, we seek a measure of how well our correlations can track the fluctuations in heat output that occur during normal stove operation. We found that the residuals were essentially the same for radiometer and temperature-sensor correlations.

Rather than presenting the summations of residuals for all tests, some typical comparisons of measured and predicted heat output are plotted in figures 2 through 13. They compare predictions of instantaneous heat output with the heat output measured every two minutes by the calorimeter room. Figures 2 through 7 individually compare predictions made with the three radiometer correlations and the three types of temperature-sensor correlation, with the measured heat output of a Fisher Baby Bear. Figures 8 through 13 show similar comparisons for the fourth Earthstove test.

The two sets of comparisons show similar results. We see that the convective correlation for the temperature sensor and the LL2 radiometer correlation track the measured heat output better than the other correlations. The linear temperature-sensor correlation tends to underpredict the size of the heat output fluctuations; the radiative temperature-sensor correlation, as well as the LL1 and LL3 radiometer correlations, tend to overpredict the fluctuations.

CONCLUSIONS AND RECOMMENDATIONS

The first and most important conclusion from this study is that a single-channel wood stove monitor is both possible and practical. Based on our limited tests of five stoves, it appears that a single-parameter correlation can predict full-cycle (start-up to cool-down) heat output to within 20% of the actual output. We have also seen that these accuracies can be much higher when using an individual correlation from multiple tests on a single stove. However, we found that the accuracy of the predictions was significantly reduced for the stove that was fitted with a forced convection blower.

Although we achieved the stated goal of this project (i.e. to find a single-channel wood stove monitor for long-term energy balances), the experimental data have not been fully exploited. It appears that further analysis can provide more accurate, more general wood stove correlations. During the present analysis, some very promising analysis

schemes were discovered. One scheme is to incorporate some of the physical characteristics of a stove (surface area, type of surface) into a single independent variable that includes both convective and radiative heat transfer. This technique incorporates into one variable the changes in heat transfer mode (radiative vs. convective) that occur with changing heat output. It should thus be able to provide better tracking and consistent parameters within a single correlation. Another advantage is that by incorporating some easily determined characteristics of a stove into the correlation, the measured correlations can be more easily extrapolated to stoves that have not been tested. The validity of both this new correlation and our present correlations could be confirmed by further analysis and field tests of one or two of the stoves tested in the calorimeter room.

Recommendations

Both radiometers and surface temperature sensors are suitable as single-channel wood stove monitors. The above analysis shows that they both provide adequate accuracy and repeatability. Therefore, our recommendation to the Hood River Conservation project must be based on other criteria. Temperature sensors are considerably less expensive, but they require considerable labor for packaging and mounting on the stove. Radiometers can be purchased commercially, and their mounting system requires considerably less assembly labor. We recommend radiometers for this project based on two considerations: (1) if we decide to use a single correlation for all stoves, tested and untested, the radiometer correlations show less variation between stoves; and (2) the long-term stability of mounting the surface temperature probe (magnetic mounts, glue, and straps) is less certain than the mounting of the radiometers. Finally, we recommend the LL3 radiometer location (and correlation) over the other two radiometer locations. The LL3 correlation has a lower percentage variation between stoves and tests than either LL1 or LL2. Although the LL2 correlation seems to track the heat output better, we are more interested in long-term heat output for this application. In addition, the location of LL2, in front of the stove, may be impractical in many situations.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Systems Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

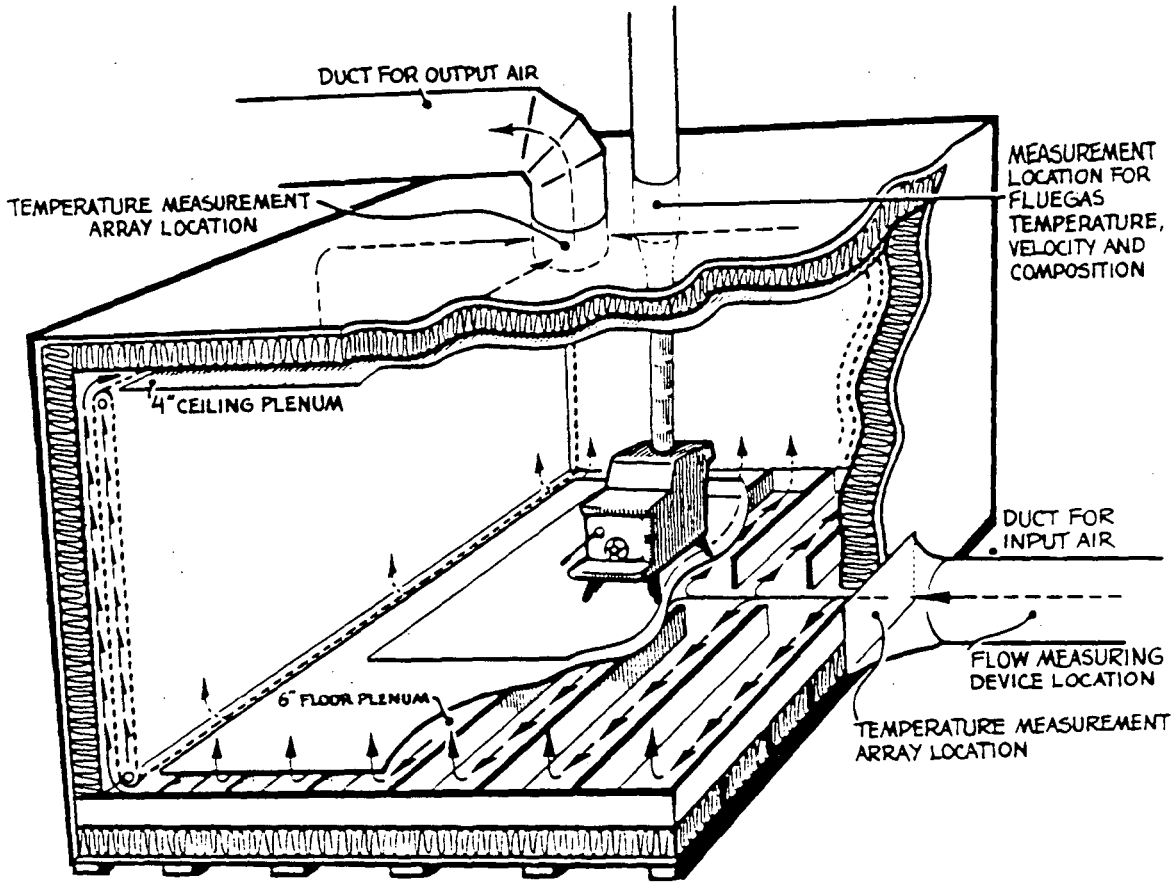

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Figure 1: Calorimeter room used to measure wood stove heat output.

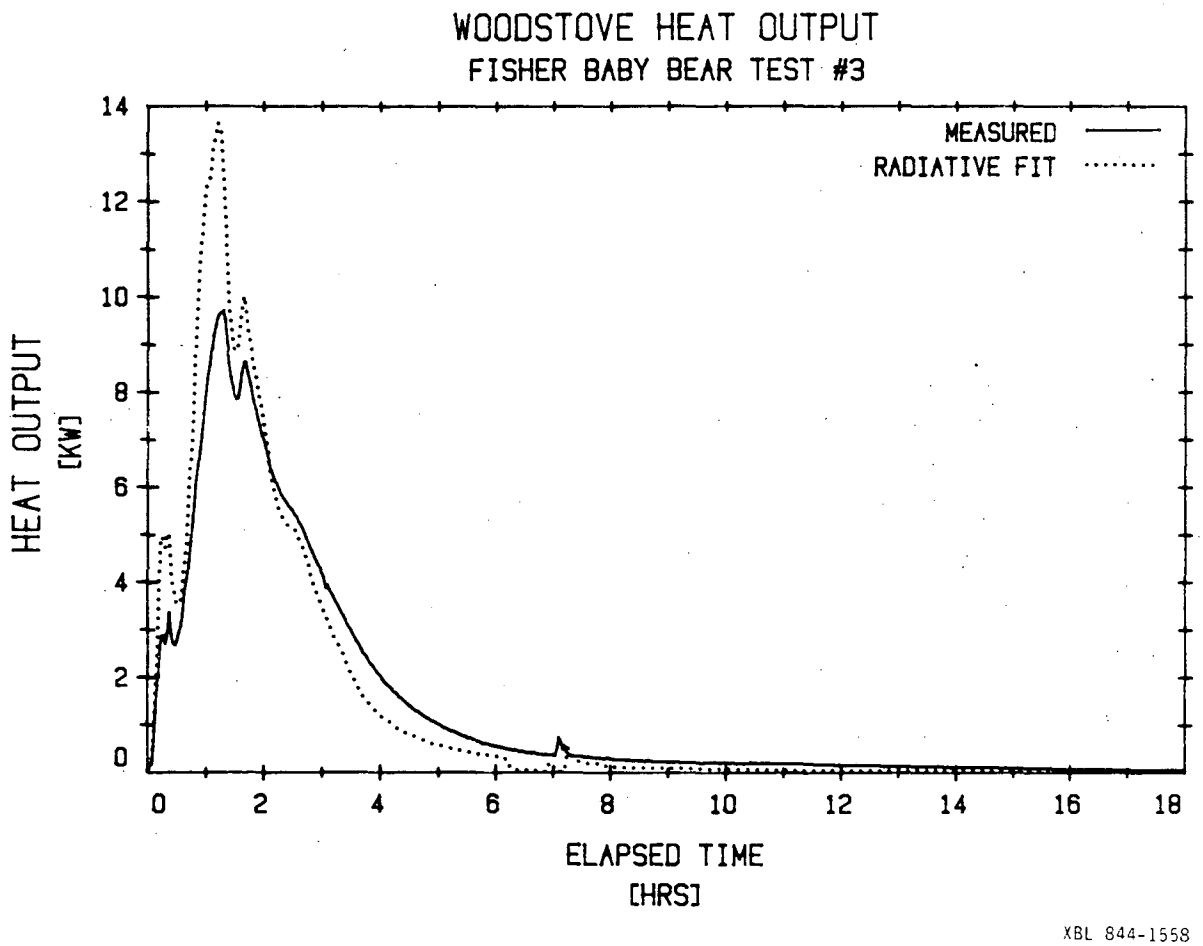


Figure 2: Measured and predicted heat output of Fisher Baby Bear stove, radiative temperature-sensor correlation.

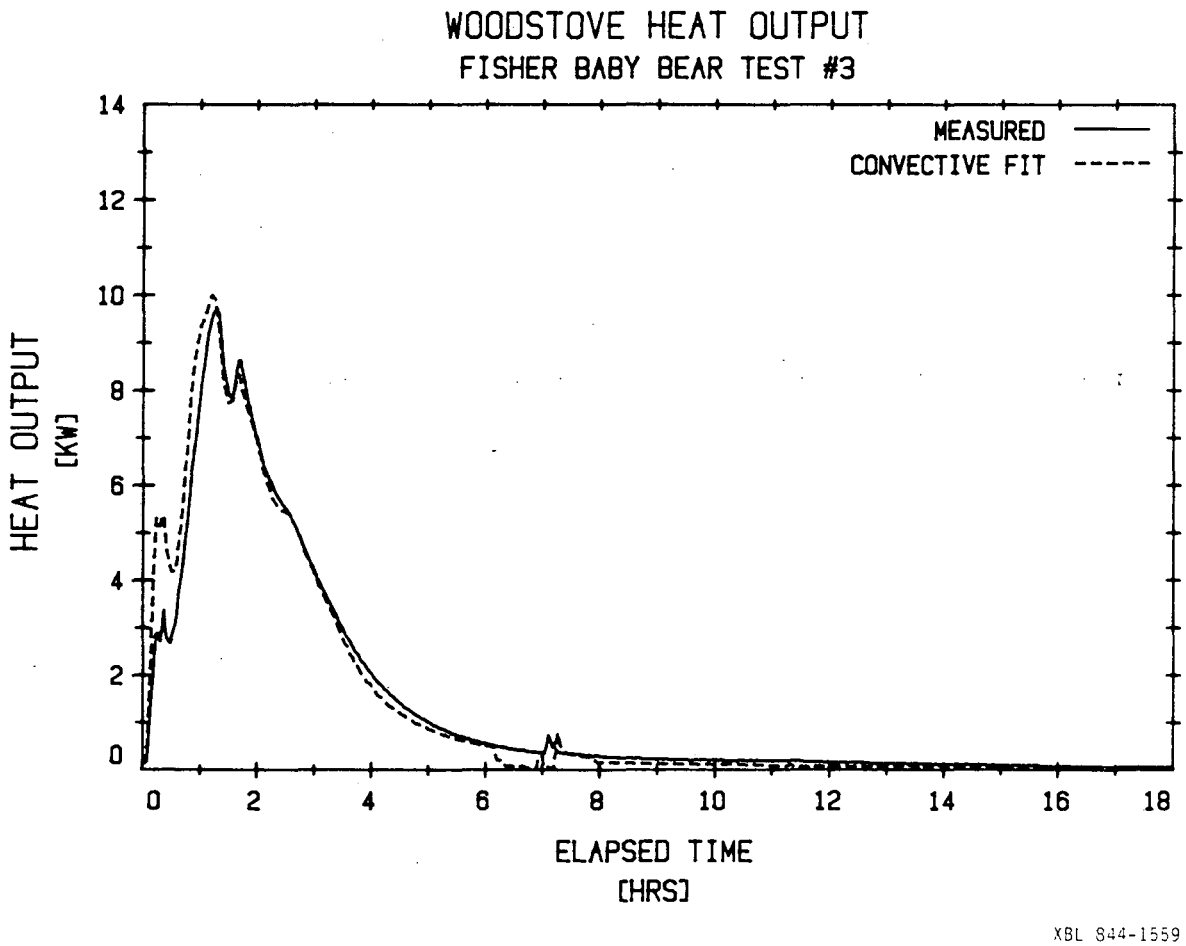


Figure 3: Measured and predicted heat output of Fisher Baby Bear stove, convective temperature-sensor correlation.

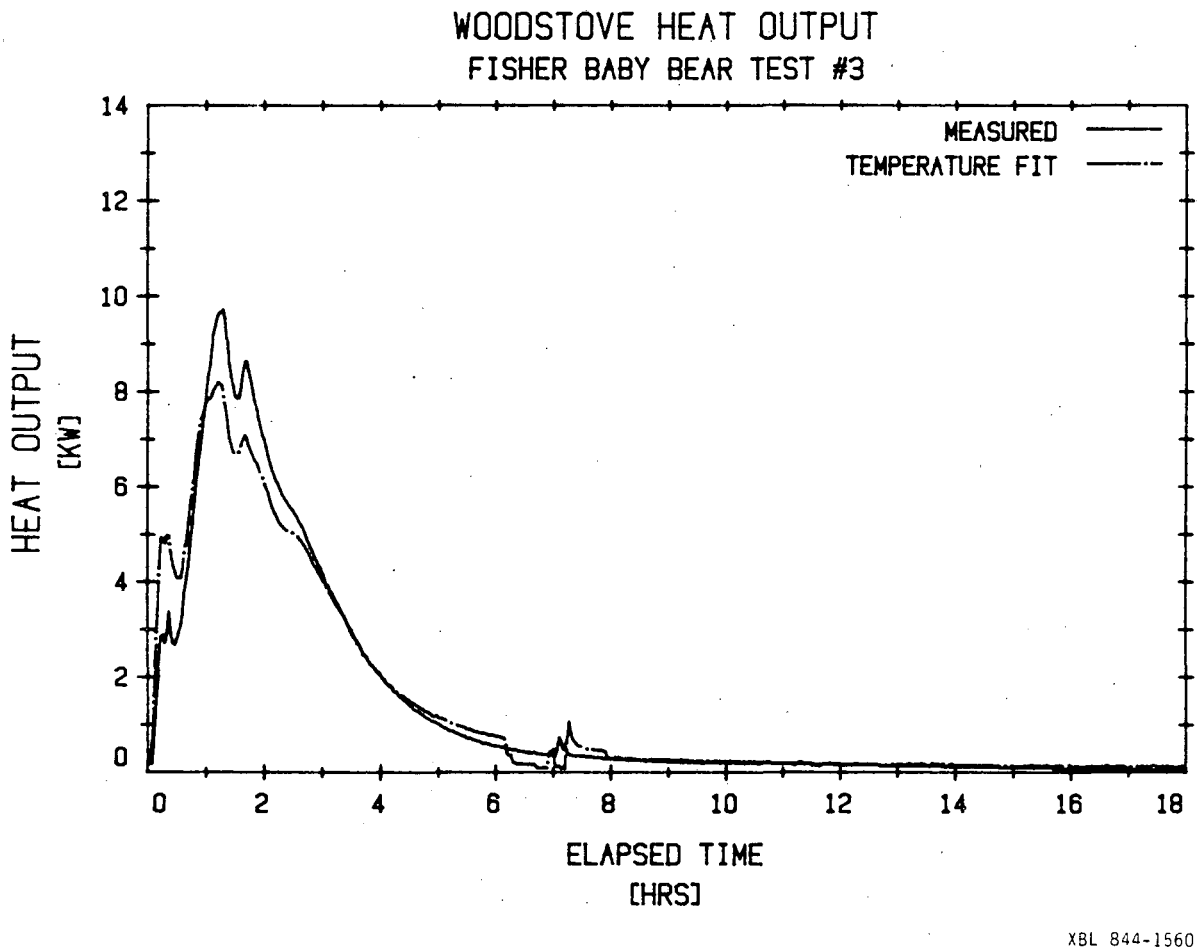


Figure 4: Measured and predicted heat output of Fisher Baby Bear stove, linear temperature-sensor correlation.

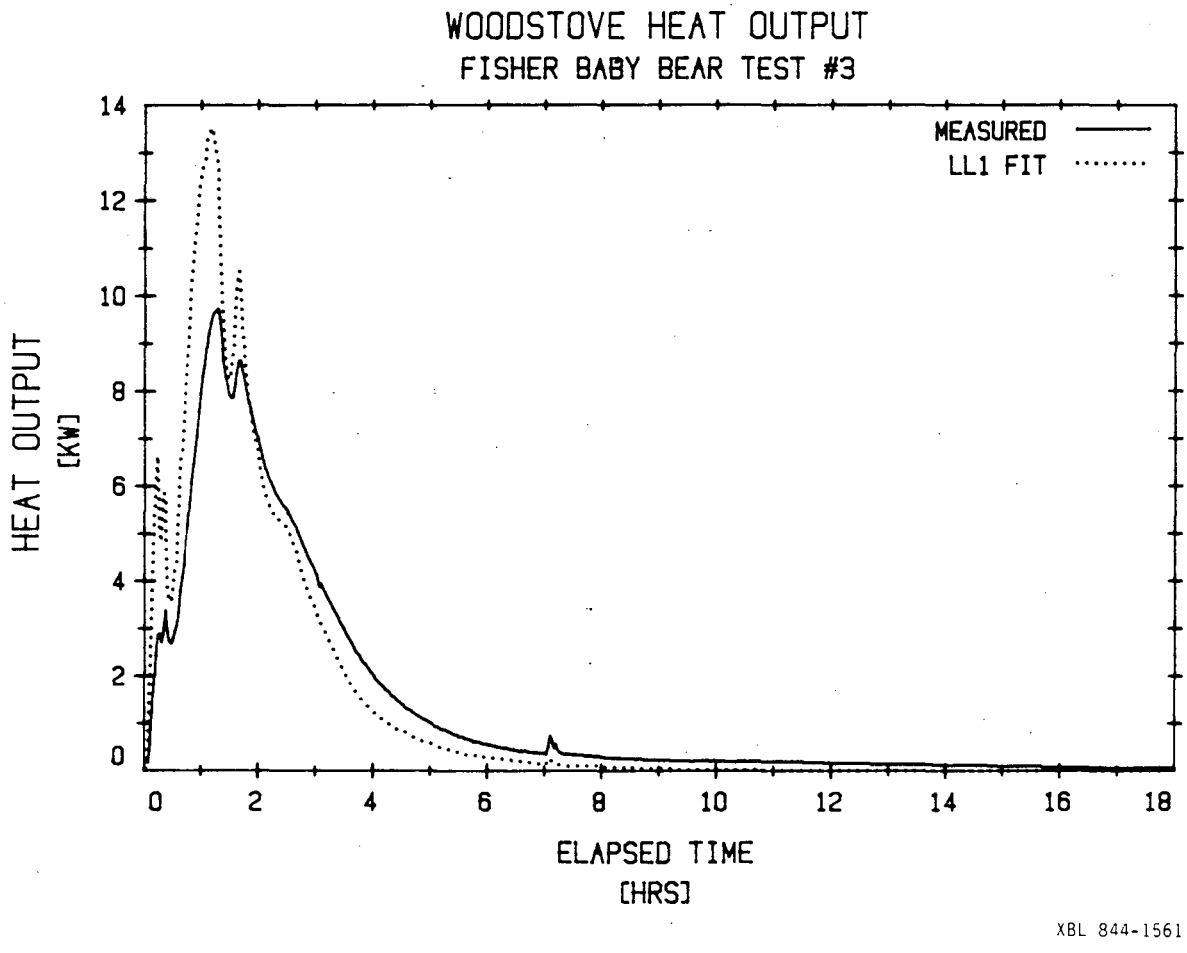


Figure 5: Measured and predicted heat output of Fisher Baby Bear stove, radiometer LL1 correlation.

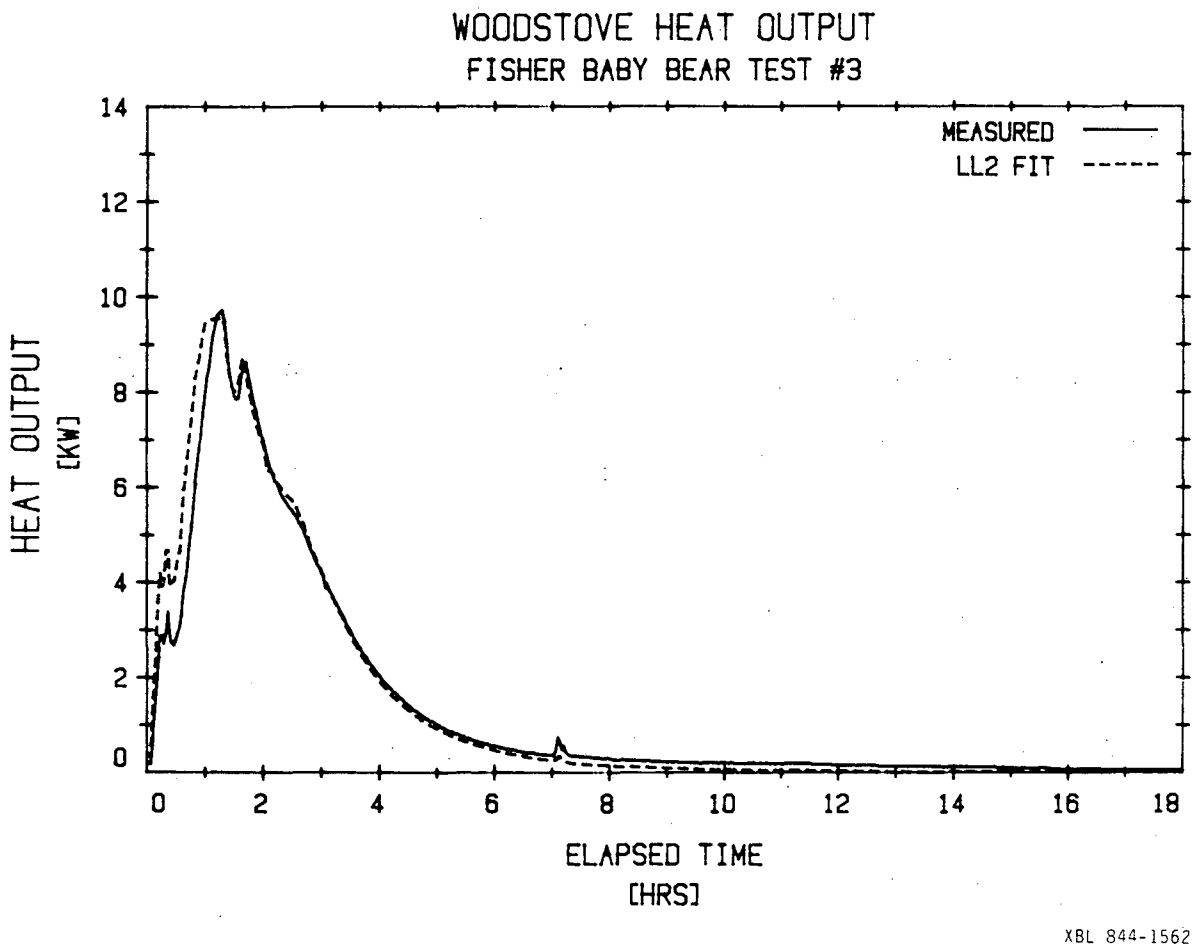


Figure 6: Measured and predicted heat output of Fisher Baby Bear stove, radiometer LL2 correlation.

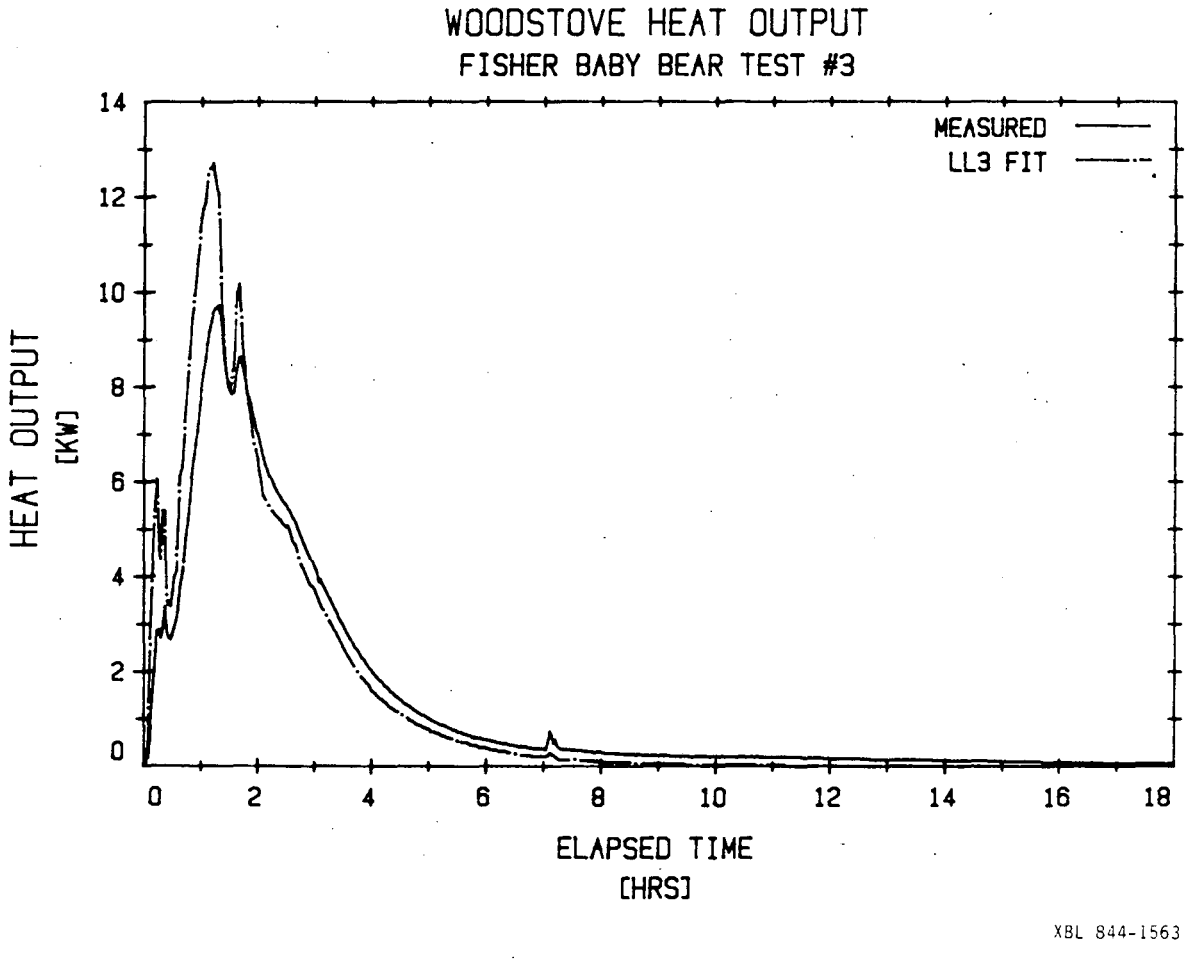


Figure 7: Measured and predicted heat output of Fisher Baby Bear stove, radiometer LL3 correlation.

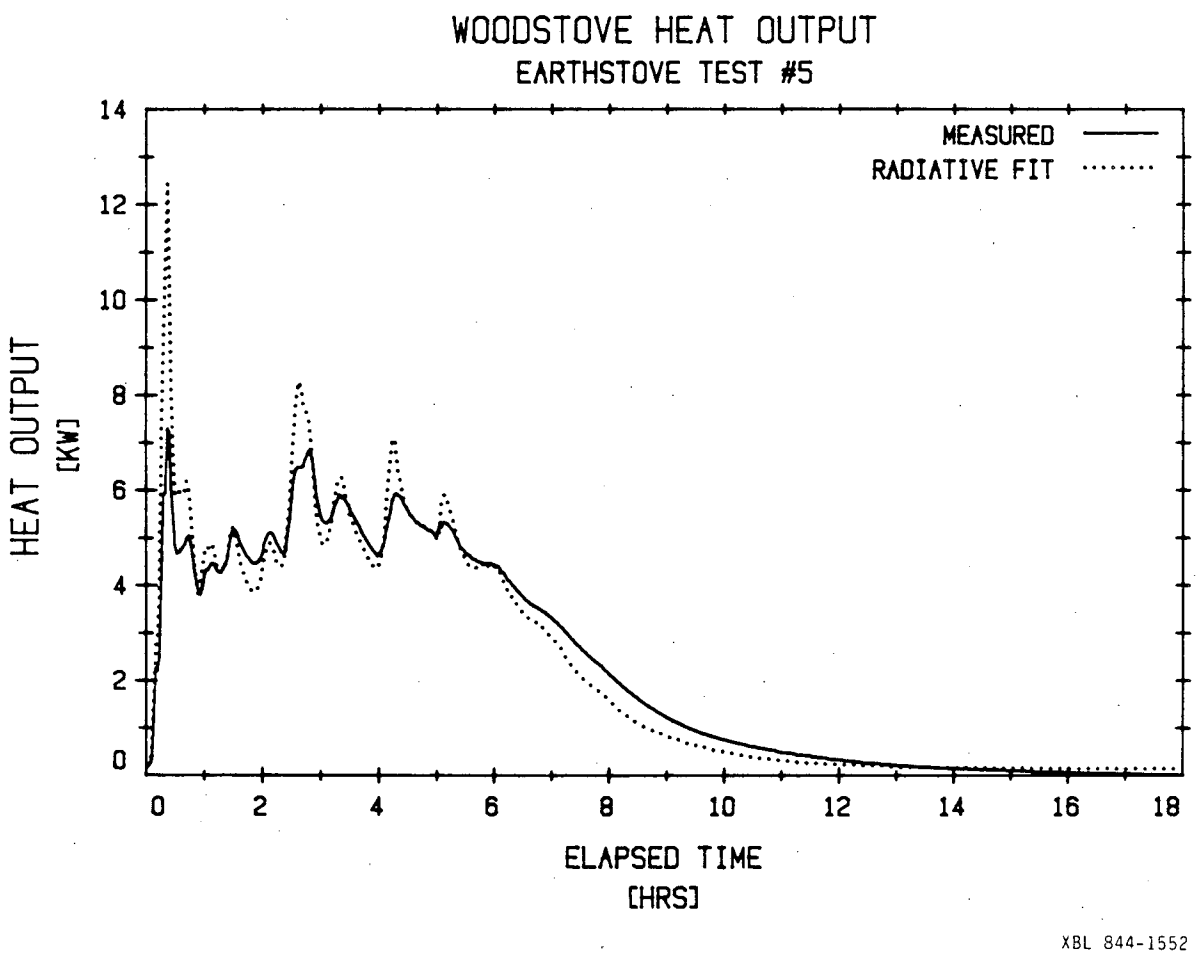


Figure 8: Measured and predicted heat output of Earthstove, radiative temperature-sensor correlation.

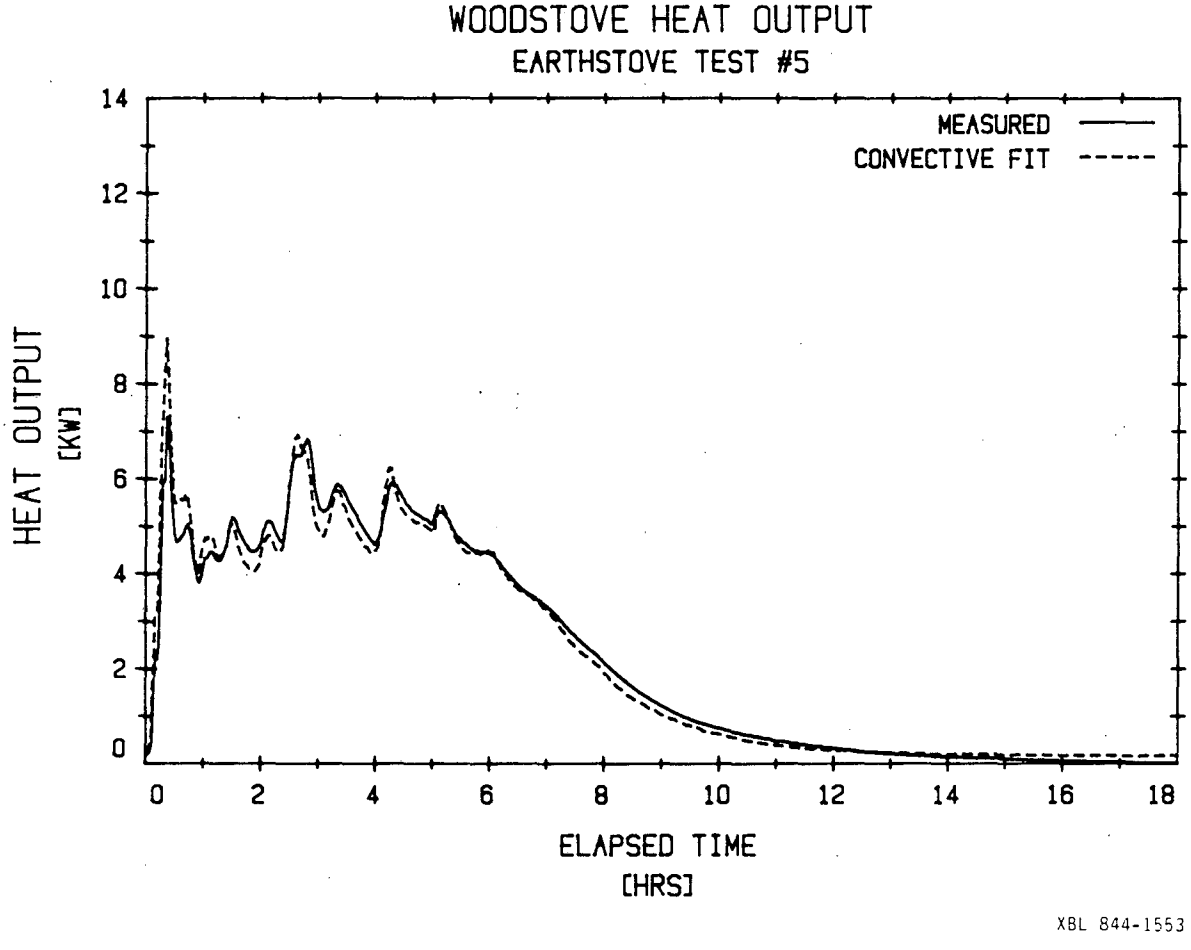


Figure 9: Measured and predicted heat output of Earthstove, convective temperature-sensor correlation.

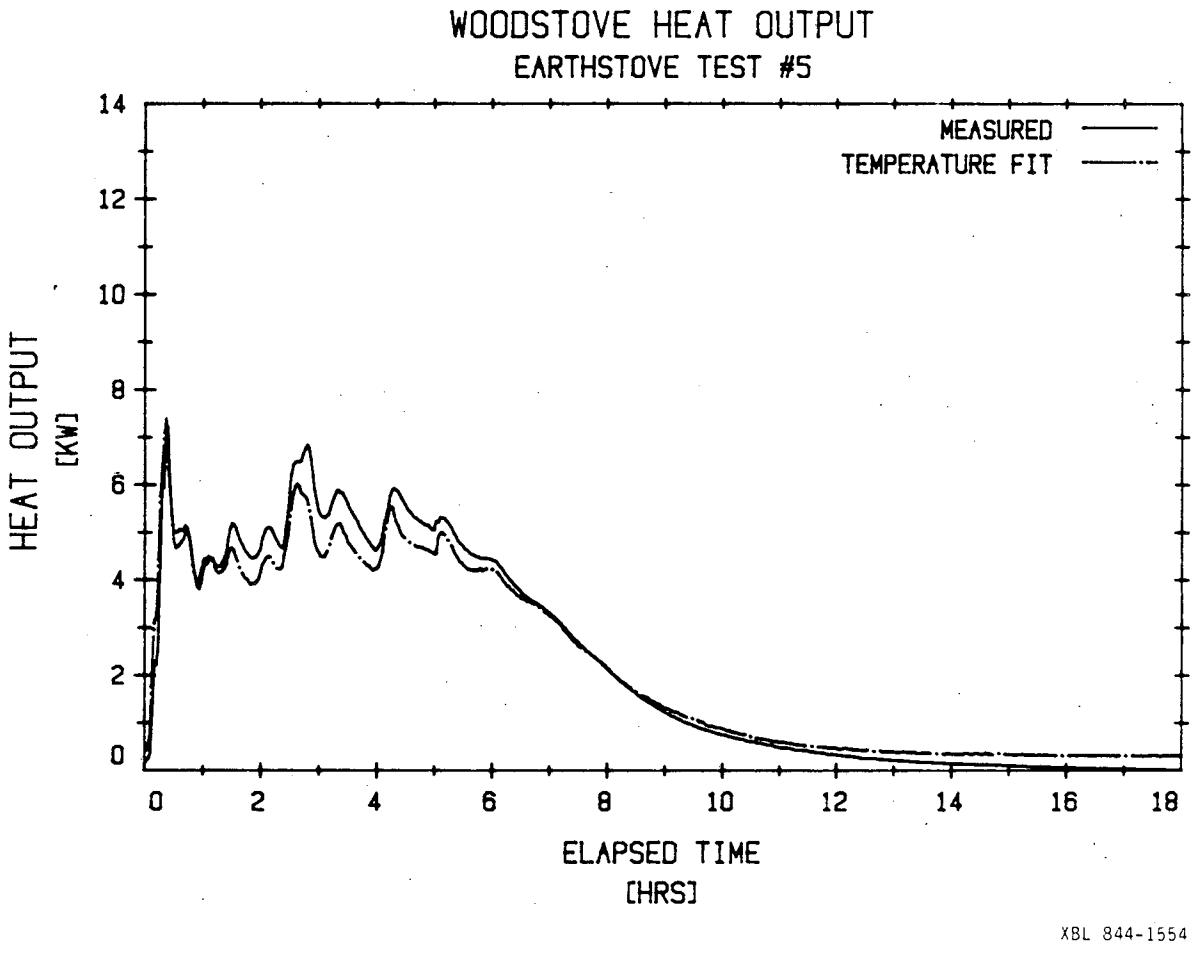


Figure 10: Measured and predicted heat output of Earthstove, linear temperature-sensor correlation.

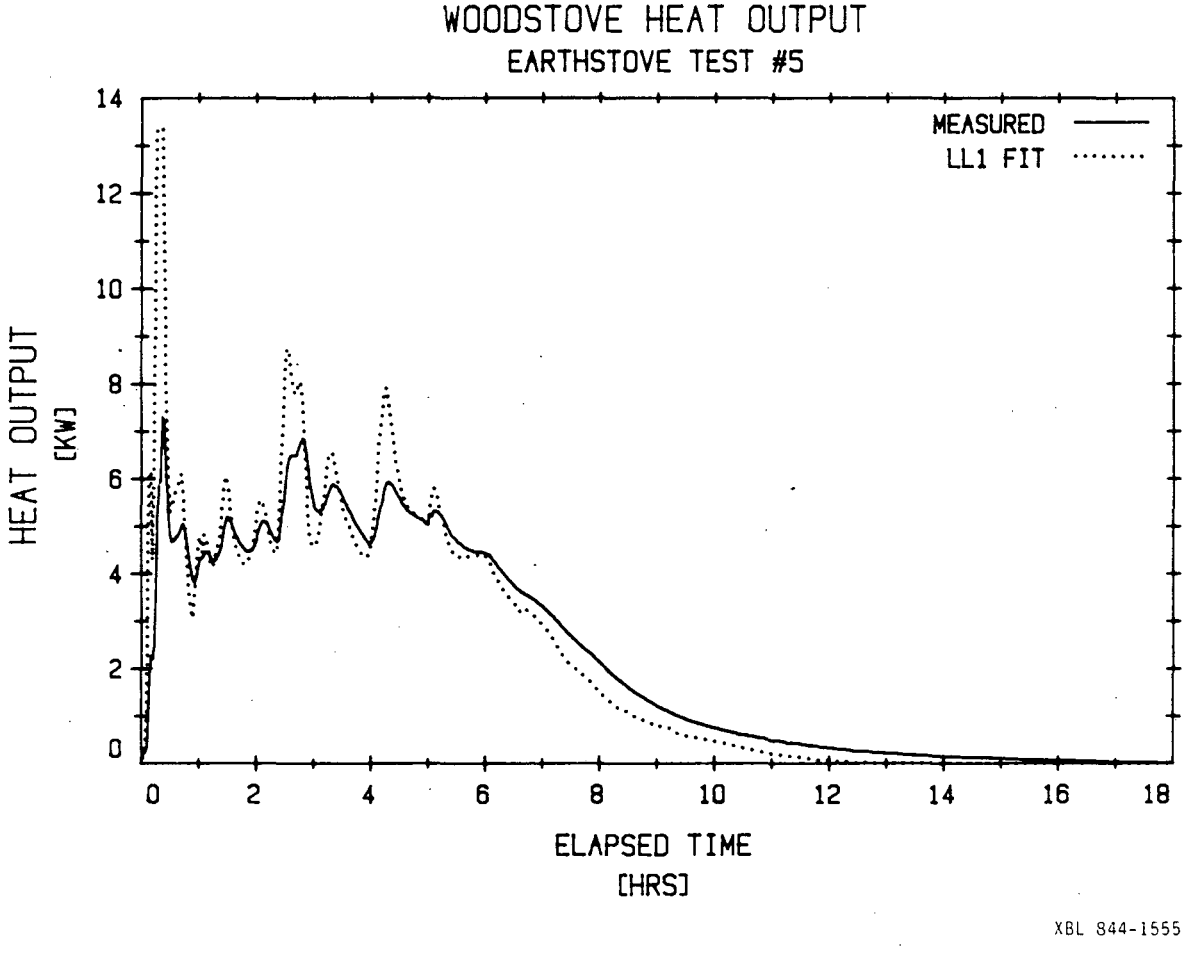


Figure 11: Measured and predicted heat output of Earthstove, radiometer LL1 correlation.

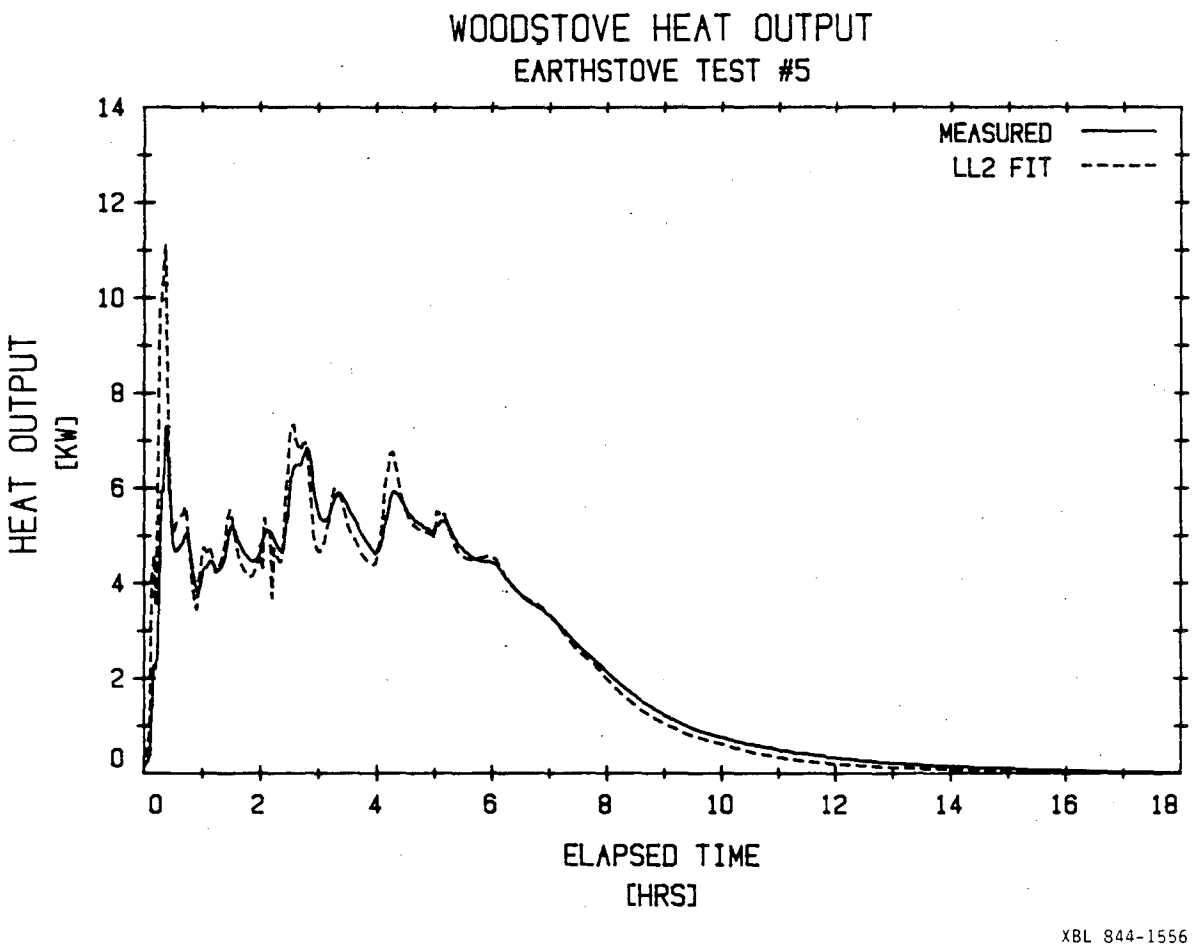


Figure 12: Measured and predicted heat output of Earthstove, radiometer LL2 correlation.

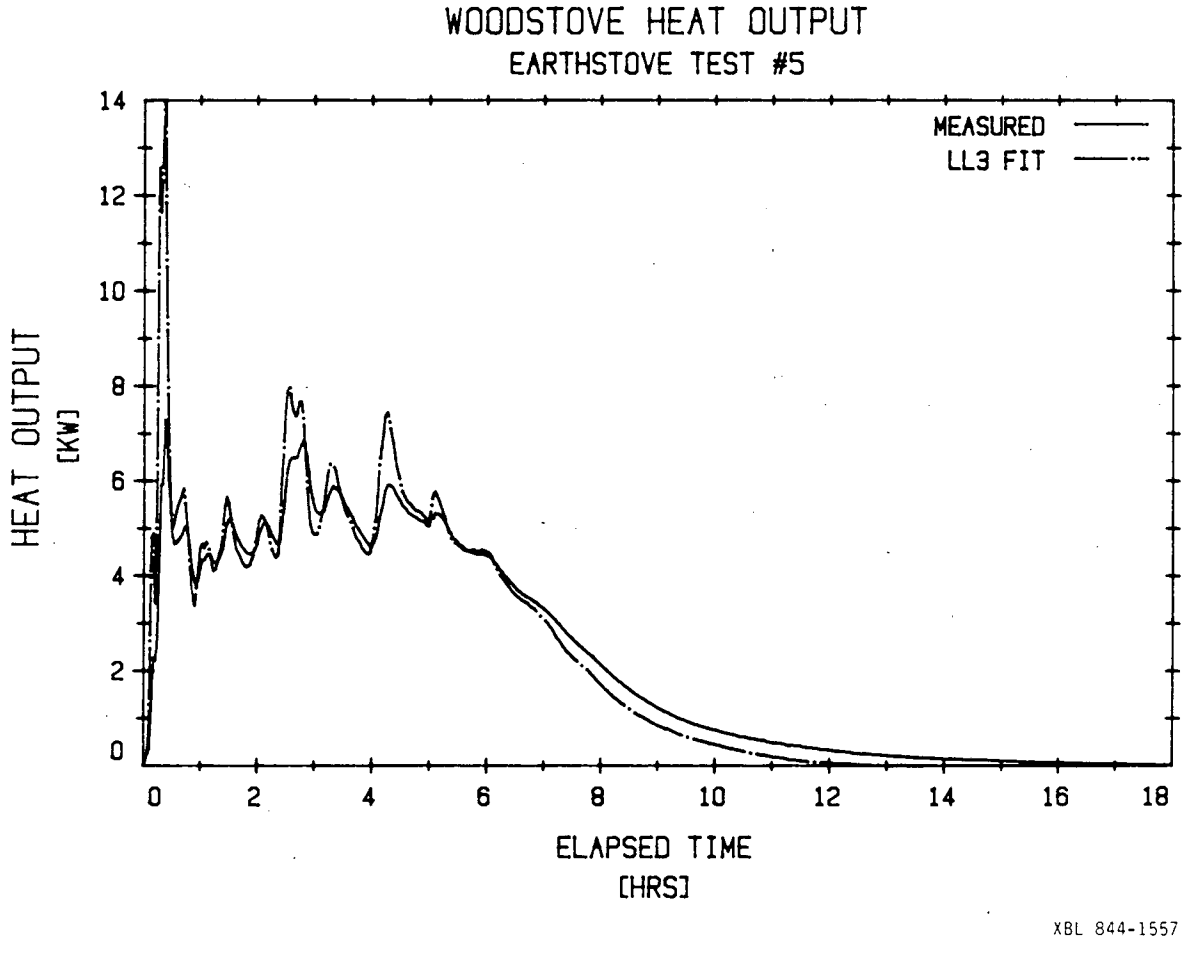


Figure 13: Measured and predicted heat output of Earthstove, radiometer LL3 correlation.

APPENDIX I: INSTALLATION NOTES FOR RADIOMETERS

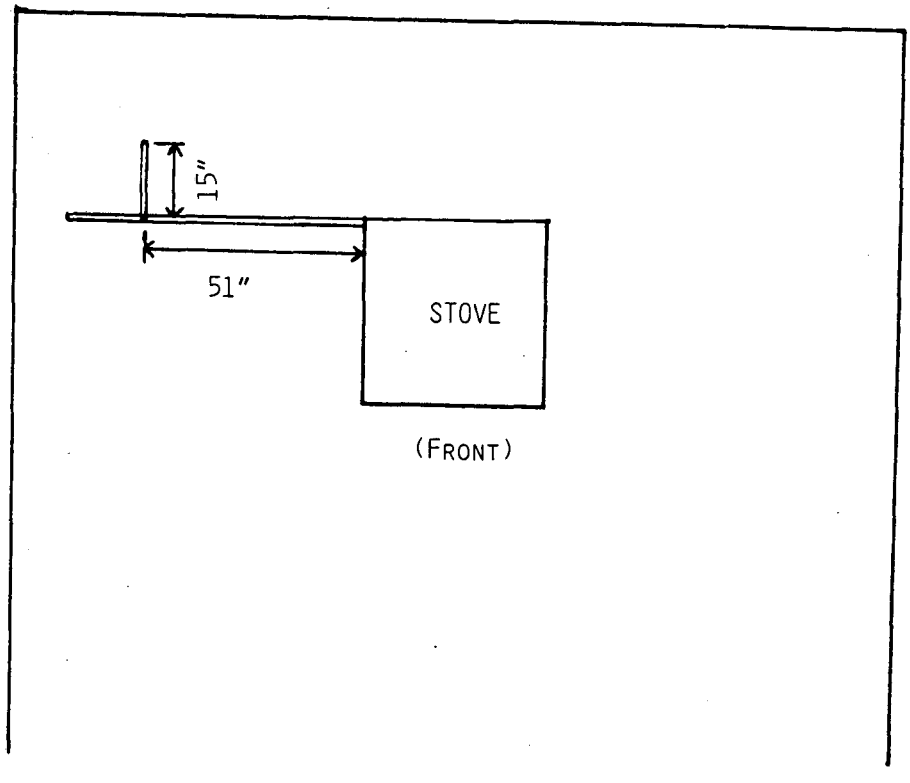
This appendix briefly discusses some of the issues involved in installing Linear Laboratories radiometers (Model EM-200) in the field.

As background, the radiometer is housed in a plastic case approximately 20 cm (7.9 in.) long, 12 cm (4.7 in.) wide and 5 cm (2 in.) deep. The detector is behind a white polyethylene window near one end of the radiometer. A small screw eye is located on the front of the case as close to the window as is practical.

Begin the installation procedure by unpacking the radiometer and power supply. Open the plastic radiometer case by inserting a small screwdriver between the top and bottom halves at the end of the case opposite the polyethylene window. With gentle leverage the case should open easily. Check the wiring at the printed circuit board. With the case back lying on a table (the wire through the case back will cause some rocking of the case) and the detector away from you, observe the wiring at the screw terminal located on the printed circuit board. From left to right, the wires should be white, black, ground (braid), and red. The power supply leads are the white and ground braid, while red is the positive signal and black the negative signal. If the wires are in any other order, change them on the board and document the change, noting the radiometer serial number. Check that the wires are held securely by the strain relief bushing and that there are no loose or frayed wires at the terminal block or on the printed circuit board. Reassemble the case before continuing.

The radiometer will be mounted on a spring-loaded pole similar to those used to mount reading lights. First unpack and assemble the spring-loaded pole. For ordinary, eight-foot ceilings there will be four sections in the assembly. For higher ceilings additional 8" sections may need to be added. The order of the sections is not important except that the foot piece must be at the bottom and the spring-loaded section at the top.

The pole must be installed at a specific location relative to the left rear corner of the stove. Facing the front of the stove, the left rear corner is the one farthest from you on your left. The radiometer will be placed about 4 ft to the left and 14 in. behind the stove. It is acceptable to measure from either a square corner or the part of a rounded corner nearest to where the radiometer will be placed. The center of the pole should be placed 51 in. to the left and 15 in. behind the left rear (L/R) corner. The proper placement is shown in the figure below.



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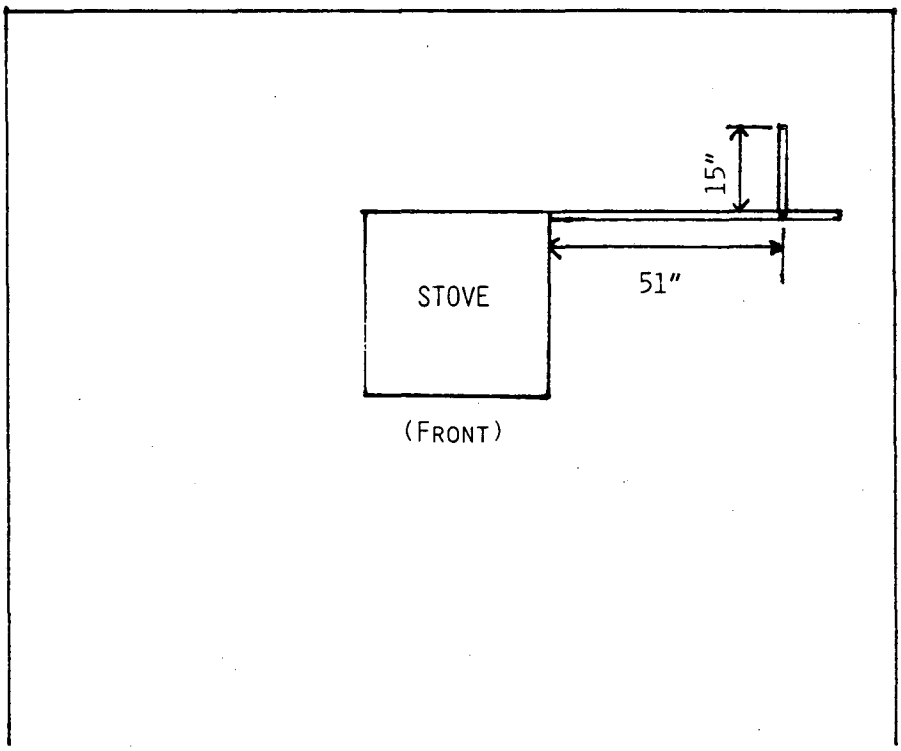
As shown in the figure above, place a tape measure on the floor in the line of sight along the back of the stove. Place the zero of the tape measure at the L/R corner of the stove. The tape measure should be perpendicular to the side of the stove; this can be checked with a carpenter's square. Find the pre-marked line at 51 in. on the tape measure and place a 15 in. ruler on the floor, facing away from the stove. The ruler should be perpendicular to the tape measure and the back of the stove; the edge of the ruler closest to the stove should be on the 51 in. mark. On the end of the ruler not touching the tape measure, the corner closest to the stove marks the correct location for the center of the pole. Mark this spot with a cross made from two small pieces of masking tape.

In some cases it may be impossible to install the pole in the prescribed location. If the left-side location is not available, you may be able to install the radiometer on the right side of the stove. This is acceptable but you must measure from the right rear corner, as shown in the figure below.



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The correct place for the center of the pole in this case is 51 in. to the right of the right rear (R/R) corner and 15 in. behind the stove (see diagram above). The installation procedure is as described for the L/R corner, except that the zero of the tape measure should be placed at the R/R corner of the stove. In some cases, you may be able to install the radiometer in almost the correct place. Come as close as possible and document any discrepancies. In a few cases, it may be impossible to install the radiometer anywhere near the correct location. These cases must be treated on an individual basis. An example of such a difficulty might be a stove installed within a masonry alcove. The solution will probably be to point the radiometer at the front of the stove rather than the rear, although general procedures for treating these type of situations should be defined before field installation begins.

With the pole in the proper position, attach the radiometer to the clamp. Tighten the lock nuts so that the long dimension of the radiometer is horizontal. This means the radiometer is installed sideways instead of vertically. Raise the clamp on the pole until the center of the swivel is 82 in. above the floor (the installer should probably have a step-ladder). Loosely tighten the screw on the swivel. Mark the height on the pole so that in subsequent operations you can quickly and easily return the clamp to the correct height.

Now, attach one end of a thin string or wire to one of the magnets supplied with the installation kit. Thread the other end of the string through the second magnet. Place the second magnet on top of the stove as close to the L/R corner as you can, and place the first magnet on the top of the stove about 6 to 8 in. away from the second. Take the free end of the wire or string and attach it to the screw eye on the front of the radiometer. This device will allow you to aim the radiometer at the L/R corner of the stove.

The radiometer is correctly aimed at the L/R corner of the stove by insuring that the radiometer face is perpendicular to the string in all directions. This requires adjusting the angle between the radiometer and the string in two directions. First, by holding the second magnet on the corner of the stove lightly with one hand and moving the first magnet with the other hand it is possible to get the wire fairly taut between the stove and the radiometer. Once this is done, rotate the mounting pole until the wire is at 90° to the front plane of the radiometer. A protractor held against the radiometer's polyethylene-window boss is helpful. The corner of a piece of cardboard is another way of determining 90°. It is usually necessary to rotate the pole, retighten the wire, and recheck the angle. This procedure may have to be repeated several times. When you have aligned the pole correctly, take a permanent magic marker and make corresponding marks on the base of the pole and on the masking tape. This will allow you to return the pole to its correct position if it is accidentally moved. Second, rotate the swivel so that the longer dimension of the radiometer is vertical. Again, tighten the wire from the stove corner to the radiometer. Rotate the radiometer on the swivel until the wire makes a 90° angle with the vertical (longer dimension) plane of the radiometer. Use your protractor or the corner of a piece of cardboard to measure the angle. When the angle is correct, tighten the swivel to prevent any further movement.

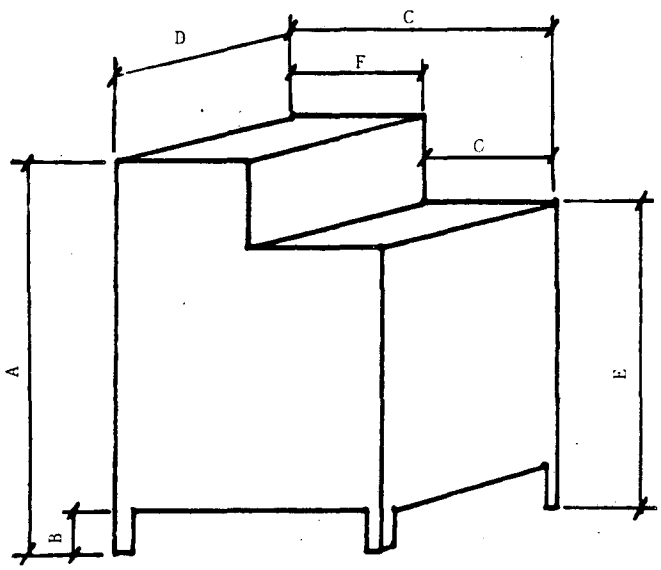
With a tape measure, measure the distance from the radiometer face (the front face of the polyethylene window is the best place) to the left rear corner of the stove. (If you have installed the radiometer in a position other than behind the left rear corner of the stove, this distance should be measured to the nearest corner of the stove.) This distance should be approximately 75 in.. If the distance is incorrect, check the height of the radiometer on the pole and the location of the pole.

It is also necessary to measure the size of the stove. Measure the following (see figure below):

A. height of stove top above the floor,
B. height of bottom of stove above the floor,
C. length of stove top,
D. width of stove top,

If the stove has a stepped top, then also measure:

E. height of lower step above the floor,
F. length of upper step,
G. length of lower step.



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If the stove has an unusual shape, measure as many dimensions as you can and draw a picture. These dimensions should be measured to the nearest 1/2 in.. This completes the installation of the radiometer.

To install the electrical portion of the radiometer, unpack the power supply brick. Be sure that the two wires from the AC wall outlet are connected to the AC terminals of the power supply. The white wire in the radiometer cable should be connected to the "+ OUT" terminal.

The ground braid should be connected to the "- OUT" terminal. Locate the power supply in a convenient place close to the data transmitter. Connect the red wire of the radiometer cable to the "±" point of the data acquisition channel and the black wire to the "-" point.

To test whether the radiometer is operating correctly, hold a match or a lighted propane torch approximately 12 in. from the polyethylene window of the radiometer and check that a signal is being generated.

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