Wood Heating Safety Research: An Update

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(Manuscript received April 1987, accepted September 1987)

ABSTRACT

The Center for Fire Research at the National Bureau of Standards has been involved in research related to wood heating safety for more than seven years.

Areas of interest have included: typical operating conditions of modern heating appliances, intensity and duration of chimney fires in factory-built and masonry chimneys, clearance reduction systems for protection of combustible walls and ceilings, and wall pass-through systems for connection of appliances to chimneys through combustible walls. This paper presents a review of research at NBS and elsewhere related to wood heating safety and provides an assessment of the impact of the research on the fire safe use of wood heating appliances.

Extensive references of research related to solid fuel heating safety are included.

INTRODUCTION

RECENT STATISTICS ON FIRES AND INJURIES related to wood burning appliances are alarming:[1,2,3]

Year	Fires	Percent Change from Previous Year	Deaths	Property Damage (unadjusted)
1978	66,800		290	$134 million
1979	70,700	+6%	210	$178 million
1980	112,000	+58%	350	$245 million
1981	130,100	+16%	290	$265 million
1982	139,800	+7%	250	$257 million
1983	140,600	+0.6%	280	$296 million
1984	125,600	-11%	140	$257 million

Reference: Richard D. Peacock, "Wood Heating Safety Research: An Update," *Fire Technology*, Vol. 23, No. 4, November 1987, pp. 292-312.
Key Words: Chimneys; creosote; fireplaces; fire safety; fire tests; flues; heating equipment; stoves; wood.

This marked increase is attributed to the growing number of installations and expanded use of wood burning stoves in homes throughout the United States and the fact that most homes are made of combustible construction. Clearly, accidental fires from wood burning systems are an important problem.

National projections based on 1983 U.S. Fire Administration data attribute 140,600 residential fires to solid fuel burning equipment, and report 280 deaths and 2550 injuries due to these fires. These fires accounted for over 65 percent of all residential heating equipment fires. Fire incidence from the use of solid fuel burning equipment rose from 66,800 to 130,100 between 1978 to 1981. This trend slowed from 1981 to 1982 to slightly less than a 7 percent increase. The frequency of fire incidence stabilized between 1982 and 1983 (increasing during this time less than 1 percent) and actually decreased in 1984 (dropping nearly 11 percent). Positive actions by the Center for Fire Research (CFR) at the National Bureau of Standards (NBS) and others are believed responsible for improving the safety of these appliances and, thus, reversing an increasing fire incidence rate. New technical information to supplant out-of-date research, along with code changes based on the research, have provided a new and safer set of installation and operation guidelines to reduce the fire risk of solid fuel heating.

With funding from the U. S. Consumer Product Safety Commission and the U. S. Department of Energy, CFR has concentrated efforts to study solid fuel heating safety since 1978. Programs have been targeted to raise consumer awareness through education and to improve the standards and codes governing the construction, installation, and testing of appliances. Much of the supporting technical information for the codes and standards changes and for consumer education has come from NBS research. The point has finally been reached when much of the 40-year-old wood heat data and folklore originally used to develop the codes, standards, and public educational materials is being replaced by solid technical information. This is most evident in the areas of:

- Clearances needed between wood burning appliances and combustible construction materials.[4]
- Creosote buildup and burnout.[5]
- Protective barriers to allow reduced clearances of appliances to combustible walls.[6]
- Safe methods of joining a chimney connector to a masonry chimney through a combustible wall.[7]
- Theoretical prediction of appliance/wall heat transfer with arbitrary wall protection.[8]

This paper presents a review of the NBS research in the area of wood heating safety and of other research related to the topic and provides an assessment of the impact of the research on the codes and standards used to insure the safe installation and use of solid fuel heating appliances.

A REVIEW OF RELATED RESEARCH

Recommendations for minimum acceptable clearances to combustible materials for the installation of chimneys, chimney connectors, and appliances are specified in the various standards, model building codes, and recommended practices manuals. NFPA 211-1984 is typical of the specifications found in the codes.[9] For simplicity, 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. Table 1 summarizes the requirements in current standards and recommendations in the research cited below.

Typically, 0.91 m of clearance is specified between a radiant heater and unprotected combustible construction. For a residential solid fuel chimney, typically 51 mm of clearance is required. Chimney connectors require a clearance of at least 0.46 m to combustible materials. However, as with appliances, these clearances may be reduced by the use of appropriate protection applied either to the appliance or to the combustible surface.

The experimental basis for these code requirements is not, in many cases, quite so clear. Several experimental studies have been carried out to determine minimum acceptable clearances to combustible materials. Voigt,[10] in a 1933 publication, recommends a minimum clearance of 0.30 m for chimney connectors 0.23 m in diameter. A more extensive study, performed by Underwriters Laboratories in 1943,[11] presents minimum safe clearances for both unprotected surfaces and surfaces protected by various methods. Distances at which a maximum temperature rise of 50°C 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 surfaces is also examined. Lawson, Fox, and Webster[12] and Lawson and Simms[13] 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 restrict the maximum wall temperature to 100°C, 0.15 m pipe should not exceed 350°C in surface temperature at a clearance of 0.46 m.[13]

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces[14, 15] established a limiting temperature rise of 190°C on the outer surface of the chimney for a flue gas temperature of 537°C. With this limitation, wood framing spaced 51 mm or more away from the chimney was considered safe. Shoub[14] concluded that combustible materials will be ignited if maintained in continued contact with a masonry chimney of 120 mm wall thickness with flue gas temperatures higher than 400°C.

To establish performance requirements for lightweight prefabricated chimneys, tests were conducted with lined and unlined masonry chimneys

Table 1. Summary of reported minimum clearances and maximum temperatures cited in literature received.

Source	Appliance Clearance (m)	Appliance Temperature (°C)	Chimney Clearance (m)	Chimney Temperature (°C)	Chimney Connector Clearance (m)	Chimney Connector Temperature (°C)	Maximum Wall Temperature (°C)
CURRENT REQUIREMENTS							
NFPA 211-1984[9]	0.91		.051		0.46	537[a]	50[b]
CITED RESEARCH							
Voigt[10] (1933)					0.30		
Neale[11]		350 - 450[c]			0.46		50
Lawson, Fox, Webster[12] (1952) Lawson & Simms[13] (1952)					0.46	350	80
Shoub14 (1963) NBS (1941, 1952)[15]			.051	400[d]			
Thulman[16,17] (1944, 1952)			.051 .051	482 592			
Fox and Whittaker[18] (1955)						287 - 815	
Underwriters Laboratories[19]							50[e] 65[f] 97[g]

Notes:
a Flue gas temperature at appliance outlet.
b Maximum allowable temperature rise above ambient temperature.
c Maximum appliance surface temperature.
d flue gas temperature at chimney inlet.
e unexposed surfaces, normal operation.
f exposed surfaces, normal operation.
g overfire operation.

having 102 mm thick walls.[16,17] Hazardous conditions on wood framing spaced 51 mm away from the chimney were noted with a continuous flue gas temperature of 482°C for the unlined chimney and 592°C for the lined chimney. However, these hazardous conditions were not reached in the lined chimney tests until after 13 hours. In order to study operating conditions with typical fuels, a number of firing tests[18] were conducted with heating appliances known to give high flue gas temperatures, using wood and soft coals as fuels. With a coal-fired, jacketed-type heater, gas temperatures ranging from 648 to 704°C were measured for an hour or more in the flue at the ceiling level above the heater.

Lawson, Fox, and Webster[12] presented results of tests to measure surface temperature of flue pipes. Measured for a variety of flue systems using solid fuels—mostly coal and coke—they report temperatures of about 150°C under "normal" conditions, and temperatures as high as 815°C for over fire conditions.

Fox and Whittaker[18] report temperatures on metal flues of several heating appliances operated over a range likely to encountered in normal use. Maximum flue pipe surface temperatures ranged from 704 to 815°C at the appliance flue outlet, 360 to 510°C at a distance of 0.91 m from the appliance flue outlet, and 287 to 326°C at a distance of 1.8 m from the appliance flue outlet.

These experimental studies established limits for two important parameters: (1) appliance surface temperature, and (2) clearance to combustibles for unprotected and protected surfaces. Maximum appliance surface temperatures for the appliances studied ranged from 300 to 450°C; average appliance surface temperatures ranged from 200 to 250°C. Minimum safe wall clearances for unprotected surfaces ranged from 0.31 to 0.91 m. Most of the current code provisions are only adequate for maximum appliance surface temperatures up to 300 to 350°C.

Listings of heat-producing appliances and methods for setting clearances between appliances and combustible surfaces are based upon criteria in Underwriters Laboratories test standards:[19]

- maximum temperature rise of 65°C above room temperature on exposed surfaces; and
- maximum temperature rise of 50°C above room temperature on unexposed surfaces, such as beneath the appliance, floor protector, or wall-mounted protective device.

These requirements are based upon the fact that while the ignition temperature of wood products is generally quoted to be on the order of 200°C,[20] wood that is exposed to constant heating over a period of time may undergo chemical change resulting in a much lowered ignition temperature and increased potential for self-ignition.

Mitchell[21] presents data on wood fiberboard exposed to temperatures as low as 109°C that resulted in ignition after prolonged exposure. MacLean[22,23] reports charring of wood samples at temperatures as low as 93°C. He concludes that wood should not be exposed to temperatures appreciably higher than 66°C for long periods. McGuire[24] suggests that the maximum safe temperatures on the surface of a combustible material adjacent to a constant heat source should be no more than 100°C.

Clearly, the ignition of wood at moderately elevated temperatures is a complex phenomenon; the time of exposure is indeed an important parameter.[25,26] While exact limits recommended in the literature vary due to exposure time and details of the tests conducted, the numerous documented fires involving the ignition of wood members near low pressure steam pipes[27] suggest an upper temperature limit for combustible materials exposed to long-term, low-level heating should not be appreciably higher than 100°C.

TYPICAL OPERATING CONDITIONS OF MODERN WOOD-BURNING APPLIANCES

Much of the data used in the development of the codes and standards covering the installation and construction of solid fuel burning appliances is more than 40 years old. To evaluate the differences between the appliances tested in earlier programs to those available currently in the marketplace, a number of full-scale experiments were conducted to establish typical operating conditions including temperatures on the appliances, chimneys, and adjacent wall and floor surfaces.[4] Several generic types of appliances were included to exemplify those available in the market. Figure 1 presents some of the results of those experiments.

Appliance surface temperatures during steady-state operation in the 17 tests were similar for all five appliances tested. The steady-state maximum temperatures ranged from a low of 297°C to a high of 436°C — a range of only 139°C. The average maximum steady-state appliance surface temperature was 374°C with a coefficient of variation of 6 percent. Flue pipe surface temperatures near the flue outlet of the appliance were similar to the appliance surface temperatures. The average maximum flue pipe surface temperature was 375°C, practically identical to the average appliance surface temperature.

Understandably, the wall surface temperatures varied inversely with the clearance between the appliance and wall surfaces. Temperatures ranged from a low of 54°C for Appliance 1 at a clearance of 0.91 m to a high of 189°C for Appliance 4 at a clearance of 0.15 m. In this latter test, the wall ignited soon after the beginning of the 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.

Temperatures measured on floor surfaces during steady-state operation varied from appliance to appliance. Like the wall temperatures, two factors are apparent: appliance/floor clearance, and appliance size. Floor temperatures measured during tests of Appliance 1 were considerably lower than those measured during tests of the other appliances. The average floor surface

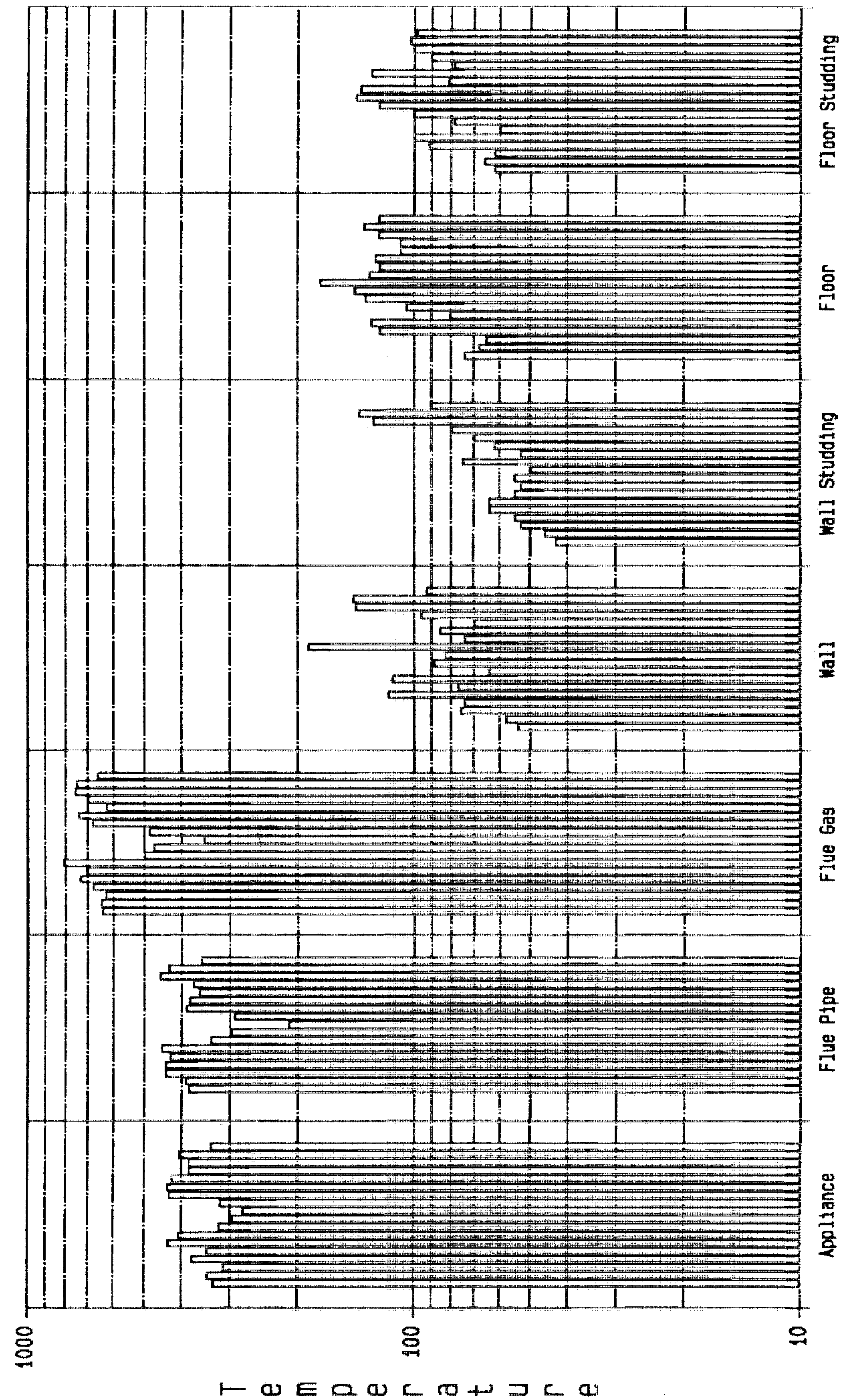

*Figure 1. Summary of operating conditions measured during eighteen tests offive different wood burning appliances. * Reference 4 provides details of the individual tests.*

temperature during continuous operation of Appliance 1 was 69°C, while it was 125°C 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.

INTENSITY AND DURATION OF CHIMNEY FIRES IN SEVERAL CHIMNEYS

A series of experiments was conducted in six instrumented chimneys to study the intensity and duration of chimney fires due to the ignition and burning of combustible deposits accumulated on chimney linings over a prolonged period of time. These tests were conducted (1) to establish typical conditions including temperatures in the chimneys and on combustible surfaces nearby, and (2) to determine the duration of the burnout as evidenced by elevated temperatures within the chimney.

Flue gas temperature at the base of the chimney during the buildup phase was maintained between 80 to 90°C. Temperature profiles during the buildup tests on the five chimneys were understandably similar due to the controlled flue gas temperature. The flue gas temperatures during the buildup phase were somewhat lower in the masonry chimney due to its high mass and larger size. A reduced draft in the masonry chimney kept firing rates low and made control of the flue gas temperature difficult. The high mass of the chimney led to slow response to changes in the air inlet. However, once operating temperatures were reached in the masonry chimney, steady temperatures, within the 10°C controller range setting, were easily maintained with little variation in the flue gas temperature.

Surprisingly, significant levels of creosote deposits were generated on the linings of all chimneys in very short periods of time in a laboratory space whose air temperature averaged approximately 25°C in the vicinity of the chimneys. The buildup of deposits prior to two tests resulted from a total of only seven days continuous burning. After this short period, deposits up to 3 to 6 mm were evident in the chimneys. During the longer tests, connector pipe elbows became clogged with deposits after about six weeks. The heaviest buildup was noted for the test of a factory-built chimney (Chimney 5 in Figure 2). Since this chimney was allowed to build deposits over a longer period of time and was exposed to ambient temperatures much lower than the other chimneys, this result was expected.

Figure 2 presents profiles of maximum temperatures measured during burnout tests of the five chimney systems. The highest flue gas temperatures were usually noted in the section of the chimney connector closest to the appliance. Peak temperatures for all chimneys ranged from a low of 908°C to a high of more than 1370°C. In this figure, Chimney 1 is an air-insulated factory-built chimney; Chimneys 2, 4, and 5 are solid-packed factory-built chimneys (from different manufacturers and differing mainly in the design of the connection of the chimney sections); and Chimneys 3 and 6 are masonry

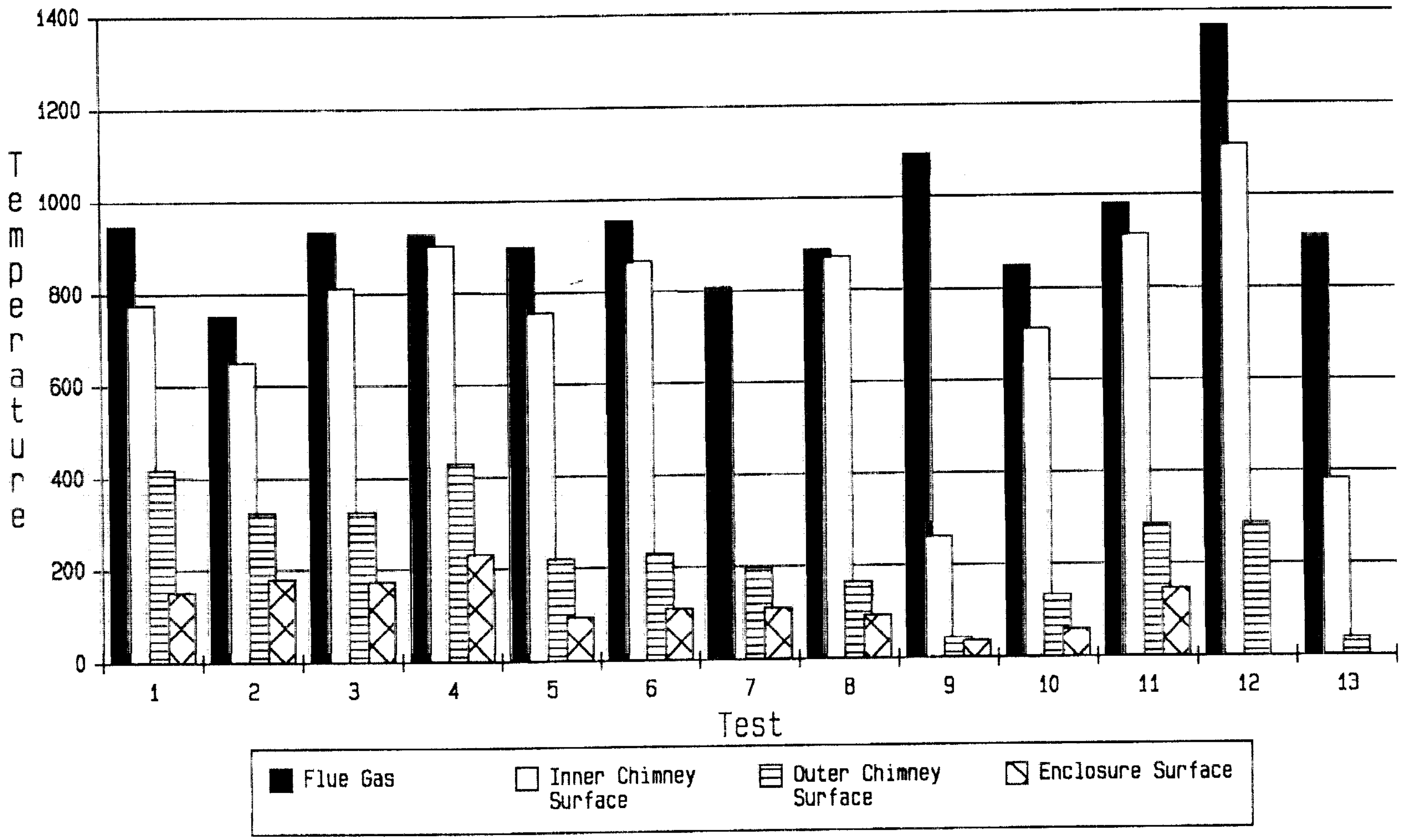

Figure 2. Maximum temperatures measured during chimney fires in several chimneys.

Figure 2 Legend. Buildup prior to burnout test.[a]

Test	Chimney	Ambient Temperature[e] (°C)	Total Wood Burned kg (lb)	Average Burning Rate kg/hr (lb/hr)	Total Length of Buildup (hr)	Thickness of Deposit[c] (mm)	Wood Type
1	1 (Air-Insulated)	24	115 (254)	1.5 (3.)	76[b]	3-13	Green Pine
2		19	1206 (2659)	2.1 (4.6)	568	13-19	Green Pine
3[d]		20	—	—	—	—	—
4		23	1015 (2238)	2.4 (5.3)	429	13-19	Green Pine
5	2 (Solid-Packed)	25	115 (254)	1.5 (3.3)	76[b]	3-13	Green Pine
6		23	1255 (2767)	2.1 (4.6)	594	13-19	Green Pine
7[d]		21	—	—	—	—	—
8		20	1015 (2238)	2.4 (5.3)	429	13-19	Green Pine
9	3 (Masonry)	22	746 (1646)	0.9 (2.0)	823	6-13	Seasoned Oak
10	4 (Solid-Packed)	22	565 (1246)	0.9 (2.0)	630	6-13	Seasoned Oak
11		23	639 (1409)	0.9 (2.0)	674	6.13	Seasoned Oak
12	5 (Solid-Packed)	-6	2733 (6012)	1.5 (3.3)	1752	13-64	Seasoned Oak
13	6 (Masonry)	-2	1794 (3954	1.3 (2.9)	1368	13-51	Seasoned Oak

Notes:

a Flue gas temperature monitored and controlled at 80 to 100°C throughout the buildup tests.

b Total length of low temperature burning. Tests were run eight hours per day.

c Thickness of deposit is an estimation based upon an examination of the chimney sections prior to each burnout test. Thickness varied over the length of the chimney (thickest at the bottom of the chimney).

d Test 3 and 7 were run as a follow on to test 2 and 6, respectively, since deposit did not burn completely during these tests. Approximately 25 percent of the deposit remained after test 2 and 6.

e Ambient air temperature at the beginning of the burnout test.

chimneys which were constructed to minimum building code requirements. Chimneys 1 through 4 were tested in a conditioned laboratory space whose air temperature averaged approximately 25°C. Chimneys 5 and 6 were tested outside, exposed to winter conditions.

Significant levels of buildup were noted in all chimneys using both seasoned hardwoods and green softwoods. While buildup rates and quantities of deposits were not measured quantitatively, little difference was observed in the amount of buildup thickness during the various tests. Gas temperature, chimney surface temperature, and duration of the buildup period appear to be more important to creosote buildup than the type of chimney used or the type of wood burned.

Gas temperatures in excess of 1370°C were obtained for short periods of time during one of the chimney fire "burnout tests." Maximum temperatures, measured on the chimney surfaces, of over 1100°C were recorded. The presence of these extremely elevated temperatures was further reinforced by considerable damage to the stainless steel chimney wall. Severe damage was noted after one chimney fire in one of the factory-built chimney tests. In this case, holes were found in the inner wall of the chimney near the base and buckling of the metal lining was noted in all sections of that chimney. The fire clay flue lining of one of the masonry chimneys was severely cracked during the chimney fire "burnout test." However, because of the chimney's high mass, temperatures on the outside brick surface never approached an unacceptable level of 50°C above ambient temperature as defined in the various testing standards.

Temperatures on surrounding combustible surfaces reached as high as 234°C during the "burnout tests," far in excess of acceptable limits and nearing the ignition temperature commonly reported for wood. The highest enclosure temperatures were noted during tests of the air-insulated chimney, the lowest during tests of the masonry chimney. Enclosure temperatures exceeded the criterion used for testing and listing of chimneys of 50°C above ambient temperatures for times as long as 56 minutes. In some tests, temperatures on surrounding combustibles were elevated above acceptable limits for periods of time equal to or greater than the duration of the creosote fire in the chimney.

Some specific conclusions can be drawn from the results of these tests:

- Based upon the tests reported herein, either the duration of chimney fire simulations in test procedures should be longer or higher temperatures should be used for the test. Current test procedures for factory-built chimneys include provisions for testing to simulate chimney fires by a 10-minute test at a flue gas temperature of 927°C or three 10-minute tests at 1149°C. Little damage to chimney systems was noted at temperatures of 927 to 1149°C, and significantly higher temperatures were recorded during a test of one chimney in cold climatic conditions, with notable damage to the chimney. However, the results presented in this paper are based upon a limited number of tests. Other chimney systems, and colder climatic conditions, for instance, could lead to more severe results. More tests would be necessary to provide information on reproducibility and temperature levels for other appliances and chimneys.

- Since burning occurs on and near the chimney walls, measurement of flue gas temperature near the walls and/or distributed throughout the cross section of the flue, or of chimney wall surface temperature is more appropriate than measurement of flue gas temperature at a single point on the centerline of the flue.
- Maximum temperatures in the flue gas and on the chimneys surfaces provide an indication of the "worst case" temperatures measured during the tests and were used to evaluate the performance of the chimney systems during chimney fire conditions.

Changes in both testing standards and in NFPA 211 have raised the temperature levels required for chimneys constructed for use with wood heating systems. Chimney systems tested must now meet a test designed to simulate a chimney fire with flue gas temperatures up to 1149°C for up to 30 minutes.

WALL AND CEILING PROTECTION

An evaluation was made of the effects of radiant heat from hot appliance and chimney pipe surfaces to unprotected and protected room walls and ceilings. Pipe surface temperatures of 350°C for normal operation and 400 to 450°C were used to simulate over fire conditions. Unprotected ceilings at 0.46 m clearance met code recommended temperature rise limits for normal operation, but protection was needed for over fire exposures. Some protected walls allowed for clearance reductions to 76 mm for all exposures, while others needed at least 0.3 m for normal and 0.46 m for over fire exposures. Test results obtained in investigating clearances between chimney pipes and building surfaces involving 14 different full-scale room wall/ceiling systems provided a number of conclusions from an analysis of the data.

Based upon an analysis of test results, the following conclusions were drawn:

- Tests confirm NFPA code recommendations for installation of appliances near unprotected room walls and ceilings at clearances of 0.91 m and 0.46 m respectively, from a hot stove and chimney connector operating at an average stove surface temperature of 350°C.
- To accommodate over fire conditions (average stove temperatures in excess of 350°C), clearances between the stove and unprotected room walls need to be increased significantly beyond 0.91 m.
- Protective barriers for room walls such as air space / metal plate, air space /inorganic insulation board, and air space / metal plate sandwich panels were found effective in helping to reduce temperatures on room walls nearby hot appliance and chimney surfaces.
- The most effective systems found for thermally protecting room walls were the air space /metal plate sandwich panel systems which allowed for clearance reductions to 76 mm to a stove operating at over fire conditions of 450°C.
- Room ceilings were found to need protective barriers to accommodate

clearances less than 0.46 m at over fire conditions represented by average stove surface temperatures ranging from 400 to 450°C.

Based upon the results of these tests, a number of changes were proposed to NFPA 211 to modernize the requirements related to wall and ceiling protection. These changes were adopted in the 1984 edition of the standard.

EVALUATION OF WALL PASS-THROUGH SYSTEMS FOR SOLID FUEL BURNING APPLIANCES

For this segment, a total of 17 different thimble-chimney connector (wall pass-through) systems connected to chimney connector pipes from a stove were evaluated for their ability to provide thermal protection for combustibles in room walls. Flue gases passing through the thimbles were monitored over a range of 538 to 649°C and temperature rise measurements were made on the surface of the combustibles located in proximity to the thimbles.

From an analysis of the results of evaluation tests on the 17 wall pass-through systems, it was found that the NFPA 211 recommendation for temperature rise on the surfaces of partitions and combustibles in room walls was met by a total of nine systems when the exposure level was 538°C, the continuous operating temperature as recommended in the codes. When the exposure level was increased to 593°C, the number of acceptable systems was reduced to six. On one further rise to 649°C, the number of systems which limited surface temperature rise to 50°C or less was four. Figure 3 presents some of the data obtained during the test series.

Briefly, those systems passing all test exposures up to and including 649°C were:

- a commercial insulated chimney section at 0.23 m clearance,
- a single wall metal chimney connector at 0.46 m clearance,
- a brick masonry patch measuring 0.31 m, and
- a tubular sheet metal thimble with two air channels and a 0.15 m layer of glass fiber insulation between the thimble and combustible surfaces.

Additional systems passing the tests up to and including the 593°C exposure level were:

- a single wall chimney connector separated from room wall combustibles by a 0.23 m air space and sheet metal sleeve protector, and
- a commercial insulated chimney section with a diameter of 0.2 m which served as a pass through for a 0.15 m diameter single wall chimney connector with a clearance of 51 mm.

Systems passing the tests at only the 538°C exposure level included all of the above plus the following:

- a brick masonry patch measuring 0.2 m,
- a tubular sheet metal thimble with two air channels and a clearance of 0.15 m from combustibles, and
- a tubular sheet metal thimble with two air channels and a 76 mm thick layer of glass fiber insulation between the thimble and combustible surfaces.

Recommended code changes based upon this research were submitted to the NFPA for incorporation in NFPA 21. Several systems were accepted by the Tentative Interim Amendment process for immediate inclusion in the standard.

THEORETICAL PREDICTION OF APPLIANCE/WALL HEAT TRANSFER

From most of the data presented earlier, it is apparent that a fairly simple predictive model to describe the transfer of heat from a hot appliance surface to a cooler wall surface can be developed. In addition to providing a simple tool for the designer to evaluate among numerous design criteria and narrow the designs that need to be tested in large scale, the model ties together much of the research conducted over the years.

Figure 4 presents a schematic diagram of a heating appliance/wall system with an arbitrary protection system between the appliance and the wall. Heat transfers from the hot stove surface through any intervening protection to the wall surface, through the wall, and to the cooler surroundings. A few assumptions, reasonable to the system being modeled, simplify the model considerably:

- The stove is operating at steady state conditions (thus, we assume the stove has been operating for a period of time and has reached a steady operating condition). Although this condition is rarely achieved in a wood burning appliance, assuming steady state allows worst case conditions to be modeled.
- Stove is at a constant uniform surface temperature.
- Heat transfer through air spaces in the system takes place by radiation and convection only.
- Heat transfer through solids in the system takes place by conduction only.

With these assumptions, a one-dimensional model of the stove/protector/wall heat transfer was developed.[8] The only loss in generality of the predictive capability of the model is the inability to predict any time dependent behavior of the system. Since the intended purpose of the model is to study the fire safety of the stove/protector/wall system under worst case conditions, this loss is acceptable. By assuming steady state conditions with a constant stove temperature, the worst case conditions can be modeled.

To illustrate the usefulness of the model developed, consider the following case. Figures 5 and 6 show calculated wall surface temperatures as a function of appliance/wall clearance for a medium size appliance (an appliance 0.5 by 0.5 m on the side parallel to the wall surface) adjacent to a protected wall surface, for appliance surface temperatures from 150 to 350°C. The outside air temperature was assumed equal to 0°C. The wall protector consisted of two sheets of aluminum (2.5 mm in thickness) separated by a ventilated 25 mm air space. The wall protector was spaced from the wall by a ventilated 25 mm air space. The wall consisted of 12 mm gypsum wallboard, a 92 mm stud space with glass fiber insulation, and a 92 mm common brick facing on the outside of the wall exposed to the outdoors. With the surfaces of the protector painted

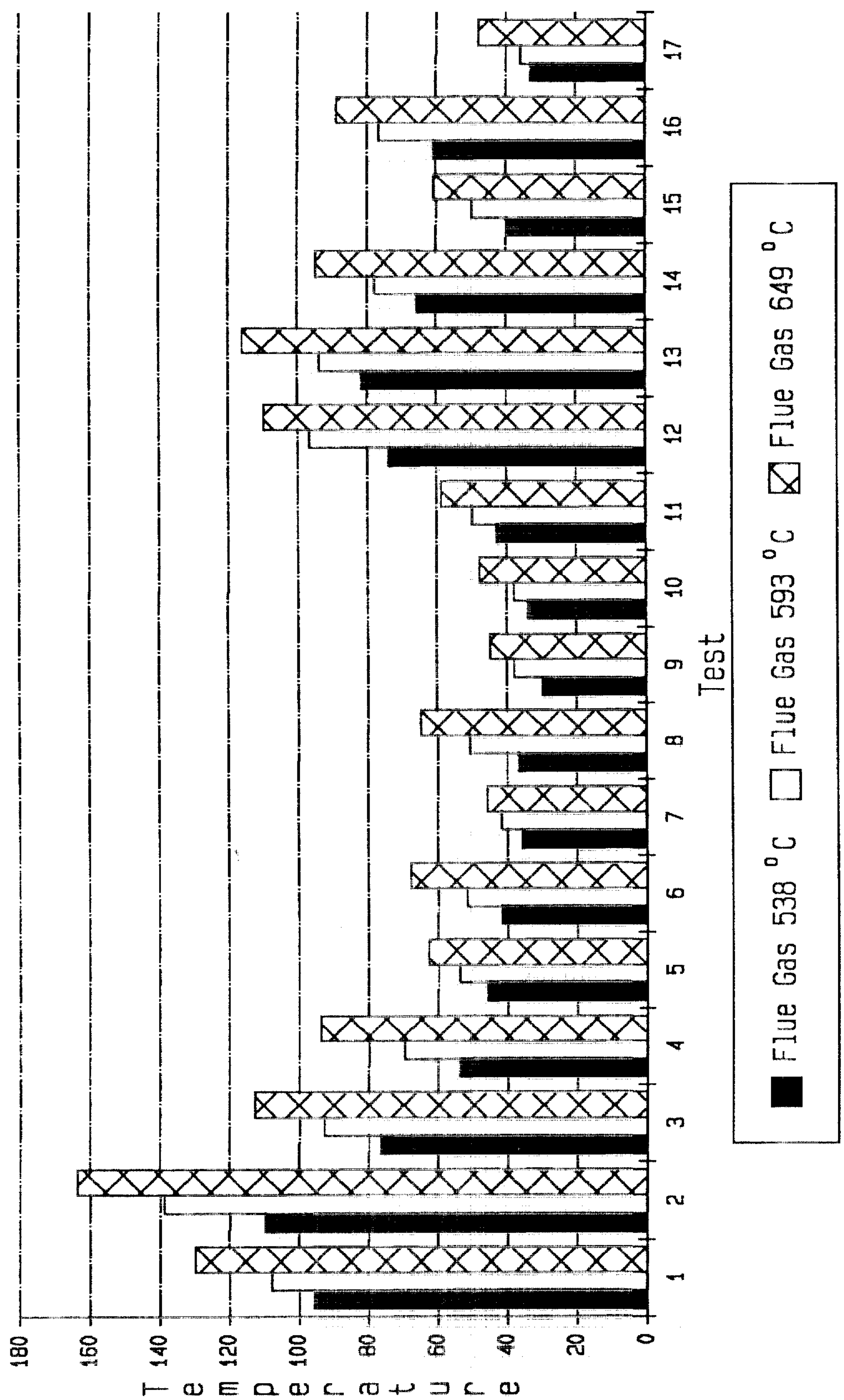

Figure 3. Maximum temperatures on combustible surfaces during tests of several generic wall pass through systems.

Figure 3 Legend.

Test	Type	Air Channels[a]	Clearance[b] (mm)	Metal Liner[c]
1	Square (457 x 457 mm) Vented	None	0	None
2	Chimney Connector (152 mm ID)	None	76	None
3	Tubular Sheet Metal	1	76	Yes
4	Tubular Sheet Metal	2	76	Yes
5	Tubular Sheet Metal	2	76[d]	Yes
6	Tubular Sheet Metal	2	152	Yes
7	Tubular Sheet Metal	2	152[d]	Yes
8	Masonry Brick Patch (203 mm)	None	0	None
9	Masonry Brick Patch (304 mm)	None	0	None
10	Chimney Connector (152 mm ID)	None	457	None
11	Chimney Connector (152 mm ID)	None	259	None
12	Masonry Chimney Block	None	38	None
13	Commercial Chimney Section	2	51	None
14	Commercial Chimney Section (Insulated 152 mm ID)	None	51	None
15	Commercial Chimney Section (Insulated 203 mm ID)	None	51	None
16	Tubular Sheet Metal	None	51	None
17	Commercial Chimney Section (Insulated 152 mm ID)	None	229	None

a Number of 25 mm air channels between inner wall and outer wall of system.
b Air space clearance between outer wall of system and combustible studding.
c Metal liner was used to line combustible studding adjacent to wall pass through system.
d Void filled with unfaced glass fiber insulation.

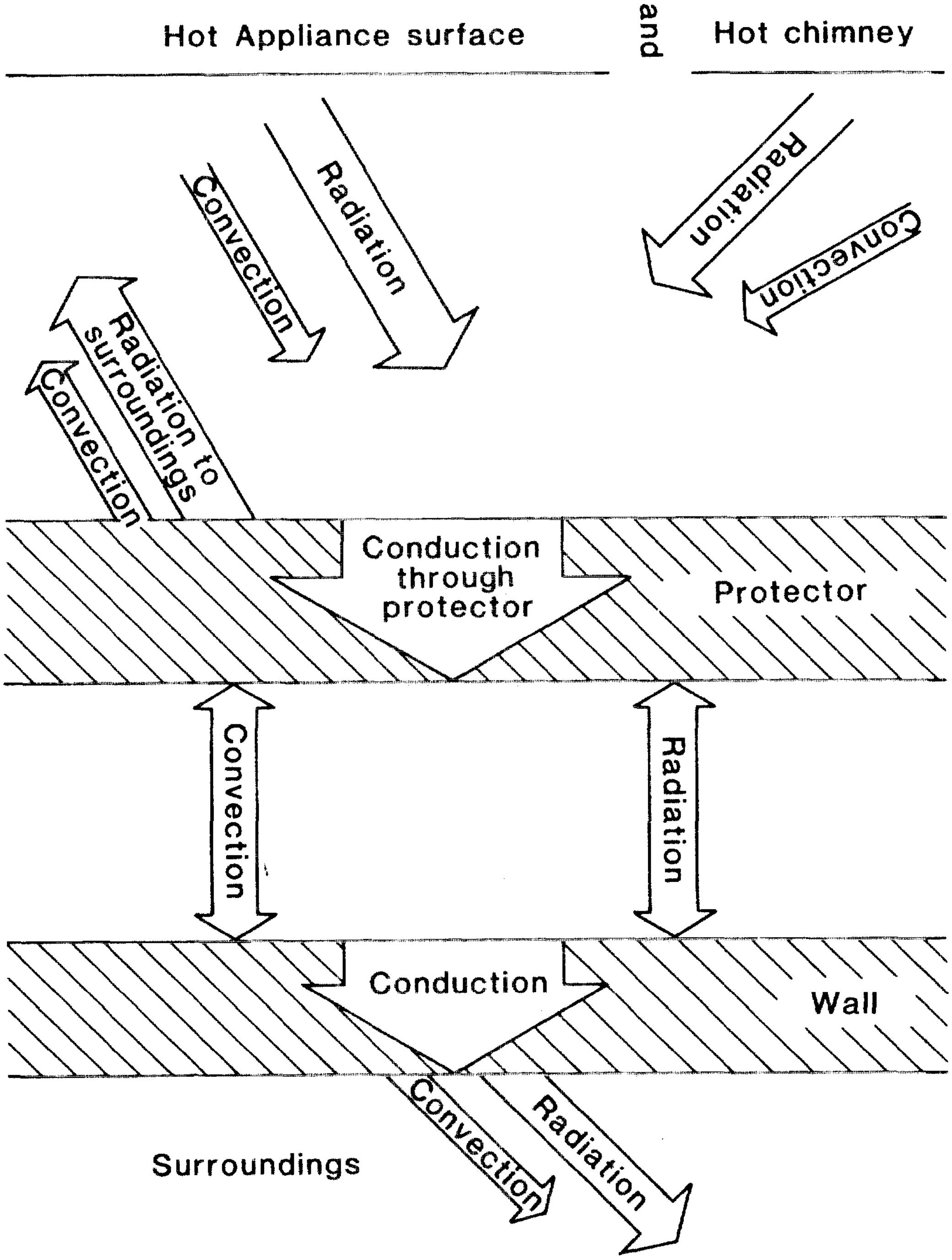

Figure 4. Heat transfer from an appliance surface to a nearby wall surface.

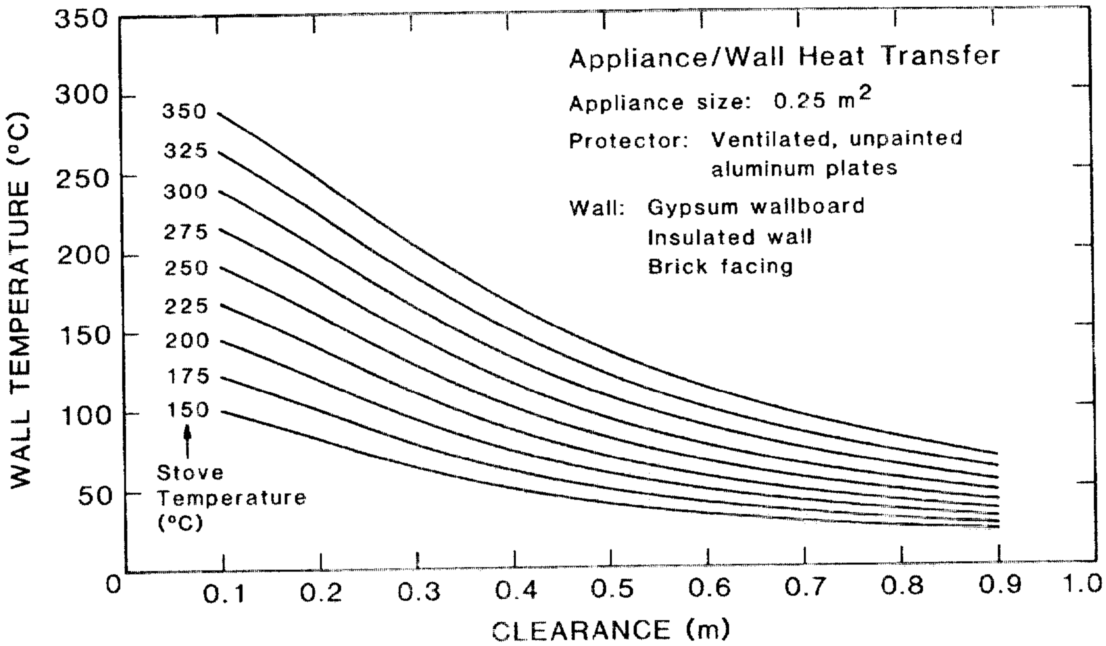

Figure 5. Predicted temperatures on a wall surface protected by an unpainted, sheet aluminum wall protector.

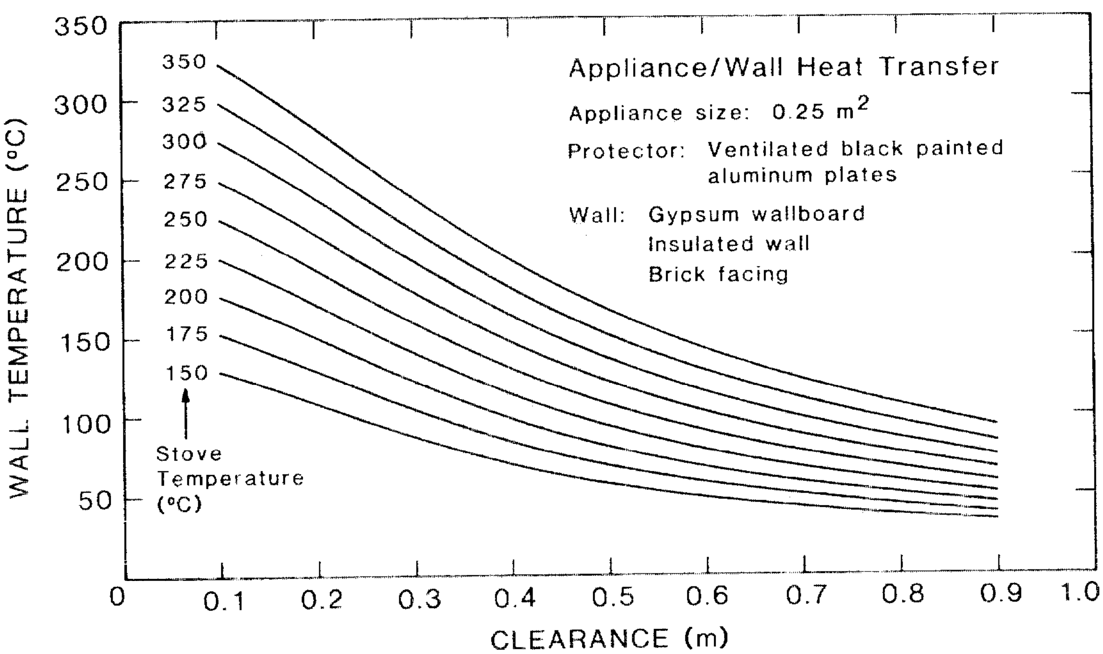

Figure 6. Predicted temperatures on a wall surface protected by a black painted sheet aluminum wall protector.

black and at an appliance clearance of 0.91 m, appliance surface temperatures greater than about 300°C would lead to temperatures on the wall in excess of the recommended limit of 50°C above room ambient temperature. However, when the surfaces of the protector are left unpainted (shiny aluminum surfaces), appliance surface temperatures higher than 350°C are required to raise the temperature of the wall surface above acceptable limits. Conversely, the clearance of the appliance to the wall could be reduced from 0.91 m to 0.3 m with an average appliance surface temperature of 200°C.

CONCLUSIONS

It is apparent after several years of extensive research and activity in the area that standards covering the fire safe installation and use of solid fuel heating appliances are finally catching up to the dramatically increased demand experienced over the last ten years. New and up-to-date technical information in several areas has contributed to reversing a dramatically increasing fire problem:

- Modern appliances operate at hotter temperatures than those of 40 years ago. Changes in codes and standards have since limited maximum operating temperatures of the appliances.
- Temperature levels attained during chimney fires have been quantified along with their effects on masonry and factory-built chimneys. New higher limits in testing standards for factory-built chimneys and new construction requirements for masonry fireplaces and chimneys are in place to insure the structural and thermal integrity of the chimneys during chimney fires.
- Changing appliances and new materials have necessitated reevaluation of appropriate generic protection methods in building codes. A number of generic protection methods are available in the model codes which allow reductions of minimum clearances to combustibles of up to 66 percent.
- Methods used in existing codes for joining of chimney connectors to masonry chimney through combustible walls are inadequate for modern appliances. A number of tested wall pass-through systems are available to allow interconnection of single wall chimney connectors and masonry chimneys at clearances as small as 51 mm.

This information, either newly developed or rediscovered after more than a generation of disinterest, is available and based upon careful scientific studies by NBS and others. From here, it is largely a matter of getting the word out to those actually installing and using the appliances. Insuring up-to-date standards by continued activity of committees such as those responsible for NFPA 211 is part of the solution. Careful inspections of installed systems by local building officials is another. Additional information, written for the homeowner, can provide the rest.

ACKNOWLEDGEMENTS : J. Loftus, T. Maher, and N. Breese of the Center for Fire Research provided experimental support and data processing for the studies reported herein. The program was funded jointly by the U. S. Consumer Product Safety Commission (E. Perry, contract monitor) and by the U. S. Department of Energy (D. Lim, contract monitor). The support provided by all those involved is gratefully acknowledged.

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