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Fire Safety of Wood-Burning Appliances, Part 1: State of the Art Review and Fire Tests, Volume I

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Final Report

Prepared for:
U.S. Department of Energy
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PREFACE

The U.S. Department of Energy, as part of a program to facilitate the increased use of wood as an alternate energy source, has sponsored studies at the Center for Fire Research of the National Bureau of Standards to investigate the fire safety of wood-burning appliances. This report, the first presenting information from the Department of Energy sponsored experimental program, details the results of fire tests performed on a number of wood-burning appliances.

The report is separated into two volumes:

Volume I, which includes the text of the report with figures and tables and presents a review of previous work, details the test program and provides an analysis of the test results; and

Volume II, which includes the two appendices to the report that present detailed graphs of the measurements made during the 18 room experiments (appendix A) and calculated averages and maximums taken from the data in appendix A (appendix B).

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NOMENCLATURE

d - distance between stove surface and adjacent wall surface (m)

e_h, e_w - edge length (height, width) of stove surface (m)

F - configuration factor for an appliance or flue pipe surface with respect to the adjacent wall surface

h - convective heat transfer coefficient ($W/m^2\ K^{4/3}$)

m - length of flue/diameter of flue (dimensionless)

n - distance of axis of flue from panel/radius of flue (dimensionless)

T_a - ambient temperature of surroundings near the opposite side of the wall (K)

T_o - surface temperature of the opposite side of the wall (K)

T_r - temperature of the room surroundings near the wall surface (K)

T_s - appliance or flue pipe surface temperature (K)

T_w - wall surface temperature (K)

U - conductive heat transfer coefficient ($W/m^2\ K$)

ε - emissivity

σ - Stefan-Boltzmann constant ($W/m^2\ K^4$)

EXECUTIVE SUMMARY

The U.S. Department of Energy, as part of a program to facilitate the increased use of wood as an alternate energy source, has sponsored studies at the Center for Fire Research of the National Bureau of Standards to investigate the fire safety of wood-burning appliances used for space heating in single-family dwellings and similar small-scale applications. The program includes:

- a survey of fire incidents involving wood-burning appliances;

- a review of codes and standards dealing with solid-fuel appliances;

- experimental studies to develop information in the areas of clearances to combustibles, chimney creosoting and chimney fires, fireplace inserts, and products of combustion; and

- technical input to a public education effort by DOE and other government agencies.

This report, the first presenting information from the DOE sponsored experimental program on wood-burning safety at NBS, details the results of fire tests performed on a number of wood-burning appliances. The tests were conducted to establish typical operating conditions including temperatures on the appliances, chimneys, and adjacent wall and floor surfaces.

Several generic types of appliances were included to exemplify those available in the market. A total of 28 tests were conducted. In these tests, a total of more than one-half million individual readings of temperature, heat flux, or velocity were obtained. Two series of tests were conducted:

- full-scale room experiments where measurements of appliance temperature and surrounding surface temperature were obtained using a standard wood brands as fuel, and

- "log tests" where seasoned oak logs were used as a fuel source to compare with a standard wood "brand" fuel source. Only appliance surface temperature and flue gas temperature were monitored in the "log tests."

Some conclusions from these tests were apparent:

- Appliance firebox surface temperatures measured during steady-state operation were very similar for all five appliances tested. For appliance 5, a jacketed circulating room heater, outside jacket temperatures were lower. No correlation was found between appliance surface temperature and clearance between the appliance and wall surfaces.

- The temperature of the lightweight single wall flue pipe used for testing was more greatly affected by the clearance between the pipe and wall surface, an effect not noted for the appliance surface temperature measurements.

- Understandably, wall surface temperatures were found to vary inversely with the clearance between the appliance and wall surface. Wall temperatures as high as 189°C were recorded (for an improperly installed appliance).

- Appliance design and appliance size were found to affect temperatures on wall surfaces.

- Due to the small clearances between appliances and flooring, temperatures developed on unprotected floor surfaces were typically higher than wall temperatures during the tests.

- Wall surface temperatures and interior wall studding temperatures were considerably higher during tests with wall insulation or with a front wall than without.

- Average maximum appliance surface temperatures measured during tests using seasoned oak logs as the fuel source were similar to those developed during the "brand" tests.

- Theoretical calculations of wall surface temperature agreed within an average of 10°C with measured wall temperatures. Individual calculation agreement, however, ranged from excellent to poor.

These tests provide the basis for future research on proper clearances between combustible surfaces and wood-burning appliances and on protective devices used to allow reduced clearances. The research is expected to lead to recommendations for modifications to the appropriate model codes, to improved installation guidelines, and to the preparation of manuals of recommended practices for the safe and optimum use of the wood resource.

FIRE SAFETY OF WOOD-BURNING APPLIANCES, PART 1: STATE OF THE ART REVIEW AND FIRE TESTS, VOLUME I

Richard D. Peacock, Efrain Ruiz, and Roberto Torres-Pereira

Abstract

A series of 18 full-scale tests was conducted in an instrumented test room using five different wood-burning appliances. These tests were designed (1) to establish typical operating conditions including temperatures on the appliances, chimneys, and adjacent combustible surfaces; (2) to study the effects of a variety of combinations of appliance design, clearance to combustibles, and room construction on temperatures on adjacent combustible surfaces; and (3) to compare these measured values with theoretical predictions of wall surface temperature. Additional tests were conducted to compare a standardized fuel source with typical oak logs.

A review of literature related to wood-heating safety included in this study revealed that current codes are based on data almost 40 years old. The results of these tests point out some areas where the codes should be modernized to accurately reflect the newer appliances and construction techniques.

Key words: Chimneys; fire models; fire safety; fire tests; flues; heating equipment; heat transfer; literature reviews; radiant energy; stoves; wood.

1. INTRODUCTION

The U.S. Department of Energy (DOE), as part of a program to facilitate the increased use of wood as an alternate energy source, has sponsored studies at the Center for Fire Research (CFR) of the National Bureau of Standards (NBS) to investigate the fire safety of wood-burning appliances used for space heating in single-family dwellings and similar small-scale applications. It is important that the potential fire risks associated with these uses be evaluated and that the appropriate codes, standards, recommended practices, and test methods be developed and implemented to assure an adequate level of fire safety.

During the first year of the program, an accident survey, literature review, and codes and standards analysis was performed to establish accident patterns, to determine the types of risks involved with the use of wood-burning appliances, and to ascertain the adequacy of existing codes and standards in addressing the risks associated with wood-burning appliances [1-3][1]. Overwhelmingly, conditions related to the installation, operation, and maintenance were responsible for the fire incidents studied. Only a small percentage of the fires were attributed to product design or product defects. Thus, the safe installation and use of wood-burning appliances is a critical requirement for preventing fire accidents involving the equipment. Existing criteria for the installation of wood-burning appliances are based on data developed nearly 40 years ago and do not provide information on materials of construction or appliances available in the current market or allow for variations based on the use of alternate materials.

Accordingly, the plan proposed for a continued experimental program stresses the installation, operation, and maintenance of wood-burning appliances with some specific objectives for the work during the second and third years of the program:

- perform necessary experimental studies to develop and quantify safe but reasonable limits for important fire safety parameters including clearances to combustibles, chimney creosoting and chimney fires, and products of combustion;

- provide the technical input to a public education program to be developed in conjunction with public education efforts at NBS, DOE, and other government agencies;

- interface with the appropriate model code agencies and consensus standards groups to initiate the prompt adoption of changes that are desirable for the safe and optimum use of the wood resource.

This report, the first presenting information from the DOE sponsored experimental program on wood-burning safety at NBS, presents the results of fire tests performed on a number of wood-burning appliances. The tests were

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[1] Numbers in brackets refer to literature references listed in section 11 at the end of this report.

conducted to establish typical operating conditions including temperatures on the appliances, chimneys, and adjacent wall and floor surfaces. The data gathered from these tests will be used to design and confirm laboratory scale experiments to study minimum acceptable clearances to combustibles and to study various methods to protect combustibles from the heat generated by wood-burning appliances.

2. REVIEW OF PREVIOUS WORK

2.1 Fire Incidents Involving Wood-Burning Appliances

An analysis of fire incidents involving solid fuel heating appliances was conducted by NBS during the first year of the project with fire incident data from the following sources:

- U.S. Fire Administration;
- National Electronic Injury Surveillance System;
- Massachusetts State Fire Marshal's Office;
- Oregon State Fire Marshal's Office;
- National Fire Protection Association;
- Flammable Fabrics Accident Case and Testing System.

Product malfunctions, construction defects, design deficiencies, or worn out equipment were attributed to be the cause in only 13% of the solid fuel related fires recorded in the U.S. Fire Administration data base [1,2]. Overwhelmingly, conditions related to the installation, operation, or maintenance of the appliances were reported as responsible for the fires. Shelton [3,4] supports this conclusion with studies in the state of Massachusetts and from an insurance company in Wisconsin. A further analysis of the data presented in references [1] and [2] is presented in figure 1. The breakdown of solid fuel related fire incidents by probable cause and by equipment type indicates that except for improper maintenance, the appliances themselves were involved in most of the fires rather than chimneys or chimney connectors--over 70% in these cases. However, under the category of improper maintenance, appliances were involved in only 26% of the recorded fires. Improper maintenance is the significant problem associated with chimneys and chimney connectors while improper installation and operation is more important with appliances.

2.2 Clearances in Existing Codes and Standards

Recommendations for minimum acceptable clearances to combustible materials for the installation of chimneys, chimney connectors, and appliances are specified in the various model codes and recommended practices manuals [1 5-13]. For simplicity and ease of enforcement, a single, hopefully conservative clearance is given for each type of appliance installed without protection. No allowance is made for the size, heat output, heat transfer characteristics or other features unique to individual models. Similarly, only a few, specific methods of protection employed to allow reduction of these clearances are recommended. Shelton [4] illustrates the effect of appliance size on minimum safe clearances with theoretical calculations for two radiant room heaters. Assuming equal surface temperatures, a small heater [surface area of the side parallel to a wall of about 930 cm^2 (1 ft^2)] is equally safe at a clearance of 0.5 m (20 in) as a larger heater [surface area of the side parallel to a wall of about 0.51 m^2 (5.5 ft^2)] at a clearance of 0.91 m (36 in).

Typically, 0.91 m (36 in) of clearance is specified between radiant heaters and unprotected combustible construction. For circulating heaters, clearances of 0.61 m (24 in) from the front of the appliance and 0.30 m (12 in) from the sides and back of the appliance are recommended [13]. For single wall metal chimney connectors [13], 0.46 m (18 in) is usually recommended as a minimum clearance.

Several experimental studies have been carried out to determine minimum acceptable clearances to combustible materials. Voigt, in a 1933 publication, recommends a minimum clearance of 0.30 m (12 in) for chimney connectors 0.23 m (9 in) in diameter [14]. A more extensive study, performed by Underwriters Laboratories in 1943, presents minimum safe clearances for both unprotected surfaces and surfaces protected by various methods. Distances at which a maximum temperature rise of 50°C (90°F) above room temperature is reached are presented as a function of the temperature of the exposed face of a heat producing appliance. The relative protection afforded by various materials used as heat barriers between the appliance and combustible surface is also examined [15]. Lawson, Fox, and Webster [16] and Lawson and Sims [17] have studied the heating of wall panels and wood by radiation. With experimentation and theoretical predictions, they present safe clearances between flue pipes and wall surfaces as a function of the pipe diameter and the pipe surface temperature. To maintain a maximum wall temperature of 100°C (212°F), a 0.15 m (6 in) pipe should not exceed 350°C (660°F) in surface temperature at a clearance of 0.46 m (18 in) [16].

2.3 Temperatures Developed in Heating Appliances

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces established a limiting temperature rise of 190°C (375°F) on the outer surface of the chimney for a flue gas temperature of 540°C (1000°F). With this limitation, wood framing spaced 5 cm (2 in) or more away from the chimney was considered safe. Satisfactory insulation of the chimneys to reduce the outer surface temperatures to acceptable levels was obtained with asbestos paper plies totaling about 4.5 cm (1-3/4 in) in thickness. Some asbestos-cement pipe coverings were also found to be capable of reducing heat transmission to the extent required for safety to nearby combustibles [18,19].

To establish performance requirements for lightweight prefabricated chimneys, tests were conducted with lined and unlined masonry chimneys having 10 cm (4 in) thick walls. Hazardous conditions on wood framing spaced 5 cm (2 in) away from the chimney were noted with a continued flue gas temperature of 480°C (900°F) for the unlined chimney and 590°C (1100°F) for the lined chimney. However, these hazardous conditions were not reached in the lined chimney tests until after 13 hours [20]. As a comparison with typical fuels, a number of firing tests were conducted with heating appliances known to give high flue gas temperatures, using wood and soft coal as fuels. With a coal-fired, jacketed type heater, flue gas temperatures at the floor level above the heater of 650°C to 705°C (1200°F to 1300°F) were obtained for an hour or more [20].

Lawson, et al. [16] present the results of tests to measure surface temperatures of flue pipes to validate theoretical predictions. Measured for a variety of flue systems using solid fuels--mostly coal and coke--they report temperatures of about 148°C (300°F) under "normal conditions" and temperatures as high as 815°C (1500°F) under overload conditions.

Fox and Whittaker [21] report temperatures on metal flues of several heating appliances over a range likely to be encountered in normal use. Maximum flue pipe surface temperatures ranged from 700°C to 815°C (1300°F to 1500°F) at the appliance flue outlet, 360°C to 510°C (680°F to 950°F) at a distance of 1 m (3 ft) from the appliance flue outlet and 280°C to 330°C (550°F to 620°F) at a distance of 2 m (6 ft) from the appliance flue outlet.

Larsson [18] concludes that combustible materials will be ignited if maintained in continued contact with a chimney of 12 cm (4-3/4 in) wall thickness and with flue gas temperatures of 400°C (750°F).

Current test procedures for prefabricated chimneys require testing of chimney assemblies with hot flue gases [22]. Flue gas temperatures of 540°C (1000°F) are maintained until steady-state conditions are reached, followed by 760°C (1400°F) for 1 hour and 925°C (1700°F) for 10 minutes. These conditions are intended to simulate worst-case conditions.

2.4 Limiting Safe Temperatures on Combustible Surfaces

Listings of heat producing appliances by nationally recognized testing laboratories and methods for reducing clearances to combustible surfaces are based on upper limits for temperature on adjacent surfaces of

- 65°C (117°F) rise above room temperature on exposed surfaces, and

- 50°C (90°F) rise above room temperature on unexposed surfaces such as beneath the appliance, floor protector, or wall mounted shield [23].

While the ignition temperature of wood products is generally quoted to be on the order of 200°C (400°F), wood that is exposed to a constant heating over a period of time may undergo a chemical change resulting in a much lowered ignition temperature and increased potential for self-ignition [24].

Mitchell [25] presents tests on wood fiberboard exposed to moderately elevated temperatures as low as 109°C (228°F) that resulted in ignition after prolonged exposure. MacLean [26,27] reports charring of wood samples at temperatures as low as 93°C (200°F). He concludes that wood should not be exposed to temperatures appreciably higher than 66°C (150°F) for long periods. McGuire [28], suggests that the maximum safe temperature on the surface of a combustible material adjacent to a constant heat source should be no more than 100°C (212°F).

Clearly, the ignition of wood at moderately elevated temperatures is a complex phenomenon. The time of exposure is indeed an important parameter [29]. The ignition and self-heating properties of charcoal may be more important than that of "natural" wood according to Shelton [4]. Still, the numerous documented fires involving the ignition of wood members near low pressure steam pipes [30] suggest an upper temperature limit for wood exposed to long-term low-level heating should not be appreciably higher than 100°C (212°F).

2.5 Theoretical Prediction of Adjacent Wall Surface Temperatures

Under steady-state conditions, the heat gained by the adjacent wall from an appliance or flue pipe surface will equal the heat lost by the adjacent wall to the surroundings. Thus, a heat balance for the appliance or flue pipe near an adjacent wall can be derived:

Net heat absorbed by the wall surface by radiation from the stove or flue pipe: $F\sigma\varepsilon(T_s^4 - T_w^4)$.

Net heat lost by the wall surface to the surroundings by radiation: $(1-F)\sigma\varepsilon(T_w^4 - T_r^4)$.

Net heat lost by the wall surface to the surroundings by convection: $h(T_w - T_r)^{4/3}$.

Net heat lost by the wall surface by conduction through to the opposite side of the wall: $U(T_w - T_o)$.

Net heat lost by radiation and convection from the opposite side of the wall: $\sigma\varepsilon(T_o^4 - T_a^4) + h(T_o - T_a)^{4/3}$.

Balancing the heat gain and heat loss terms gives:

$$F\sigma\varepsilon(T_s^4 - T_w^4) = (1-F)\sigma\varepsilon(T_w^4 - T_r^4) + h(T_w - T_r)^{4/3} + U(T_w - T_o) + \sigma\varepsilon(T_o^4 - T_a^4) + h(T_o - T_a)^{4/3}.$$

Shelton [4], Lawson [16], and Thulman [31] have also applied the principles of heat transfer theory to predict temperatures on adjacent surfaces exposed to heating by stoves and flue pipes. They have developed configuration factors for radiative heat transfer as described below.

2.5.1 Configuration Factor for Flue Pipe Surfaces

For heat transfer from flue pipe surfaces, Lawson [16] presents the configuration factor for straight sections of flue pipe as seen from a point directly opposite the midpoint of the pipe as:

$$F = \frac{2}{\pi}\left[\frac{mn}{[m^2n^2 + [n^2 - 1]^2]^{1/2}} \tan^{-1} \frac{[n^2 - 1]^{1/2}}{[m^2n^2 + [n^2 - 1]^2]^{1/2}} + \frac{1}{n}\tan^{-1}\frac{m}{[n^2 - 1]^{1/2}}\right]$$

2.5.2 Configuration Factor for Appliance Surfaces

For heat transfer from appliance surfaces, the configuration factor for an appliance of width e_w and height e_h at a distance of d from a parallel wall can be expressed as:

$$F = \frac{2}{\pi}\left[\frac{1}{\left[1 + \left[2d/e_w\right]^2\right]^{1/2}} \tan^{-1} \frac{1}{\left[\left[e_w/e_h\right]^2 + \left[2d/e_w\right]^2\right]^{1/2}} + \frac{1}{\left[1 + \left[2d/e_h\right]^2\right]^{1/2}} \tan^{-1} \frac{1}{\left[\left[e_h/e_w\right]^2 + \left[2d/e_h\right]^2\right]^{1/2}}\right]$$

for the point on the wall directly opposite the center of the appliance surface [31].

The theoretical model presented here will be used to compare theoretical predictions with measurements obtained during the experiments reported below.

3. SCOPE OF WORK

The work reported herein consists of a series of tests conducted on several different wood-burning appliances in a full-scale test room. Several generic types of appliances were included to exemplify some of the types available in the marketplace. Tests were conducted on

- three radiant room heaters, including a side-loading unit with a glass front;
- a "Franklin" type fireplace stove; and
- a circulating or convective type room heater.

The study was primarily designed to provide data on both normal and overload conditions for the appliances to be used in the development of laboratory-scale tests of methods employed to allow reduced clearances to adjacent combustible surfaces. In addition, it was also formulated to obtain information on several aspects of fire safety of wood-burning appliances. Areas of interest included:

- temperature and heat transfer rates on adjacent combustible surfaces;

- temperatures on appliance surfaces;

- temperatures of flue pipe surfaces and flue gas;

- the effects of changes in room geometry and wall construction on temperatures developed on combustible surroundings.

4. DESCRIPTION OF EXPERIMENTAL FACILITIES AND INSTRUMENTATION

4.1 Test Enclosure

The appliances were tested in an enclosure approximately 2.4 m x 2.4 m x 2.4 m (8 ft x 8 ft x 8 ft). Three permanent walls were erected and instrumented as shown in figure 2. A fourth wall, erected with a doorway for some tests, allowed different room ventilation conditions to be explored. Room construction followed standard practices. Wall and ceiling linings consisted of 13 mm (1/2 in) gypsum wallboard over 5 cm x 10 cm (2 in x 4 in) wood studding spaced 41 cm (16 in) apart on center. Flooring used was 1.9 cm (3/4 in) plywood over 5 cm x 10 cm (2 in x 4 in) studding spaced 41 cm (16 in) apart on center.

Wall and ceiling insulation was applied for some tests to study the effects of typical insulation on temperatures developed in the test enclosure and gain information on any increased fire risk due to the insulation.

4.2 Instrumentation

The test enclosure, appliances, and flue were instrumented to measure conditions throughout the tests. All instrument data were automatically recorded at regular intervals on a high-speed digital data acquisition system. Data obtained included:

Temperature measurements. 24-gauge chromel-alumel thermocouples were used to measure temperatures on appliance surfaces, flue pipe surfaces, exposed face of the test enclosure, and rear surfaces of walls and flooring in contact with wood studs. During tests where insulation was applied, the temperature of the insulation was monitored as well as the surface temperature of the opposite face of the insulated wall. Flue gas temperatures were monitored with shielded thermocouples mounted in the center of the flue. Thermocouple locations are indicated in table 1 and figures 3 (appliances) and 4 (test enclosure).

Heat flux measurements. Gardon-foil type water-cooled heat flux meters were used to measure heat flux incident on the wall surface behind the appliances. Heat flux meter locations are presented in table 1 and figure 4.

Velocity measurements. A bidirectional low-velocity probe was located in the flue approximately 6 m (20 ft) from the appliance outlet to measure the velocity of the flue gas. This type of probe was developed by Heskestad [32] for obtaining low-velocity measurements under fire conditions. McCaffery and Heskestad [33] have provided calibration techniques for these probes. The probe used was 12.7 mm in diameter, with construction details as given in the above reference. The basic equation for determining velocity is

$$\frac{\sqrt{2\Delta P/\rho}}{u} = C(Re)$$

where ΔP is the measured differential pressure, ρ is the gas density (obtained from temperature readings adjacent to the probe), u is the gas velocity, and C(Re) is a constant dependent upon the Reynolds number. For low velocities, the constant can be taken as C(Re) = 1.08, according to the recommendation of McCaffrey and Heskestad.

4.3 Data Recording and Instrumentation Accuracy

The test series conducted during this phase of the project and reported herein represents over one-half million individual readings of temperature, heat flux, and velocity. Data for all channels were recorded automatically at 1 minute intervals using a digital data acquisition system for the duration of each test--typically 4.5-5.5 hours. Obviously, the voluminous amount of data collected requires the use of a digital computer for the reduction of the data into a useable form. A general purpose computer program for the reduction of data collected by automatic data acquisition systems, documented in reference [34], was used throughout the test series for the reduction and analysis of the data collected.

The overall accuracy of a system used to measure physical quantities is an important parameter when studying the significance of scientific data. A discussion of the accuracy of the measurements taken during this test series is included below:

Temperature measurements. Errors in the measurement of temperature arise from two sources--the accuracy and repeatability of the thermocouple wire used and the technique used to convert the thermocouple EMF to engineering units. For Type K thermocouples and the data system used in these tests, these errors are ±2°C and ±1°C, respectively, or a total overall error of ±3°C [35,36,37]. Ambient temperatures recorded for all temperature channels prior to each test and data system calibration checks performed twice during the series were well within these limits.

Heat flux measurements. The accuracy of the heat flux transducers used for the tests is stated as ±3% in the manufacturers' specifications. Calibrations supplied with each meter were verified against a working standard in a test chamber [38] that had been previously calibrated by the NBS Optical Radiation Group relative to the NBS standard electrically calibrated thermopile radiometer [39]. Detector precision within 3% was obtained with this calibration. Including data system error [36,37] yields an overall system accuracy of ±6%.

Velocity measurements. McCaffery and Heskestad [33] have provided calibration techniques for the probes used in this study. Accuracy is valid to about ±5% [33].

5. TEST PROGRAM

A total of 18 experiments were conducted on five different appliances in the test room described previously. Table 2 provides a description of the salient features of the appliances tested. Typically, at least two tests were conducted with each appliance--one test with 0.91 m (36 in) of clearance between the rear wall of the test enclosure and the appliance and one test with 0.46 m (18 in) of clearance. Additional tests were conducted with some appliances when smaller rear wall/appliance clearances could be obtained. In several tests, the room construction and geometry was changed to study their effects on test results. Table 3 gives details of the test conditions for each experiment.

5.1 Test Procedure

Underwriters Laboratories standard 1482 for solid fuel room heaters provides guidelines for testing wood-burning appliances [23]. Each appliance was installed and instrumented with the specified wall clearance and the instrumentation checked to verify its proper operation. An experiment consisted of two tests--a "brand fire test," and a "flash fire test" run as a continuation of the "brand Fire test."

In the "brand fire test," specially constructed, oven-dry douglas fir brands are added at 75 minute intervals after ignition until it is apparent that steady-state conditions have been attained. This is indicated by level temperature profiles on appliance surfaces and on surrounding combustibles. Figure 5 illustrates the construction of the brands.

The "flash fire test" is conducted as a continuation of the "brand fire test" to simulate overload conditions. Eight brands (as used for the "brand fire test") are stacked in the appliance at one time. Data are recorded until it is apparent that maximum temperatures have been attained.

5.2 Appliances

The five appliances tested were selected by their design and operating characteristics as being representative of those available in the marketplace. Obviously, with hundreds of manufacturers, it would be impossible to test every model. However, the appliances selected were chosen for the range of sizes and operating features available. A description of each appliance is included below and summarized in table 2.

<u>Appliance 1</u> is a small radiant room heater constructed of 6.4 mm (1/4 in) and 8 mm (5/16 in) plate steel for the top, sides, and bottom of the appliance. The inside of the fire chamber is lined with fire brick refractory. The door is cast iron with two draft inlets and draft control knobs to adjust the intensity of the fire. A 0.15 m (6 in) flue collar projects out the back of the unit and a sheet steel bottom heat shield is attached to block radiation from the appliance to the floor surface.

<u>Appliance 2</u> like appliance 1, is a small radiant room heater constructed of 6.4 mm (1/4 in) plate steel. The fuel loading door and flue collar are similar to appliance 1 except the door is on the right side of the appliance. On the front of the appliance is a high temperature glass window 0.15 x 0.44 m (6 x 17.5 in). Since the appliance is intended for installation on the hearth of an existing fireplace, the appliance is supported by a plate steel apron on three sides in lieu of legs to support the appliance. No heat shield is attached.

<u>Appliance 3</u> is a large radiant room heater similar in design and construction to appliance 1. The hearth area of this appliance is more than twice that of the smaller appliance 1. No heat shield is attached.

Appliance 4 is a free-standing fireplace stove--the traditional "Franklin stove," constructed of cast iron with double folding doors for the front of the appliance. A grate is supplied with the unit and was used for all tests. The flue collar, 0.2 m (8 in) in diameter, could be attached either to the back or the top of the appliance. For the tests reported herein, the flue collar was attached to the top of the appliance to allow testing at small wall/appliance clearances.

Appliance 5 is a circulating room heater, a radiant room heater with an exterior cabinet allowing air circulation around the appliance. The firebox is constructed of cast-iron with a sheet steel exterior cabinet. A thermostatically controlled damper controls the air supply for combustion. The flue collar attachment for a 0.15 m (6 in) flue is on the back of the appliance.

6. TEST RESULTS

Test measurements from all instruments used to monitor temperature, heat flux, and velocity in the 18 room experiments are presented in appendix A. Groups of measurements such as appliance surface temperature, wall surface temperature, wall studding temperature, floor surface temperature, sub-floor studding temperature, flue gas temperature, flue pipe surface temperature, heat flux, and flue gas velocity are plotted together. Each graph is labeled with the instrument identification (corresponding to the instrument identification as listed in table 1) and location. The graphs are arranged by test with a table of contents at the beginning of the appendix.

6.1 Appliance Temperatures

Measurements of appliance surface temperature, flue gas temperature, and flue pipe surface temperature during steady-state operation (the "brand fire test") and during overload conditions (the "flash fire test") are presented in table 4 for the 18 room experiments. Flue gas temperatures and flue pipe surface temperatures are also presented in figures 6 and 7, respectively, as profiles of temperature through the length of the flue.

6.2 Wall Temperatures

Measurements of wall surface temperatures are presented in table 4 for the 18 room experiments. Wall surface temperature profiles are presented in figures 8-12 for the five appliances tested and in figures 13 and 14 for the tests with wall insulation and with a front wall, respectively. These can be compared with figure 9 (tests with appliance 2 but without wall insulation or front wall) to see the effect of the insulation and reduced ventilation. Each graph presents a vertical profile of maximum steady-state temperatures for thermocouples along the appliance and flue centerline from the floor to the ceiling.

6.3 Floor Temperatures

Floor surface temperatures are listed in table 4 for the 18 room experiments. Figures 15-19 show floor surface temperature profiles for the five appliances tested. Floor surface temperature profiles for the tests with wall insulation and with a front wall are plotted in figures 20 and 21, respectively. Each graph presents a profile of maximum steady-state temperatures for thermocouples along the rear wall-appliance centerline from the rear wall forward to a distance of 1.22 m (48 in) from the rear wall.

7. ANALYSIS OF RESULTS

7.1 Appliance Temperatures

Appliance surface temperatures during steady-state operation in the 17 "brand fire tests" (not including test CLR10--the "log test") were similar for all five appliances tested. The steady-state maximum temperatures ranged from a low of 297°C (567°F) to a high of 436°C (817°F)--a range of only 139°C (250°F). The average maximum steady-state appliance surface temperature for the 17 "brand fire tests" was 374°C (706°F) with a coefficient of variation of 6%. Maximum overload temperatures for the appliance surface averaged 28% higher than the steady-state readings with an average maximum temperature of 480°C (896°F) and a higher coefficient of variation of 24%.

Appliance 5, the jacketed circulating heater exhibited temperatures on the outer surface of the jacket significantly lower than the other appliances. While firebox temperatures measured for appliance 5 were similar to those measured during tests of the other appliances, the jacket temperature, the surface radiating heat to surrounding combustibles, averaged only 135°C (275°F).

There was no significant coorelation between appliance surface temperature and clearance between the appliance and rear wall. For some appliances, the maximum steady-state appliance surface temperature was slightly higher at smaller clearances while for some appliances slightly lower. However, in all cases, these differences were small when compared to the maximum temperatures.

Flue pipe surface temperatures near the flue outlet of the appliance were similar to the appliance surface temperature. The average maximum flue pipe surface temperature for all 17 "brand fire tests" was 375°C (707°F), practically identical to the average maximum appliance surface temperature. Maximum average overload temperature was higher for the flue pipe surface than for the appliance surface--520°C (970°F). During the overload tests, it was evident that flames extended into the flue pipe, exposing the flue pipe to heating similar to the appliance surface. However, the lower mass of the flue pipe as compared to the appliances allows the flue pipe to react faster to the high intensity and relatively short duration of the overload test.

Effects related to the light weight of the flue pipe can also be seen in the flue gas temperatures in figure 6. Flue gas temperatures measured far downstream from the appliance flue outlet are nearly identical for all appliances. But for measurements closer to the flue outlet, the temperature naturally rises and the variation from appliance to appliance becomes greater. This effect is probably due to two sources. First, the higher temperatures of the flue pipe surface nearer the appliance are due not only to higher flue gas temperature but also to conduction down the length of the pipe from the massive appliance. Second, the lightweight pipe is more greatly affected by feedback radiation from the hot wall and hot appliance surface. This is evidenced by higher flue pipe surface temperatures at smaller flue pipe/wall clearances, an effect not noted in the appliance surface temperature measurements.

7.2 Wall Temperatures

Understandably, the wall surface temperature varied inversely with the clearance between the appliance and wall surfaces as illustrated in figure 22. For each appliance, the maximum steady-state wall surface temperature increased as the appliance/wall clearance decreased. Temperatures ranged from a low of 54°C (129°F) for appliance 1 at a clearance of 0.91 m (36 in) to a high of 189°C (372°F) for appliance 4 at a clearance of 0.15 m (6 in). In test CLR11 [appliance 4 at 0.15 m (6 in)], the wall ignited soon after the beginning of the overload test charring the wood studding behind the wallboard before the fire was extinguished. While the appliance, installed at this clearance, was clearly installed improperly, the result demonstrated the consequences of insufficient clearances between an appliance and surrounding combustibles.

For tests at an appliance/wall clearance of 0.91 m (36 in), the highest wall temperatures were noted surrounding the metal thimble used to pass the single wall flue pipe through the wall. The thimble, 0.46 m (18 in) larger in diameter than the pipe passing through it, still allows the minimum clearance between the hot pipe surface and the wall surface for large appliance/wall clearances (see figures 8-12). For appliance/wall clearances less than 0.91 m (36 in), the highest wall temperatures were noted behind the rear of the appliance. At these reduced clearances, the combined heating by the lower portion of the flue pipe and the large surface area of the appliance adjacent to the wall surface contribute to raising the temperature of the wall surface. For appliance 4, the added effects of heating by the flue pipe were not noted. Since the flue outlet on appliance 4 was on the top surface of the appliance, the flue pipe surface was always further away from the wall than the appliance surface. Thus, for appliance designs where the flue outlet is in the rear of the appliance, the clearance between the flue pipe and wall surface is important in addition to the clearance between the appliance and wall surface.

Two other factors, in addition to the appliance/wall clearance, which are important to the temperatures attained on wall surfaces are apparent: appliance design and appliance size.

For the three different designs of appliances tested in this study, the fireplace stove exhibited the lowest temperatures on the wall surfaces, followed by the circulating heater and finally the highest temperature by the radiant room heaters. This ranking by appliance design also corresponds to a ranking by average flue gas velocity for the different appliance designs. The lowest flue gas velocities were noted for the radiant appliances (see appendix A--velocity plots and appendix B--average steady-state velocity, instrument VEL 84) followed by the circulating heater and finally the highest flue gas velocity with the tests involving the fireplace stove. This is not a surprising finding since the higher flue gas velocity is an indicator of the amount of excess air, an important parameter in determining the efficiency of an appliance in delivering heat to a room [40].

Within a given appliance design, the size of the appliance can have a significant effect on temperatures attained on wall surfaces. For the three radiant room heaters tested, the wall surface temperatures were directly related to the size of the appliance as shown in the following data:

Appliance	Back Surface Area[a]	Average Steady-State Temperature[b]
	(cm^2)	(°C)
1	2032	65
2	3319	96
3	2942	95

[a] Area of the back surface of the appliance parallel to the rear wall of the test enclosure.

[b] Average maximum steady-state rear wall surface temperature for tests at 0.91 m and 0.46 m.

The difference between maximum steady-state wall temperatures and maximum overload wall temperatures as indicated in table 4 ranges from as little as 29°C for test CLR08 with appliance 4 to as much as 253°C (455°F) when the wall ignited during test CLR11. The magnitude of the difference depended on the wall/appliance clearance. Wall temperatures were raised more by the overload conditions during tests at smaller clearances than during tests at the larger clearances. As an example, consider tests CLR01, CLR02, and CLR03 for appliance 1. At clearances of 0.91 m, 0.62 m, and 0.46 m (36 in, 24 in, and 18 in), the difference between maximum steady-state and maximum overload wall temperatures were 40°C, 64°C, and 99°C (72°F, 115°F, and 178°F), respectively. Maintaining proper clearances between appliance surfaces and wall surfaces thus becomes even more critical at the higher firing rates of the overload tests.

The maximum wall temperatures during steady-state operation and during overload can also be compared to the generally accepted upper limits for wall temperatures as noted in section 2.4. Table 5 presents the maximum temperature rise above room temperature for the 18 room experiments. Wall temperatures at a clearance of 0.91 m (36 in) were within accepted limits. However, at clearances below 0.91 m (36 in), wall temperatures exceeded the recommended limits.

7.3 Floor Temperatures

Temperatures measured on floor surfaces during steady-state operation varied from appliance to appliance. Like the wall temperatures, two factors are apparent: 1) appliance/floor clearance and 2) appliance size. Since the appliance/floor clearance and appliance bottom area did not vary as much as wall clearances and appliance rear surface area, the effects were not as large. Floor temperatures measured during tests of appliance 1 were considerably lower than those measured during tests of the other appliances. From table 4, the average floor surface temperature during steady-state operation of appliance 1 was 69°C (156°F) while it was 125°C (257°F) during tests of the other appliances. Appliance 1 was equipped with a radiation shield between the bottom surface of the appliance and the floor surface. Clearly, this is an effective method to limit floor temperatures to acceptable levels.

For some appliances, the floor temperature increased as the clearance between the appliance and rear wall was reduced. However, this effect was not noted for appliance 1, again pointing out the merits of the radiation shield.

Overload temperatures on floor surfaces averaged only 14°C (26°F) higher than those measured during steady-state operation, with some measurements actually lower during overload than during steady-state.

7.4 Wall Insulation

The three tests with wall insulation applied, tests CLR14, CLR15, and CLR16, were conducted to ascertain any effects of the change in room construction and gain information on any increased fire risk due to the use of the insulation. Wall surface temperatures for tests with and without wall insulation conducted using appliance 2 can be noted from table 4 as:

Clearance (m)	Temperature Without Insulation (°C)	Temperature With Insulation (°C)
0.91	74	96
0.46	117	142

Wall surface temperatures during tests with wall insulation were approximately 20°C (36°F) higher than those measured without the insulation. The use of insulation provides a more severe testing requirement than testing without the insulation.

Temperatures measured on wall studding surfaces show an even larger effect:

Clearance (m)	Temperature Without Insulation (°C)	Temperature With Insulation (°C)
0.91	55	80
0.46	64	128

7.5 Tests With Front Wall

In two tests, CLR17 and CLR18, a front wall was erected on the test enclosure to study conditions in this reduced ventilation environment. An opening in the wall the size of a standard doorway was provided.

Comparing tests CLR17 and CLR18 with tests CLR15 and CLR16 (tests without a front wall), some similarities and some differences are apparent. From table 4, steady-state temperatures on appliance, wall, and floor surfaces were similar at both clearances of 0.91 m (36 in) and 0.46 m (18 in). Overload temperatures on wall and floor surfaces were higher in tests CLR17 and CLR18 (with front wall) than in tests CLR15 and CLR16 (without front wall). The rapid heat buildup during the overload tests could not be carried away as quickly with the reduced ventilation available in tests CLR17 and CLR18.

7.6 Log Tests

In order to compare the results of tests conducted with the standardized douglas fir brands with those utilizing a more realistic fuel source, a test was designed using seasoned oak logs. While no specific size of logs were used, the logs were cut to an appropriate length for each appliance--approximately two-thirds the length of the appliance floor surface. Each appliance was instrumented with thermocouples in the same configuration as used in the room experiments. Each test was continued until steady-state conditions were obtained with fuel added at fixed intervals--either 15 minutes or 30 minutes. Maximum temperatures were recorded for each instrument.

Table 6 presents the results of the 10 experiments. Figure 23 compares the results obtained from the brand test for steady-state and for overload operation with the results from the 15-minute and 30-minute log test. Several interesting observations can be made from this figure. Appliance 1 shows a close similarity for all four tests. This indicates that the rate of consumption of the fuel is fairly even. For appliance 2, however, the air inlets can be opened further permitting more air for combustion than appliance 1. Thus, the more fuel available in the log tests allowed somewhat higher temperatures to be attained. For the other three appliances, the log tests resulted in lower temperatures because of the limited air supply available for combustion. The shape and construction of the brands helped them to burn easily and attain steady-state in a shorter time period.

It can also be noticed that the 15-minute feeding interval resulted in higher temperatures than the 30-minute feeding interval due to the increased amount of fuel available.

7.7 Measurement Technique

Measuring surface temperature is not as simple as it looks. Comparing floor surface and floor studding temperatures for steady-state operation from table 4, measured studding temperatures were indicated as higher than floor surface temperatures in three tests--CLR01, CLR11, and CLR13. Surface thermocouples were mounted in these tests with the bead touching the surface with a small loop in the thermocouple wire to insure good contact with the surface. Studding temperatures were measured with the thermocouple mounted flat, sandwiched between the floor and stud. Some laboratory tests were conducted to see how these different mounting techniques affected the readings. A test was designed for this purpose.

A 10.2 x 10.2 x 1.27 cm (4 x 4 x 1/2 in) plywood specimen was placed 12.7 cm (5 in) in front of a 30.5 x 30.5 cm (12 x 12 in) electric radiant panel. Both were surrounded by a calcium silicate box to minimize unwanted drafts. Four thermocouples were placed at the horizontal centerline of the plywood, separated from each other by 0.63 cm (1/4 in). The radiant panel with a voltage-controlled blower attached was used to deliver different heating rates and airflows to the specimen (figure 24).

The first set of tests were run using different airflows and four different thermocouple mountings: first, the bead touching the surface in a loop; second, the bead touching the surface completely flat; third, a small hole was punched into the surface and the bead was placed in it, also in a loop; and finally, the bead was placed in the air, about 0.63 cm (1/4 in) from the surface. The four thermocouples were mounted identically and a set of replicates were run for a total of eight individual readings for each test. The radiant panel was heated to a constant temperature. The specimen was left in front of the radiant panel until steady-state was achieved with no forced airflow and the temperatures recorded. Then air was blown at different rates of 0.05, 0.10, 0.15, and 0.20 m/sec (10, 20, 30, and 40 ft/min) allowing it to obtain steady-state. This procedure was done with each type of mounting. More tests were run at different radiant panel temperatures, following the same procedure. Figure 25 shows the results obtained when the temperature recorded from the thermocouple mounted flat, in hole and with loop was subtracted from the temperature recorded by the one in the air and plotted against the different airflows for two different radiant panel temperatures: 260°C and 677°C (500°F and 1250°F). It can be noticed that at low temperatures the differences are rather small and are not affected very much by the changing airflow. But at high temperatures, those differences vary between 20 to 50°C (70 to 125°F). Tests run with a radiant panel temperature of 399°C (750°F) showed temperatures similar to those obtained in the brand tests conducted with the woodstoves. The difference between the thermocouple mounted flat and the one mounted with a loop ranged from 20 to 40°C (70 to 105°F). This shows that the temperature indicated by the thermocouple could be affected significantly by airflows.

Another series of tests were run, but this time the four thermocouples were mounted two in a loop and two flat to the surface with no airflow. The radiant panel temperature was raised and the readings obtained from the thermocouple were recorded. The results were plotted and were found linear.

The same arrangement was used again, but the plywood was placed 45.7 cm (18 in) from the radiant panel. Results were plotted and also were linear but the slope was nearer to the ideal 1:1 curve. Thus, a calibration curve can be made by plotting the temperatures mounted flat vs. temperatures mounted with loop (figure 26). If the critical range of 70 to 120°C for the thermocouple mounted with loop is examined in this figure against temperatures measured with the thermocouple mounted flat, the difference at 12.7 cm (5 in) is between 20 to 45°C (36 to 80°F) while at 0.46 m (18 in), the range is between 15 to 30°C (27 to 54°F).

Thus, airflow and mounting technique can significantly affect the temperature indicated by a surface mounted thermocouple. The thermocouple mounted flat with no airflow gave the highest indicated temperature and thus is the most severe and conservative of the techniques tested for use with standard test methods. However, data collected by different mounting techniques can easily be compared with the development of calibration curve comparing the techniques.

8. THEORETICAL TEMPERATURE PREDICTION

A theoretical model for predicting the heat transfer between the appliance or flue pipe surface and the wall or floor surface can be a useful tool not only in design of equipment but also in the design of future experiments to study clearances and reduced clearances for wood-burning appliances. The theoretical models discussed in section 2 are compared below with experimental results obtained during the steady-state brand tests. The following assumptions apply:

- the system is at steady-state (heat gain equals heat loss);

- the appliance and/or flue pipe are at one constant, uniform temperature; and

- the wall surface, back wall surface and surroundings are each at constant, uniform temperatures.

Figure 27 illustrates the heat transfer model.

8.1 Heat Transfer From Flue Pipe Surface

Figure 28 presents the results of these calculations for a flue pipe 0.15 m (6 in) in diameter configured similarly to the room experiments. Calculated wall surface temperatures are presented as a function of clearance between the flue pipe and wall surface for flue pipe surface temperatures from 100 to 500°C (212 to 932°F). In these calculations, the ambient air temperature and back wall surface temperature were taken to be 25°C (77°F). From these curves, it is evident that flue pipe surface temperatures higher than 250 to 300°C (480 to 570°F) would lead to wall surface temperatures exceeding the recommended limits of 50°C (90°F) above room temperature at a clearance of 0.46 m (18 in).

Table 7 presents a comparison of wall surface temperatures measured opposite the midpoint of the vertical section of flue pipe with calculated values. For prediction of wall surface temperatures adjacent to flue pipe surfaces, the following data were used:

• flue pipe surface temperature:	TC 72
• wall surface temperature:	TC 20
• wall rear surface temperature:	TC 40
• room ambient air:	TC 00
• air temperature near wall rear surface:	ambient temperature at beginning of test.

Average steady-state temperatures were taken from appendix B for all data.

Since these calculations assume the wall receives no heat from the appliance--only from the section of flue pipe adjacent to the wall surface, it would be expected that predicted values would be low. In fact, predicted wall temperatures averaged 12% lower than the measured temperatures. This points out three limitations to the calculations: 1) even at points on the wall opposite the flue pipe, the heat generated by the appliance can affect the wall temperature; 2) neither the flue pipe nor the wall are in reality at a uniform temperature; and 3) the calculations are very sensitive to the clearance between the flue pipe and wall--a change of only 2.5 cm (1 in) in clearance changes the calculated temperature by about 8%.

8.2 Heat Transfer From Appliance Surface

Figure 29 shows calculated wall surface temperatures as a function of appliance/wall clearance for a medium size appliance [area of appliance side parallel to wall of 0.26 m^2 (400 in^2)] for appliance surface temperatures from 100 to 500°C (212 to 932°F). As with the flue pipe calculations, the ambient air temperature and back wall surface temperature were taken to be 25°C (77°F). At an appliance clearance of 0.91 m (36 in), appliance temperatures higher than 300 to 350°C (570 to 660°F) would lead to temperatures on the wall in excess of recommended limit of 50°C (90°F) above room temperature.

A comparison of wall surface temperatures measured opposite the appliance during the steady-state tests and calculated values are presented in table 8. For prediction of wall surface temperatures adjacent to appliance surfaces, the following data were used:

- appliance surface temperatures: average of appliance surface temperatures excluding floor and door
- wall surface temperature: TC 15 or TC 18
- wall rear surface temperature: TC 42
- room ambient air: TC 00
- air temperature near rear wall surface: ambient temperature at beginning of test.

Average steady-state temperatures were taken from appendix B for all data.

As with the calculations for the flue pipe, the predicted wall temperatures assume heat transfer from the appliance to the wall only--with no contribution from the flue pipe. While the calculated values averaged 2% lower than the measured temperatures, there was considerably more spread in the variation than in the flue pipe calculations--ranging from 18% low to 18% high. A number of factors could account for this. Perhaps most importantly, the assumption that the appliance surface is at one uniform temperature is clearly a gross oversimplification. However, it would be extremely difficult both to measure the time dependent temperature distribution on the appliance surface as well as to incorporate this into the calculations.

9. CONCLUSIONS

A total of 28 tests were conducted on five wood-burning appliances of differing designs. In these tests, a total of more than one-half million individual readings of temperature, heat flux, or velocity were obtained. Two series of tests were conducted:

- full-scale room experiments where measurements of appliance temperature and surrounding surface temperature were obtained using a standard wood brand as fuel, and

- "log tests" where seasoned oak logs were used as a fuel source to compare with a standard wood "brand" fuel source. Only appliance surface temperature and flue gas temperature were monitored in the "log tests".

Some conclusions from these tests were apparent:

- Appliance firebox surface temperatures measured during steady-state operation were very similar for all five appliances tested. For appliance 5, a jacketed circulating room heater outside jacket temperatures were lower. No correlation was found between appliance surface temperature and clearance between the appliance and wall surfaces.

- The temperature of the lightweight single wall flue pipe used for testing was more greatly affected by the clearance between the pipe and wall surface an effect not noted for the appliance surface temperature measurements.

- Understandably wall surface temperatures were found to vary inversely with the clearance between the appliance and wall surface. Wall temperatures as high as 189°C were recorded (for an improperly installed appliance).

- Appliance design and appliance size were found to affect temperatures on wall surfaces.

- Due to the small clearances between appliances and flooring, temperatures developed on unprotected floor surfaces were typically higher than wall temperatures during the tests.

- Wall surface temperatures and interior wall studding temperatures were considerably higher during tests with wall insulation or with a front wall than without.

- Average maximum appliance surface temperatures measured during tests using seasoned oak logs as the fuel source were similar to those developed during the "brand" tests.

- Theoretical calculations of wall surface temperature agreed within an average of 10°C with measured wall temperatures. Individual calculation agreement, however, ranged from excellent to poor.

Three specific recommendations can be made based on the results of these tests:

- Current codes for the installation of appliances are based in part on data developed in 1943 by Underwriters Laboratories. Comparing the UL data with requirements in the NFPA code, the requirements were based on appliance surface temperatures ranging from 315°C (600°F) for unprotected surfaces to 480°C (900°F) and above for various protection methods. Clearly, the appliances tested here can easily exceed the lower limitation for extended periods of time. Based on the tests reported herein, a more appropriate limit would be closer to 400°C (750°F).

- Floor protection is clearly an important area that should be addressed specifically in the codes.

- Due to the higher temperatures developed during tests with wall insulation, it may be appropriate to modify current test procedures to include "typical" insulation of walls in the test enclosure.

This is a report presenting information on research ongoing at the Center for Fire Research at the National Bureau of Standards related to wood-heating safety. As such, it provides information on only a part of the research program. Future reports will be forthcoming on other areas of research including chimney creosoting and chimney fires; reduced clearances with protection and fireplace inserts.

10. ACKNOWLEDGEMENTS

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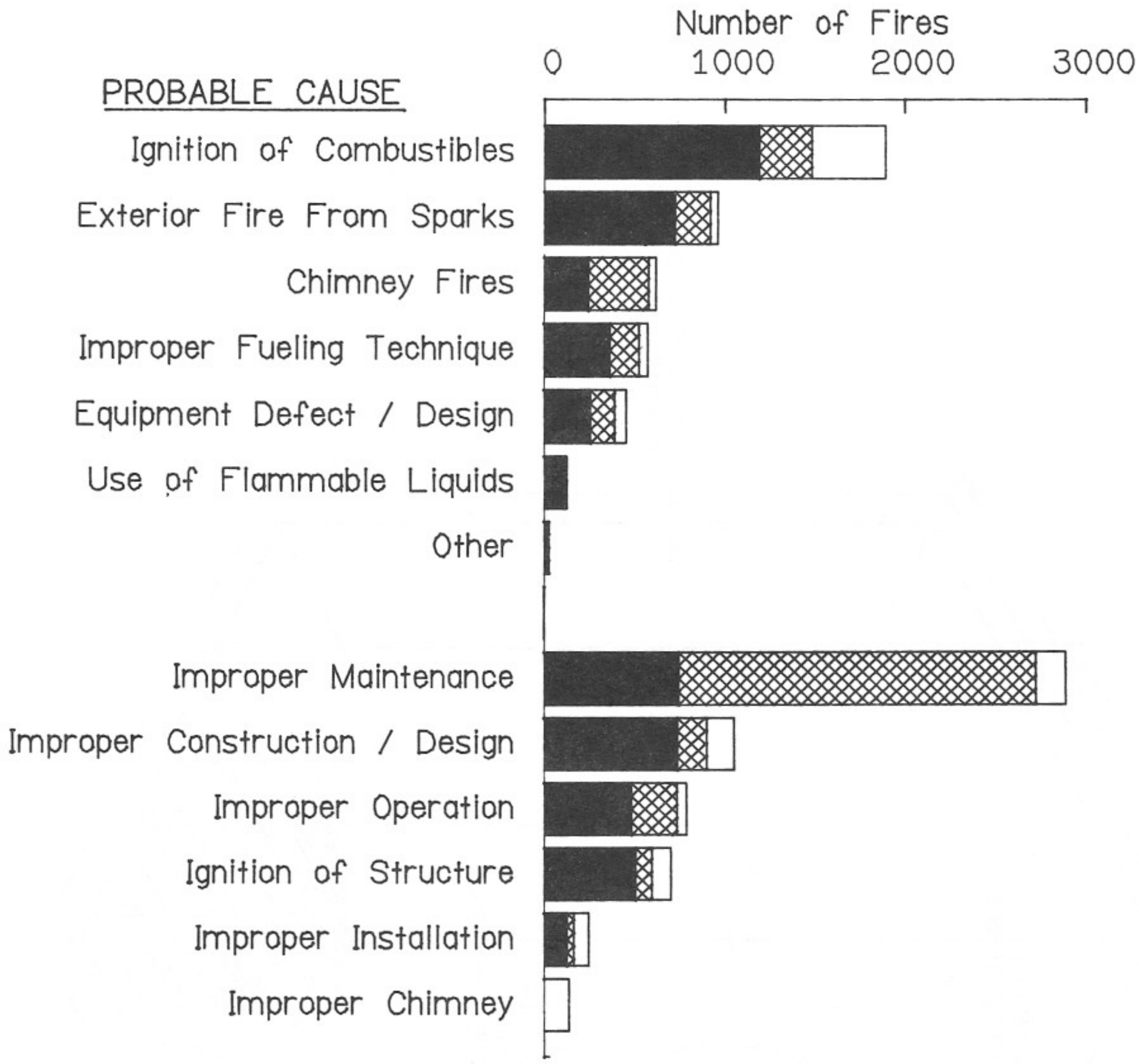
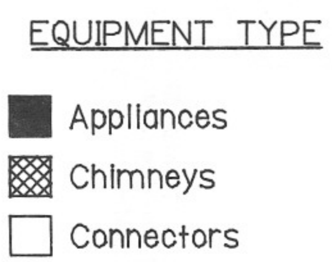


Figure 1: Breakdown of fire incidents by probable cause and equipment type as recorded in NFIRS fire incident data



SOURCE: USFA NFIRS Data Base

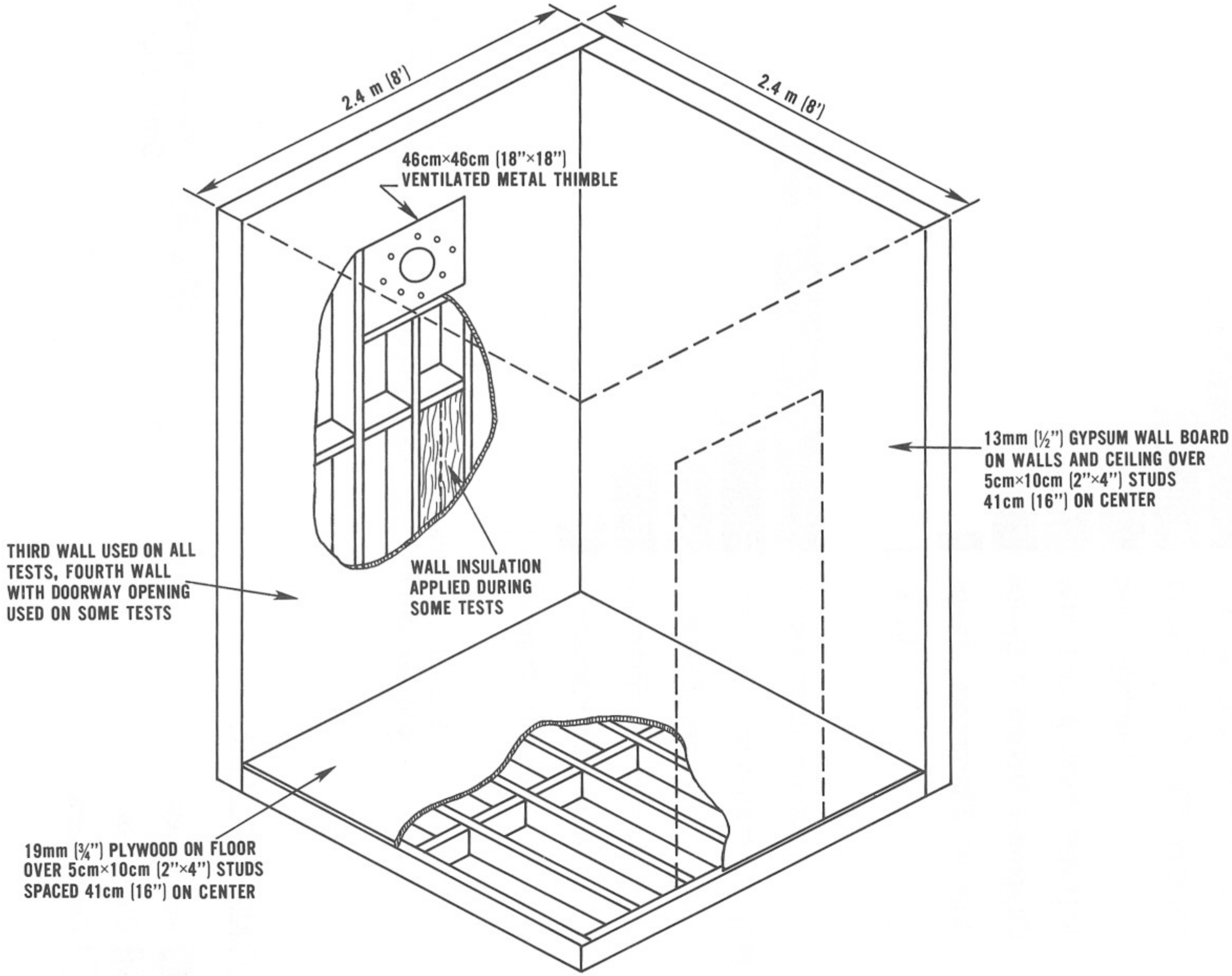


Figure 2. Construction of test enclosure used in room experiments.

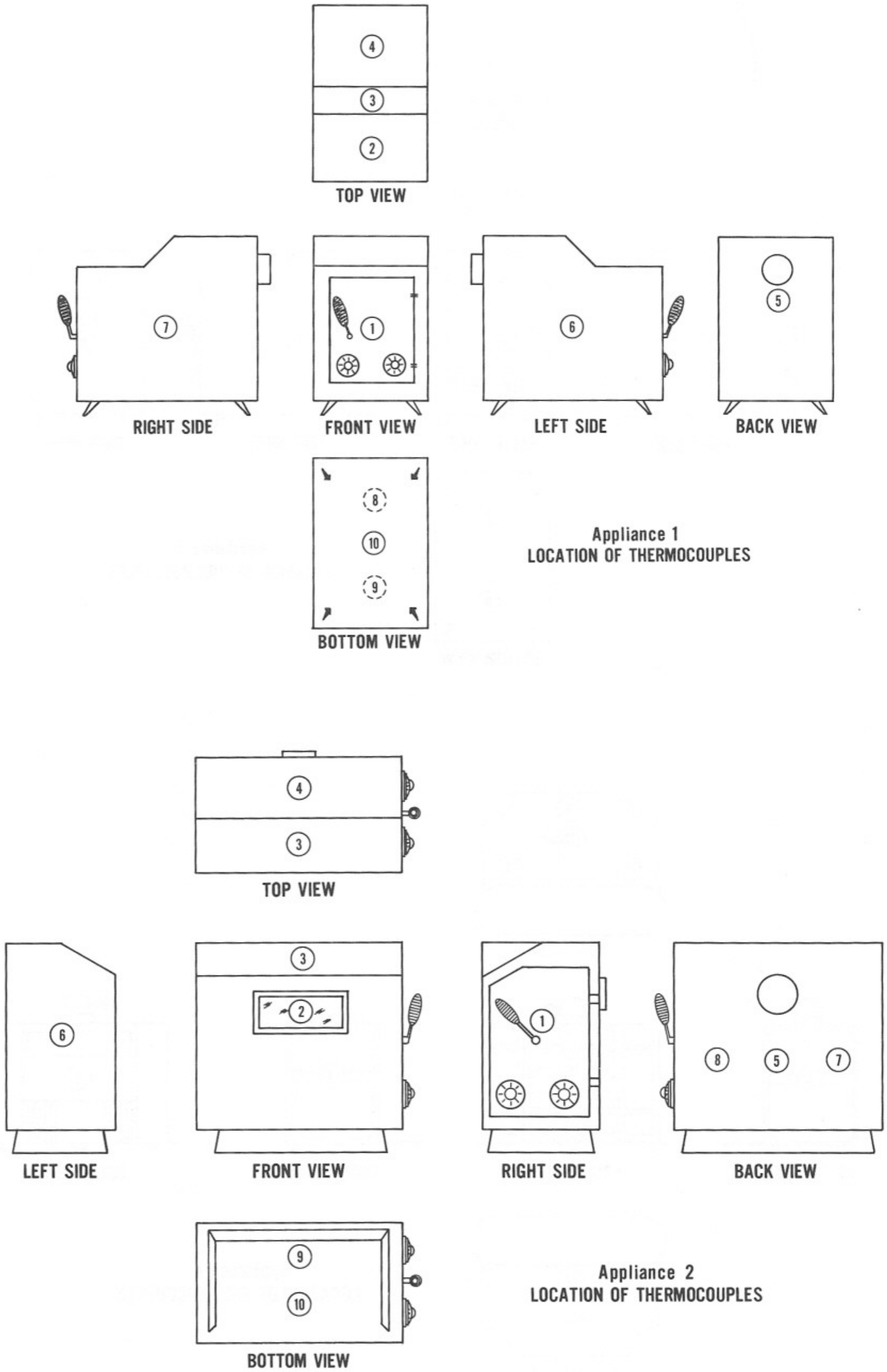
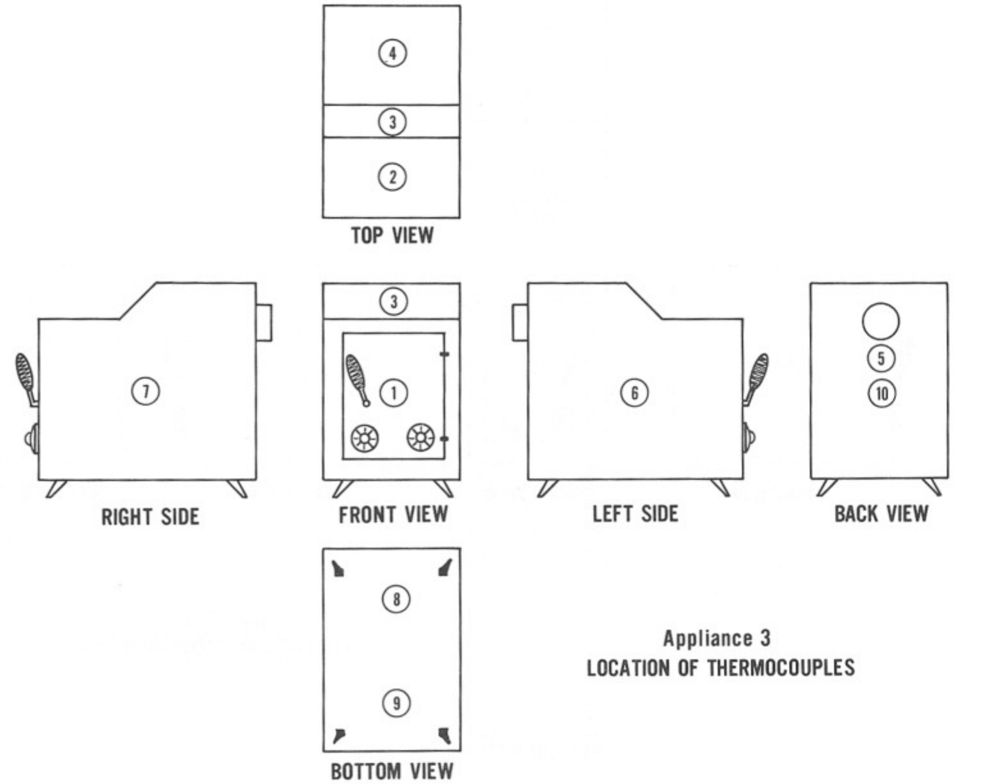


Figure 3. Instrumentation locations for appliance measurements in room experiments.



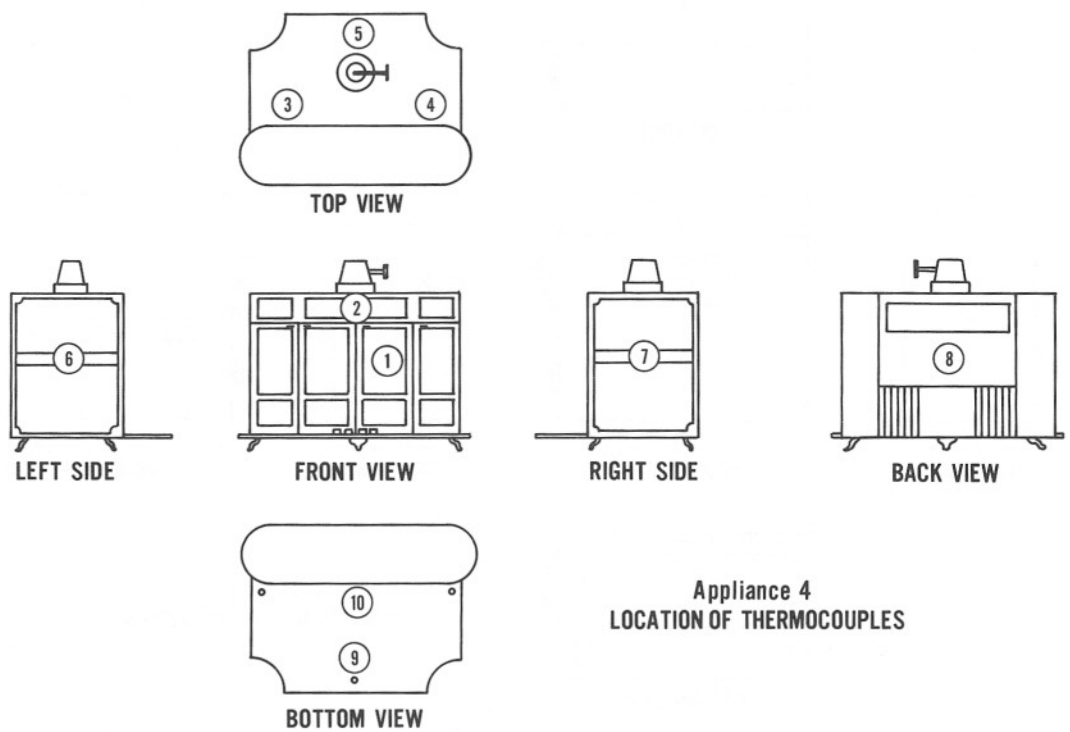


Figure 3. Instrumentation locations for appliance measurements in room experiments (con't).

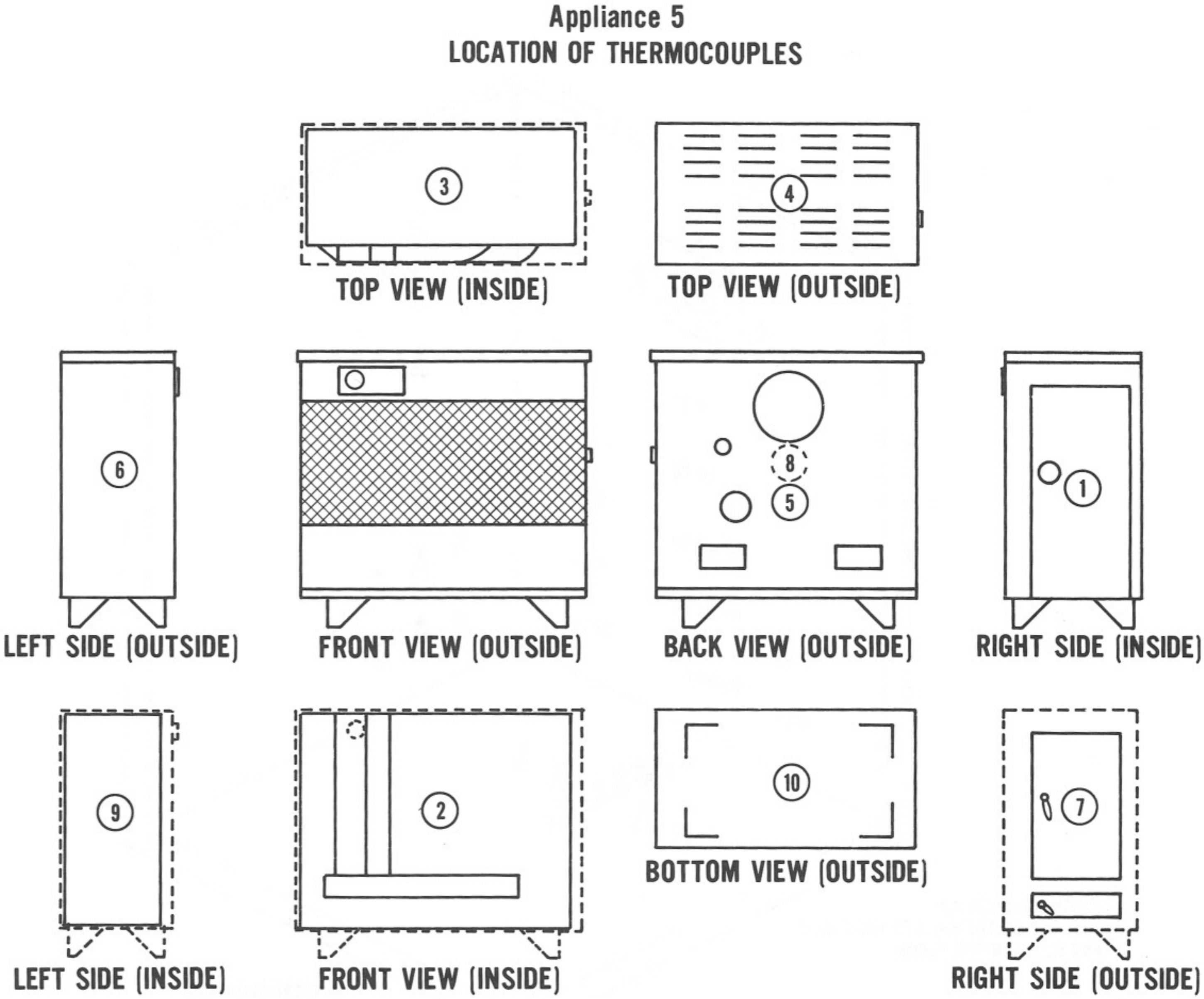


Figure 3. Instrumentation locations for appliance measurements in room experiments (con't).

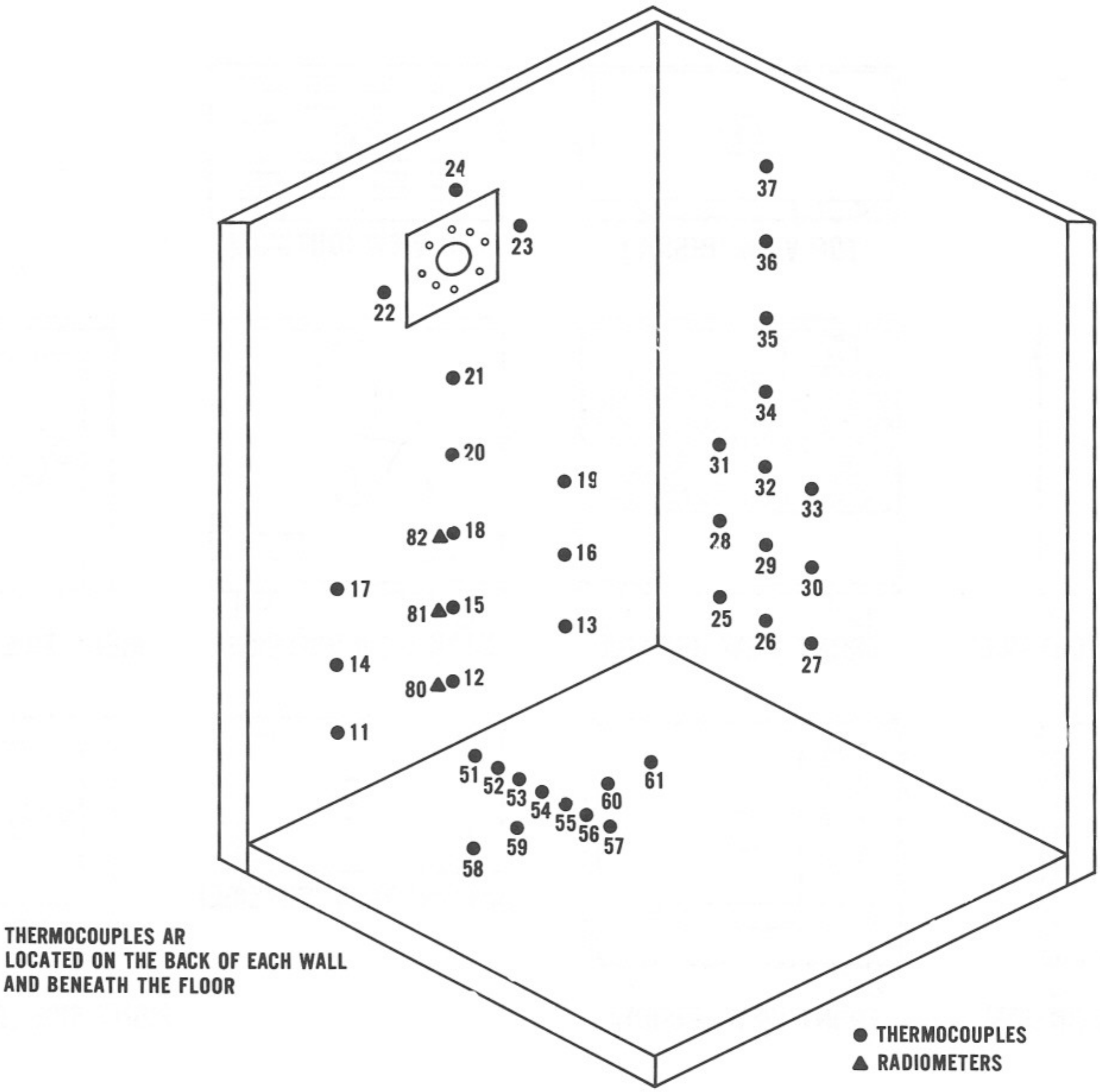


Figure 4. Instrumentation locations for test enclosure measurements in room experiments.

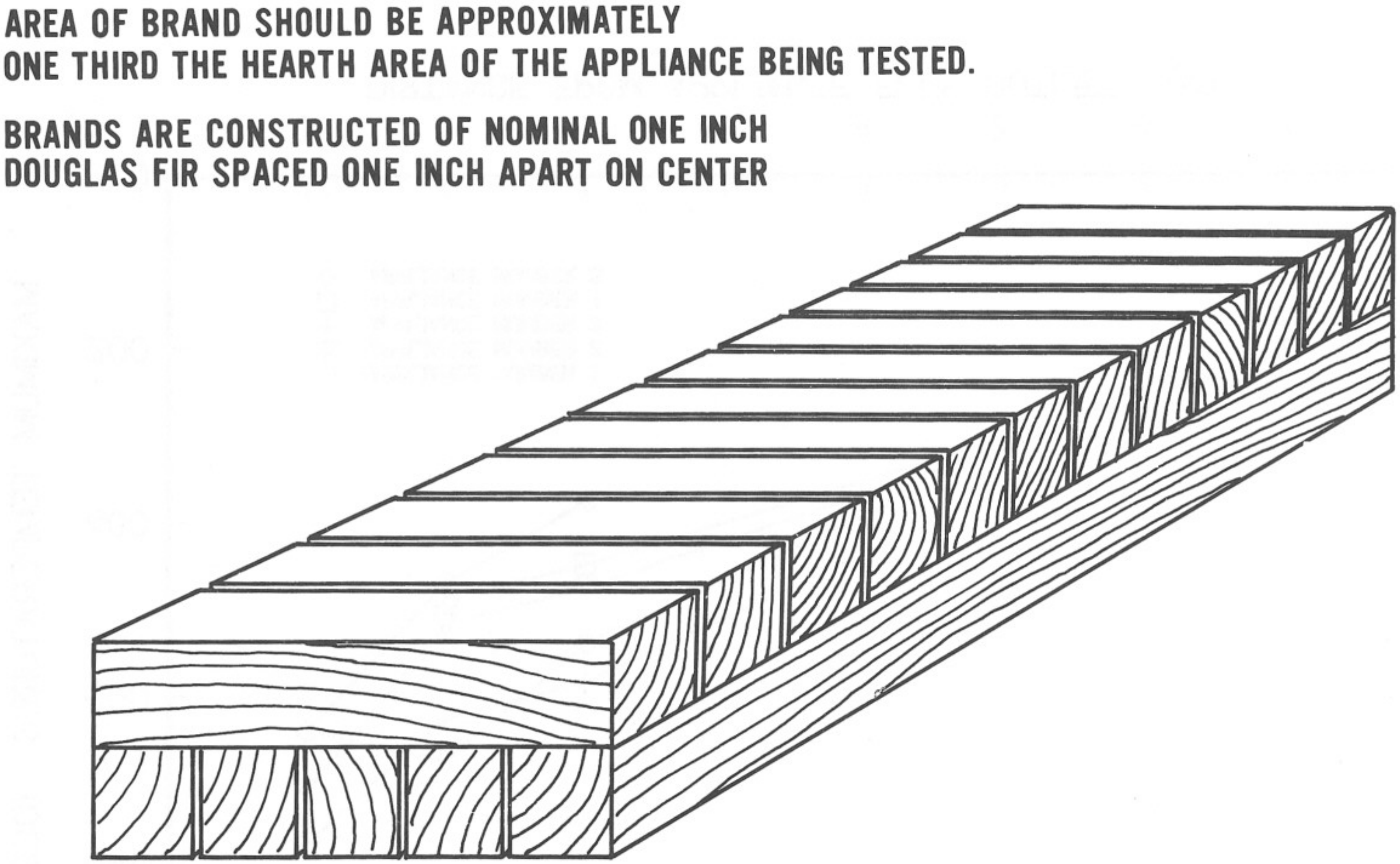


Figure 5. Construction of "brands" used in room experiments.

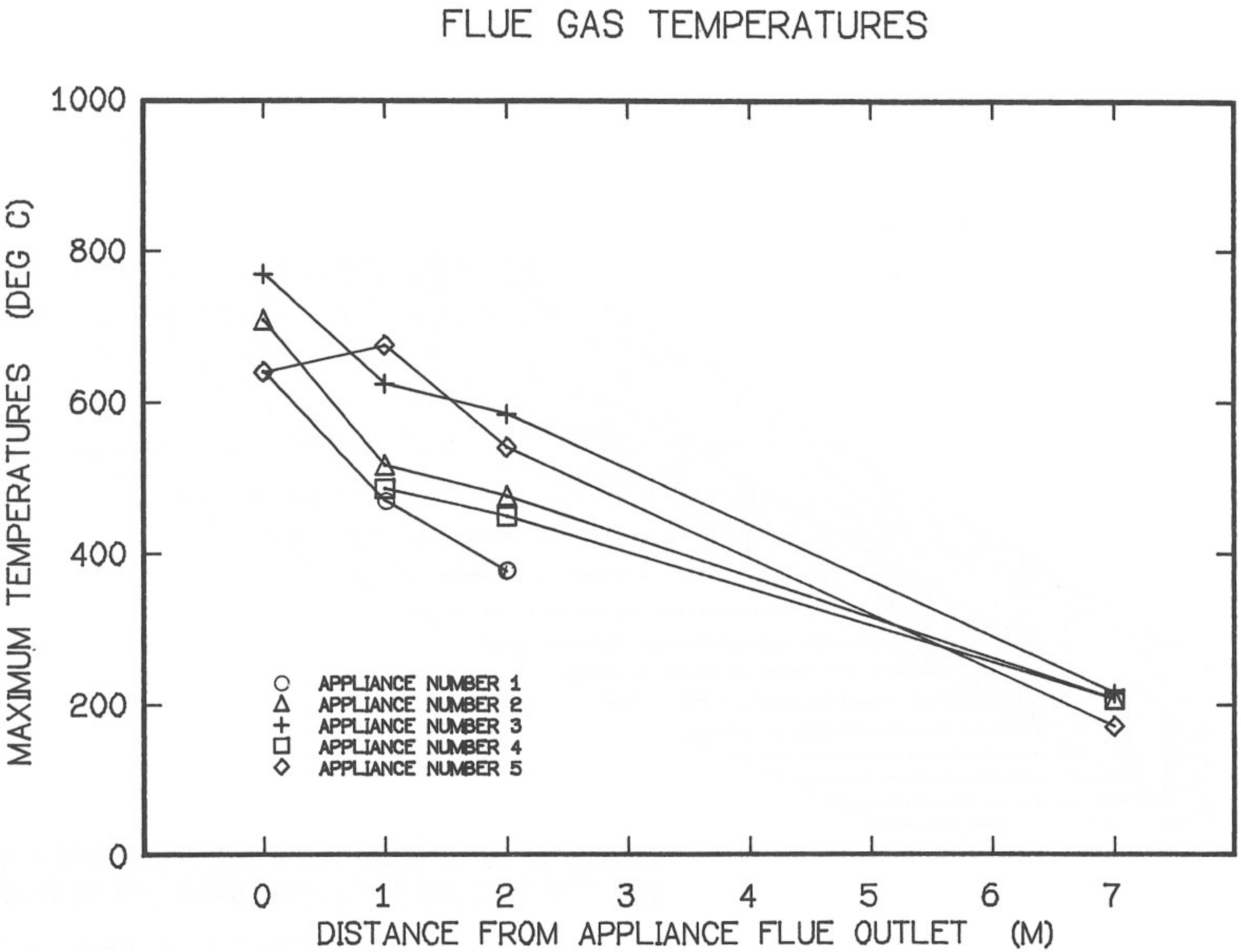


Figure 6. Flue gas temperatures measured during tests of several wood-burning appliances.

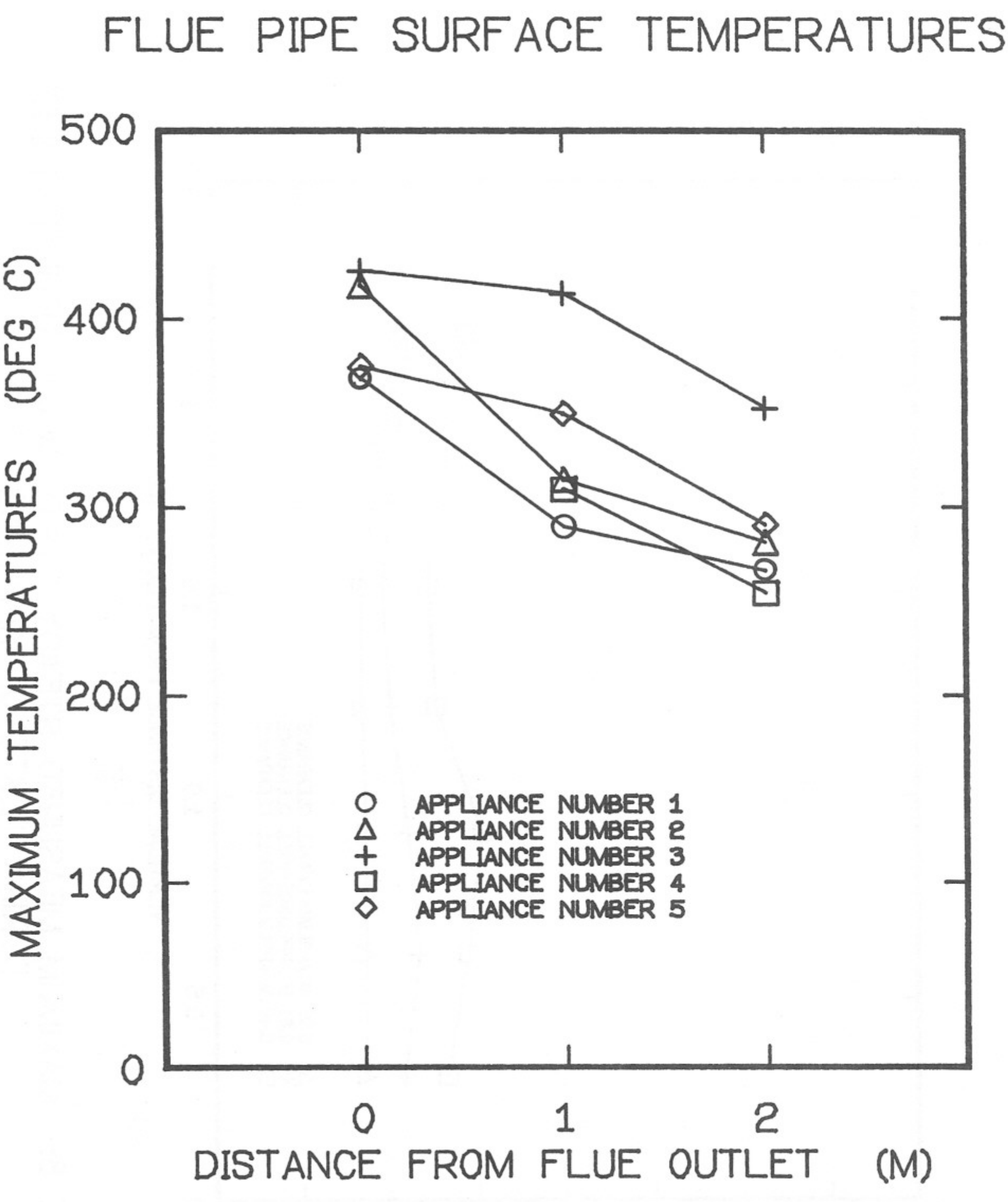


Figure 7. Flue pipe surface temperatures measured during tests of several wood-burning appliances.

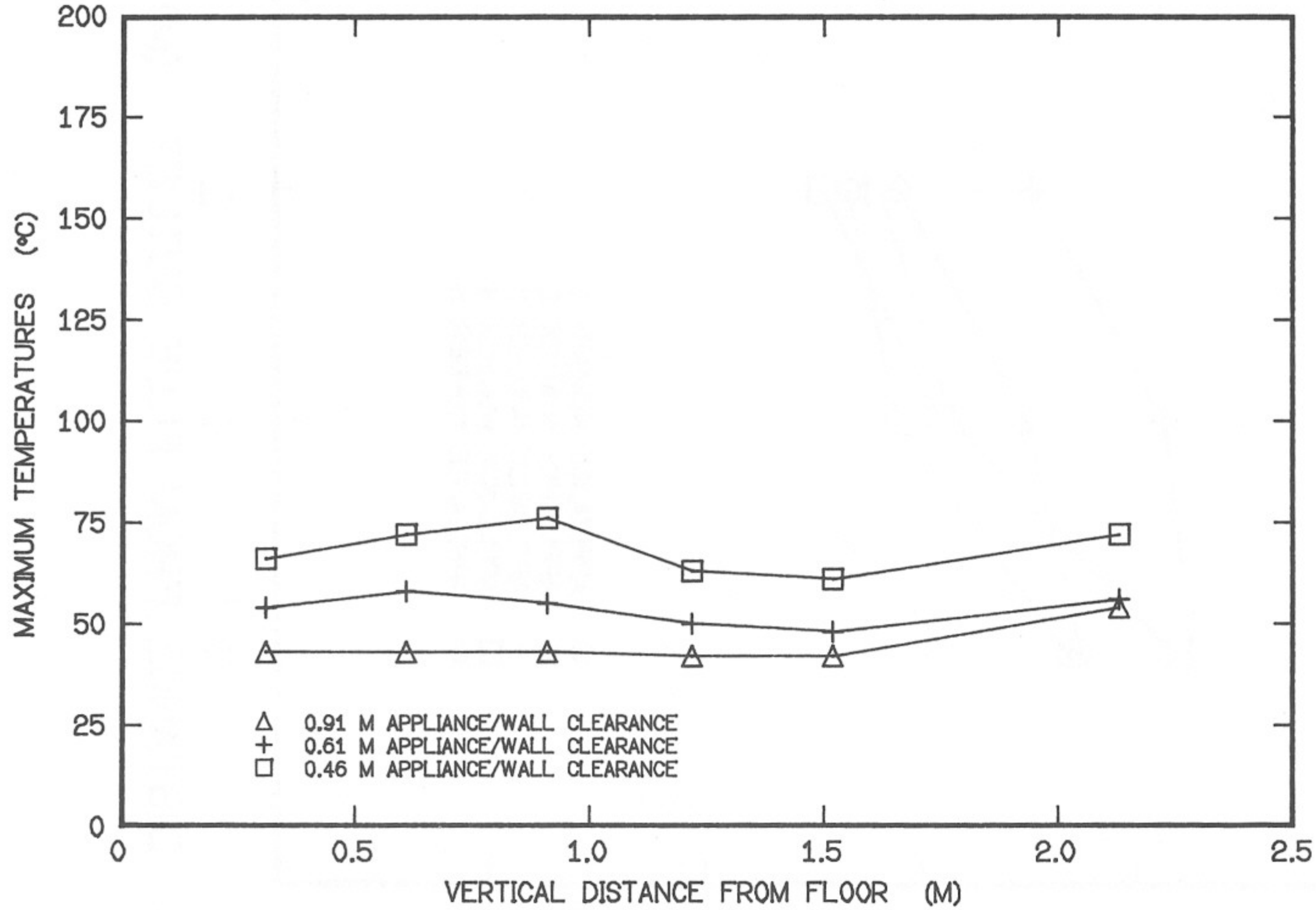


FIGURE 8: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS OF APPLIANCE 1

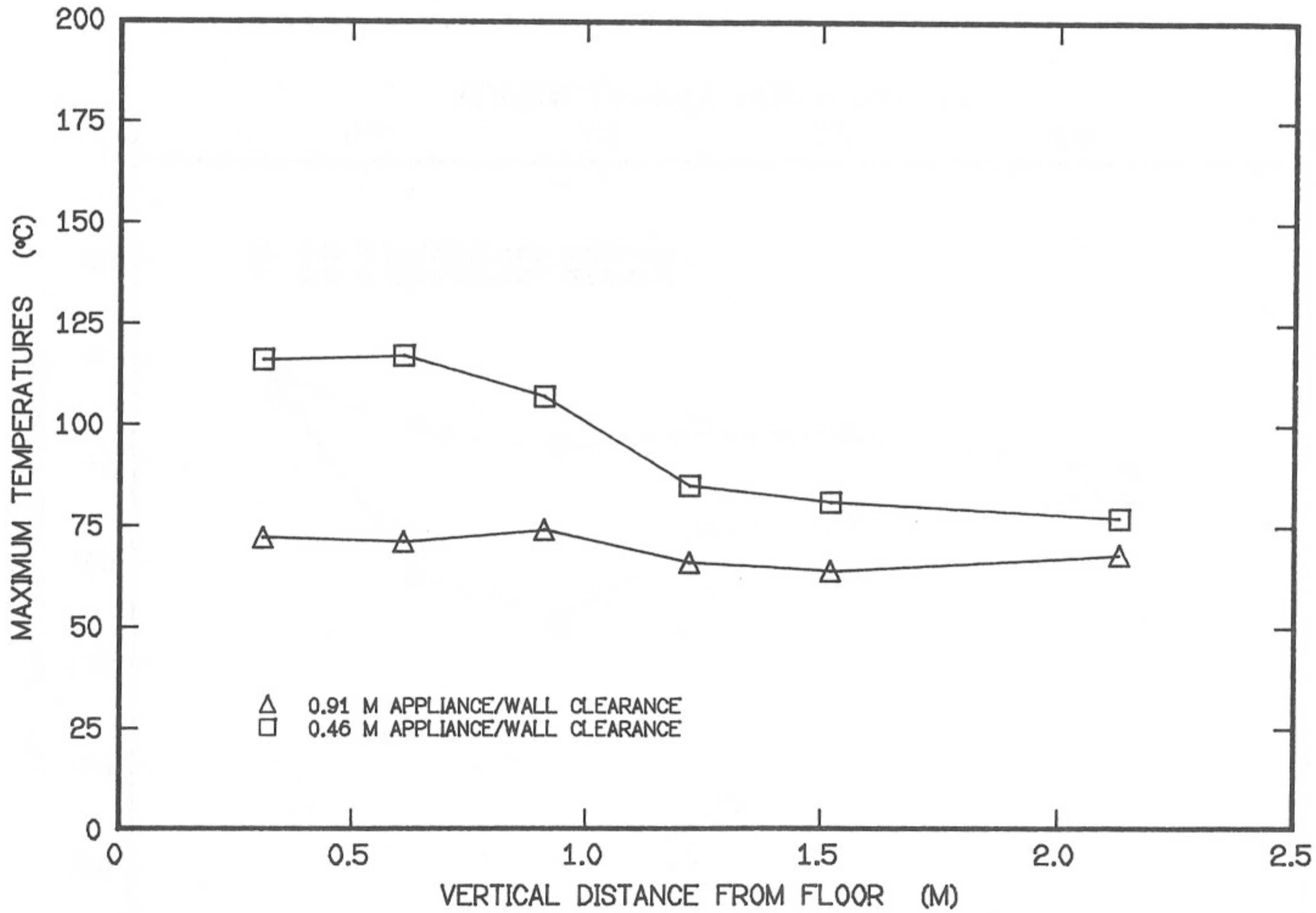


FIGURE 9: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS OF APPLIANCE 2

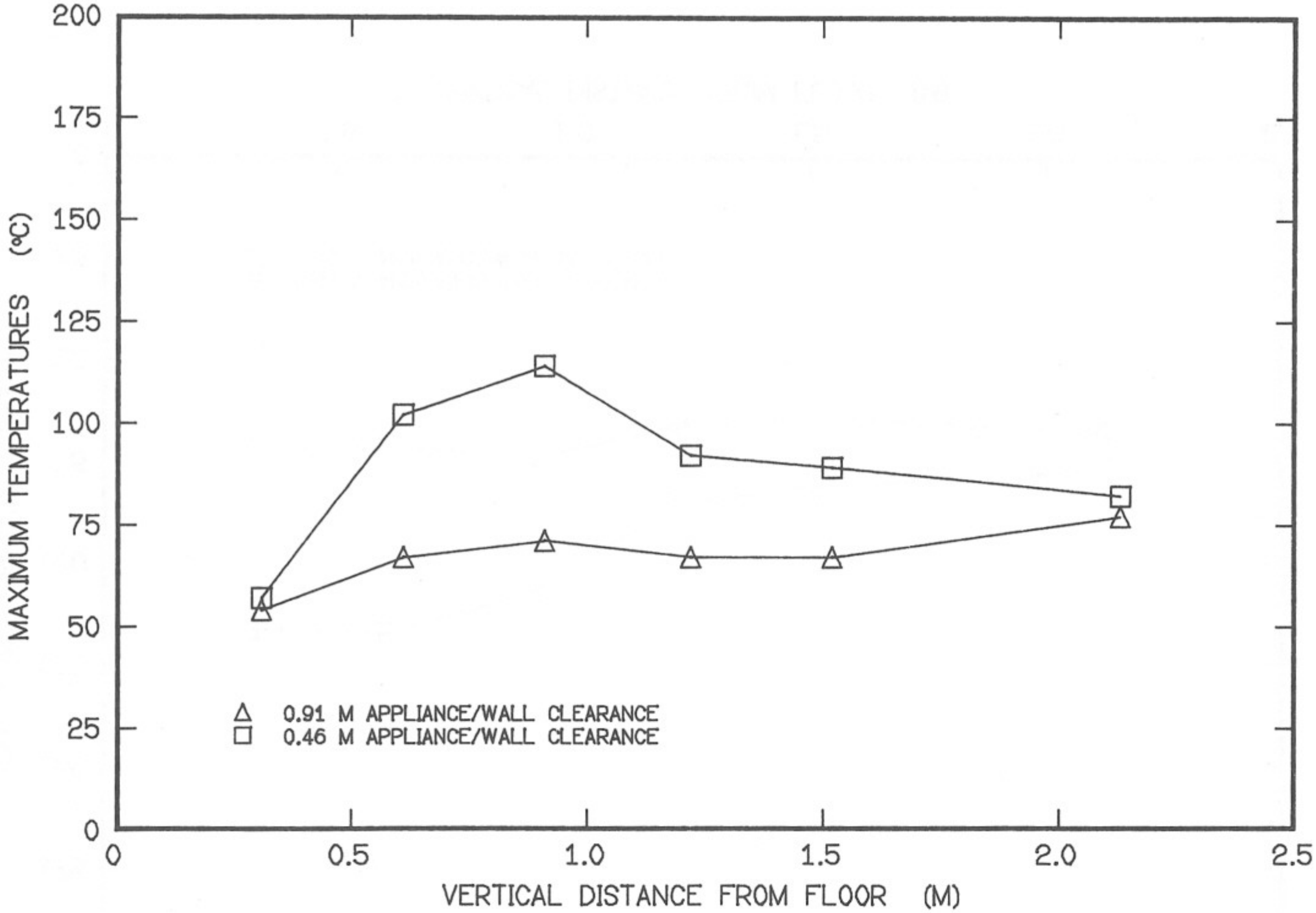


FIGURE 10: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS OF APPLIANCE 3

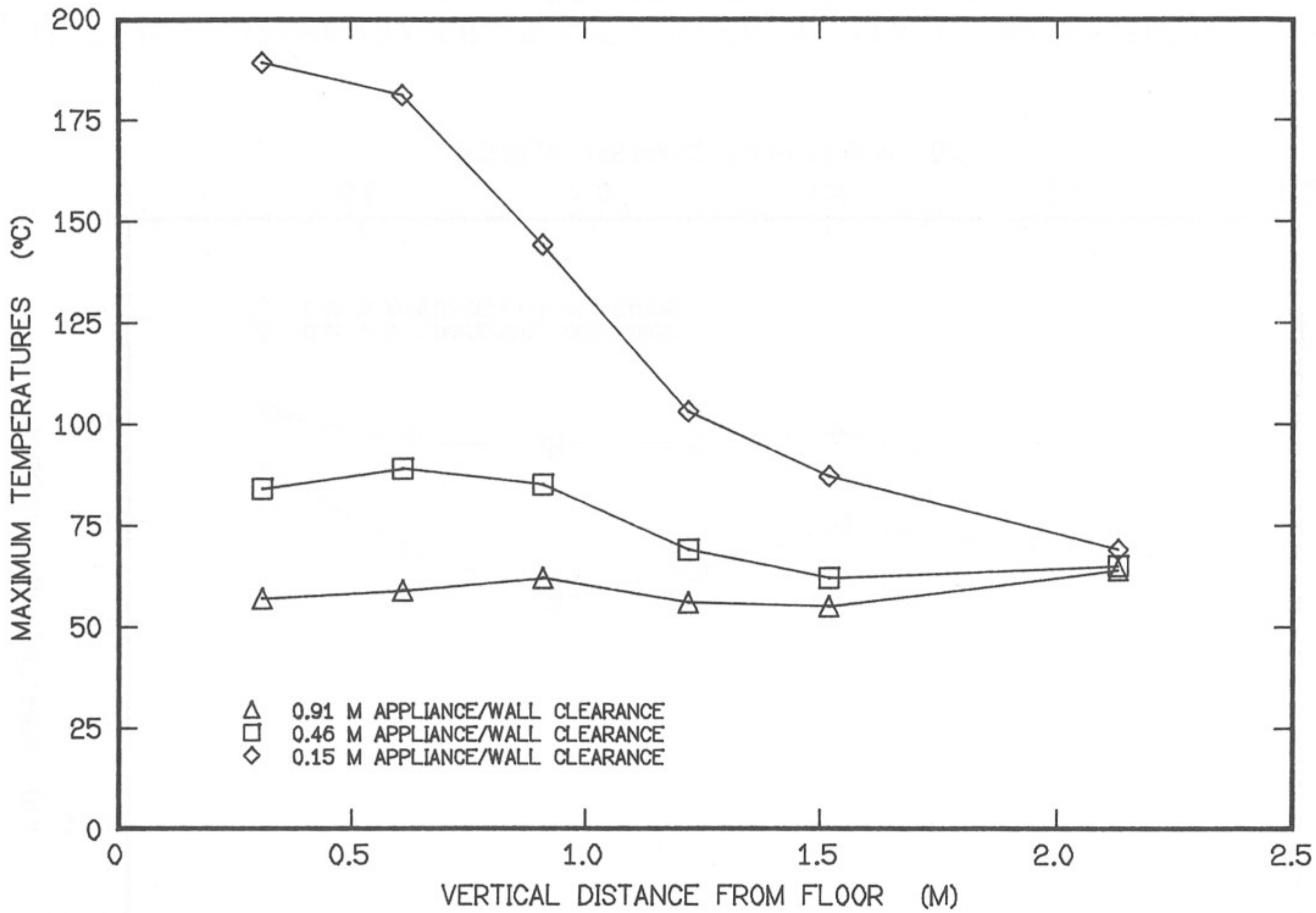


FIGURE 11: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS OF APPLIANCE 4

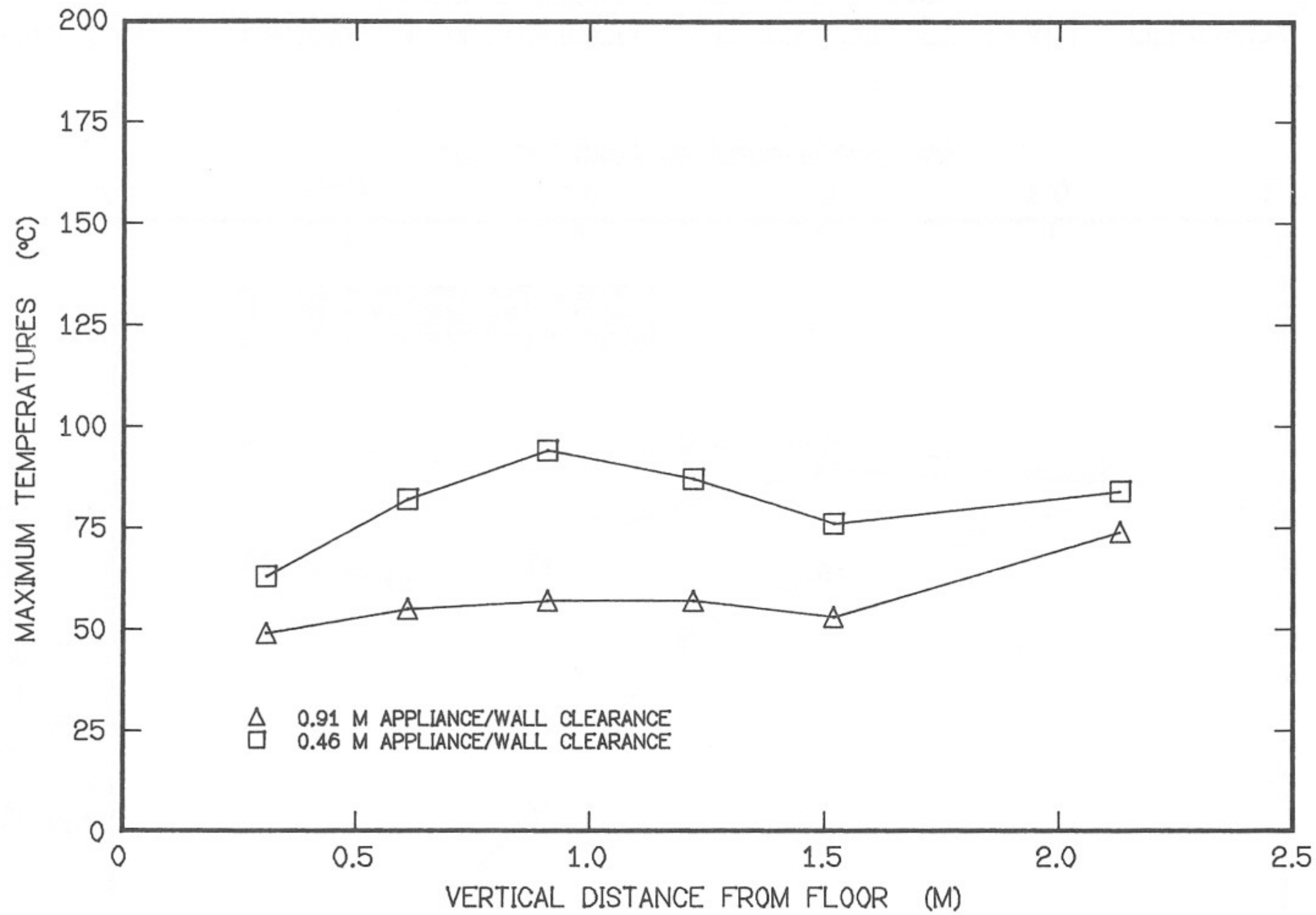


FIGURE 12: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS OF APPLIANCE 5

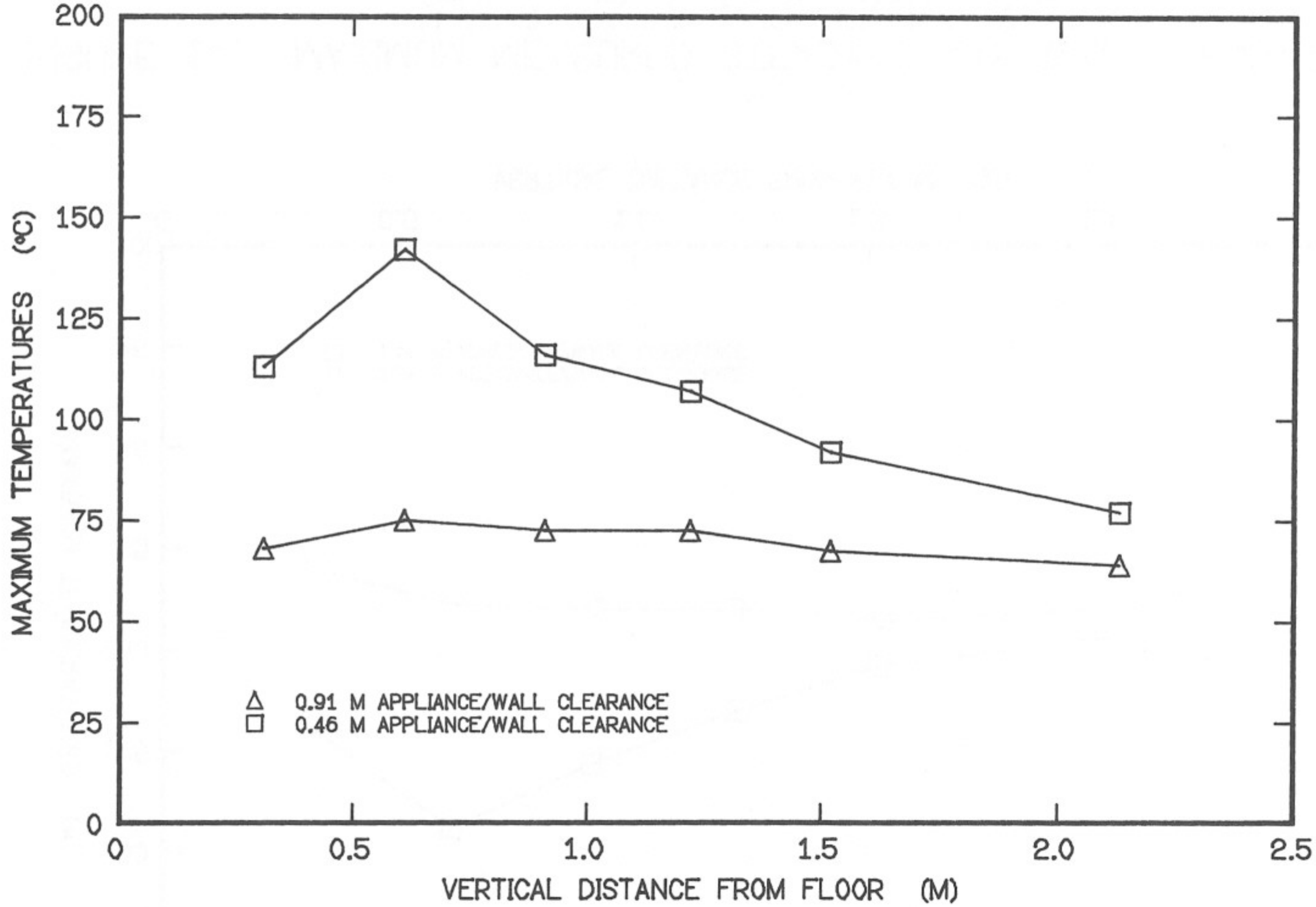


FIGURE 13: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS WITH WALL INSULATION

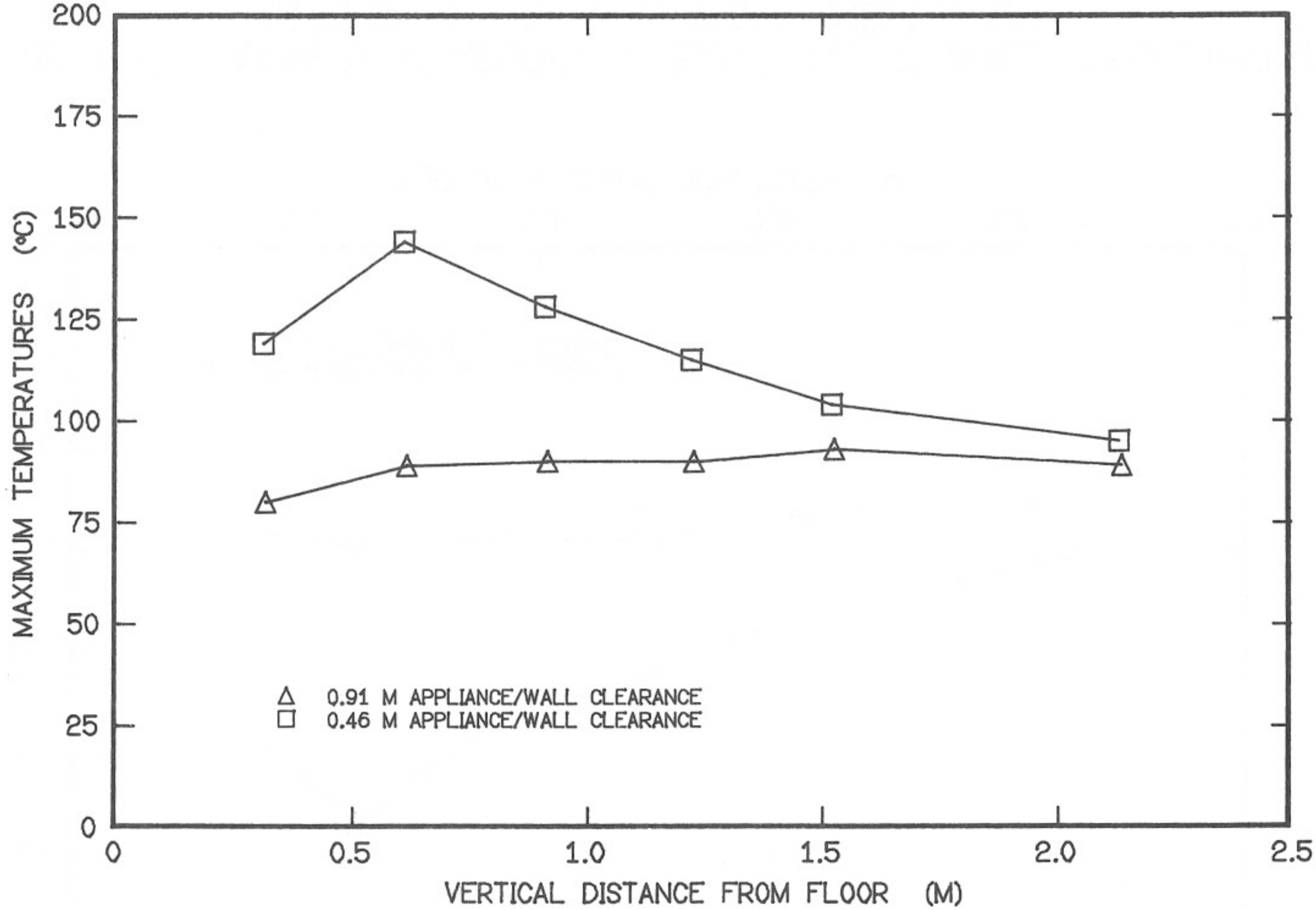


FIGURE 14: MAXIMUM MEASURED STEADY STATE WALL TEMPERATURES DURING TESTS WITH FRONT WALL

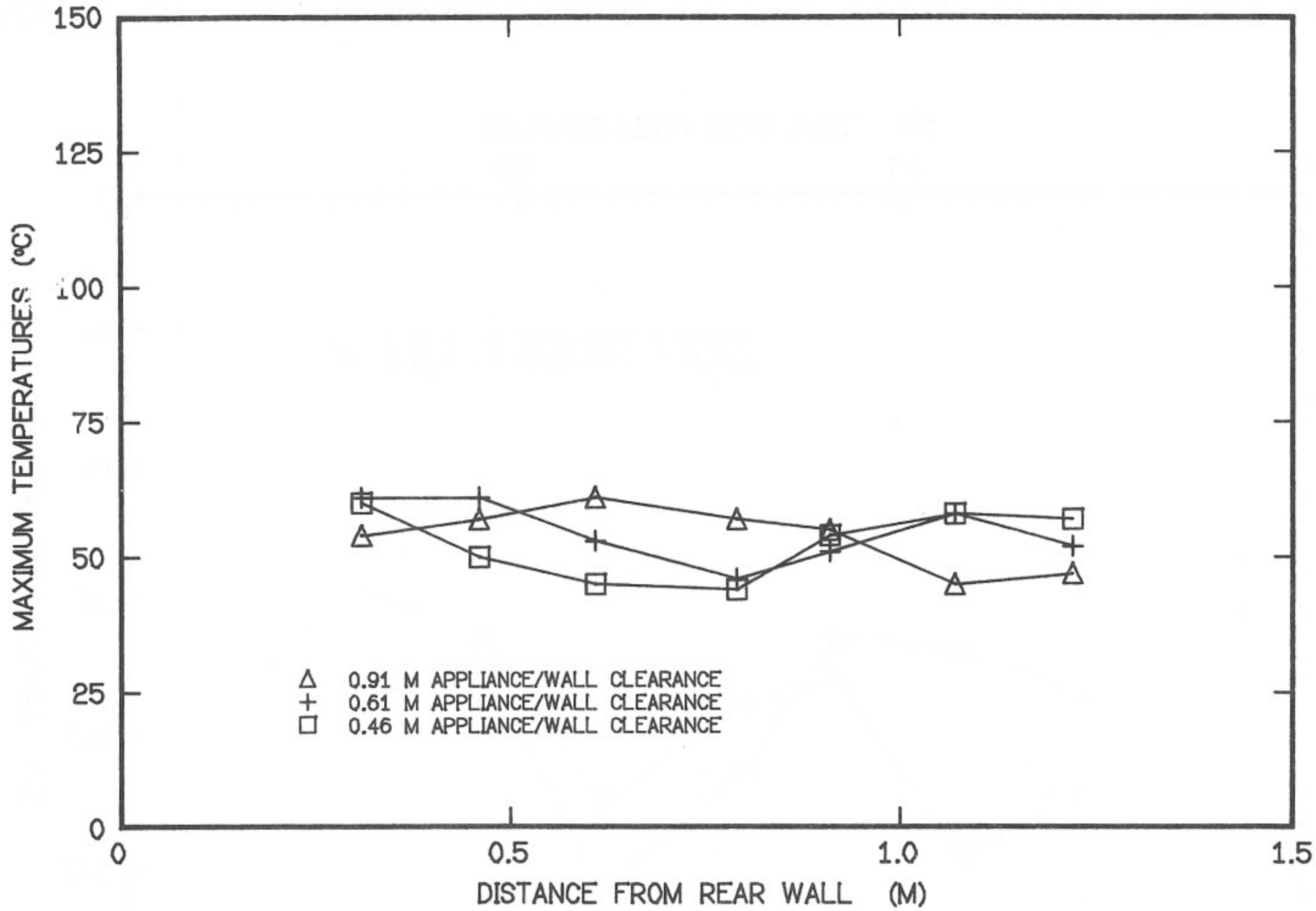


FIGURE 15: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS OF APPLIANCE 1

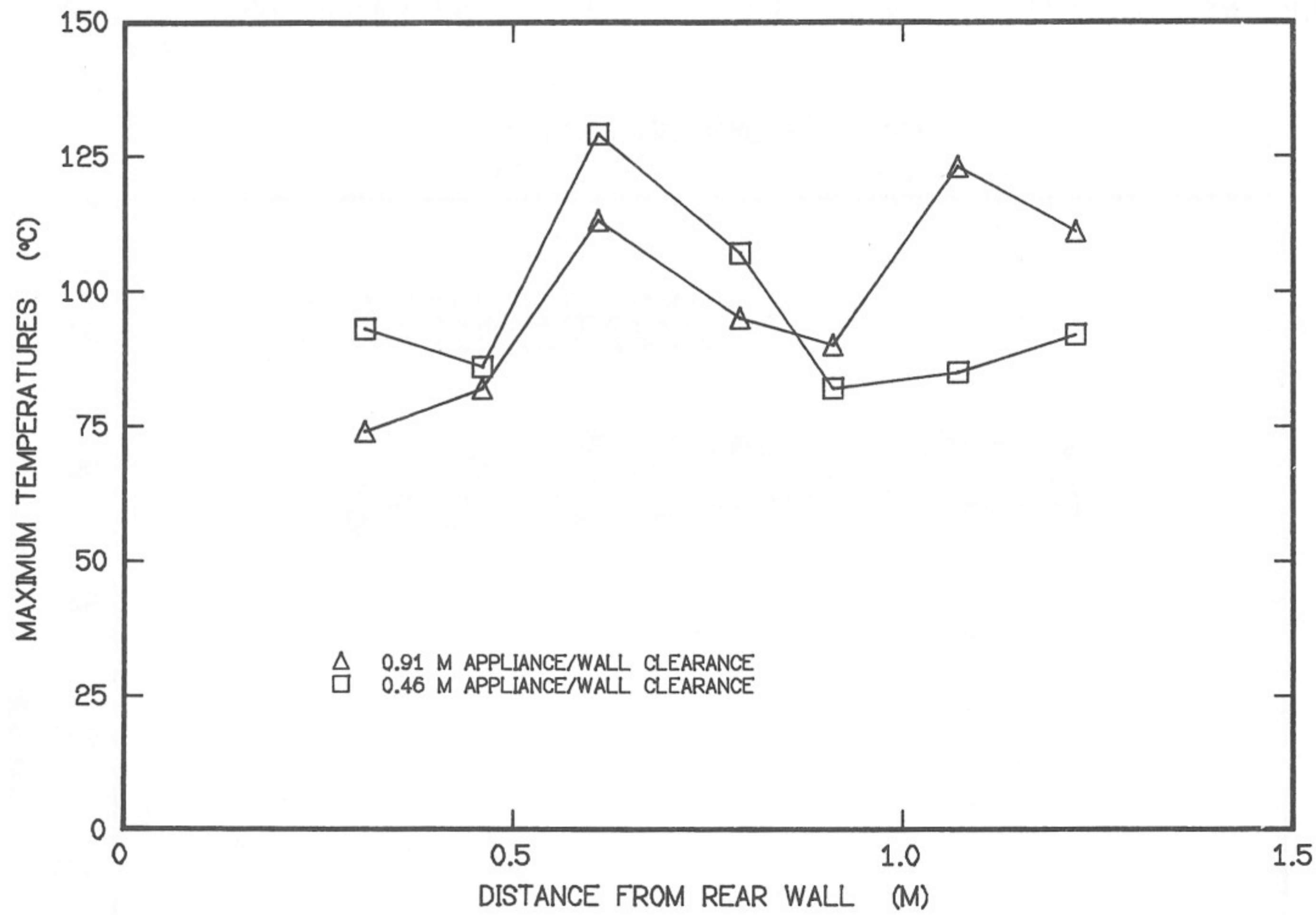


FIGURE 16: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS OF APPLIANCE 2

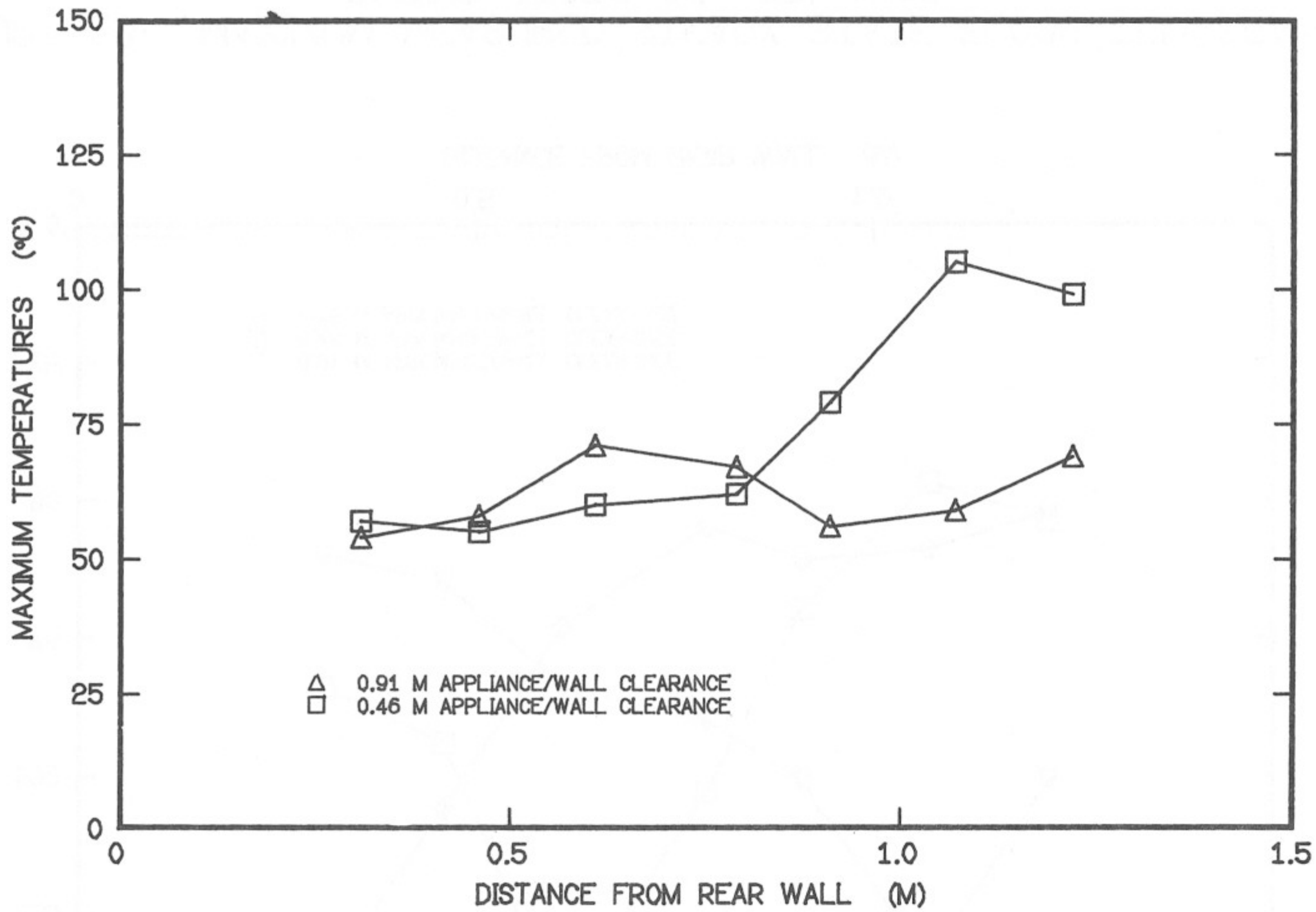


FIGURE 17: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS OF APPLIANCE 3

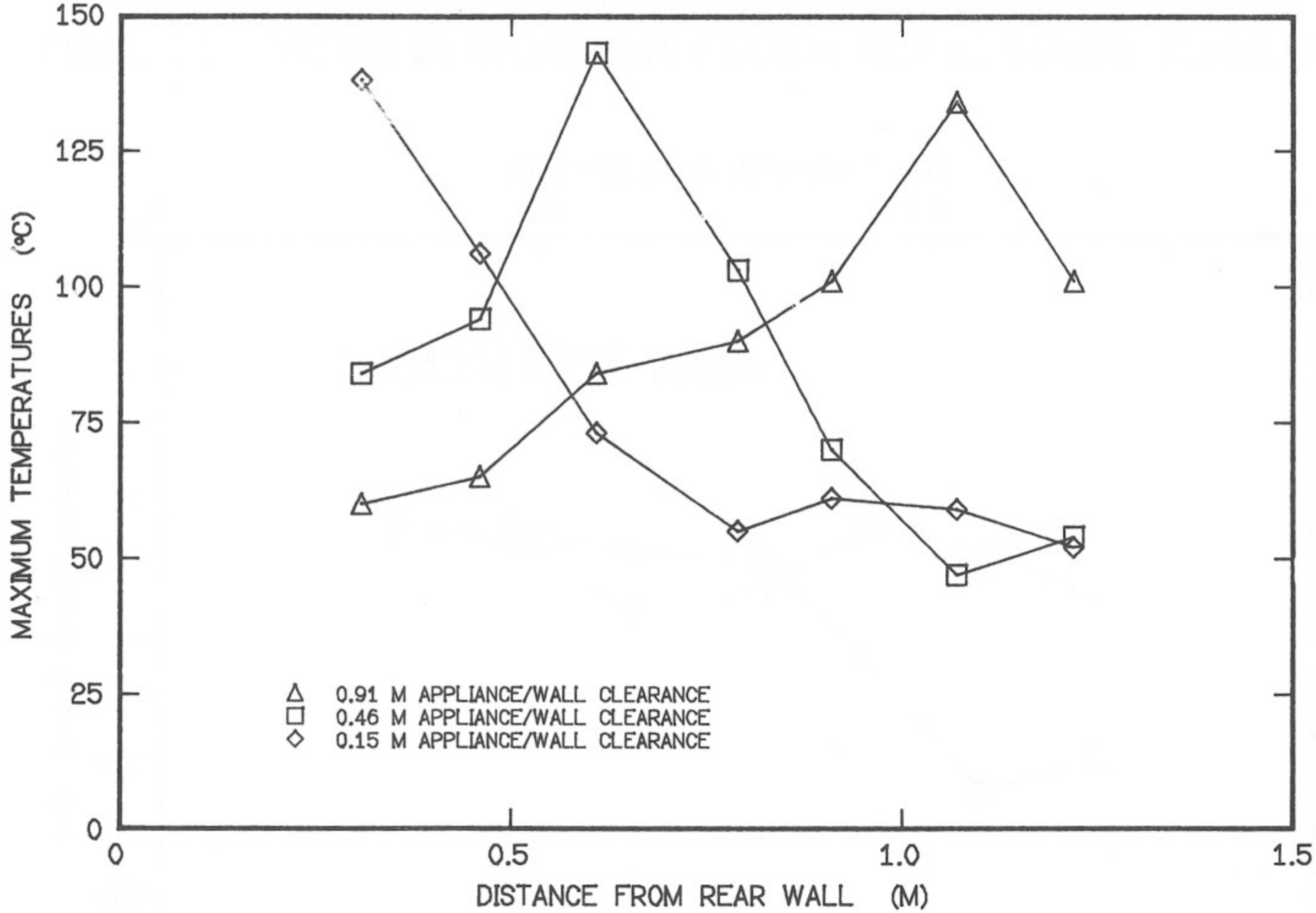


FIGURE 18: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS OF APPLIANCE 4

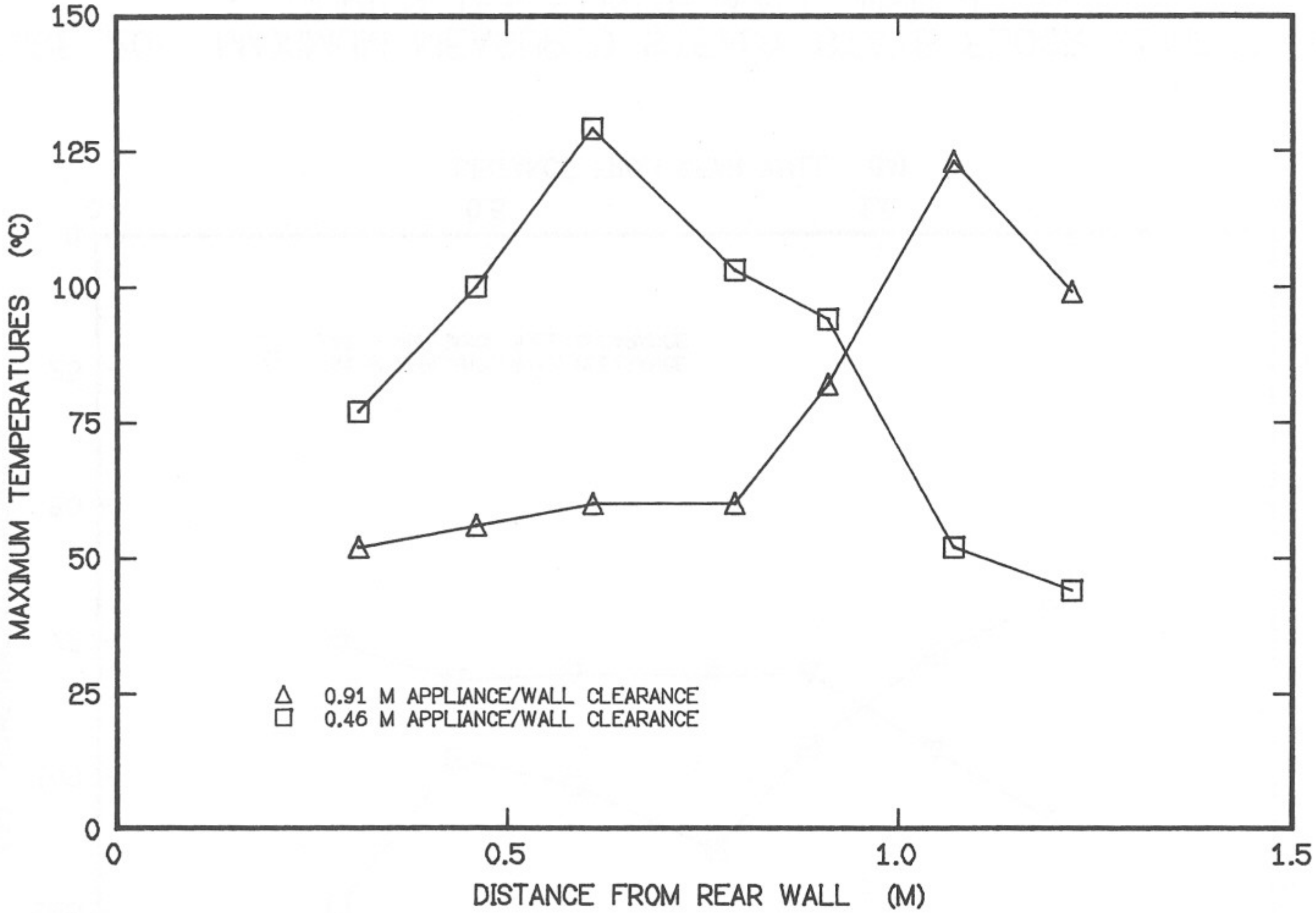


FIGURE 19: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS OF APPLIANCE 5

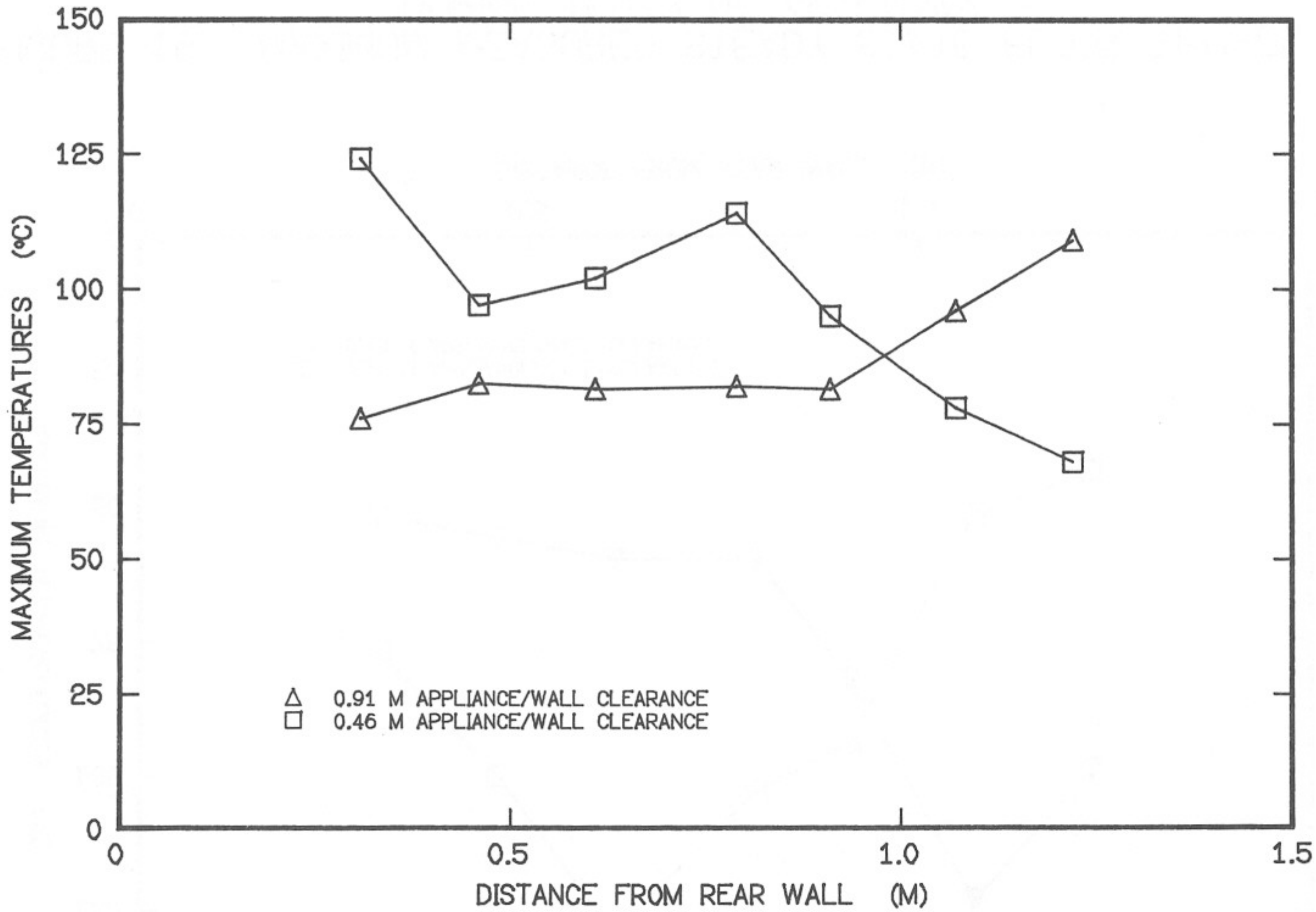


FIGURE 20: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS WITH WALL INSULATION

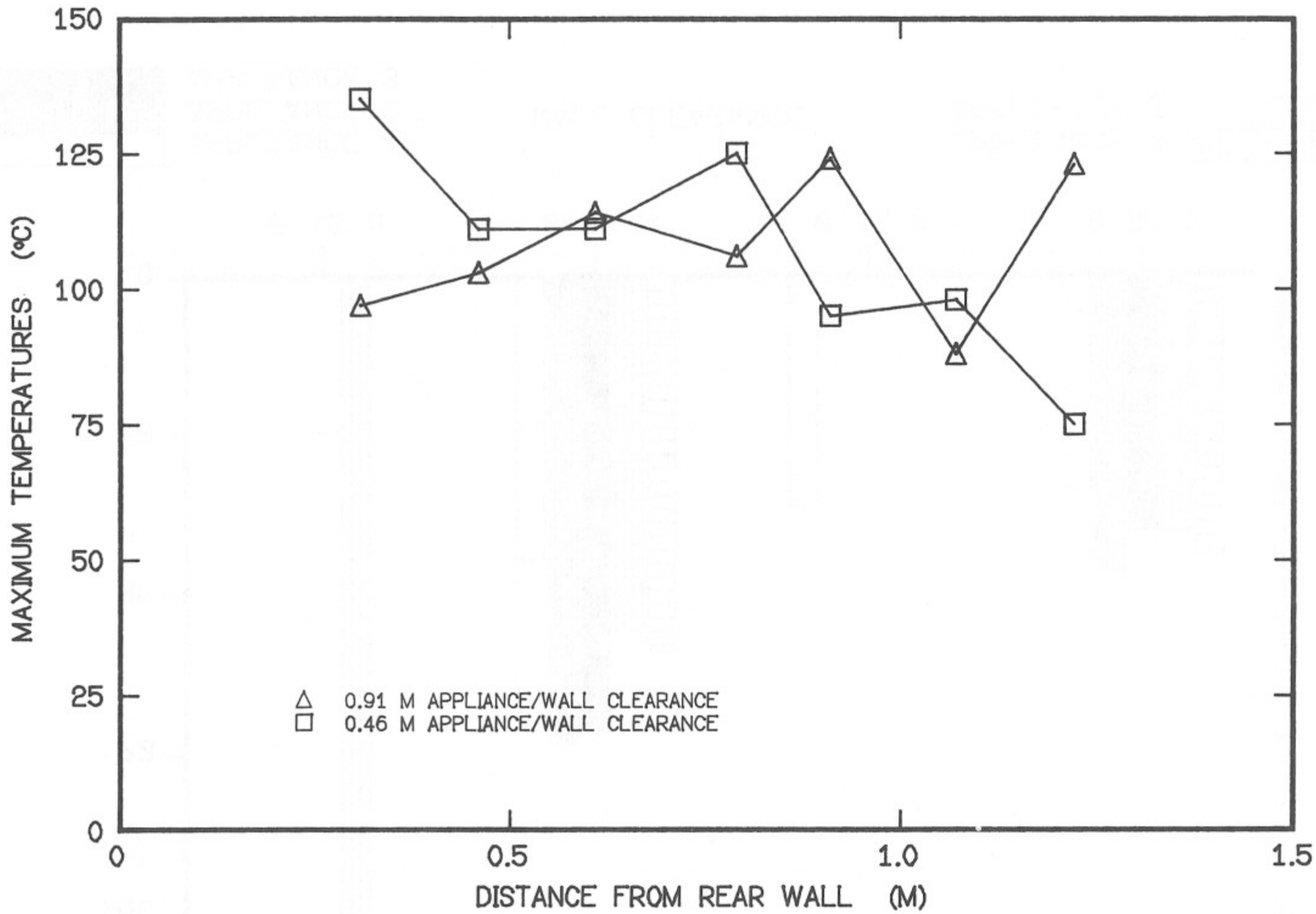


FIGURE 21: MAXIMUM MEASURED STEADY STATE FLOOR TEMPERATURES DURING TESTS WITH FRONT WALL

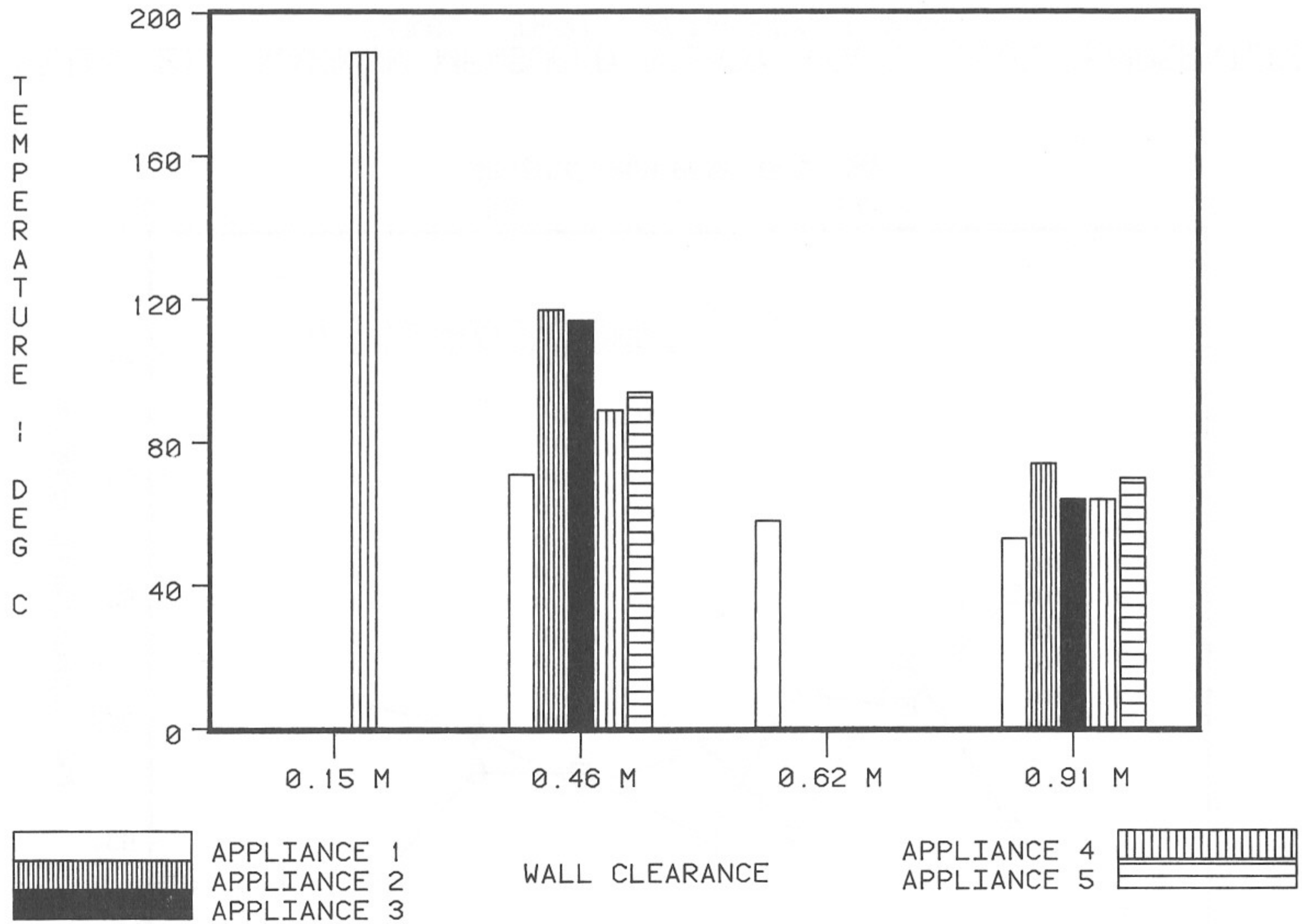


Figure 22. Effect of appliance/wall clearance on measured wall temperatures during tests of several wood-burning appliances.

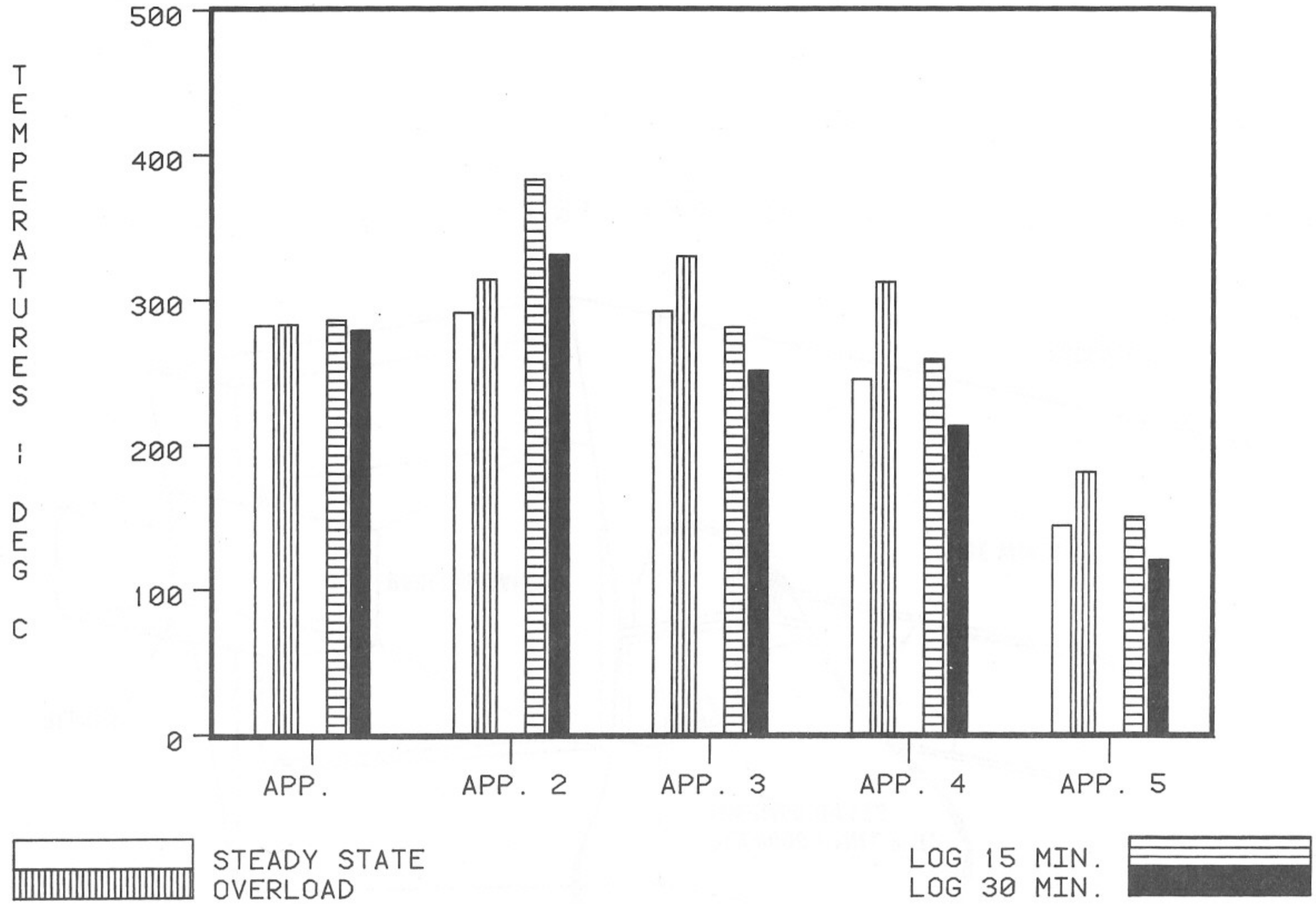


Figure 23. A comparison of maximum appliance temperatures for tests using logs as a fuel source with tests using douglas fir brands as a fuel source.

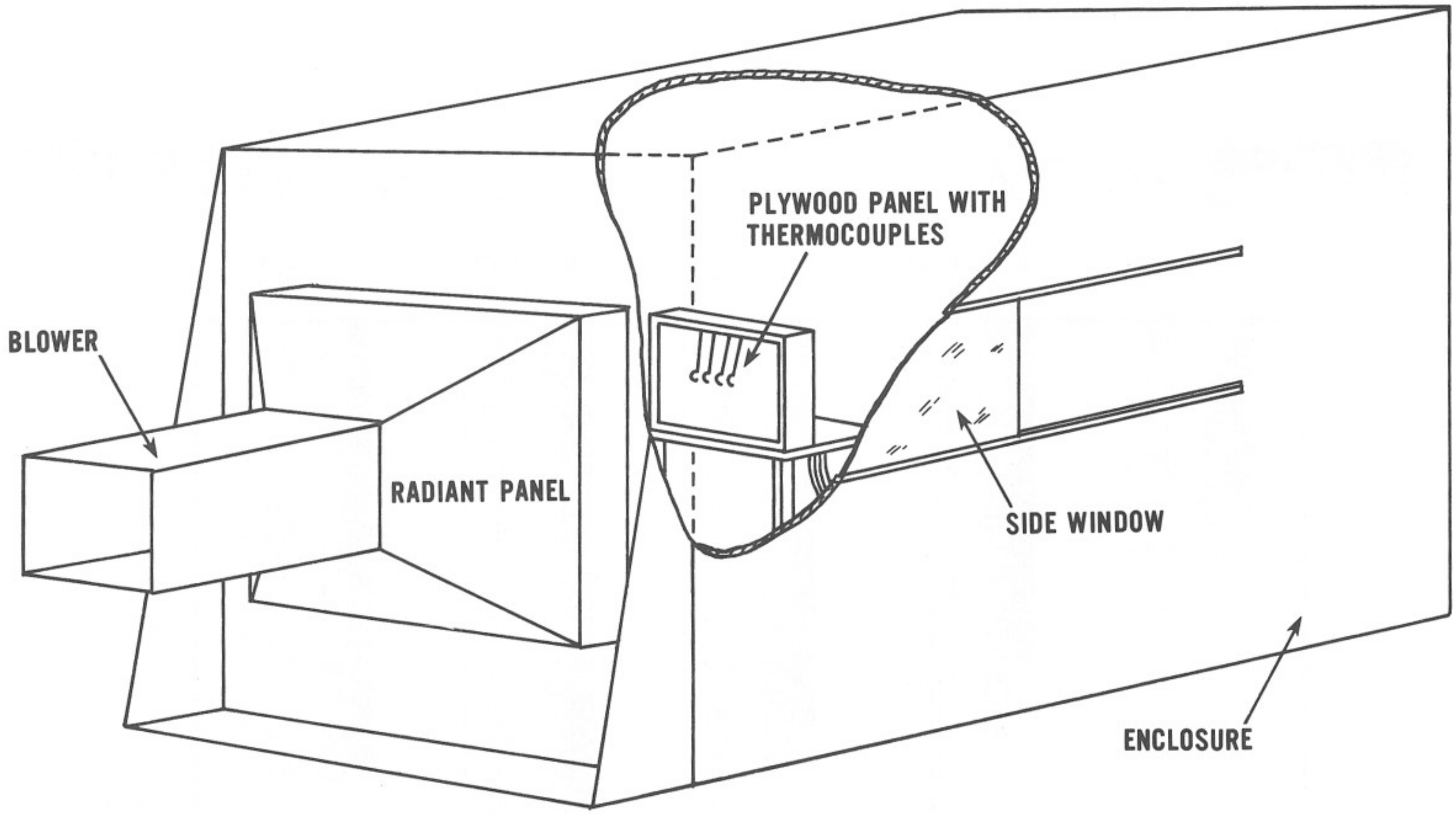


Figure 24. Test apparatus to evaluate thermocouple mounting techniques.

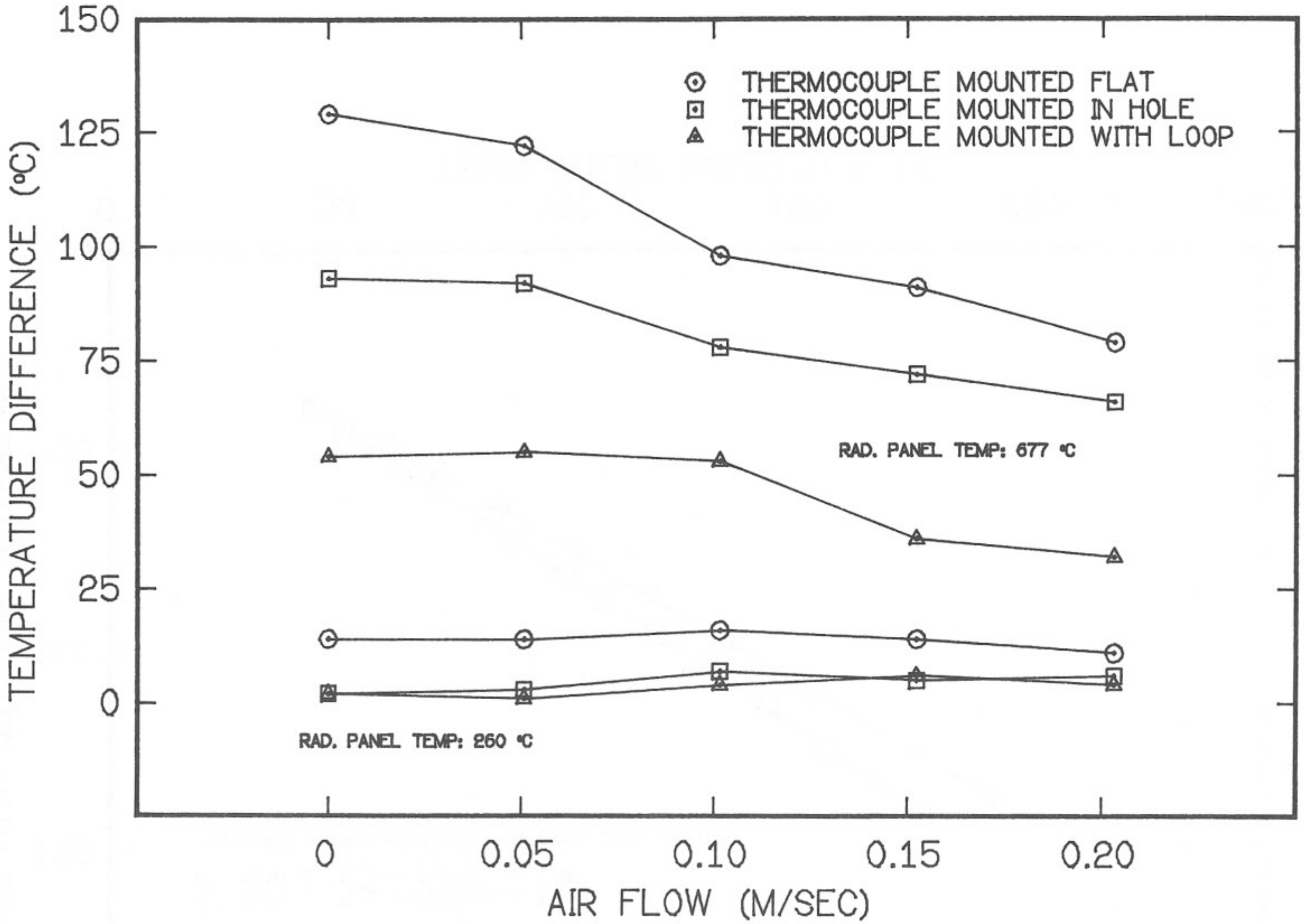


Figure 25. Surface/air temperature difference vs. airflow for different radiant panel temperatures.

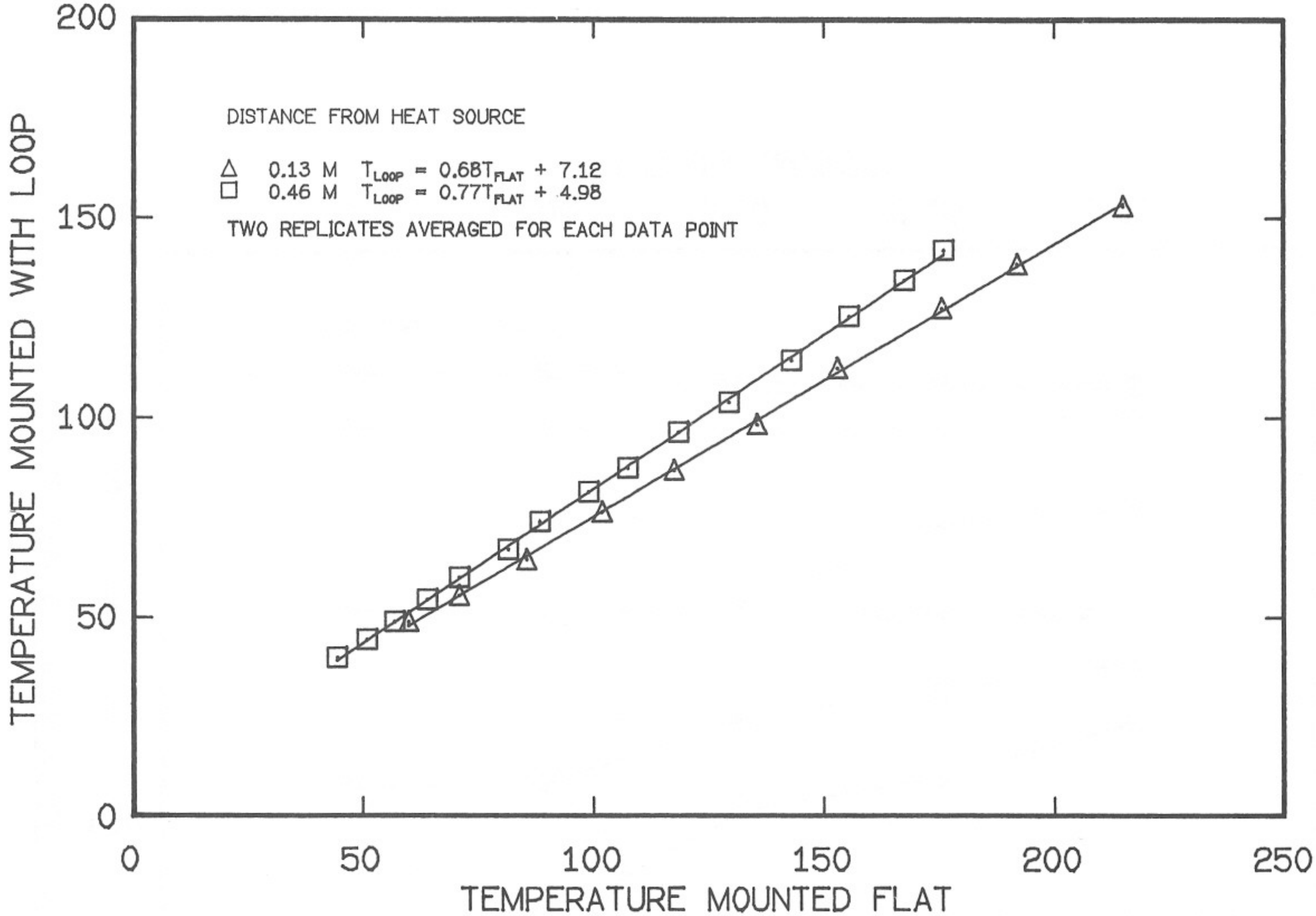


Figure 26. Surface temperatures as measured using different thermocouple mounting techniques.

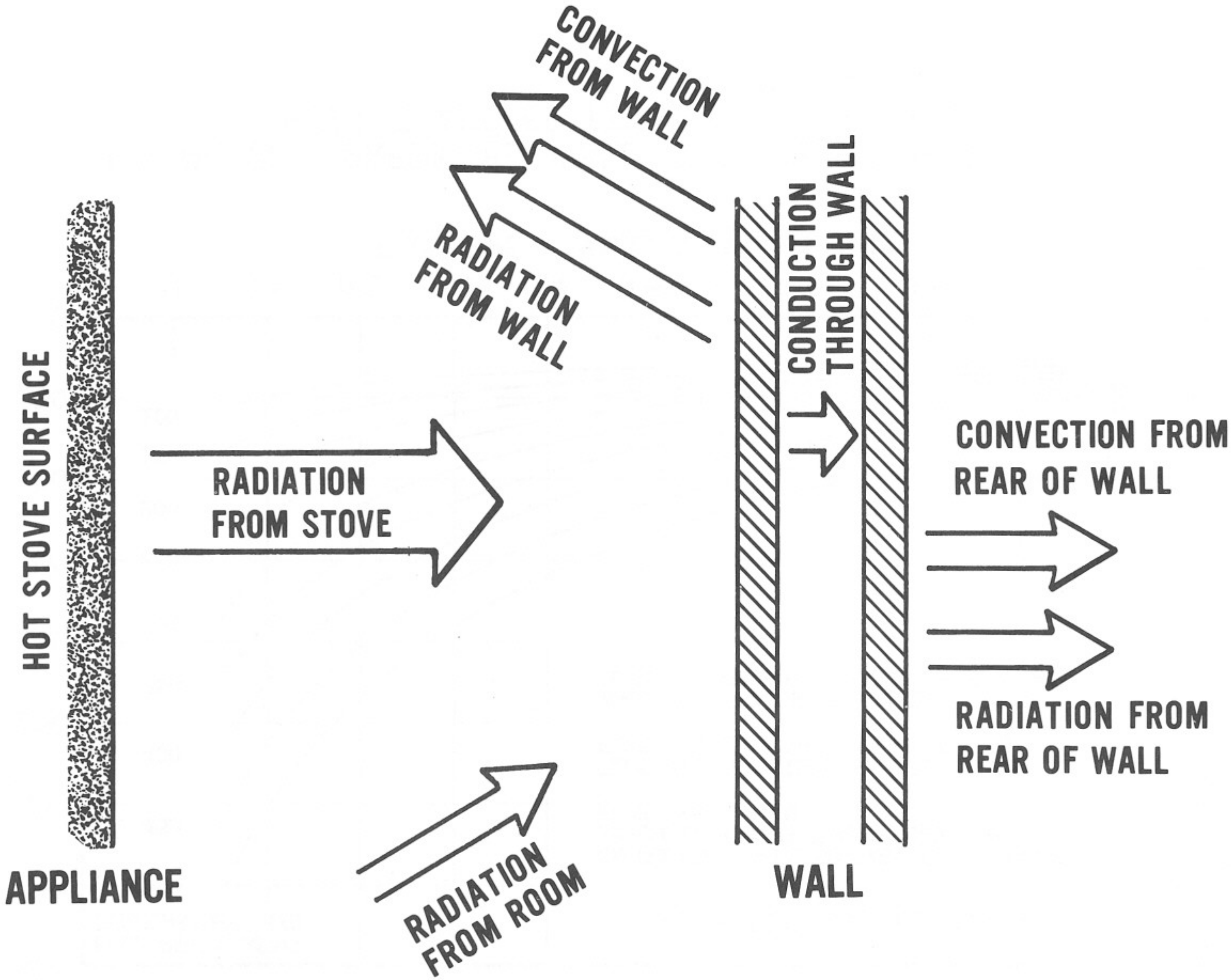


Figure 27. Heat transfer to wall surfaces.

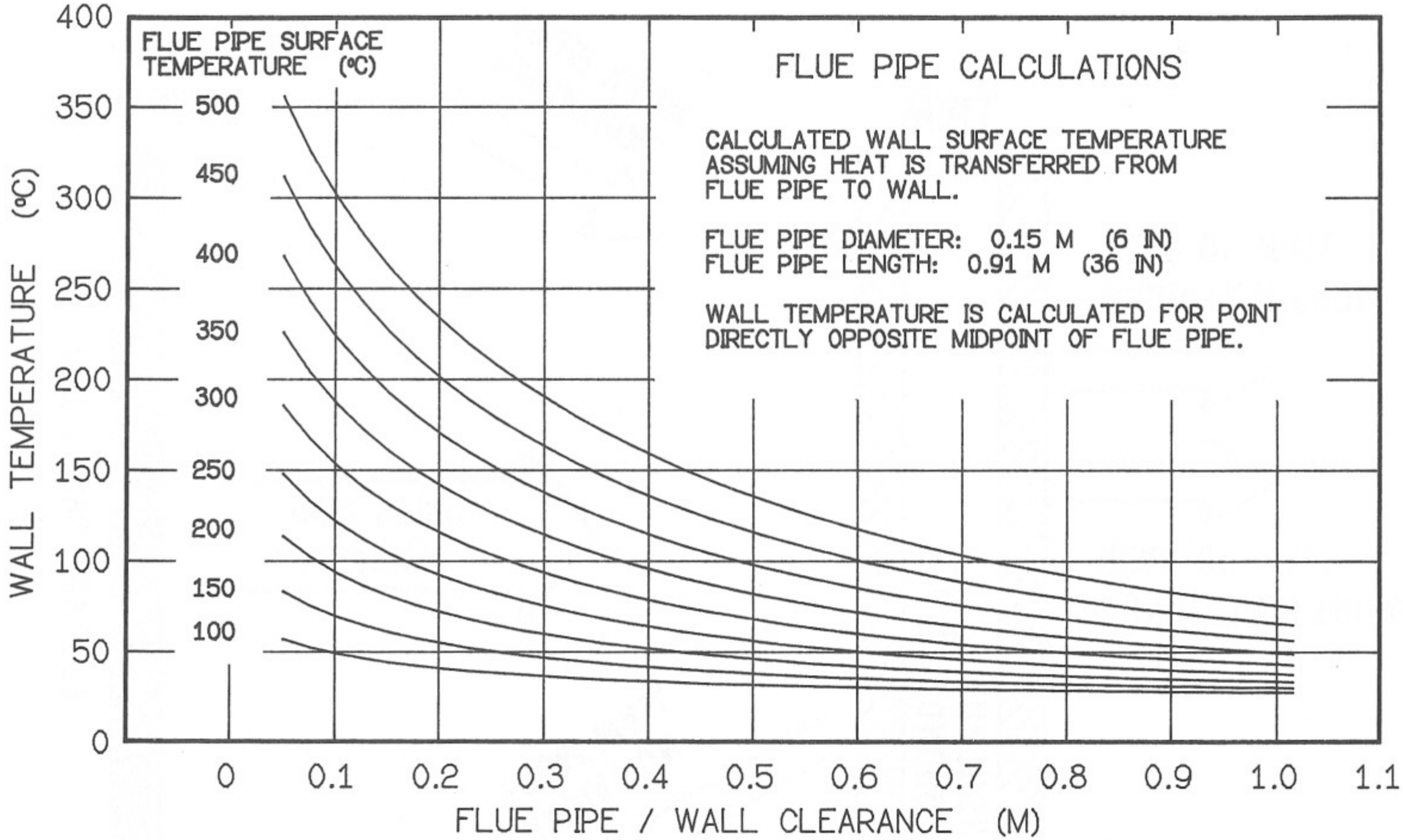


FIGURE 28: PREDICTED WALL SURFACE TEMPERATURE FOR HEAT TRANSFER FROM FLUE PIPE ONLY

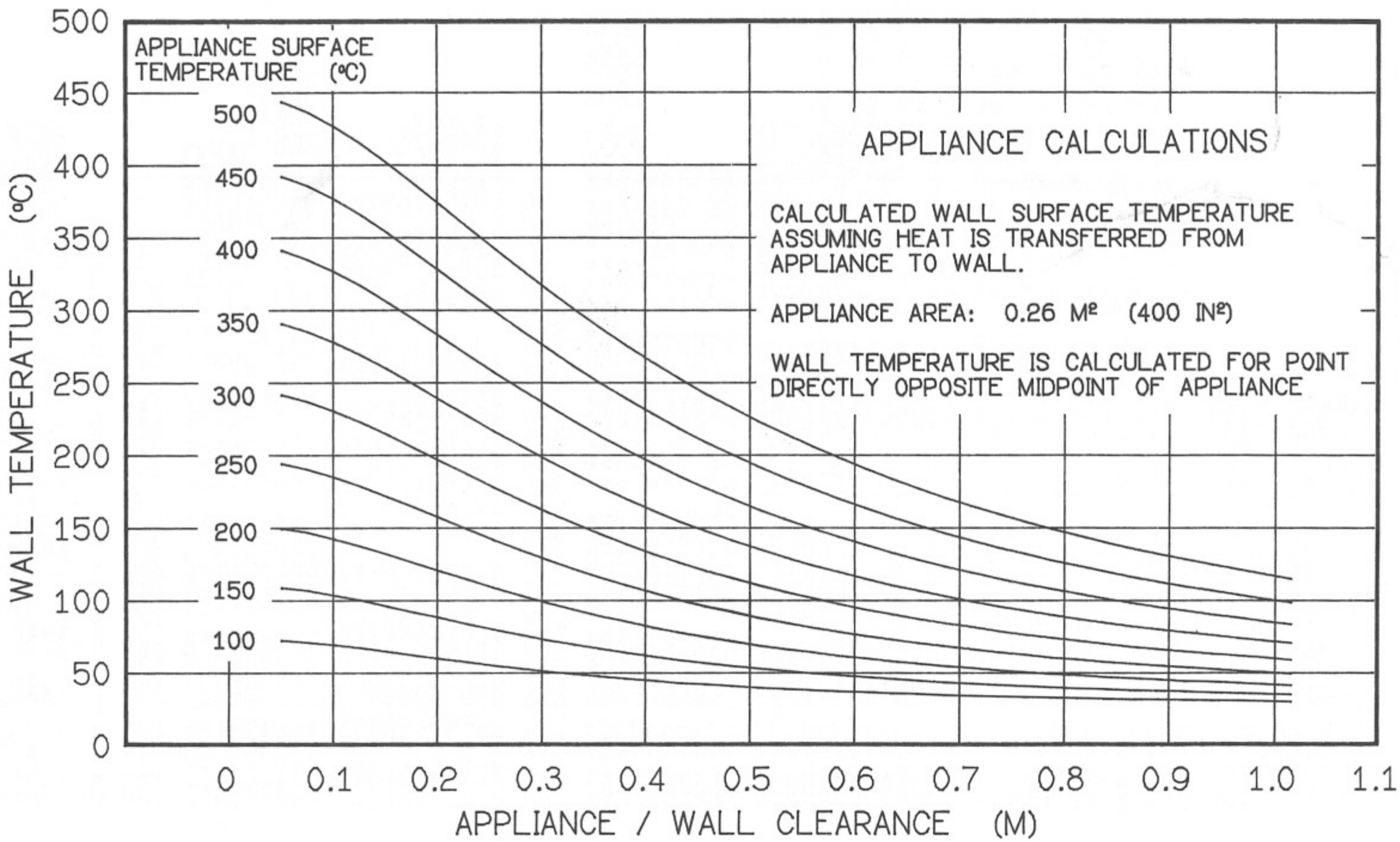


FIGURE 29: PREDICTED WALL SURFACE TEMPERATURE FOR HEAT TRANSFER FROM APPLIANCE ONLY

TABLE 1: INSTRUMENTATION LOCATIONS FOR MEASUREMENTS DURING ROOM EXPERIMENTS FOR APPLIANCES AND TEST ENCLOSURE

INSTRUMENT I.D.	DESCRIPTION
TC 00	AMBIENT ROOM AIR TEMPERATURE
TC 01	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 02	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 03	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 04	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 05	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 06	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 07	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 08	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 09	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 10	APPLIANCE SURFACE TEMPERATURE (SEE FIGURE 2)
TC 11	REAR WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR 0.3 M SOUTH OF FLUE CENTERLINE
TC 12	REAR WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR FLUE CENTERLINE
TC 13	REAR WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR 0.3 M NORTH OF FLUE CENTERLINE
TC 14	REAR WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR 0.3 M SOUTH OF FLUE CENTERLINE
TC 15	REAR WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR FLUE CENTERLINE
TC 16	REAR WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR 0.3 M NORTH OF FLUE CENTERLINE
TC 17	REAR WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR 0.3 M SOUTH OF FLUE CENTERLINE
TC 18	REAR WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR FLUE CENTERLINE
TC 19	REAR WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR 0.3 M NORTH OF FLUE CENTERLINE
TC 20	REAR WALL SURFACE TEMPERATURE 1.2 M FROM FLOOR FLUE CENTERLINE
TC 21	REAR WALL SURFACE TEMPERATURE 1.5 M FROM FLOOR FLUE CENTERLINE
TC 22	REAR WALL SURFACE TEMPERATURE 5 CM FROM THIMBLE SOUTH OF FLUE CENTERLINE
TC 23	REAR WALL SURFACE TEMPERATURE 5 CM FROM THIMBLE NORTH OF FLUE CENTERLINE
TC 24	REAR WALL SURFACE TEMPERATURE 5 CM FROM THIMBLE ABOVE FLUE CENTERLINE
TC 25	SIDE WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR 0.3 M WEST OF APPLIANCE CENTERLINE
TC 26	SIDE WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR APPLIANCE CENTERLINE
TC 27	SIDE WALL SURFACE TEMPERATURE 0.3 M FROM FLOOR 0.3 M EAST OF APPLIANCE CENTERLINE
TC 28	SIDE WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR 0.3 M WEST OF APPLIANCE CENTERLINE
TC 29	SIDE WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR APPLIANCE CENTERLINE
TC 30	SIDE WALL SURFACE TEMPERATURE 0.6 M FROM FLOOR 0.3 M EAST OF APPLIANCE CENTERLINE
TC 31	SIDE WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR 0.3 M WEST OF APPLIANCE CENTERLINE
TC 32	SIDE WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR APPLIANCE CENTERLINE
TC 33	SIDE WALL SURFACE TEMPERATURE 0.9 M FROM FLOOR 0.3 M EAST OF APPLIANCE CENTERLINE
TC 34	SIDE WALL SURFACE TEMPERATURE 1.2 M FROM FLOOR APPLIANCE CENTERLINE
TC 35	SIDE WALL SURFACE TEMPERATURE 1.5 M FROM FLOOR APPLIANCE CENTERLINE
TC 36	SIDE WALL SURFACE TEMPERATURE 1.8 M FROM FLOOR APPLIANCE CENTERLINE
TC 37	SIDE WALL SURFACE TEMPERATURE 2.1 M FROM FLOOR APPLIANCE CENTERLINE
TC 38	REAR WALL STUDDING TEMPERATURE 2.1 M FROM FLOOR FLUE CENTERLINE
TC 39	REAR WALL STUDDING TEMPERATURE 1.5 M FROM FLOOR FLUE CENTERLINE
TC 40	REAR WALL STUDDING TEMPERATURE 1.2 M FROM FLOOR FLUE CENTERLINE
TC 41	REAR WALL STUDDING TEMPERATURE 0.9 M FROM FLOOR FLUE CENTERLINE
TC 42	REAR WALL STUDDING TEMPERATURE 0.6 M FROM FLOOR FLUE CENTERLINE
TC 43	REAR WALL STUDDING TEMPERATURE 0.3 M FROM FLOOR FLUE CENTERLINE
TC 44	REAR WALL STUDDING TEMPERATURE 0.6 M FROM FLOOR 0.8 M SOUTH OF FLUE CENTERLINE
TC 45	REAR WALL STUDDING TEMPERATURE 0.6 M FROM FLOOR 0.4 M SOUTH OF FLUE CENTERLINE
TC 46	REAR WALL STUDDING TEMPERATURE 0.6 M FROM FLOOR 0.8 M NORTH OF FLUE CENTERLINE
TC 47	REAR WALL STUDDING TEMPERATURE 0.6 M FROM FLOOR 0.4 M NORTH OF FLUE CENTERLINE
TC 48	FLUE GAS TEMPERATURE IN FLUE AT APPLIANCE FLUE OUTLET
TC 49	FLUE GAS TEMPERATURE IN FLUE 1 M FROM APPLIANCE FLUE OUTLET
TC 50	FLUE GAS TEMPERATURE IN FLUE 2 M FROM APPLIANCE FLUE OUTLET
TC 51	FLOOR SURFACE TEMPERATURE 0.3 M FROM REAR WALL APPLIANCE CENTERLINE
TC 52	FLOOR SURFACE TEMPERATURE 0.46 M FROM REAR WALL APPLIANCE CENTERLINE
TC 53	FLOOR SURFACE TEMPERATURE 0.6 M FROM REAR WALL APPLIANCE CENTERLINE
TC 54	FLOOR SURFACE TEMPERATURE 0.76 M FROM REAR WALL APPLIANCE CENTERLINE
TC 55	FLOOR SURFACE TEMPERATURE 0.9 M FROM REAR WALL APPLIANCE CENTERLINE
TC 56	FLOOR SURFACE TEMPERATURE 1.05 M FROM REAR WALL APPLIANCE CENTERLINE
TC 57	FLOOR SURFACE TEMPERATURE 1.2 M FROM REAR WALL APPLIANCE CENTERLINE
TC 58	FLOOR SURFACE TEMPERATURE 0.8 M SOUTH OF APPLIANCE CENTERLINE
TC 59	FLOOR SURFACE TEMPERATURE 0.4 M SOUTH OF APPLIANCE CENTERLINE
TC 60	FLOOR SURFACE TEMPERATURE 0.4 M NORTH OF APPLIANCE CENTERLINE
TC 61	FLOOR SURFACE TEMPERATURE 0.8 M NORTH OF APPLIANCE CENTERLINE
TC 62	SUB-FLOOR STUDDING TEMPERATURE 0.3 M FROM REAR WALL APPLIANCE CENTERLINE
TC 63	SUB-FLOOR STUDDING TEMPERATURE 0.46 M FROM REAR WALL APPLIANCE CENTERLINE
TC 64	SUB-FLOOR STUDDING TEMPERATURE 0.6 M FROM REAR WALL APPLIANCE CENTERLINE
TC 65	SUB-FLOOR STUDDING TEMPERATURE 0.76 M FROM REAR WALL APPLIANCE CENTERLINE
TC 66	SUB-FLOOR STUDDING TEMPERATURE 0.9 M FROM REAR WALL APPLIANCE CENTERLINE
TC 67	SUB-FLOOR STUDDING TEMPERATURE 0.8 M SOUTH OF APPLIANCE CENTERLINE
TC 68	SUB-FLOOR STUDDING TEMPERATURE 0.4 M SOUTH OF APPLIANCE CENTERLINE
TC 69	SUB-FLOOR STUDDING TEMPERATURE 0.4 M NORTH OF APPLIANCE CENTERLINE
TC 70	SUB-FLOOR STUDDING TEMPERATURE 0.8 M NORTH OF APPLIANCE CENTERLINE
TC 71	FLUE PIPE SURFACE TEMPERATURE AT APPLIANCE FLUE OUTLET
TC 72	FLUE PIPE SURFACE TEMPERATURE AT 1 M FROM APPLIANCE FLUE OUTLET
TC 73	FLUE PIPE SURFACE TEMPERATURE AT 2 M FROM APPLIANCE FLUE OUTLET
TC 74	FLUE GAS TEMPERATURE IN FLUE AT 7 M FROM APPLIANCE FLUE OUTLET
TC 75	REAR WALL BACK SURFACE TEMPERATURE 2.1 M FROM FLOOR FLUE CENTERLINE
TC 76	REAR WALL BACK SURFACE TEMPERATURE 1.5 M FROM FLOOR FLUE CENTERLINE
TC 77	REAR WALL BACK SURFACE TEMPERATURE 1.2 M FROM FLOOR FLUE CENTERLINE
TC 78	REAR WALL BACK SURFACE TEMPERATURE 0.9 M FROM FLOOR FLUE CENTERLINE
TC 79	REAR WALL BACK SURFACE TEMPERATURE 0.6 M FROM FLOOR FLUE CENTERLINE
RAD 80	RADIANT HEAT FLUX ON REAR WALL SURFACE 0.3 M FROM FLOOR
RAD 81	RADIANT HEAT FLUX ON REAR WALL SURFACE 0.6 M FROM FLOOR
RAD 82	RADIANT HEAT FLUX ON REAR WALL SURFACE 0.9 M FROM FLOOR
VEL 84	FLUE GAS VELOCITY

TABLE 2: PHYSICAL CHARACTERISTICS OF WOOD-BURNING APPLIANCES TESTED

NUMBER	APPLIANCE TYPE	APPLIANCE DIMENSIONS LENGTH (CM)	HEIGHT (CM)	WIDTH (CM)	FLOOR CLEARANCE (CM)	HEARTH AREA (SQ CM)	COMMENTS
1	RADIANT	46	37	65	14	1250	RADIATION SHEILD LISTED APPLIANCE
2	RADIANT	62	42	65	11	1790	GLASS FRONT PLATE SIDE LOADING
3	RADIANT	83	47	77	13	2890	
4	FRANKLIN	39	85	79	7	1740	
5	CIRCULATOR	53	89	54	11	2280	THERMOSTATICALLY CONTROLLED AIR INLET

TABLE 3: TEST CONDITIONS FOR ROOM EXPERIMENTS

TEST	APPLIANCE TESTED	APPLIANCE/WALL CLEARANCE	FLUE/WALL CLEARANCE	AMBIENT TEMPERATURE	WALL INSULATION	FRONT WALL
CLR01	1	0.91	0.46	25		
CLR02	1	0.62	0.46	25		
CLR03	1	0.46	0.23	26		
CLR04	2	0.91	0.46	24		
CLR05	2	0.46	0.23	24		
CLR06	3	0.91	0.46	25		
CLR07	3	0.46	0.23	20		
CLR08	4	0.91	0.94	26		
CLR09	4	0.46	0.49	25		
CLR10	4	0.46	0.49	25		
CLR11	4	0.15	0.18	26		
CLR12	5	0.91	0.46	22		
CLR13	5	0.46	0.23	24		
CLR14	2	0.91	0.46	24	✓	
CLR15	2	0.46	0.23	20	✓	
CLR16	2	0.46	0.23	21	✓	
CLR17	2	0.46	0.23	23	✓	✓
CLR18	2	0.91	0.46	24	✓	✓

TABLE 4
TEMPERATURES MEASURED DURING FIRE TESTS OF SEVERAL WOOD HEATING APPLIANCES

TEST IDENTIFICATION	MAXIMUM STEADY STATE TEMPERATURES (DEG C)							MAXIMUM OVERLOAD TEMPERATURES (DEG C)						
	APPLIANCE	WALL	WALL STUDDING	FLOOR	FLOOR STUDDING	FLUE PIPE	FLUE GAS	APPLIANCE	WALL	WALL STUDDING	FLOOR	FLOOR STUDDING	FLUE PIPE	FLUE GAS
TEST CLR01 (APPLIANCE 1) (0.91 M WALL CLEARANCE)	332	54	43	74	62	-	644	393	94	54	88	70	-	834
TEST CLR02 (APPLIANCE 1) (0.62 M WALL CLEARANCE)	344	58	46	68	66	386	648	460	122	69	88	73	609	954
TEST CLR03 (APPLIANCE 1) (0.46 M WALL CLEARANCE)	312	76	53	65	62	349	632	378	175	79	78	68	595	980
TEST CLR04 (APPLIANCE 2) (0.91 M WALL CLEARANCE)	377	74	55	123	92	393	681	401	105	65	137	101	542	889
TEST CLR05 (APPLIANCE 2) (0.46 M WALL CLEARANCE)	346	117	64	129	100	441	734	378	183	80	132	104	550	874
TEST CLR06 (APPLIANCE 3) (0.91 M WALL CLEARANCE)	434	77	56	81	60	429	765	386	113	73	89	72	521	861
TEST CLR07 (APPLIANCE 3) (0.46 M WALL CLEARANCE)	409	114	55	105	79	453	808	415	147	74	95	77	522	868
TEST CLR08 (APPLIANCE 4) (0.91 M WALL CLEARANCE)	322	64	53	134	101	337	500	733	93	65	139	103	452	659
TEST CLR09 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	297	89	55	143	124	298	473	630	130	68	152	129	489	735
TEST CLR10 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	278	83	50	175	142	212	352	-	-	-	-	-	-	-
TEST CLR11 (APPLIANCE 4) (0.15 M WALL CLEARANCE)	319	189	75	131	138	293	485	694	442	120	143	142	417	656
TEST CLR12 (APPLIANCE 5) (0.91 M WALL CLEARANCE)	433	74	53	123	82	392	685	525	115	63	100	80	538	803
TEST CLR13 (APPLIANCE 5) (0.46 M WALL CLEARANCE)	436	86	62	126	129	384	742	497	124	72	123	120	542	875
TEST CLR14 INSULATION (0.91 M WALL CLEARANCE)	425	70	70	109	79	362	629	488	95	86	114	84	522	853
TEST CLR15 INSULATION (0.91 M WALL CLEARANCE)	386	96	80	109	91	375	700	395	111	100	119	103	516	872
TEST CLR16 INSULATION (0.46 M WALL CLEARANCE)	386	142	128	124	101	456	756	408	156	148	123	108	517	845
TEST CLR17 FRONT WALL (0.46 M WALL CLEARANCE)	407	144	139	135	103	433	750	452	187	175	284	114	521	876
TEST CLR18 FRONT WALL (0.91 M WALL CLEARANCE)	337	93	91	124	99	357	661	377	132	118	149	109	494	862

TABLE 5: MAXIMUM RISE ABOVE ROOM TEMPERATURE ON WALL AND FLOOR SURFACES DURING FIRE TESTS OF SEVERAL WOOD HEATING APPLIANCES

TEST IDENTIFICATION	MAXIMUM STEADY STATE TEMPERATURE RISE (DEG C)		MAXIMUM OVERLOAD TEMPERATURE RISE (DEG C)	
	WALL	FLOOR	WALL	FLOOR
TEST CLR01 (APPLIANCE 1) (0.91 M WALL CLEARANCE)	23	43	56	50
TEST CLR02 (APPLIANCE 1) (0.62 M WALL CLEARANCE)	29	40	84	51
TEST CLR03 (APPLIANCE 1) (0.46 M WALL CLEARANCE)	47	36	135	42
TEST CLR04 (APPLIANCE 2) (0.91 M WALL CLEARANCE)	43	93	71	102
TEST CLR05 (APPLIANCE 2) (0.46 M WALL CLEARANCE)	85	96	150	100
TEST CLR06 (APPLIANCE 3) (0.91 M WALL CLEARANCE)	44	48	71	49
TEST CLR07 (APPLIANCE 3) (0.46 M WALL CLEARANCE)	89	80	112	68
TEST CLR08 (APPLIANCE 4) (0.91 M WALL CLEARANCE)	30	100	58	101
TEST CLR09 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	57	110	94	114
TEST CLR10 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	49	140	45	109
TEST CLR11 (APPLIANCE 4) (0.15 M WALL CLEARANCE)	155	98	401	104
TEST CLR12 (APPLIANCE 5) (0.91 M WALL CLEARANCE)	44	95	79	68
TEST CLR13 (APPLIANCE 5) (0.46 M WALL CLEARANCE)	59	100	95	93
TEST CLR14 INSULATION (0.91 M WALL CLEARANCE)	39	79	53	81
TEST CLR15 INSULATION (0.91 M WALL CLEARANCE)	64	78	93	86
TEST CLR16 INSULATION (0.46 M WALL CLEARANCE)	113	96	124	93
TEST CLR17 FRONT WALL (0.46 M WALL CLEARANCE)	75	65	106	207
TEST CLR18 FRONT WALL (0.91 M WALL CLEARANCE)	26	59	53	71

TABLE 6
TEMPERATURES MEASURED DURING LOG TESTS OF SEVERAL WOOD HEATING APPLIANCES

TEST IDENTIFICATION	MAXIMUM STEADY STATE TEMPERATURES (DEG C)											
	TC 01	TC 02	TC 03	TC 04	TC 05	TC 06	TC 07	TC 08	TC 09	TC 10	TC 49	TC 72
TEST CLR19 (APPLIANCE 1) 15 MIN FEEDING INTERVAL	180	243	267	295	436	265	210	205	217	200	646	380
TEST CLR20 (APPLIANCE 1) 30 MIN FEEDING INTERVAL	160	284	270	292	400	216	210	196	190	188	570	328
TEST CLR21 (APPLIANCE 2) 15 MIN FEEDING INTERVAL	425	350	427	365	415	415	350	356	268	268	705	380
TEST CLR22 (APPLIANCE 2) 30 MIN FEEDING INTERVAL	365	310	364	312	355	375	305	295	290	290	622	343
TEST CLR23 (APPLIANCE 3) 15 MIN FEEDING INTERVAL	317	360	285	305	325	220	212	150	260	259	679	385
TEST CLR24 (APPLIANCE 3) 30 MIN FEEDING INTERVAL	170	235	235	295	355	174	210	210	248	250	517	285
TEST CLR25 (APPLIANCE 4) 15 MIN FEEDING INTERVAL	248	218	336	195	220	310	245	247	345	248	446	288
TEST CLR26 (APPLIANCE 4) 30 MIN FEEDING INTERVAL	200	166	234	150	168	278	225	220	180	220	340	225
TEST CLR27 (APPLIANCE 5) 15 MIN FEEDING INTERVAL	92	330	440	156	160	135	303	356	357	276	-	415
TEST CLR28 (APPLIANCE 5) 30 MIN FEEDING INTERVAL	55	242	380	134	125	100	215	300	267	268	-	309

TABLE 7: COMPARISON OF MEASURED AND CALCULATED WALL SURFACE TEMPERATURES FOR HEAT TRANSFER FROM FLUE PIPE TO WALL

TEST IDENTIFICATION	CLEARANCE (M)	FLUE PIPE SURFACE	WALL REAR SURFACE	ROOM AMBIENT	WALL REAR AMBIENT	MEASURED WALL SURFACE	CALCULATED WALL SURFACE	DIFFERENCE (%)	
TEST CLR02 (APPLIANCE 1) (0.62 M WALL CLEARANCE)	0.46	224	42	28	25	47	43	8	LOW
TEST CLR03 (APPLIANCE 1) (0.46 M WALL CLEARANCE)	0.23	225	49	28	26	62	65	4	HIGH
TEST CLR04 (APPLIANCE 2) (0.91 M WALL CLEARANCE)	0.46	257	51	31	24	60	45	24	LOW
TEST CLR05 (APPLIANCE 2) (0.46 M WALL CLEARANCE)	0.23	270	59	30	24	74	77	4	HIGH
TEST CLR06 (APPLIANCE 3) (0.91 M WALL CLEARANCE)	0.46	228	43	33	25	52	48	8	LOW
TEST CLR07 (APPLIANCE 3) (0.46 M WALL CLEARANCE)	0.23	267	52	27	20	69	76	10	HIGH
TEST CLR08 (APPLIANCE 4) (0.91 M WALL CLEARANCE)	0.94	247	44	34	26	53	34	36	LOW
TEST CLR09 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	0.48	230	50	31	25	62	37	39	LOW
TEST CLR11 (APPLIANCE 4) (0.15 M WALL CLEARANCE)	0.17	229	62	34	25	94	73	22	LOW
TEST CLR12 (APPLIANCE 5) (0.91 M WALL CLEARANCE)	0.46	218	44	31	25	49	43	13	LOW
TEST CLR13 (APPLIANCE 5) (0.46 M WALL CLEARANCE)	0.23	221	54	26	24	61	56	8	LOW

TABLE 8: COMPARISON OF MEASURED AND CALCULATED WALL SURFACE TEMPERATURES FOR HEAT TRANSFER FROM APPLIANCE TO WALL

TEST IDENTIFICATION	CLEARANCE (M)	APPLIANCE SURFACE	WALL REAR SURFACE	ROOM AMBIENT	WALL REAR AMBIENT	MEASURED WALL SURFACE	CALCULATED WALL SURFACE	DIFFERENCE (%)	
TEST CLR01 (APPLIANCE 1) (0.91 M WALL CLEARANCE)	0.91	274	36	32	24	43	51	18	HIGH
TEST CLR02 (APPLIANCE 1) (0.62 M WALL CLEARANCE)	0.62	248	41	28	25	54	60	10	HIGH
TEST CLR03 (APPLIANCE 1) (0.46 M WALL CLEARANCE)	0.46	248	46	28	26	73	77	5	HIGH
TEST CLR04 (APPLIANCE 2) (0.91 M WALL CLEARANCE)	0.91	267	45	31	24	63	54	14	LOW
TEST CLR05 (APPLIANCE 2) (0.46 M WALL CLEARANCE)	0.46	263	57	30	24	99	98	1	LOW
TEST CLR06 (APPLIANCE 3) (0.91 M WALL CLEARANCE)	0.91	247	35	33	25	55	56	2	HIGH
TEST CLR07 (APPLIANCE 3) (0.46 M WALL CLEARANCE)	0.46	260	42	27	20	83	96	16	HIGH
TEST CLR08 (APPLIANCE 4) (0.91 M WALL CLEARANCE)	0.91	220	40	34	26	55	51	7	LOW
TEST CLR09 (APPLIANCE 4) (0.46 M WALL CLEARANCE)	0.46	213	50	31	25	79	78	1	LOW
TEST CLR11 (APPLIANCE 4) (0.15 M WALL CLEARANCE)	0.15	229	70	34	25	167	143	14	LOW
TEST CLR12 (APPLIANCE 5) (0.91 M WALL CLEARANCE)	0.91	115	39	31	25	48	35	17	LOW
TEST CLR13 (APPLIANCE 5) (0.46 M WALL CLEARANCE)	0.46	126	50	26	24	58	47	18	LOW

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A series of 18 full-scale tests was conducted in an instrumented test room using five different wood-burning appliances. These tests were designed (1) to establish typical operating conditions including temperatures on the appliances, chimneys, and adjacent combustible surfaces; (2) to study the effects of a variety of combinations of appliance design, clearance to combustibles, and room construction on temperatures on adjacent combustible surfaces; and (3) to compare these measured values with theoretical predictions of wall surface temperature. Additional tests were conducted to compare a standardized fuel source with typical oak logs.

A review of literature related to wood-heating safety included in this study revealed that current codes are based on data almost 40 years old. The results of these tests point out some areas where the codes should be modernized to accurately reflect the newer appliances and construction techniques.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Chimneys; fire models; fire safety; fire tests; flues; heating equipment; heat transfer; literature reviews; radiant energy; stoves; wood.

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