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Evaluation of Wall Protection Systems for Wood Heating Appliances

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
Washington, DC 20234

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Prepared for:
U.S. Department of Energy
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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EVALUATION OF WALL PROTECTION SYSTEMS FOR WOOD HEATING APPLIANCES

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Abstract

Measurements of the surface heating potential of unprotected and protected gypsum wallboard materials in close proximity to irradiating surfaces of home heating appliances have been made. A total of 4 unprotected walls and 19 protected interior wall surfaces were evaluated in tests where stove-to-wall clearances were varied from 7.5 to 90 cm (3 to 36 in) and stove surface temperatures were maintained at five different temperature levels ranging from 150-350 $^{\circ}$C (300-660 $^{\circ}$F).

The systems found most effective in offering thermal protection to the base wall surface (i.e., gypsum wallboard) were those consisting of a metal plate surface offset by an air space in front of the wallboard material.

Unprotected gypsum wallboard surfaces were ignited when the stove to wall clearance was 7.5 cm (3 in) and the stove surface measured 350 $^{\circ}$C (660 $^{\circ}$F).

Key Words: Chimneys; fire tests; flues; heating equipment; literature reviews; radiant energy; stoves; wall protection; walls; wood.

1. INTRODUCTION

The Consumer Product Safety Commission (CPSC) and the Department of Energy (DOE) have sponsored studies at the Center for Fire Research (CFR) at the National Bureau of Standards (NBS) to investigate the fire safety of wood-burning appliances (stoves) used for space heating in single-family homes and similar small-scale applications.

In previous reports [1-4] submitted to the Department of Energy (DOE) on the fire safety of wood-burning appliances, CFR has presented information on a survey of fire incidents involving wood-burning appliances and a review of codes and standards dealing with solid fuel appliances. These reports provided the basis for research on proper clearances between wall lining surfaces and wood-burning appliances and on protective devices that may be used to allow for reduced clearances.

The following report details the results of such a research effort designed to study the effects of clearances between wall linings and hot (stove) surfaces on temperatures developed on the surface of the wall lining materials.

2. REVIEW OF PREVIOUS WORK

2.1 Minimum Safe 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 [2,5-13]. 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. Typically, 0.91 m (36 in) of clearance is specified between radiant heaters and unprotected combustible construction in the codes. 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 [12], 0.46 m (18 in) is usually recommended as a minimum clearance.

The experimental basis for these code requirements is not, however, quite so clear. Several experimental studies have been carried out to determine minimum acceptable clearances to combustible materials. Voigt [14], in a 1933 publication, recommends a minimum clearance of 0.30 m (12 in) for chimney connectors 0.23 m (9 in) in diameter. A more extensive study, performed by Underwriters Laboratories in 1943 [15], 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. Lawson, Fox, and Webster [16] and Lawson and Simms [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].

These experimental studies established limits for two important parameters: appliance surface temperature and clearance to combustibles for unprotected and protected surfaces. Maximum appliance surface temperature for the appliances studied ranged from 300-350°C (600-660°F). Minimum safe wall clearance for unprotected surfaces range from 0.3 m - 0.91 m (12 in - 36 in). Most of the current code provisions are only adequate for maximum appliance surface temperatures up to 300-350^{o}C. In addition, all the methods of wall protection specified in the model building codes use two materials: asbestos millboard in various thickness and sheet metal. With the current health concerns with the use of asbestos, few alternatives are left for wall and floor protection.

2.2 Temperatures Developed in Heating Appliances

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces [18,19] established a limiting temperature rise of 190^{o}C (375^{o}F) on the outer surface of the chimney for a flue gas temperature of 540^{o}C (1000^{o}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 in the same study to be capable of reducing heat transmission to the extent required for safety of nearby combustibles.

To establish performance requirements for lightweight prefabricated chimneys, tests were conducted with lined and unlined masonry chimneys having 10 cm (4 in) thick walls [20]. Hazardous conditions on wood framing spaced 5 5 cm (2 in) away from the chimney were noted with a continued flue gas temperature of 480^{o}C (900^{o}F) for the unlined chimney and 590^{o}C (1100^{o}F) for the lined chimney. However, these hazardous conditions were not reached in the lined chimney tests until after 13 hours. As a comparison with typical fuels, a number of firing tests [21] 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, gas temperatures ranging from 650^{o}C to 705°C (1200°F to 1300°F) were measured for an hour or more in the flue at the ceiling level above the heater.

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.

Shoub [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.

In tests for the U.S. Department of Energy [23], temperatures ranging from 297°C-436°C during normal operation and 378°C-694°C during overload conditions were noted on appliance surfaces during tests of several wood-burning appliances.

Clearly, from these data, surface temperatures of wood-burning appliances available in the marketplace today are hotter than the 300°C-350°C that the current codes are based upon. The temperatures measured in the tests reviewed here are all maximum temperatures of the appliance surface. Perhaps a more valid representation would be based on an average temperature of the appliance surface or a heat flux at the wall surface. Average appliance surface temperatures measured during tests of five wood-heating appliances during normal operation ranged from 213°C to 356°C (415°F to 673°F) [23]. In this study, average appliance surface temperatures are employed.

2.3 Limiting Safe Temperatures on Combustible Surfaces

Listings of heat producing appliances by nationally recognized testing laboratories and methods for setting clearances between appliances and combustible surfaces are based on:

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

- maximum temperature rise of 50°C (90°F) above room temperature on unexposed surfaces such as beneath the appliance, floor protector, or wall-mounted shield [24].

These requirements are based on the fact that, while the ignition temperature of wood products is generally quoted to be on the order of 200°C (400°F) [12], 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 [25].

Mitchell [26] presents tests on wood fiberboard exposed to temperatures as low as 109°C (228°F) that resulted in ignition after prolonged exposure. MacLean [27,28] reports charring of wood samples at temperatures as low as

$93^{o}C$ ($200^{o}F$). He concludes that wood should not be exposed to temperatures appreciably higher than $66^{o}C$ ($150^{o}F$) for long periods. McGuire [29], suggests that the maximum safe temperature on the surface of a combustible material adjacent to a constant heat source should be no more than $100^{o}C$ ($212^{o}F$).

Clearly, the ignition of wood at moderately elevated temperatures is a complex phenomenon. The time of exposure is indeed an important parameter [30]. The ignition and self-heating properties of charcoal may be more important than that of "natural" wood according to Shelton [31]. Still, the numerous documented fires involving the ignition of wood members near low pressure steam pipes [32] suggest an upper temperature limit for wood exposed to long-term low-level heating should not be appreciably higher than $100^{o}C$ ($212^{o}F$).

3. WALL PROTECTION SYSTEMS

Table 1 presents sketches of the 4 unprotected walls and the 19 different wall protection systems evaluated in this study. The systems were especially designed to obtain as wide a spectrum of information as possible on temperature protection devices for walls exposed to radiant heat from home heating appliances. As shown, gypsum wallboard served as the base material for each of the systems. This particular wallboard was chosen because of its widely accepted use in room wall constructions found in homes or other dwelling places. For 12 of the 23 systems the wallboard surfaces were painted black. In 11 of the systems, protector surfaces were also painted black.

Since "worst-case conditions" were created by black painted surfaces, it was expected that the effectiveness of the different wall protection systems might be judged by their ability to reflect or absorb radiation and/or to dissipate absorbed radiation.

The exposed surface of each wall system measured 1.2 x 1.2 m (4 x 4 ft) and the panels were mounted vertically with an allowance made for a 2.5 cm (1 in) air space from the floor.

For the purposes of brevity and clarity a key on the following page identifies the various components used for the wall protection systems shown in table 1 and in system descriptions throughout this report. The following outlines the rationale used in the selection of the particular wall systems for this evaluation study.

1. Compare the surface temperature rise on unprotected and unpainted base gypsum wallboards "W" (nos. 2 and 7) with unprotected and black painted "WB" wallboards (nos. 11 and 16).

2. Determine the protection afforded to the base wallboard material by metal plate/air space(s) combinations. No. 1 (W,A,Al), no. 6 (W,A,28G) and no. 9 (W,AA,28G).

3. Measure the effect of black painted metal plate surfaces and air space combinations on unpainted wallboard surface temperatures. Systems no. 8 (W,A,28GB) and no. 10 (W,A,28GB,A,28GB).

4. Determine the effect of black painted wallboard surfaces, black painted metal plates and air space combinations on wallboard surface temperatures. Systems no. 12 (WB,A,24GB), no. 13 (WB,AA,24GB), no. 14 (WB,A,24GB,A,24GB), and no. 15 (WB,A,AlB).

5. Determine the effect of protection devices (attached directly to the base wallboard material) on wallboard surface temperatures. Systems no. 3 (W,M), no. 5 (W,M,28G), no. 17 (WB,FG,CB), and no. 22 (WB,BRV).

KEY

Wall Protection Systems		Thickness		
Identification	Material	mm	in	gage
W	Gypsum wallboard	10	0.375	-
A	Air space	25	1.0	-
AA	Air space	50	2.0	-
Al	Aluminum metal plate	3	0.125	-
M	Inorganic insulation board "M"	12	0.50	-
28G	Galvanized metal plate	0.4	0.015	28
24G	Galvanized metal plate	0.6	0.024	24
FG	Fiberglass	25	1.0	-
C	Inorganic insulation board "C"	6	0.25	-
CB	Inorganic insulation board "C" painted black	6	0.25	-
CC	Inorganic insulation board "C"	12	0.50	-
BRV	Brick veneer	6	0.25	-
BR	Brick wall	90	3.50	-
WB	Gypsum wallboard black painted surface exposed	10	0.375	-
28GB	Galvanized metal black painted surface exposed	0.4	0.024	28
24GB	Galvanized metal black painted surface exposed	0.6	0.015	24
AlB	Aluminum plate black painted surface exposed	3	0.125	-

6. Determine the effect of unpainted and painted insulation boards and a brick wall each offset by air space from the base wallboard on wallboard surface temperatures. No. 4 (W,A,M), no. 18 (WB,A,CB), and no. 23 (WB,A,BR).

7. Measure the protection offered to the wallboard by black painted metal plate sandwich panels separated by air space from wallboard (exposed side of sandwich blackened). No. 19 (WB,A,24GB,FG,24GB), no. 20 (WB,A,24GB,C,24GB), and no. 21 (WB,A,24GB,CC,24GB).

4. TEST APPARATUS

A mock-up heating stove apparatus was constructed for the test series. The stove enclosure was fabricated with 6 mm (1/4 in) thick steel plates and measured 50 x 50 x 50 cm (20 x 20 x 20 in). The fire box was supported 35 cm (14 in) from the floor by steel angles attached to the box. The test apparatus, illustrated in figure 1, has a radiant panel mounted on the floor of the stove enclosure (Note: The radiant panel is the same type used in ASTM Standard E 162 for measuring the surface flammability of building materials.) The panel consists of a porous refractory material mounted in a cast-iron frame which allows for the combustion of gas over its surface which measures 30 x 45 cm (12 x 18 in). Regular laboratory supplied natural gas was used for the tests and no air was mixed with the gas for this testing program. Venting for the stove was provided by a conventional 15 cm (6 in) diameter stovepipe system.

Figure 2 shows the location of five 24-gauge, 0.5 mm (0.020 in) chromel alumel thermocouples attached to the irradiating surface of the stove facing the test walls. One thermocouple was located at the center of the 50 x 50 cm (20 x 20 in) surface and each of the four remaining thermocouples were positioned at 15 cm (6 in) distances from the center couple in both the horizontal and vertical planes. The thermocouples were attached to the steel plate by metal washers fastened to the plate with sheet metal screws.

Figure 3 shows the thermocouple system (24-gauge chromel alumel), used to monitor the temperatures generated on the irradiated and protected wallboard surfaces of the wall systems during tests. One thermocouple was mounted at the center of each test panel (measuring 1.2 x 1.2 m) and from this thermocouple additional thermocouples were positioned in horizontal and vertical planes at distances of 15, 30, and 45 cm (6, 12, and 18 in). For temperature averaging purposes, each circle of thermocouples were connected in parallel.

5. TEST PROCEDURES

Wall test panels were mounted in a vertical position and stove to wall clearances were adjusted over the following six different test distances: 90, 60, 45, 30, and 7.5 cm (36, 24, 18, 12, and 3 in). (Note: the clearance established by Fire Codes [8], i.e., 90 cm (36 in), was used as the starting point for tests.) With the center thermocouples on the stove and wall panel surfaces in alignment, the stove's gas radiant panel was fired. Gas flows to the panel were monitored over a range of 14 to 76 ℓ/s (30 to 160 SCFM) to provide the desired test temperature levels on the stove surface; i.e., 150, 200, 220, 250, 300, and 350°C. The selection of these temperatures is based on previous work with actual wood-burning appliances [2]. Functions describing the relation between wall surface temperature and distance are derivable from theory and these are discussed in detail in reference [23].

Stove surface temperatures were quickly and easily maintained; however, the irradiated wall test surfaces did not reach a reasonable level of constancy until 2 to 3 hours of exposure time had passed. Typically, a test was started with the test wall 90 cm (36 in) away from the radiant stove surface. When the temperature on the wall reached steady state, that temperature was recorded for the test location. The wall was then moved to the next closer test location and the testing procedures were repeated exactly. After temperatures were recorded for the series of test locations, the entire procedure was again repeated until a total of four measurements were made for each test location. All recorded temperatures were averaged for data analysis and plotting.

In most cases the time required for obtaining a complete set of data for all temperature and clearance tests was 1 to 1-1/2 working days.

6. TEST RESULTS AND DISCUSSION

Figures 4 through 15 show the range of temperatures generated on the radiated surfaces of protectors for the 19 gypsum wallboard - wall protector combinations and 4 unprotected wallboard surfaces when the stove to wall clearances were varied from 7.5 - 90 cm (3 - 36 in). As expected, the highest temperatures were recorded for the smaller clearances, i.e., 7.5 cm (3 in) and the lowest for the 90 cm (36 in) clearance. (Note: surface temperature values for nos. 2, 7, 11 and 16 are for wallboards, since no protectors were used.)

Figures 16 through 27 show the range of temperatures measured on the surfaces of the 9 mm (3/8" in) thick gypsum wallboard used in every test.

For discussion and comparison purposes, data for the different wall systems will address "worst-case conditions", i.e., a 350^{o}C stove surface temperature and 7.5 cm (3 in) stove-wall clearance.

6.1 Unprotected Gypsum Wallboard - Painted Versus Unpainted Surfaces

For walls nos. 2 and 7 the base wallboard (W) was unpainted, walls 11 and 16 had black painted (WB) surfaces. Tests showed that in every case the black painted surfaces had higher temperatures than the unpainted surfaces. This was to be expected, however, as the black surfaces have a higher radiation absorptivity. When each of the walls was tested at the 7.5 cm clearance the paper surfaces on the wallboards ignited and flamed from 3 to 12 minutes. Surface damage amounted to a 30 cm (12 in) diameter circle of paper being burned away before extinguishment.

6.2 Effect of a Metal Protector and Air Space on Wallboard Surface Temperature

Data for peak surface temperatures on three wall systems are presented as follows:

Peak Surface Temperatures

	Unpainted Gypsum Wallboard (W)	Protector
No. 1 (W,A,Al)	44°C	78°C
No. 6 (W,A,28G)	36°C	78°C
No. 9 (W,AA,28G)	36°C	114°C

The above data shows that all three metal plate-air space systems were successful in providing for reasonable surface temperatures, i.e., 36-44°C on the (W) boards. The board protected by an (Al) plate in system no. 1 registered an 8°C higher temperature than the other (W) board protected by the (28G) metal plate in system no. 6 but this difference was considered negligible. The double air space (AA) used by system no. 9 and the single air space (A) used by system no. 6 (with the same type 28G metal protector) showed the same temperature rise (36°C) on the (W) board surfaces. The protector plate in system no. 9 had a higher surface temperature (114°C) simply because this plate was closer by 2.5 cm (1 in) to the stove surface than the plate in system no. 6. The significance of these temperature rise values will be discussed in greater detail in the Summary and Conclusions, sections 7-8.

6.3 Effect of Black Painted Metal Protector and Air Space on Wallboard Surface Temperature

Tests on two wall systems produced the following information:

Peak Surface Temperatures

	Unpainted Gypsum Wallboard (W)	Protector
No. 8 (W,A,28GB)	85°C	194°C
No. 10 (W,A,28GB,A,28GB)	38°C	225°C

Before comparing results of system no. 8 with no. 10, it should be noted here that for system no. 6 discussed above the wallboard (W) protected by unpainted metal (28G) showed a surface temperature of 36°C. For system no. 8 the painted metal (28GB) allowed for a (W) board temperature of 85°C or 29°C higher. This resulted from the fact that the protector (metal) surface temperature for no. 6 reached only 78°C while for no. 8 the temperature reached 194°C. The higher protector surface temperature in no. 8 was due to the higher absorptivity of its blackened surface. A comparison of wallboard (W) surface temperatures for system no. 8 and no. 10 (i.e., 85°C and 38°C, respectively) showed that the presence of an extra metal plate (28GB) and air space (A) in system no. 10 helped to maintain the surface temperature on the (W) board at a reasonable level (38°C or almost the same as was observed for system no. 6 (36°C)), while the single air space - 28GB combination used in system no. 8 allowed for a temperature of 85°C. Again it was shown, that the metal plate closest to the stove surface, exhibited the highest surface temperature (225°C for system no. 10).

6.4 Effect of Black Painted Metal Protectors and Air Space on Black Painted Wallboard

Data obtained in tests on four wall systems are listed as follows:

Peak Surface Temperatures

	Painted Gypsum Wallboard (WB)	Protector
No. 12 (WB,A,24GB)	97°C	239°C
No. 13 (WB,AA,24GB)	62°C	225°C
No. 14 (WB,A,24GB,A,24GB)	35°C	226°C
No. 15 (WB,A,AlB)	106°C	225°C

A comparison of results for wall systems nos. 12 and 14 showed that use of an extra metal plate and air space in no. 14 resulted in a considerable decrease in WB surface temperatures, i.e., 35°C versus 97°C for system no. 12. Also, use of additional air space (AA) in system no. 13 provided for a lower temperature (62°C) on the (WB) board surface than was obtained with the single air space (A) in system no. 12 (97°C). The value of using different thicknesses for metal protectors, i.e., 24 gage (0.024 in) in system no. 14 and 28 gage (0.015 in) in system no. 10 was not clearly demonstrated in these tests since almost identical temperature results were obtained for the wall systems. However, the effectiveness of the double metal plate double air space system was such that there was a negligible difference (3°C) between the surface temperatures on the unpainted (W) board in system no. 10 and the painted (WB) board in no. 14. The aluminum metal (AlB) protector system in no. 15 allowed for a higher surface temperature on the (WB) board (106°C) than was observed on the (WB) board protected by the (24GB) metal plate in system no. 12 (97°C). The black painted surfaces of the four metal protectors tested showed temperatures ranging from 225 to 239°C.

6.5 Effect of Protective Devices Attached Directly to Wallboard

Results of tests on four different wall systems are listed as follows:

Peak Surface Temperatures

	Gypsum Wallboard	Protector
No. 3 (W,M)	134°C*	180°C*
No. 5 (W,M,28G)	41°C	51°C
No. 17 (WB,FG,CB)	88°C	257°C
No. 22 (WB,BRV)	216°C	236°C

*Data for system no. 3 for 300°C stove surface temperature.

The value of a combination, metal plate (28G) - insulation board (M), attached directly to the base (W) board in wall system no. 5 was evidenced by the low surface temperature (41°C) measured on the (W) board. The ability of the unpainted metal surface to reflect heat combined with the insulation qualities of M board helped produce these low temperatures. System no. 3 used the same insulation board (M) but did not have the benefit of a metal cover plate and thus the protected (W) board surface temperature reached 134°C.

System no. 17 using a fiberglass - "C type" insulation board package attached to the (WB) board showed a considerably high temperature (257°C) on the painted C board surface and a temperature of 88°C on the (WB) board surface.

In system no. 22, the 6 mm (1/4 in) thick brick veneer attached to (WB) board developed a surface temperature of 236°C. This high temperature together with the thin veneer having a relatively high thermal conductivity "k" caused the (WB) board surface to register a temperature of 216°C.

6.6 Effect of Air Space Combined with Protective Insulating Boards, and a Brick Wall on Wallboard

Peak Surface Temperature

	Gypsum Wallboard	Protector
No. 4 (W,A,M)	60°C	154°C
No. 18 (WB,A,CB)	81°C	220°C
No. 23 (WB,A,BR)	72°C	241°C

An evaluation of the above data shows that black painted surfaces again provided for worst-case testing conditions. In system no. 18 the black painted protector (insulation board "CB") developed a temperature of 220°C on its surface and the painted wallboard (WB) separated from this board by an air space, registered a surface temperature of 81°C. System no. 4 by comparison, showed unpainted insulation board "M" with a surface temperature of 154°C and unpainted wallboard (W) with a value of 60°C.

Both of these boards were calcium silicate types and had similar densities. "M" board had a thermal conductivity "k" value 3 times that of "C" board. However, since the protector wall systems were not tested in the exact same manner; (i.e., both painted and unpainted the effect of "k" values on temperature performance cannot be determined in these tests.

The solid brick wall in system no. 23 registered a peak surface temperature of 241°C and even with a 2.5 cm (1 in) air space (A) separation from the WB board allowed the wallboard surface to develop a temperature of 72°C.

6.7 Effect of Black Painted Metal Sandwich Panels and Air Space on Wallboard Surface Temperature

Results for tests on three different wall systems are listed as follows:

Peak Surface Temperatures

	Gypsum Wallboard (WB)	Protector
No. 19 (WB,A,24GB,FG,24GB)	34°C	254°C
No. 20 (WB,A,24GB,C,24GB)	39°C	249°C
No. 21 (WB,A,24GB,CC,24GB)	38°C	256°C

An evaluation of the above data shows that each of the sandwich panels (while developing high surface temperatures of 249-256°C on the exposed painted metal protector covers) was successful in helping to maintain low surface temperatures of 34-39°C on the surfaces of the (WB) board material. Results indicate negligible differences between the different sandwich fill materials and their effect on temperatures.

7. SUMMARY

Work was completed on an evaluation of wall and wall protection systems for home heating appliances. In the tests a total of 4 unprotected walls and 19 different protection systems were exposed to radiant heat from a gas fired stove surface maintained at five different temperature levels from 150°C to 350°C. Clearances between the stove and wall surfaces were varied from 7.5-90 cm (3-36 in).

Figures 4 through 15 show the peak temperatures recorded on the surfaces of the wall protectors and 4 unprotected walls for each of the different stove temperatures for the clearance minimum of 7.5 cm (3 in) and maximum of 90 cm (36 in).

Figures 16 through 27 show the peak temperatures recorded on the surface of the base gypsum wallboard (W) and on painted gypsum wallboard (WB) surfaces for the same stove to wall clearances, i.e., 7.5 cm and 90 cm.

Table 2 lists the wall system number, peak temperatures for the protector and wallboard surfaces, the test room temperature and the temperature rise for the protector and wallboard surfaces above room temperature. All of these values are for "the worst-case conditions of 350°C stove surface temperature and stove to wall surface clearances of 7.5 cm (3 in).

An examination of this table shows that a total of 7 wall and wall systems are not included; namely, numbers 2, 7, 11, 16, 1, 3 and 4. The first four listed were unprotected gypsum wallboards (2 and 7 unpainted and 11 and 16 painted) which ignited during test and the latter three were not included because data was not obtained for these systems at 350°C stove surface temperatures.

8. CONCLUSIONS

The criteria used for the evaluation of data listed in table 2 was based on recommendations made in reference [24] that the upper limit for temperature rise above room temperature on unexposed surfaces such as beneath an appliance, floor protector, or wall mounted shield, be 50°C (90°F).

Reference [24] also cites a temperature limit of 65°C (117°F) on exposed combustible surfaces but this limit was not considered applicable to the protector surface data also listed in table 2 since the protectors were noncombustible materials.

Based on an analysis of the data the following conclusions are drawn.

1. A total of 12 wall systems were successful in limiting temperature rise to less than $50^{\circ}C$ on unexposed base gypsum wallboard surfaces under worst-case conditions of $350^{\circ}C$ stove surface temperature and clearance of 7.5 cm (3 in).

2. For 8 of the 12 systems, temperature rises were less than $10^{\circ}C$. These low values were registered by the following:

   Simple wall Systems: no. 6 W,A,28G; no. 9 W,AA,28G

   By two wall systems containing an extra metal plate protector and air space: no. 10 W,A,28GB,A,28GB; no. 14 WB,A,28GB,A,28GB

   By three metal covered sandwich panels plus air space: no. 19 WB,A,24GB,FG,24GB; no. 20 WB,A,24GB,C,24GB; no. 21 WB,A,24GB,CC,24GB

   By a system consisting of a metal faced insulation board attached directly to the surface of the base gypsum wallboard: no. 5 W,M,28G.

3. A total of 4 wall systems allowed the base wallboard surface temperature to rise to values between $28^{\circ}C$ and $48^{\circ}C$, these were:

   A simple system with a black painted metal protector: no. 8 W,A,28GB

   Three wall systems with black painted wallboard surfaces protected by air space and each with different protectors: no. 13 WB,AA,24GB (black painted metal); no. 18 WB,A,CB (black painted insulation board); no. 24 WB,A,BR (brick wall).

4. A total of 4 wall systems showed wallboard surface temperatures higher than the 50°C temperature rise limitation (range 57°C-180°C). These were:

   Two wall systems with black painted wallboard surfaces, air space and black painted metal protector plates: no. 12 WB,A,24GB; no. 15 WB,A,A1B

   Two wall systems with black painted wallboard surfaces and protection systems attached directly to the base wallboard: no. 17 WB,FG,CB (fiberglass, black painted insulation board); no. 22 WB,BRV (brick veneer).

5. Of the remaining 7 wall systems not listed in table 2, 4 were unprotected gypsum wallboard materials. Nos. 2 and 7 were unpainted (W) boards and nos. 11 and 16 were black painted (WB) boards. The paper surfaces on each of the wallboards were ignited at the 7.5 cm (3 in) clearance. Surface temperatures ranged from 190-240°C before ignition. The other three wall system nos. 1, 3, and 4 were not tested at 350°C.

6. The data listed in table 2 is illustrated in figure 28. Wallboard surface temperature rises are plotted versus stove-wall clearances. The figure shows the 12 wall systems that meet the 50°C temperature rise limitation.

7. Also indicated in the figure are the clearances needed by four of the wall systems to meet the 50°C temperature rise limitation. Nos. 15 and 17 require a clearance of 30 cm (12 in), no. 12 a 45 cm (18 in) separation, and no. 22 the brick veneer sample a clearance of 90 cm (36 in).

9. RECOMMENDATION

1. Room walls in close proximity to home heating appliances need thermal protection from irradiating hot stove surfaces.

2. Wall protection systems using air space(s) will help to provide for adequate thermal protection for room walls.

3. Highly reflective metal plate surfaces are more effective than heat absorbing painted surfaces.

4. Thin masonry veneers attached directly to a combustible wall offers little thermal protection to combustible materials and are not recommended.

10. REFERENCES

[1] Peacock, R. D., A Review of Fire Incidents, Model Building Codes, and Standards Related to Wood-Burning Appliances, Nat. Bur. Stand. (U.S.), NBSIR 79-1731 (May 1979).

[2] Peacock, R. D., et al., Fire Safety of Wood-Burning Appliances, Part 1: State of the Art Review and Fire Tests, Volumes I and II, Nat. Bur. Stand. (U.S.), NBSIR 80-2140 (November 1980).

[3] Peacock, R. D., A Review of Fire Incidents Related to Wood-Burning Appliances, Wood Energy Institute, Proceedings of Wood Heating Seminar IV, Portland, Oregon, March 21-24, 1979, 43-46.

[4] Shelton, J. W., Analysis of Fire Reports on File in the Massachusetts State Fire Marshal's Office Relating to Wood and Coal Heating Equipment, Nat. Bur. Std. (U.S.), NBS-GCR-78-149 (November 1978).

[5] The BOCA Basic Building Code/1978, Model Building Regulations for the Protection of Public Health, Safety and Welfare, Seventh Edition, Building Officials and Code Administrators International, Homeward, Illinois (1978).

[6] The BOCA Basic Mechanical Code/1978, Model Mechanical Regulations for the Protection of Public Health, Safety and Welfare, Third Edition, Building Officials and Code Administrators International, Homeward, Illinois (1978).

[7] The National Building Code, 1976 Edition, American Insurance Association, New York, New York (1976).

[8] Standard for Chimneys, Fireplaces, and Vents, NFPA 211-1977, National Fire Protection Association, Boston, Massachusetts (1978).

[9] Standard Building Code, 1976 Edition, Southern Building Code Congress, International, Incorporated, Birmingham, Alabama (1976).

[10] Amendments to the Standard Building Code, 1977 and 1978 Revisions to the 1976 Edition, Southern Building Code Congress, International, Incorporated, Birmingham, Alabama (1978).

[11] Uniform Building Code, 1976 Edition, International Conference Building Officials (1976).

[12] 1977 Supplement to the Uniform Building Code, U.B.C. Standards, Uniform Housing Code, Uniform Code for the Abatement of Dangerous Buildings and the Uniform Fire Code, International Conference of Building Officials (1977).

[13] Manual on Clearances for Heat Producing Appliances, NFPA 89M-1976, National Fire Protection Association, Quincy, Massachusetts (1978).

[14] Voigt, G. Q., Fire Hazard of Domestic Heating Installations, Nat. Bur. Stand. (U.S.), NBS Research Paper RP596 (September 1933).

[15] Neale, J. A., Clearances and Insulation of Heating Appliances, Underwriters Laboratories, Incorporated, UL Bulletin of Research #27 (February 1943).

[16] Lawson, D. I., Fox, L. L., and Webster, C. T., The Heating of Panels by Flue Pipes, Fire Research Special Report No. 1, Fire Protection Association, London, England (1952).

[17] Lawson, D. I. and Simms, D. L., The Ignition of Wood by Radiation, British Journal of Applied Physics, Vol. 3, 288-292 (September 1952).

[18] Shoub, H., Survey of Literature on the Safety of Residential Chimneys and Fireplaces, Nat. Bur. Stand. (U.S.), NBS Misc. Pub. 252 (December 1963).

[19] Prefabricated Metal Chimneys, National Bureau of Standards, Fire Research Section, unpublished reports to Federal Public Housing Authority (1941-1945).

[20] Temperatures Developed in Chimneys for Low Cost Houses, Nat. Bur. Stand. (U.S.), Tech. News Bull. 328 (August 1944).

[21] Fox, L. L. and Whittaker, D., Some Measurements of Temperatures of Metal Flues of Domestic Heating Appliances, Journal of the Institution of Heating and Ventilation Engineers, Vol. 23, 183-192 (August 1955).

[22] Standard for Chimneys, Factory-Built Residential Type and Building Appliance--UL 103 Underwriters Laboratories, Inc., Northbrook, Illinois (March 1971).

[23] Peacock, R. D., et al, Fire Safety of Wood Burning Appliances, Part 1: State of the Art Review and Fire Tests, Nat. Bur. Stds. (U.S.), NBSIR 80-2140 (1980).

[24] Standard for Room Heaters, Solid Fuel Type--UL 1482, First Edition Underwriters Laboratories, Inc., Northbrook, Illinois (August 1979).

[25] McKinnon, G. P. and Tower, K., Eds., Fire Protection Handbook, 14th Edition, National Fire Protection Association, Boston, Massachusetts, pages 3-2 to 3-7 (1976).

[26] Mitchell, N. D., New Light on Self-Ignition, NFPA Quarterly, Vol. 45, No. 2, 165-172 (October 1951).

[27] MacLean, J. D., Effect of Heat on Properties and Serviceability of Wood: Experiments on Thin Wood Specimens, Forest Products Laboratory Report No. R1471, Madison, Wisconsin (1945).

[28] MacLean, J. D., Rate of Disintegration of Wood Under Different Heating Conditions, American Wood-Preservers Association (1951).

[29] McGuire, J. H., Limiting Safe Surface Temperature of Combustible Materials, Fire Technology, Vol. 5, No. 3 (August 1969).

[30] Ignition and Charring Temperatures of Wood, Forest Products Laboratory Report No. 1464, Madison, Wisconsin (January 1958).

[31] Shelton, J. W., Wood Heat Safety, Garden Way Publishing, Charlotte, Vermont (September 1979).

[32] Matson, A. F., Dufori, R. E., and Breen, J. F., Performance of Type B Gas Vents for Gas-Fired Appliances, Part II, Survey of Available Information on Ignition of Wood Exposed to Moderately Elevated Temperatures, Underwriters Laboratories, Inc., Bulletin of Research, No. 51, Northbrook, Illinois (May 1959).

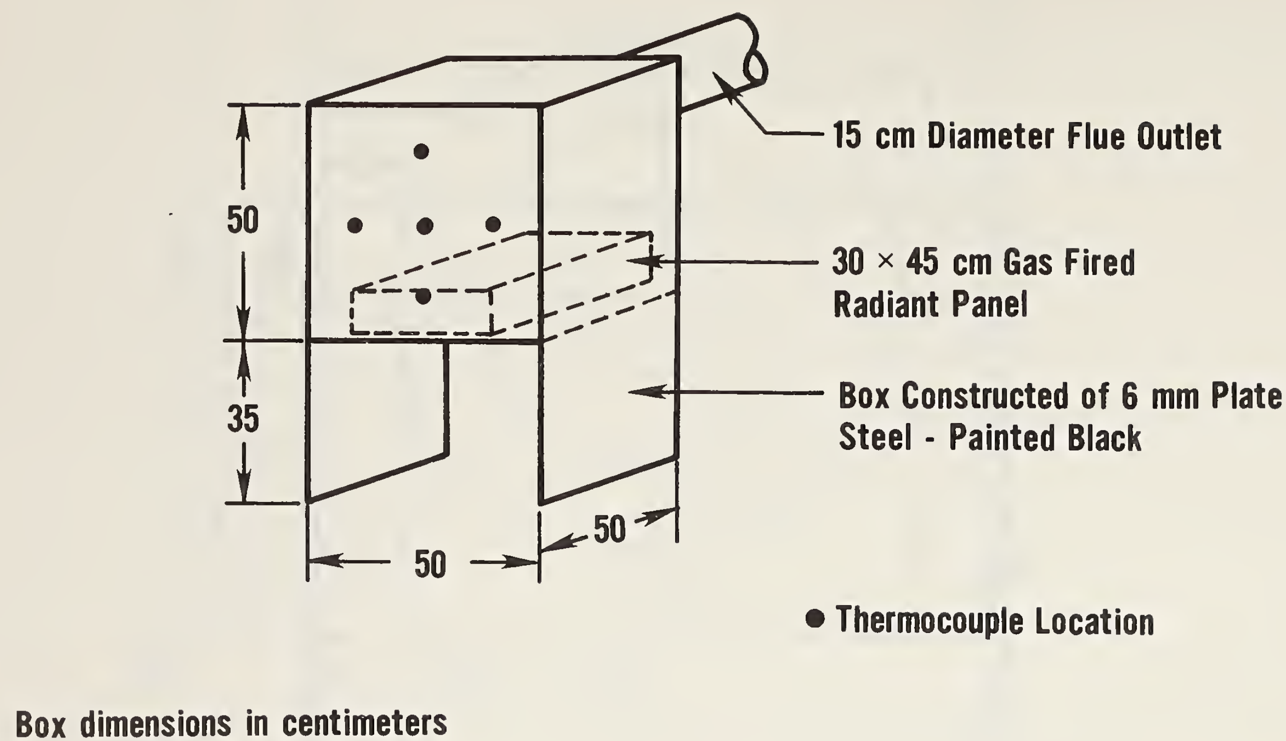


Figure 1. Appliance Construction details for gas-fired stove used in wall protection tests

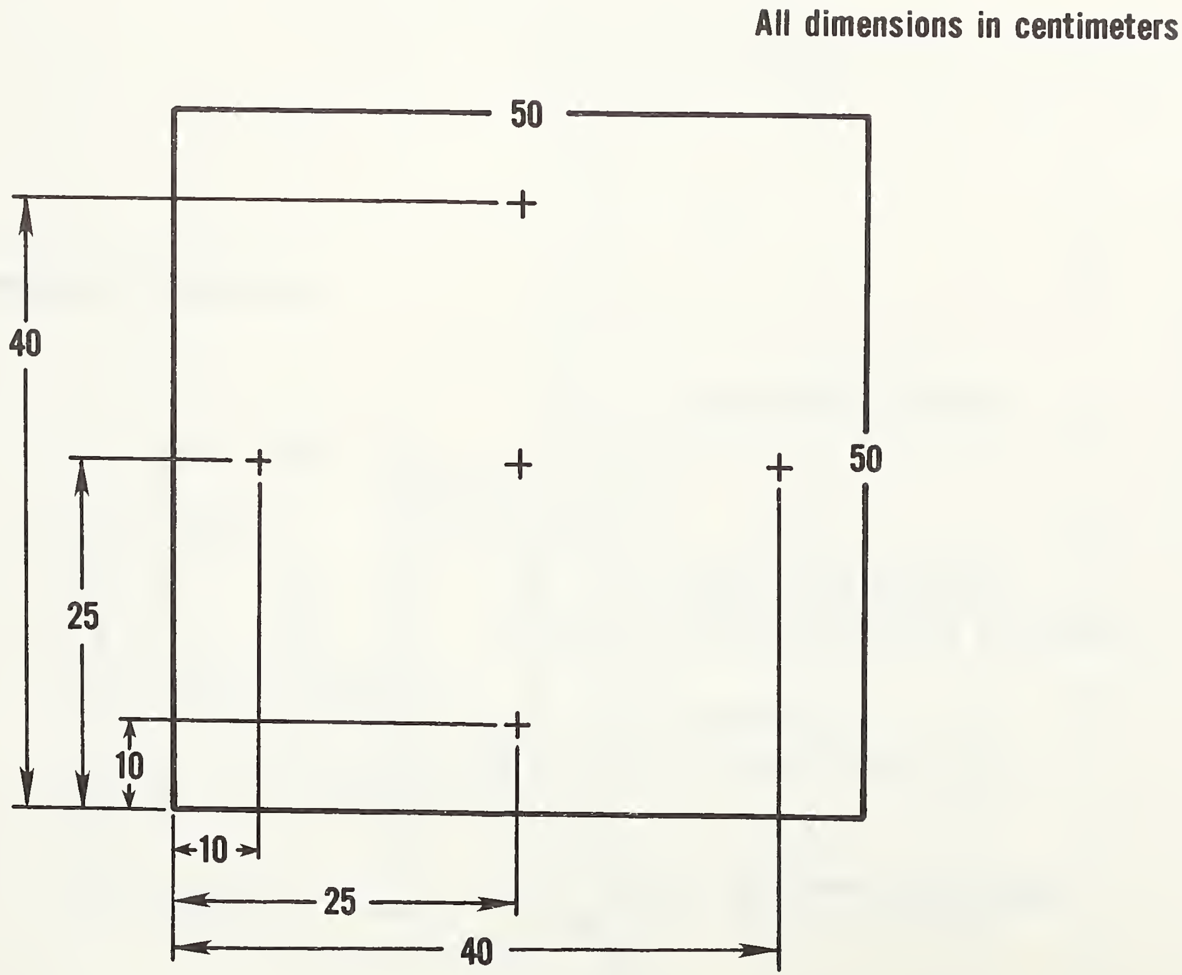


Figure 2. Thermocouple placement on appliance surface

All dimensions in centimeters

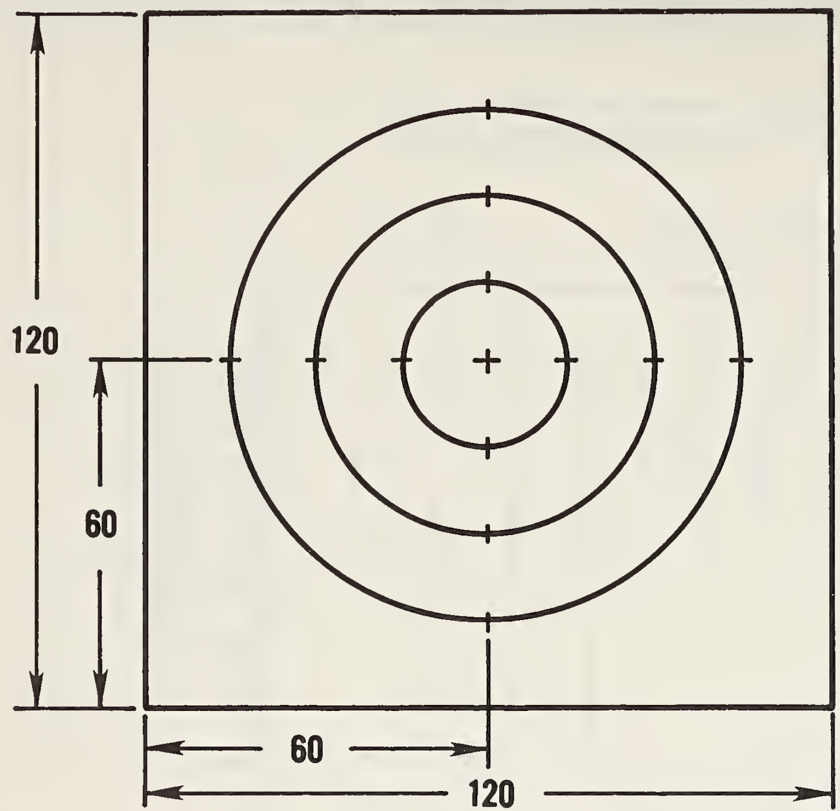
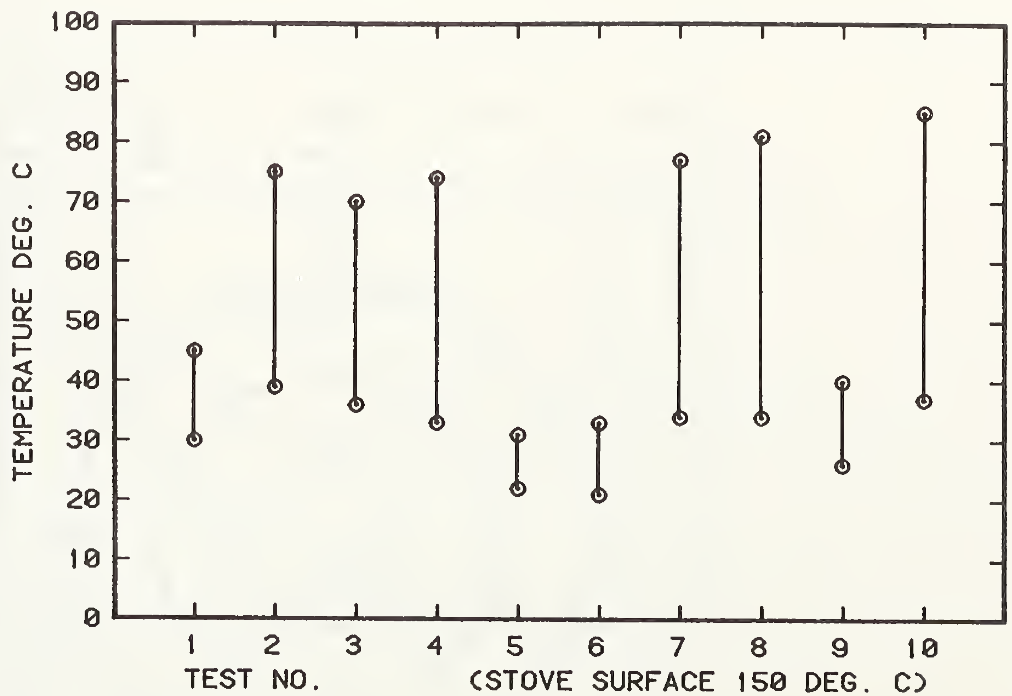


Figure 3. Thermocouple placement on protector and wallboard surface

NOTE: Temperatures for 2 and 7 in figures 4 to 14 are for wallboard surfaces (no protector used)



* high temperatures - 7.5 cm clearance
low temperatures - 90.0 cm clearance

Figure 4. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

NOTE: Temperatures for 11 and 16 in figures 5 to 15 are for wallboard surfaces (no protector used in these tests)

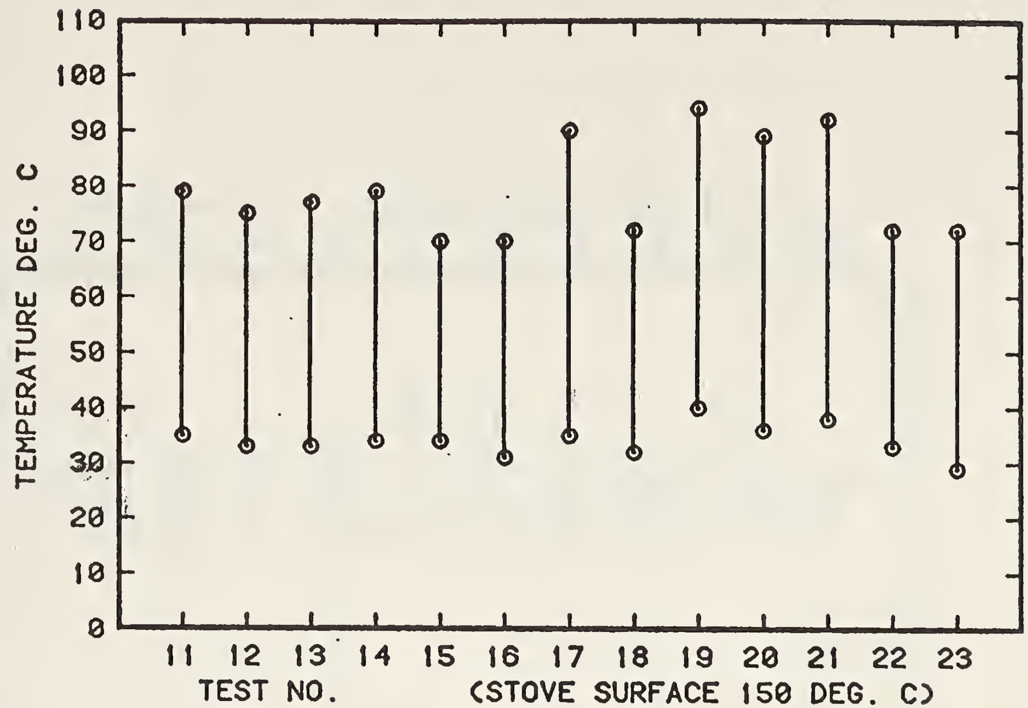


Figure 5. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

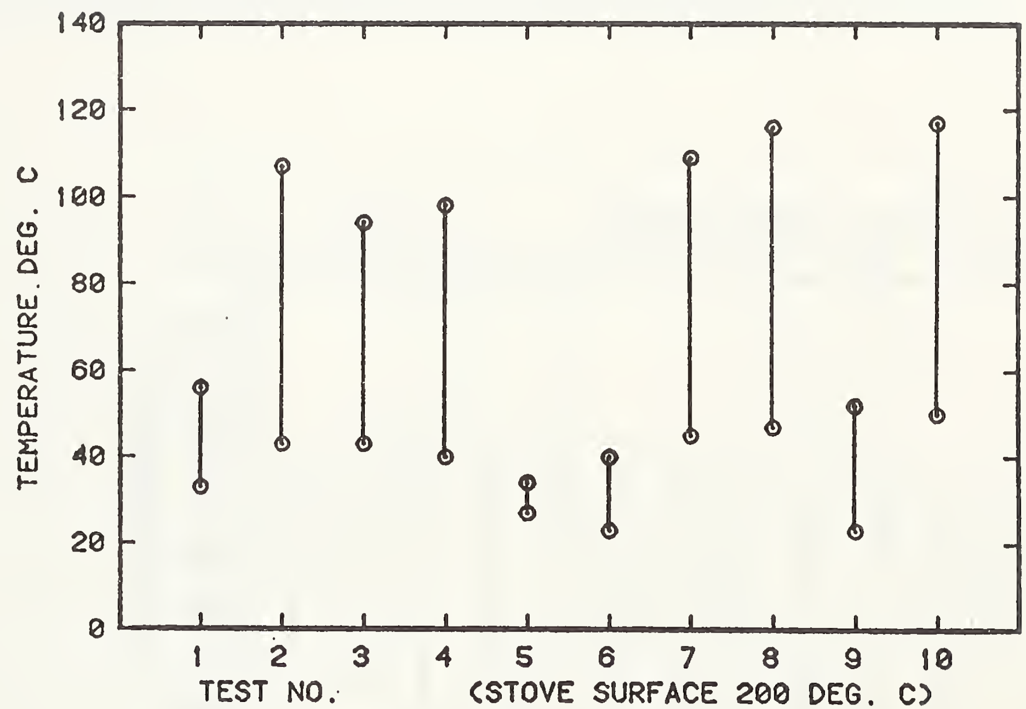


Figure 6. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

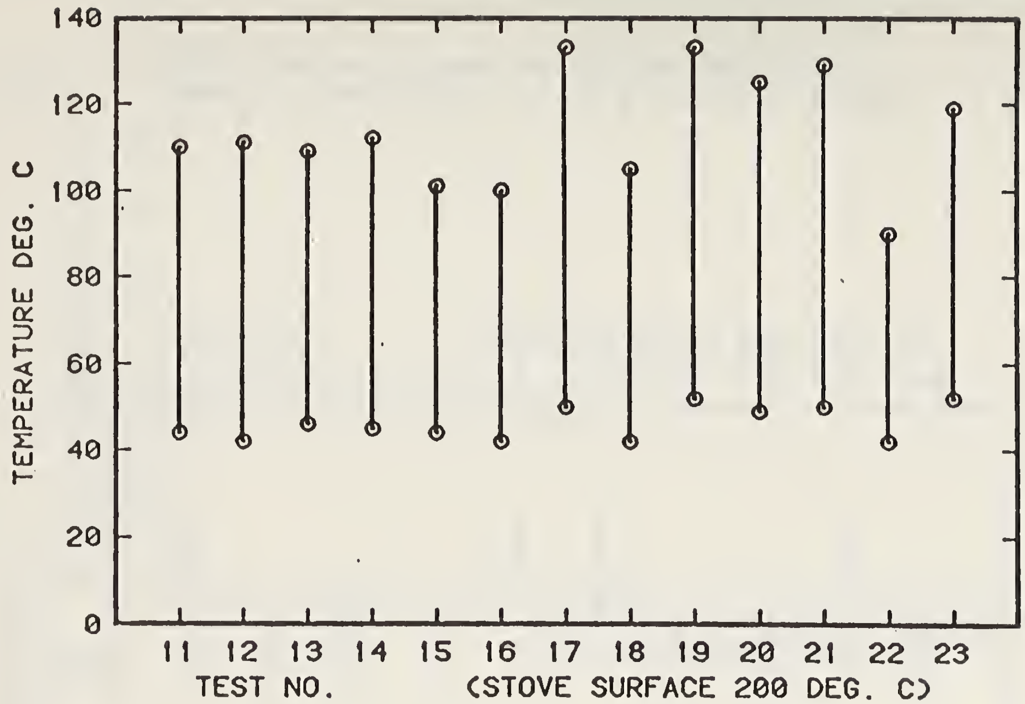


Figure 7. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

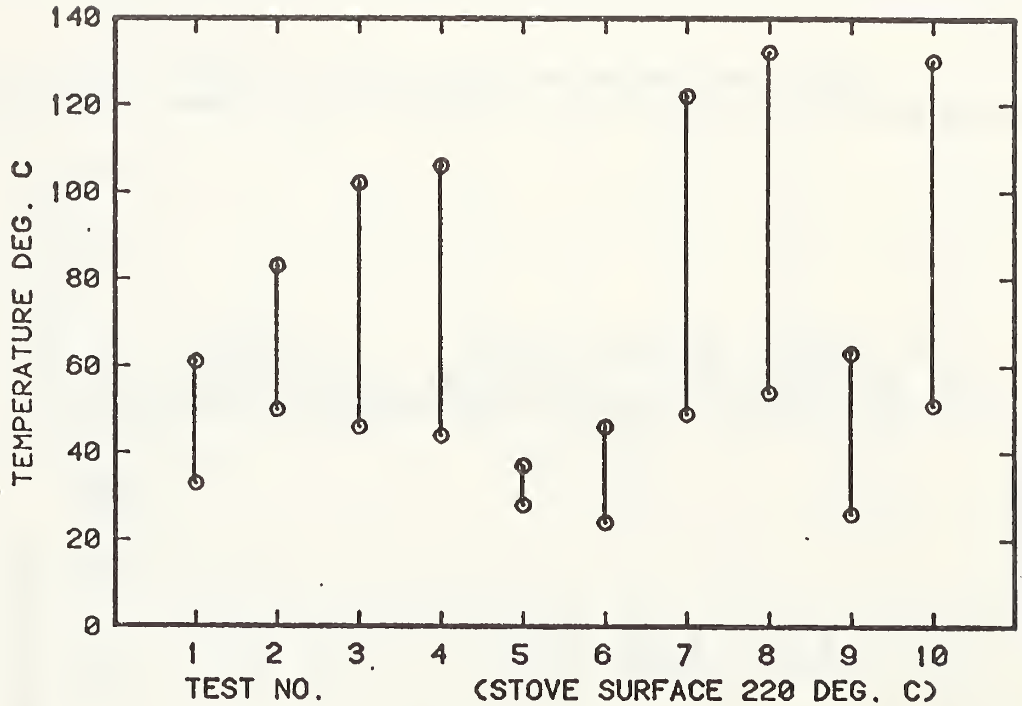


Figure 8. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

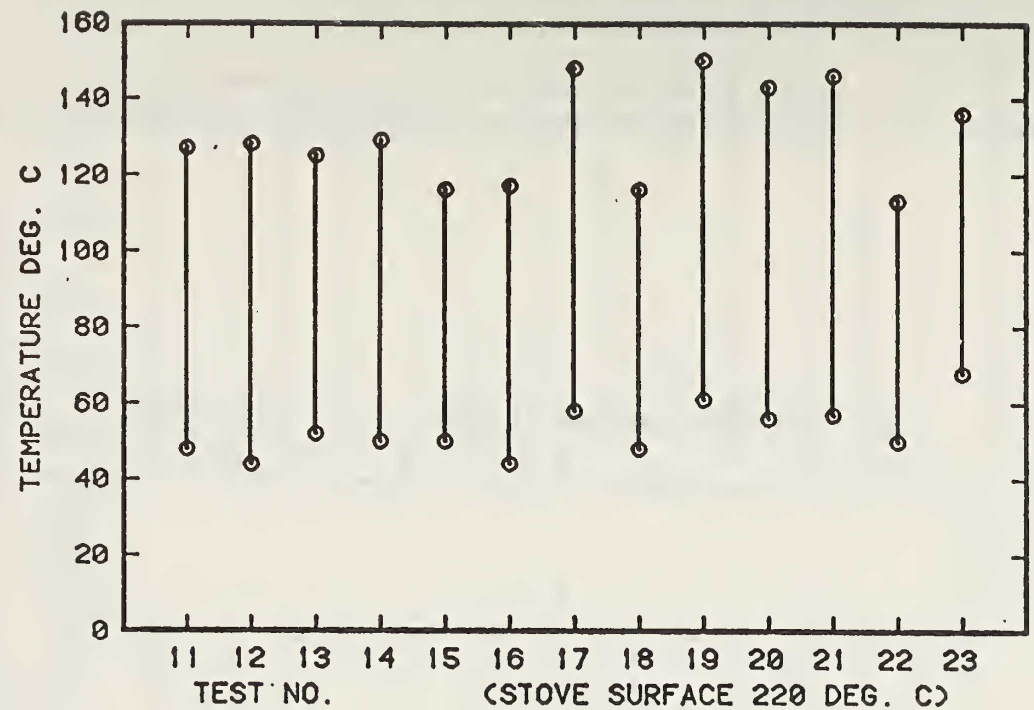


Figure 9. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

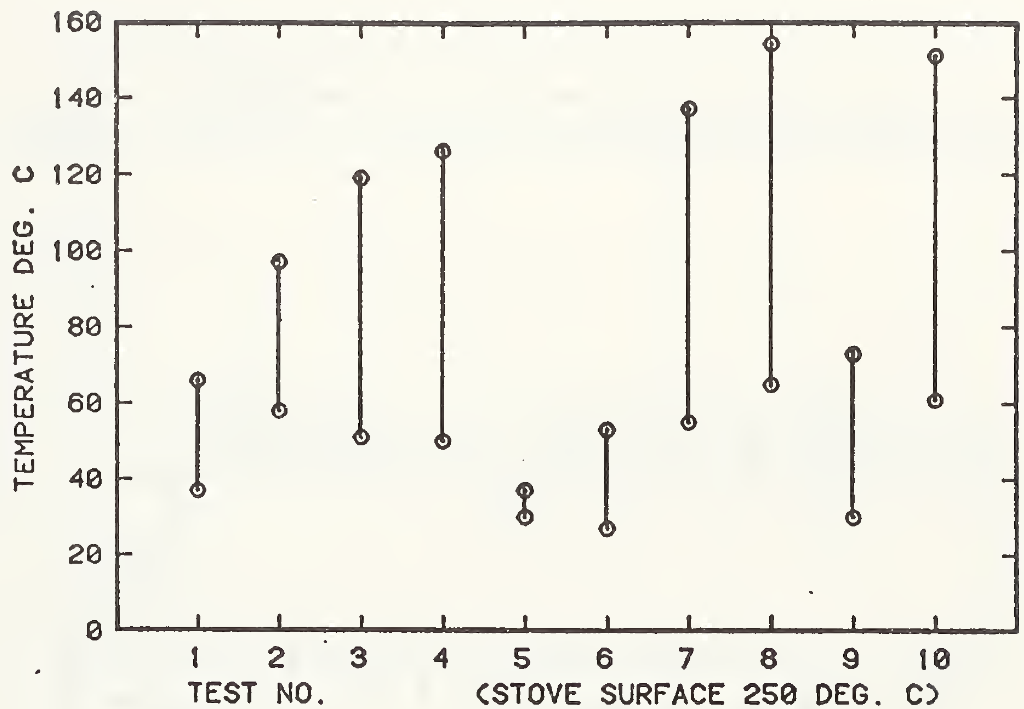


Figure 10. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

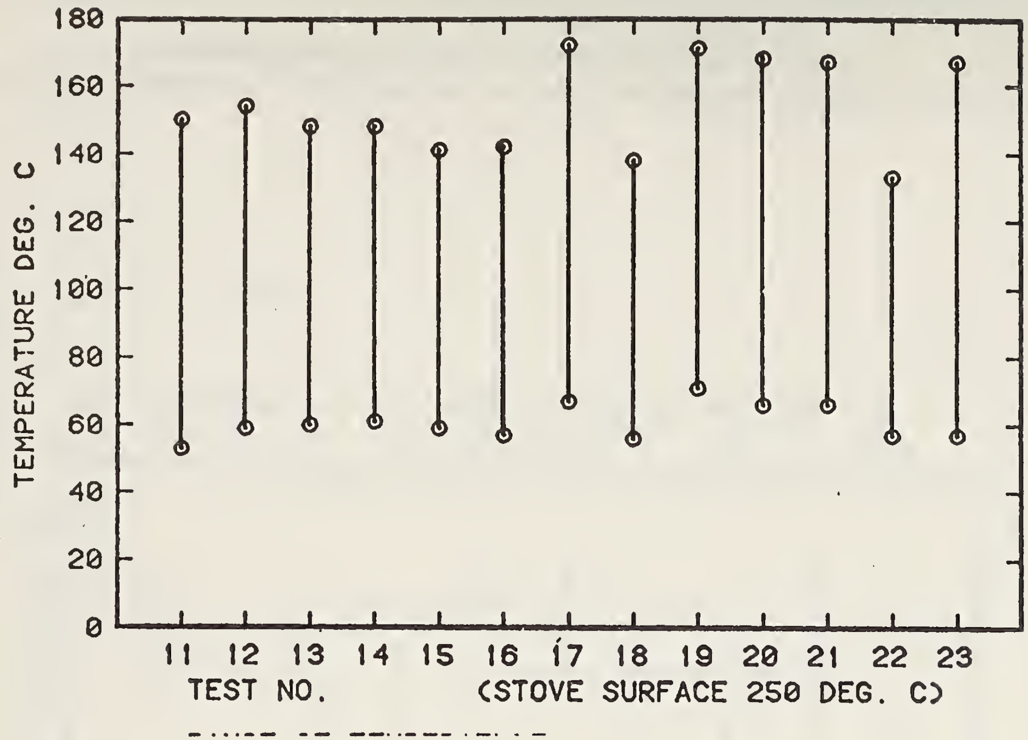
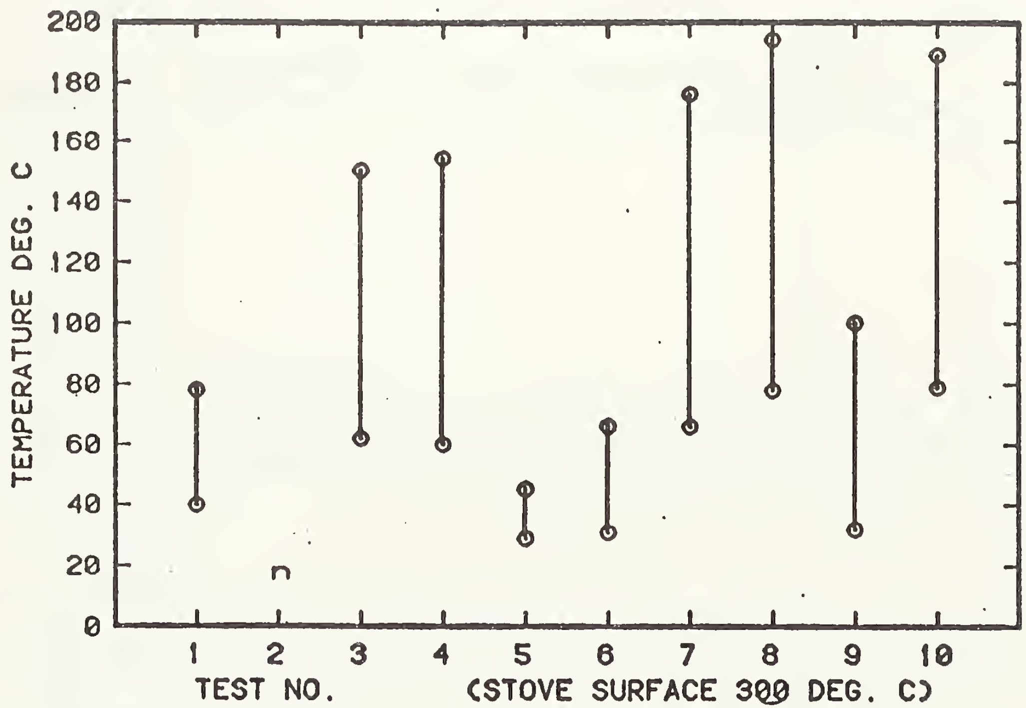


Figure 11. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.



n = no data

Figure 12. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

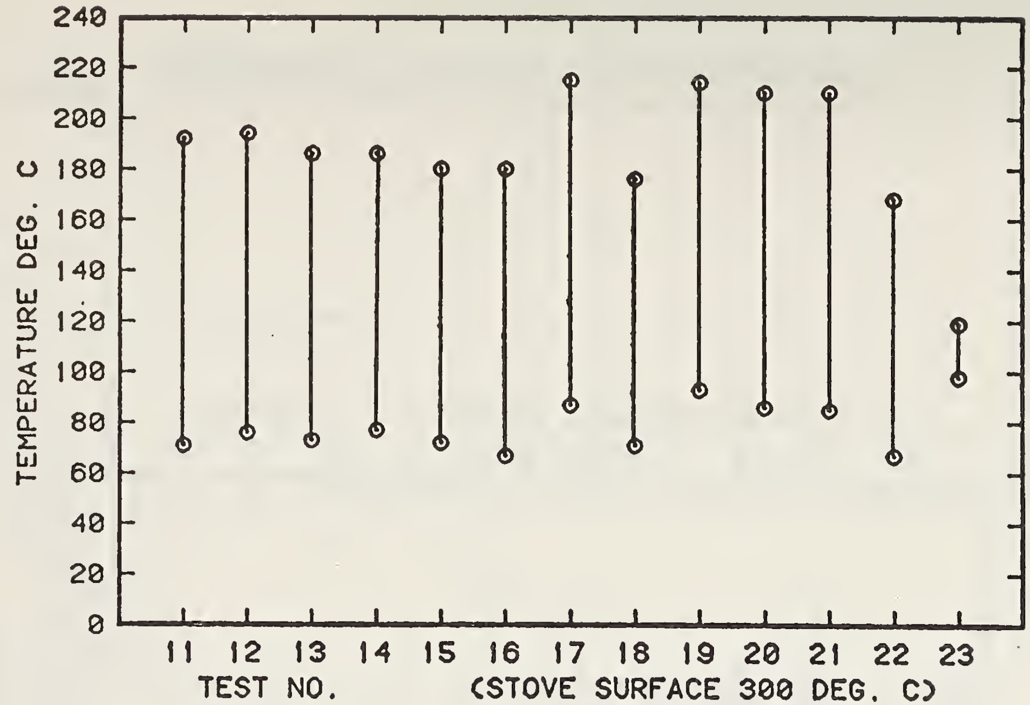


Figure 13. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

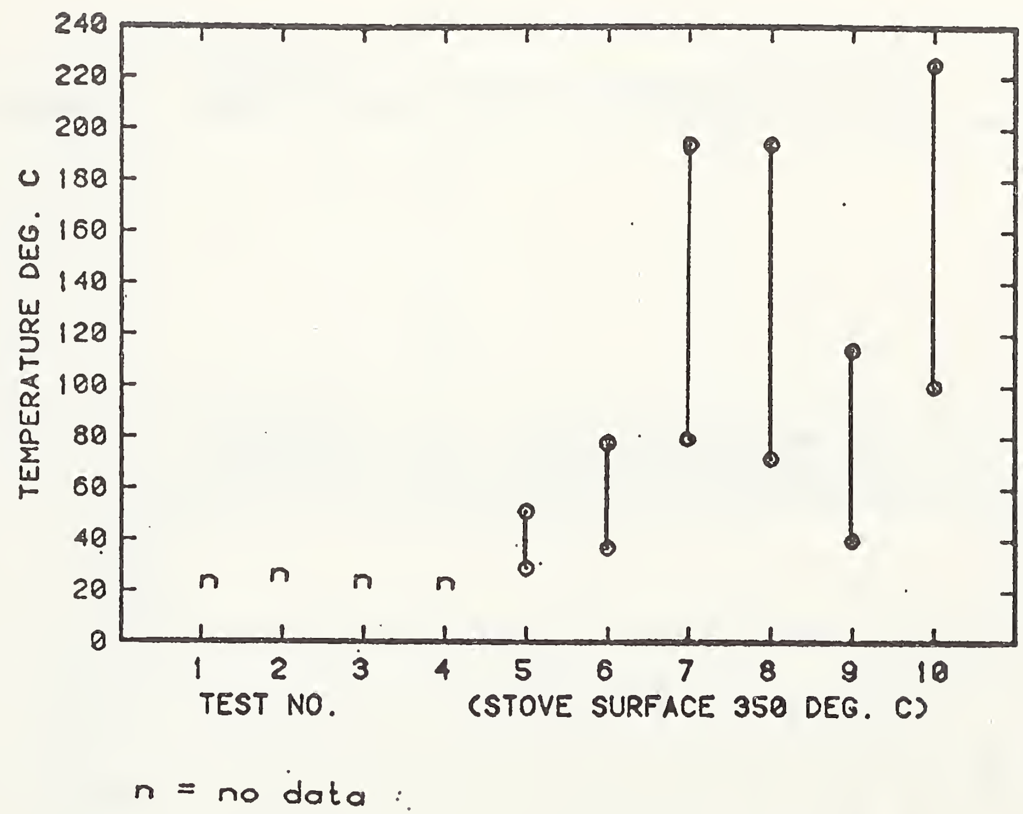


Figure 14. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

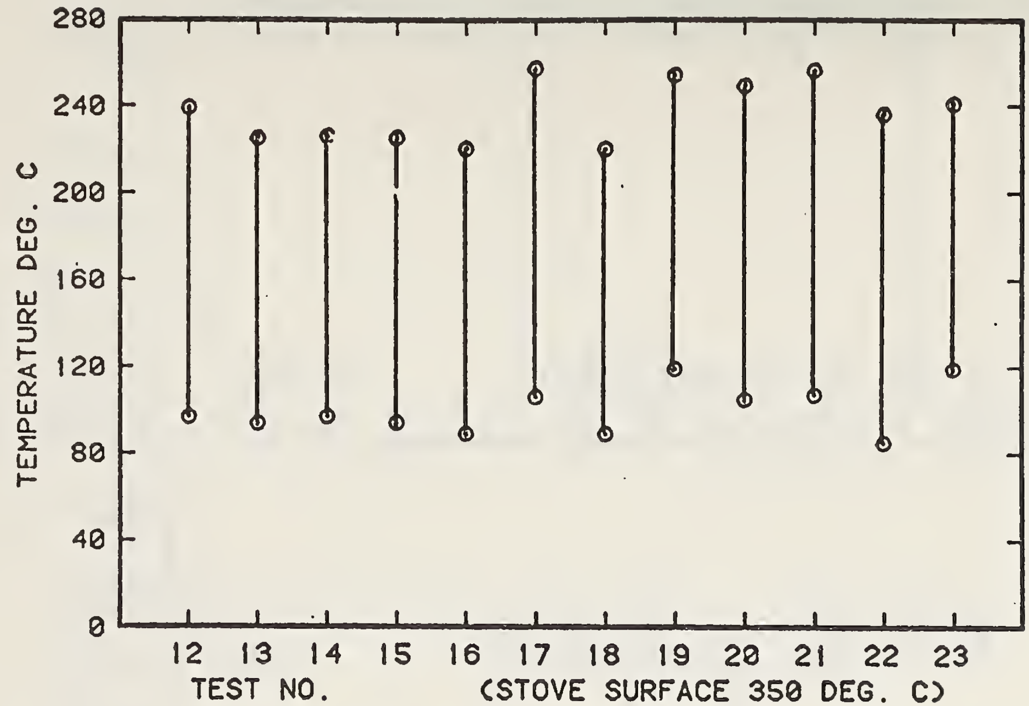


Figure 15. Range of temperatures on wall protector surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

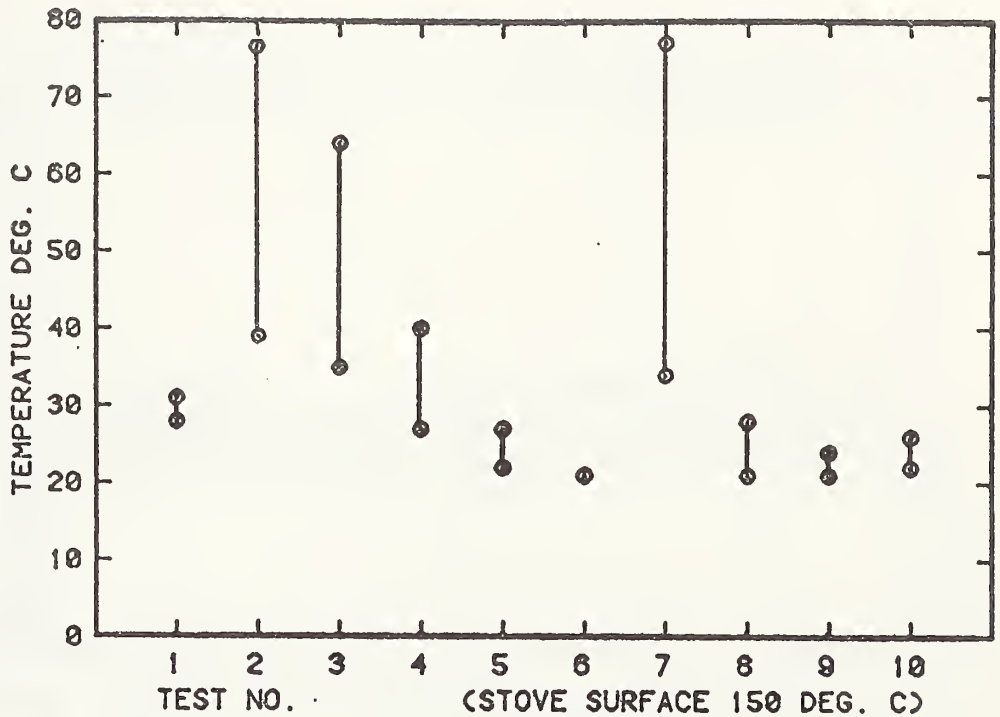


Figure 16. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

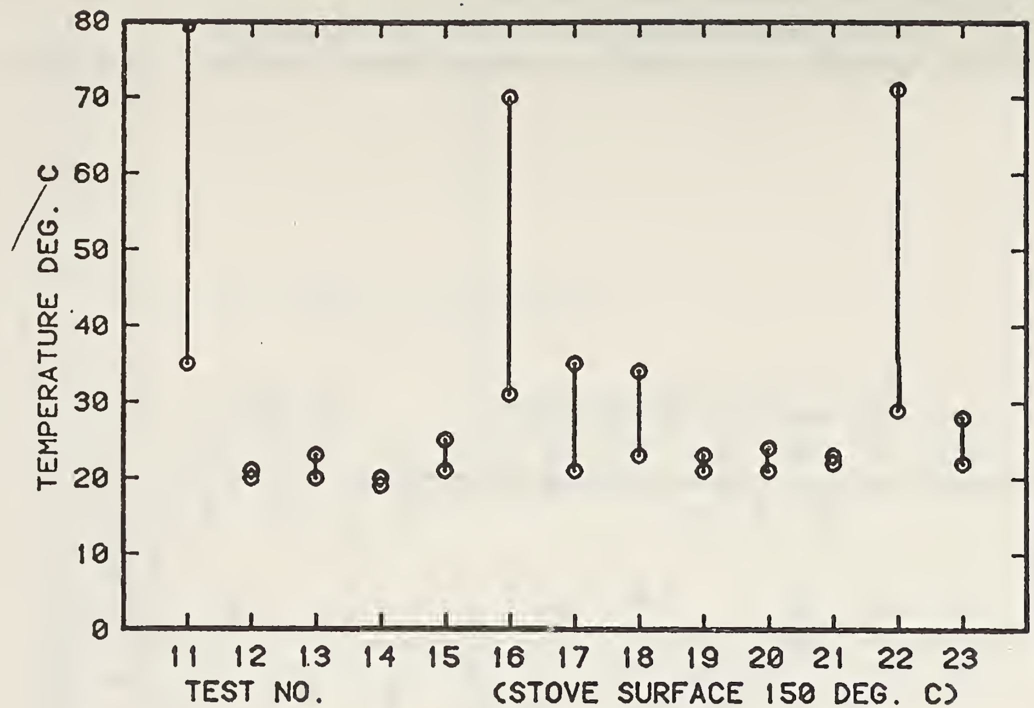
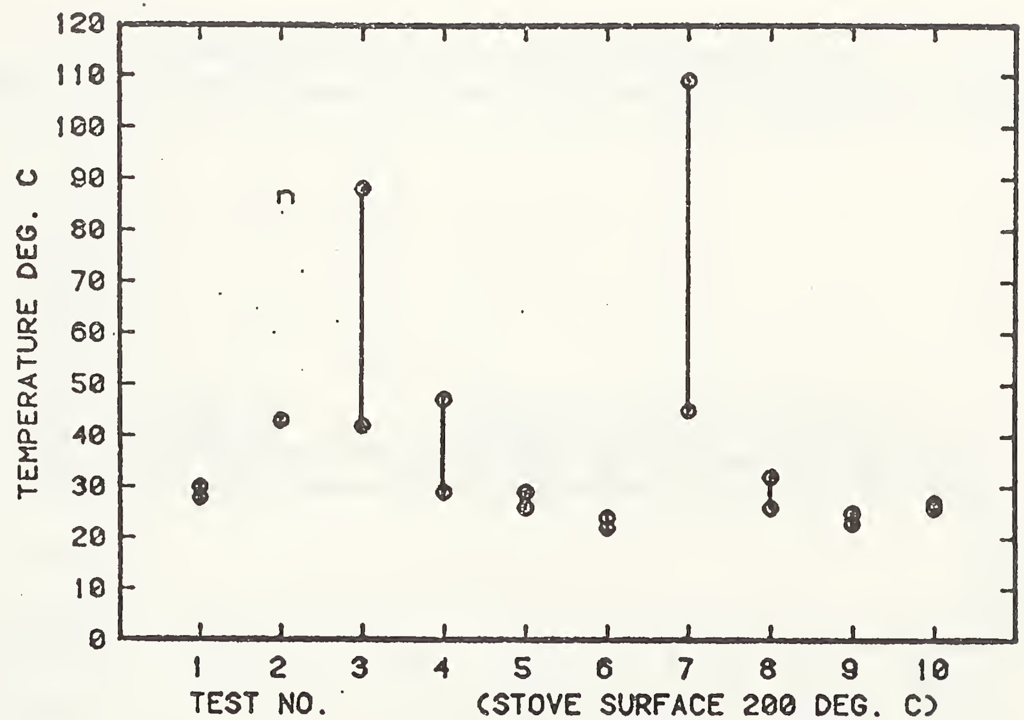


Figure 17. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.



n = no data for 7.5 cm

Figure 18. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

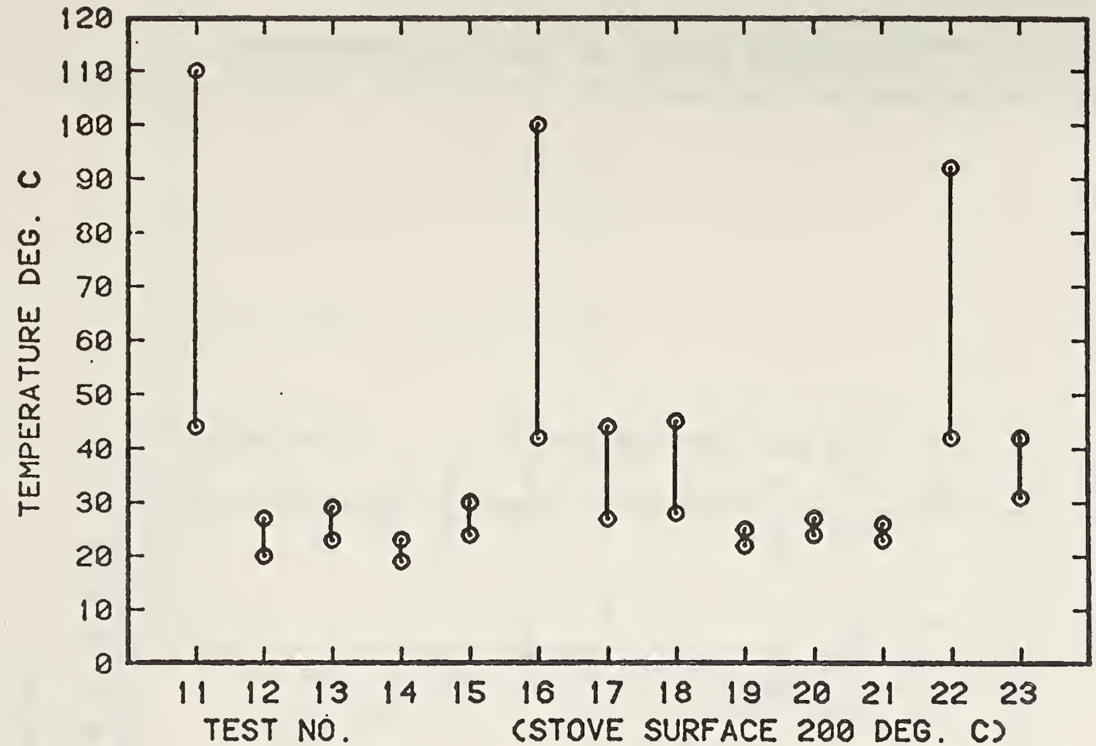
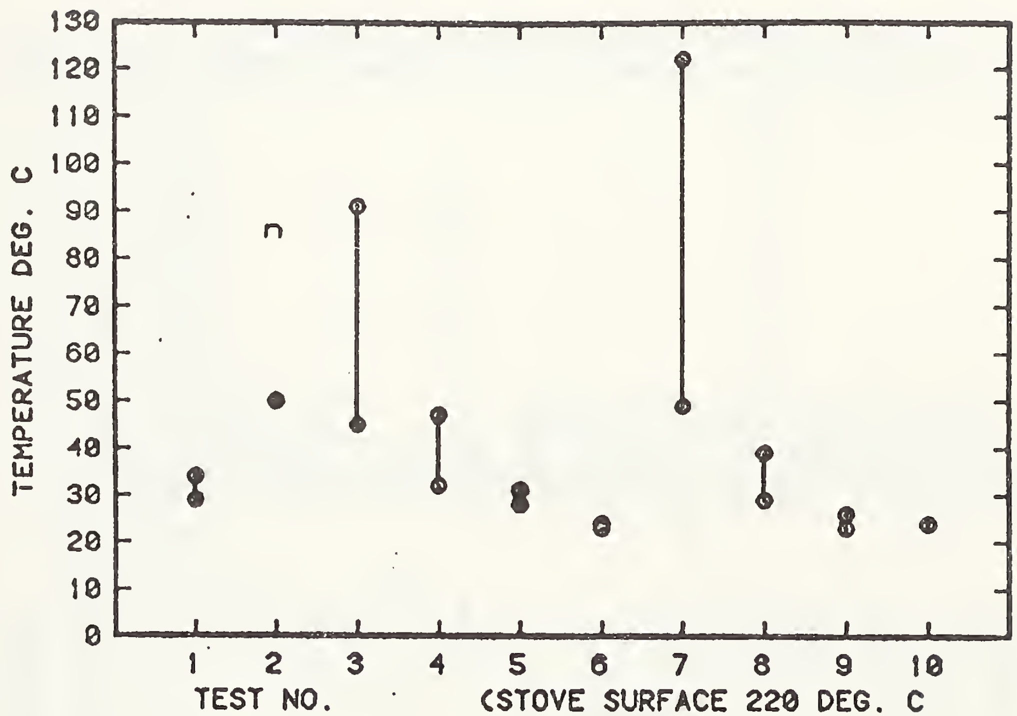


Figure 19. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.



n = no data for 7.5 cm

Figure 20. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5–90 cm) during tests 1–10.

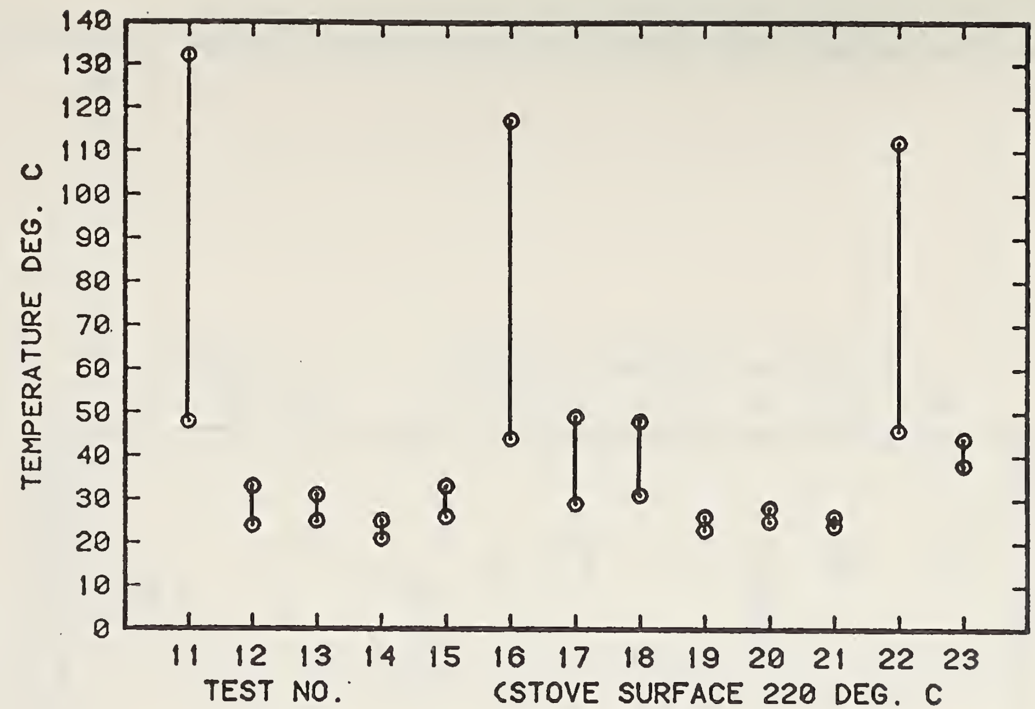


Figure 21. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

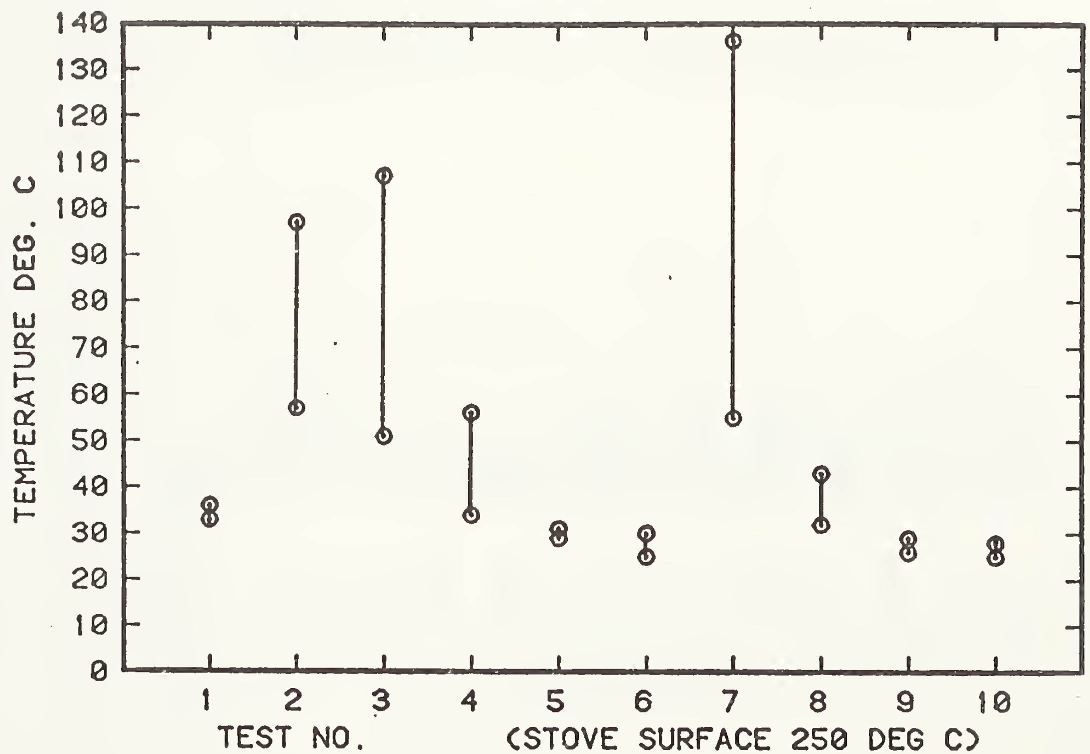


Figure 22. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

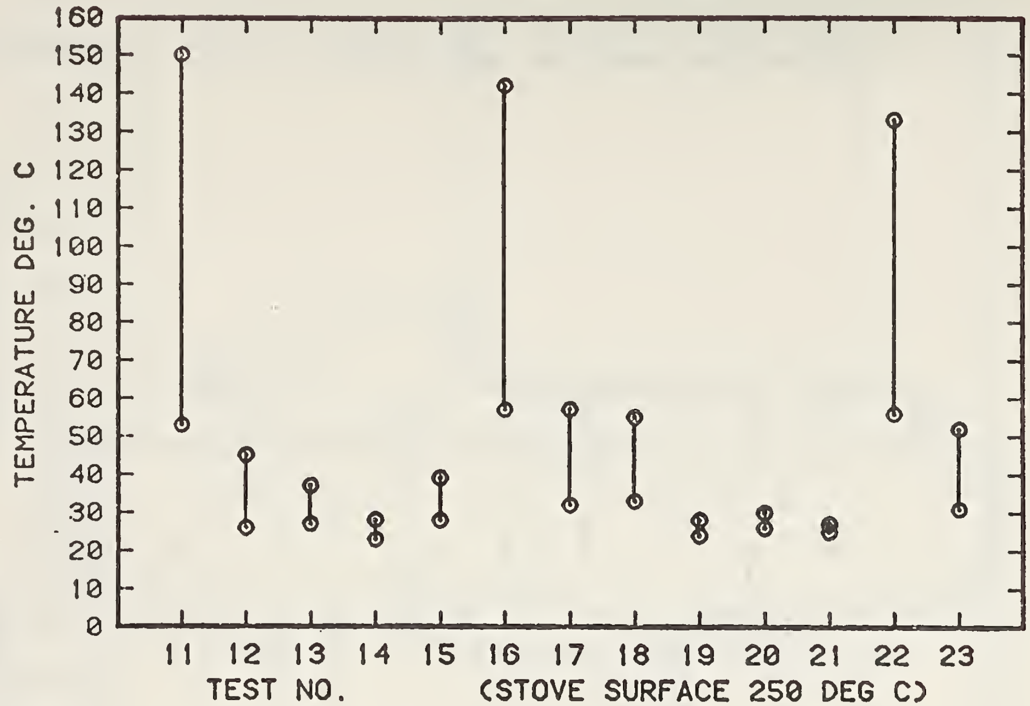


Figure 23. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

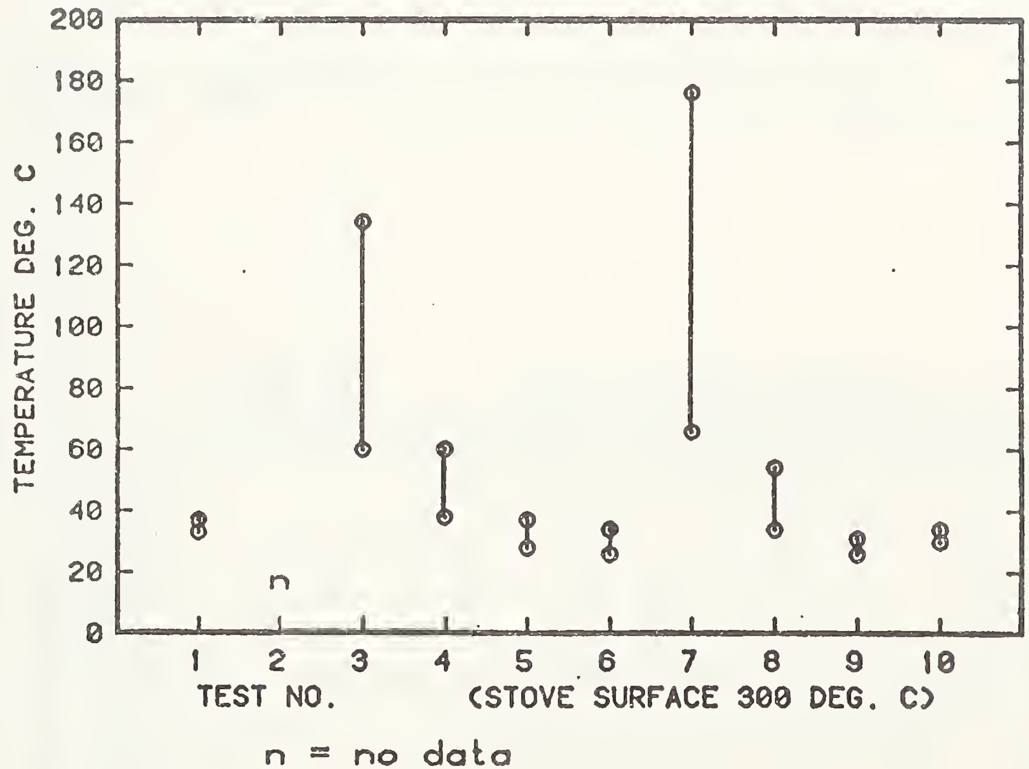


Figure 24. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

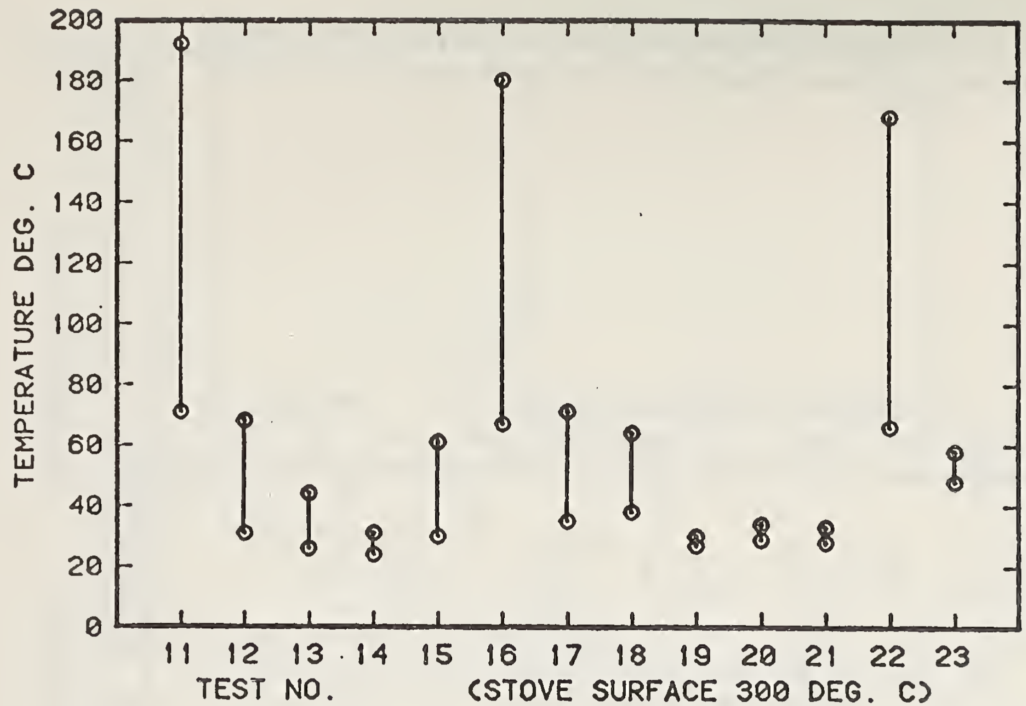


Figure 25. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

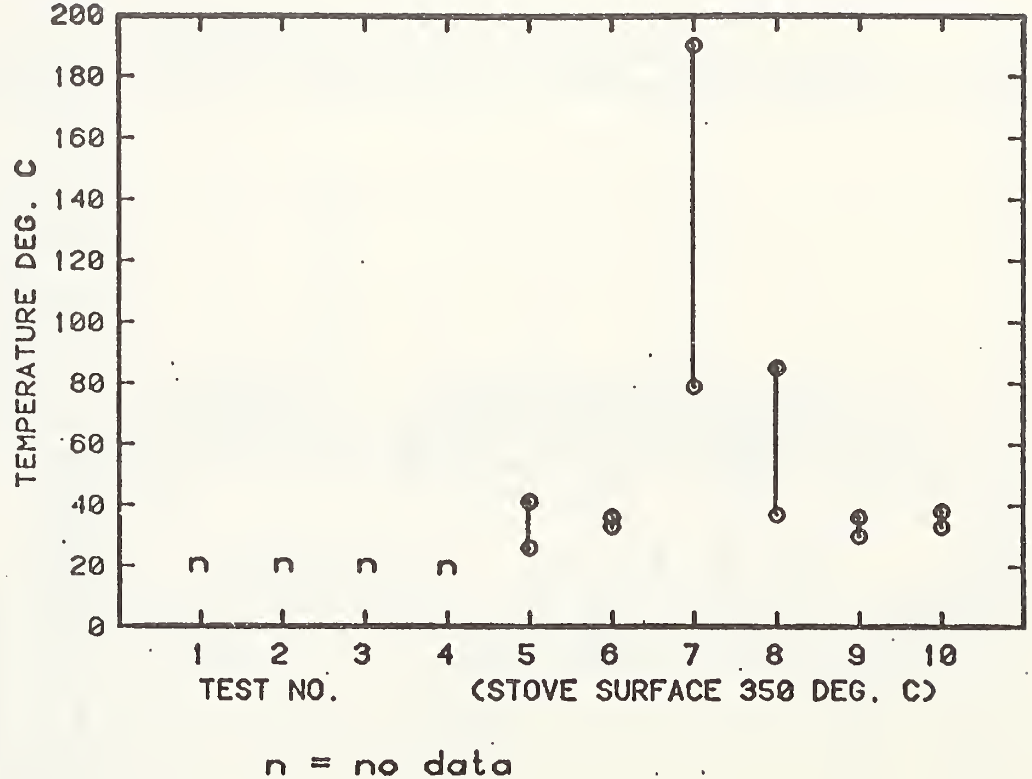


Figure 26. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 1-10.

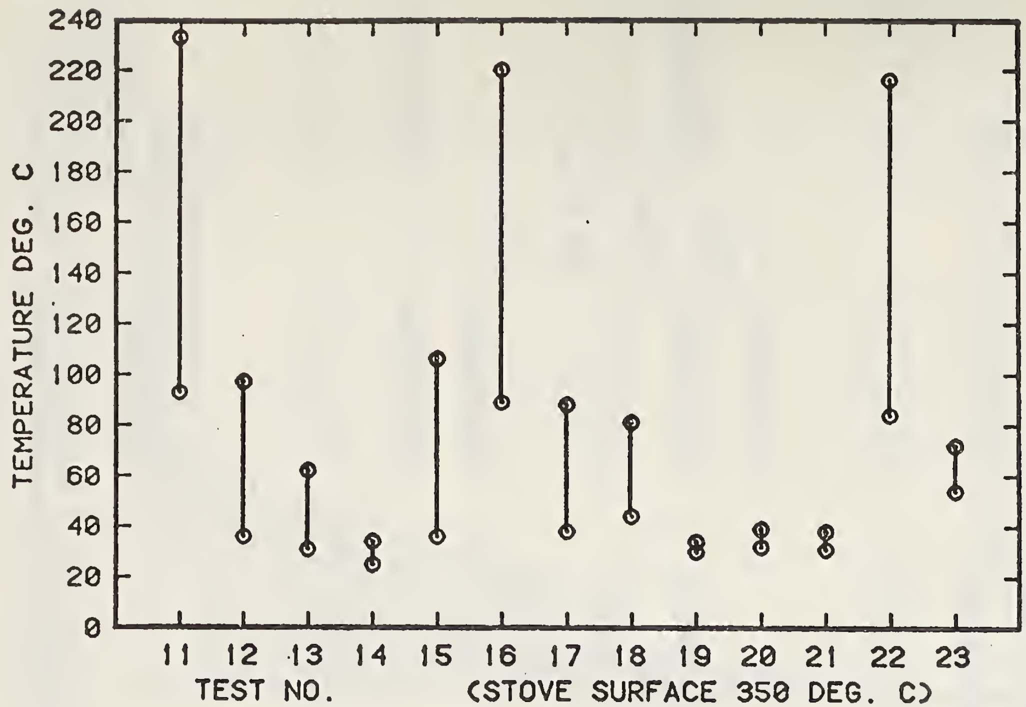


Figure 27. Range of temperatures on gypsum wall surface for stove-wall clearances of (7.5-90 cm) during tests 11-23.

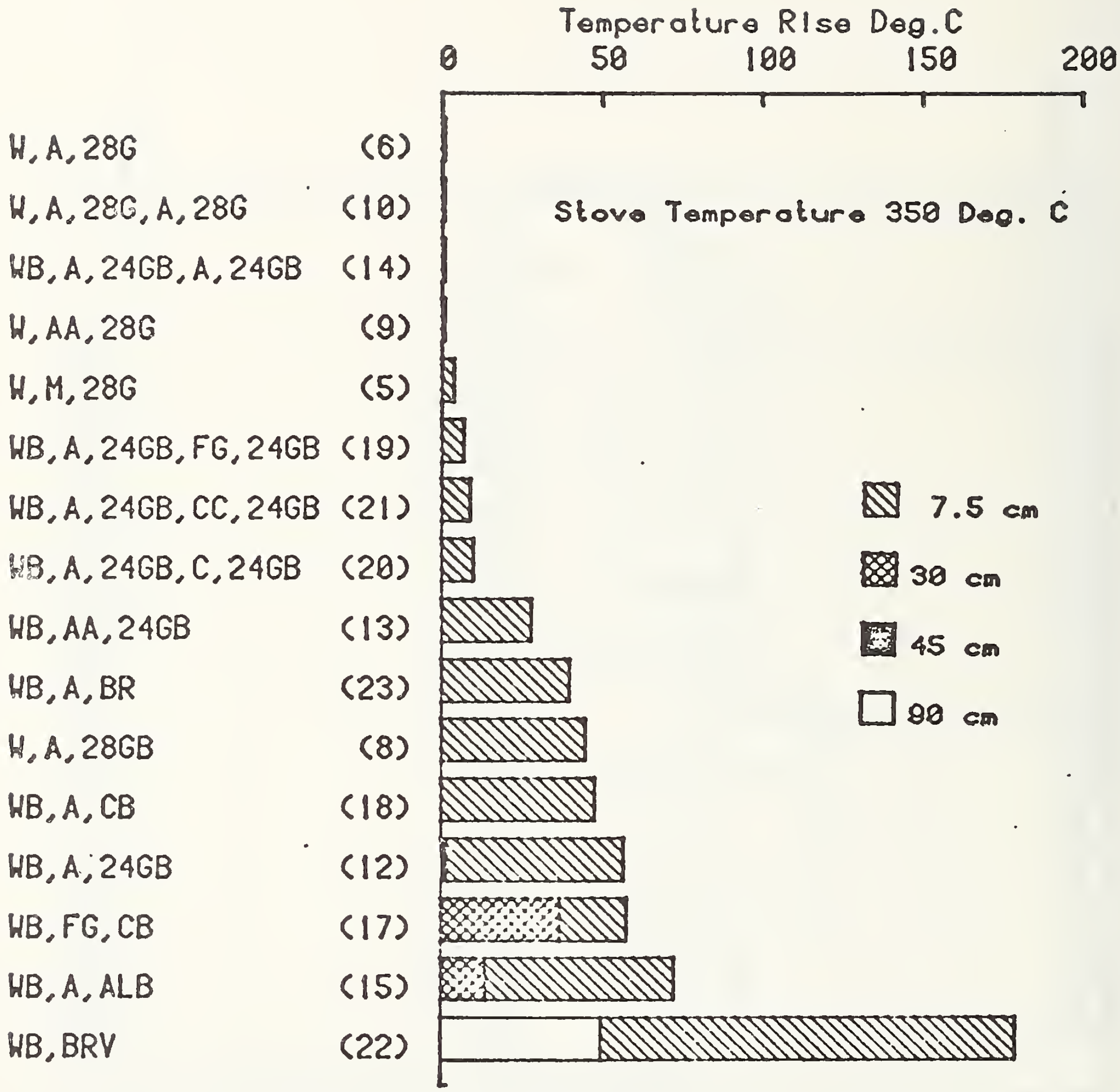


Figure 28. Surface Temperatures and Clearances for (Protected) Gypsum Wallboard

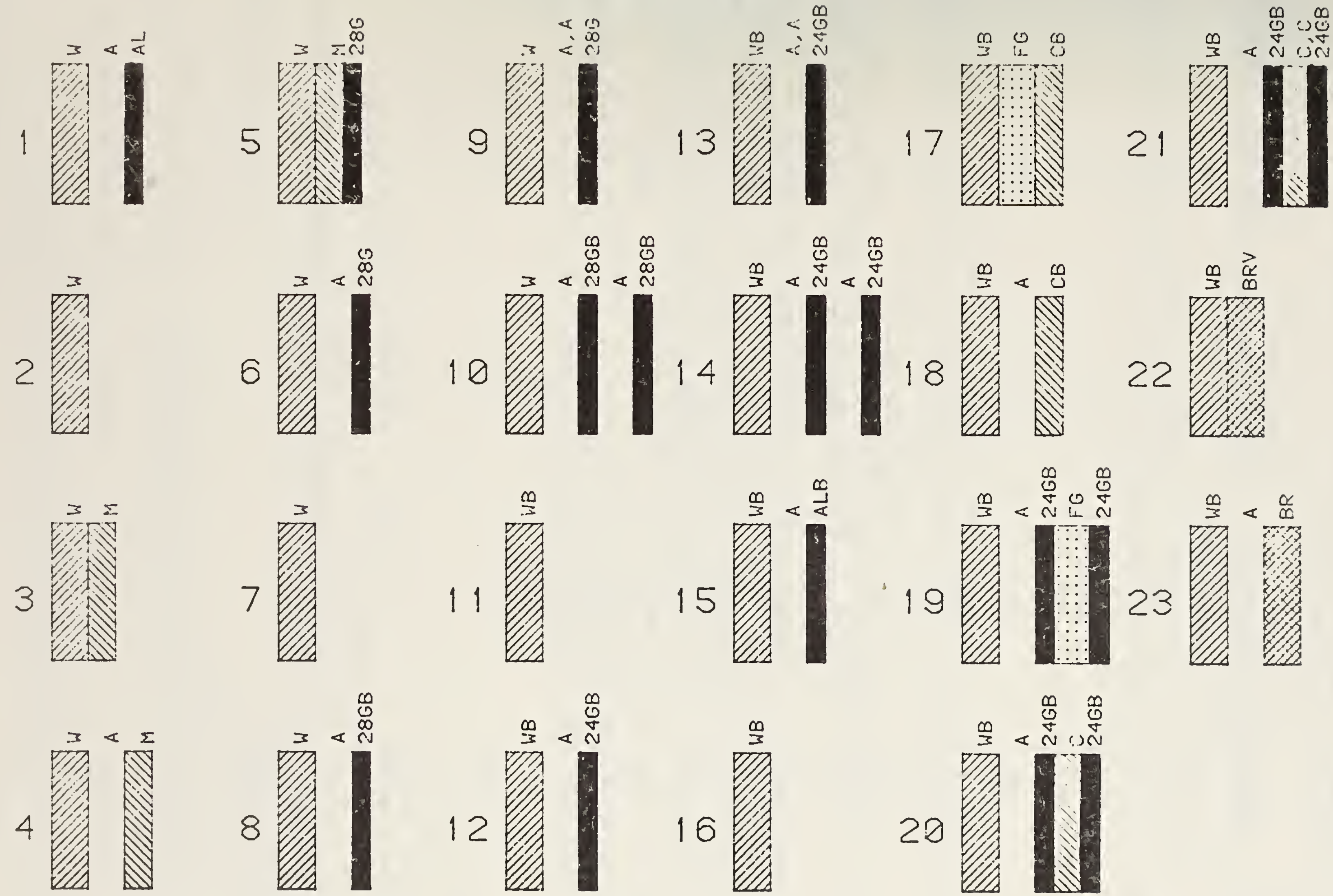


Table 1. Twenty-three Wall Protection Systems Tested

Table 2. Temperature Rise above Room Temperature for Protector and Gypsum Wallboard Surfaces for "Worst-Case" Conditions*

Wall System No.	Peak Temperature °C		Temperature °C	Temperature Rise °C	
	Protector	Wallboard	Test Room	Protector	Wallboard
5	51	41	37	14	4
6	76	36	36	40	0
8	194	85	40	154	45
9	114	36	35	79	1
10	225	38	38	187	0
12	239	97	40	199	57
13	225	62	34	191	28
14	226	35	35	191	0
15	225	106	33	192	73
17	257	88	30	227	58
18	220	81	33	187	48
19	254	34	27	227	7
20	249	39	29	220	10
21	256	38	29	227	9
22	241	216	36	205	180
23	241	72	32	209	40

*Worst case conditions = stove surface 350°C, stove-wall clearance 7.5 cm (3 in).

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10. SUPPLEMENTARY NOTES

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

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

Measurements of the surface heating potential of unprotected and protected gypsum wallboard materials in close proximity to irradiating surfaces of home heating appliances have been made. A total of 4 unprotected walls and 19 protected interior wall surfaces were evaluated in tests where stove-to-wall clearances were varied from 7.5 to 90 cm (3 to 36 in) and stove surface temperatures were maintained at five different temperature levels ranging from 150-350°C (300-660°F).

The systems found most effective in offering thermal protection to the base wall surface (i.e., gypsum wallboard) were those consisting of a metal plate surface offset by an air space in front of the wallboard material.

Unprotected gypsum wallboard surfaces were ignited when the stove to wall clearance was 7.5 cm (3 in) and the stove surface measured 350°C (660°F).

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Chimneys; fire tests; flues; heating equipment; literature reviews; radiant energy; stoves; wall protection; walls; wood

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