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STOVE: A Predictive Model for Heat Transfer From Solid-Fuel Appliances

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

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NOMENCLATURE

F_{dA}	radiant exchange configuration factor	dimensionless
F_{12}	radiant exchange configuration factor	dimensionless
h	convection heat transfer coefficient	$kW / m^2 \cdot K$
k	thermal conductivity	$kW / m \cdot K$
L	characteristic length	m
Nu	Nusselt number	dimensionless
Pr	Prandtl number	dimensionless
R_i	thermal resistance	$m^2 \cdot K / kW$
Ra	Raleigh number	dimensionless
R_{TOTAL}	total thermal resistance = ΣR_i	$m^2 \cdot K / kW$
$\dot{q}$	heat transfer rate	kW/m^2
T	temperature	K
X	characteristic horizontal dimension	m
Y	characteristic vertical dimension	m
ϵ	emissivity	dimensionless
σ	Stephan-Boltzmann constant	$kW / m^2 \cdot K^4$

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Abstract

A computer implementation of a model to predict temperatures on wall and wall protector surfaces exposed to the heating of an appliance such as a solid fuel heating appliance is described. A steady state heat transfer model with flexibility to describe a generalized method of protection for a combustible wall surface is presented along with a computer program implementing the model.

Good agreement was found comparing the model predictions with data previously collected during full scale experiments conducted to evaluate the effectiveness of generic methods of wall protection in reducing temperatures on combustible wall surfaces.

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

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

1. INTRODUCTION

The U.S. Consumer Product Safety Commission and the U.S. Department of Energy, as part of a program to investigate safety risks involved with the use of solid fuel burning appliances, have sponsored experimental research at the Center for Fire Research (CFR) at the National Bureau of Standards (NBS) to identify hazards associated with solid fuel heating. The studies were conducted to provide information to improve safety practices for the use of the appliances, and to provide data upon which to base improved codes and standards.

During the first years of the program, an accident survey, literature review, and codes and standards analysis were 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 these risks [1-3].[1] Overwhelmingly, conditions related to installation, operation, and maintenance were responsible for the fire incidents studied. Only a small percentage of the fires was attributed to product design or product defects. Thus, safe installation and use of wood burning appliances is a critical requirement for preventing fire accidents involving the equipment. Much of the criteria for the installation and use of wood burning appliances are based upon data developed over forty years ago and do not provide information on materials of construction, or appliances available in the current market.

The present program at CFR includes research on:

- clearances to combustibles from appliances and chimney connectors [4];

- methods of protection to allow reduced clearances to walls and

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1 Number in brackets refer to literature references listed in section 8 at the end of this report.

ceiling surfaces exposed to radiant heating by appliances and chimney connectors [5];

- temperatures developed in and around fireplaces with and without fireplace inserts installed [6,7];

- intensity and duration of chimney fires in factory-built and masonry chimneys [8];

- temperatures on combustible material surrounding chimney connectors passing through walls and / or connecting to chimneys [9], and;

- prediction of temperatures on surfaces of combustible walls exposed to heating from a typical radiant heating appliance.

This report, one of a series of reports providing information from the experimental program on wood burning safety at NBS, presents the results of the development of a computer based implementation of a model to predict temperatures on a wall surface exposed to heating from a radiant heating appliance such as a wood stove. The resulting computer program allows the user to specify thermal protection to reduce temperatures on the wall surface.

2. REVIEW OF PREVIOUS WORK

2.1 Fire Incidents Involving Wood Burning Appliances

Recent statistics on fires and injuries related to wood burning appliances are alarming:

Year	Fires	Change From Previous Year	Deaths	Dollar Loss
1978	66,800		250	$134 million
1979	70,700	+14%	210	$175 million
1980	112,000	+58%	350	--
1981	130,100	+16%	290	$265 million
1982	139,800	+7%	250	$257 million
1983	140,600	+0.6%	280	$296 million

Source: U.S. Consumer Product Safety Commission [10, 11]

There were more fires in solid fuel burning equipment, and a larger percentage increase over previous years, than were reported for any other kind of heating equipment -- including gas, electric, and oil burning appliances [10-11].

This marked increase is attributed to the growing installation and 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 appliances are an increasingly important problem.

2.2 Clearances in Existing Codes and Standards

Recommendations for minimum acceptable clearances to combustible materials for the installation of chimney, chimney connectors, and appliances are specified in the various model building codes and recommended practices manuals. Reference [12] is typical of the specifications found in the codes. 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.

Typically, 0.91 m of clearance is specified between radiant heaters and unprotected combustible construction. For residential solid fuel chimneys, typically 51 mm of clearance is required. Chimney connectors for solid fuel burning residential appliances 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 [13], 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 [14], 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 [15] and Lawson and Simms [16] 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, 0.15 m pipe should not exceed 350°C in surface temperature at a clearance of 0.46 m [15]. Loftus and Peacock [5] present the results of research studying clearances and methods of protection for wall and ceiling surfaces exposed to radiant heating appliances. A number of recommended methods of protection to reduce temperatures on combustible wall and ceiling surfaces to acceptable levels were found. In the study, appliance surface temperatures from 300 to 450°C were used.

These experimental studies established limits for two important parameters: appliance surface temperature and 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 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.

2.3 Temperatures Developed in Heating Systems

Tests made with prefabricated porcelain-enameled metal chimneys for solid or liquid fuel furnaces [17,18] 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 space 51 mm 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 totalling about 45 mm in thickness. In the same study, some asbestos cement pipe coverings were also found to reduce 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 102 mm thick walls [19,20]. 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 [21] 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 [15] 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 [21] 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.

Shoub [17] 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 of 400°C.

In tests for the Department of Energy [4], temperatures ranging from 297 to 436°C during normal operation and 377 to 693°C during over fire conditions were noted on the surfaces of several wood burning appliances when tested to prescribed test methods [22]. A total of 11 different short term tests, ranging from 1.9 to 25.6 hours duration, were conducted to establish normal firing conditions in wood burning appliances [23]. An examination of the data from these tests shows spikes occurring at the beginning and end of tests and, apparently, whenever the door to the stove was opened. These sharp increases in temperature were attributed to a "high fire" in the morning and to the rapid increase in active flaming when the door was opened for refueling the fire. The average stove surface temperature rise for normal burning ranged from 177 to 218°C, flue gases from 140 to 269°C, inner chimney wall surface 119 to 241°C, and the outer chimney wall surface 14 to 48°C.

2.4 Limiting Safe Temperatures on Combustible Surfaces

Listings of heat producing appliances and methods for setting clearances between appliances and combustible surfaces are based upon Underwriters Laboratories listings [22]:

- 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 [24], wood that is exposed to 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.

Mitchell [25] presents data on wood fiberboard exposed to temperatures as low as 109°C that resulted in ignition after prolonged exposure. MacLean

[26,27] 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 [28] 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 [29,30]. 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 [31] suggest an upper temperature limit for wood exposed to long-term low-level heating should not be appreciably higher than 100°C.

Nearby combustible materials other than wall and ceiling surfaces, such as chairs or draperies must also be kept a sufficient distance from combustible materials to prevent ignition of the materials. The testing standards and model codes treat all combustibles with the same requirements. Thus, the 0.91 m clearance requirements in NFPA 211 and maximum temperature rise requirements in the Underwriters Laboratories testing standards apply equally well to other combustibles as well. Similarly, a temperature limit of 100°C is more than adequate to protect most combustibles used in furnishings.

2.5 Data for Model Validation

Much of the available literature related to wood heating safety provides a significant amount of data that can be used to compare theoretical predictions with experimental measurements. In the above literature, references [4], [5], and [9] provide measurements of appliance surface temperatures and wall surface temperatures and provide a full description of the experimental setup to be modeled. Reference [22] provides acceptable limits on combustible surface temperatures for use in predicting minimum clearances, maximum appliance surface temperatures, minimum acceptable protector thermal properties, and the like. These references will provide the majority of data for the comparison of theoretical predictions with measured temperatures on surfaces of appliances, on protector systems, and on combustible walls.

3. THEORETICAL BASIS FOR THE MODEL

Figure 1 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).

- 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, steady state model of the stove / protector / wall heat transfer is appropriate. 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 will be modeled.

3.1 Radiative Heat Transfer

For heat exchange between two surfaces, the net radiative heat transfer between surfaces 1 and 2 is given by [32]:

$$\dot{q} = \frac{\sigma\,(T_1^4 - T_2^4)}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{1}{F_{12}} + \frac{1-\epsilon_2}{\epsilon_2}} \qquad (1)$$

F_{12}, the configuration factor for radiative exchange between surface 1 and surface 2, is defined as the fraction of the radiation leaving surface 1 which is intercepted by surface 2. Compilations of configuration factors are available in the literature [33,34]. For the stove / wall protector geometry, the following equations are appropriate. The configuration factor for a differential element to a plane parallel rectangle with the normal to the element passing through the corner of the rectangle is given by [33]:

$$F_{dA} = \frac{1}{2\pi}\left[\frac{X}{(1+X^2)^{1/2}}\tan^{-1}\frac{Y}{(1+X^2)^{1/2}} + \frac{Y}{(1+Y^2)^{1/2}}\tan^{-1}\frac{X}{(1+Y^2)^{1/2}}\right] \qquad (2)$$

where X = (width of rectangle) / (distance from rectangle to element) and Y = (height of rectangle) / (distance from rectangle to element). Since the configuration factor for a surface equals the sum of configuration factors for any subdivision of the surface, the configuration factor for any point (X_w, Y_w) on the wall (or first protector) surface can be defined from equation (2) as

$$F_{12} = F_{dA}(X_W - X_S, Y_W - Y_S) - F_{dA}(X_W - X_S - W_S, Y_W - Y_S) +$$

$$F_{dA}(X_W - X_S - W_S, Y_W - Y_S - H_S) - F_{dA}(X_W - X_S, Y_W - Y_S - H_S) \quad (3)$$

For radiant heat exchange between two identical, directly opposed rectangles (such as two protective surfaces of the same size), the configuration factor is given by [33]

$$F_{12} = \frac{2}{\pi XY} \left[\ln \left[\frac{(1+X^2)\ (1+Y^2)}{1 + X^2 + Y^2} \right]^{1/2} + X(1+Y^2)^{1/2} \tan^{-1} \frac{X}{(1+Y^2)^{1/2}} \right.$$

$$\left. + Y(1+X^2)^{1/2} \tan^{-1} \frac{Y}{(1+X^2)^{1/2}} - X \tan^{-1} X - Y \tan^{-1} Y \right] \quad (4)$$

3.2 Convective Heat Transfer

For convective heat transfer between two surfaces separated by an air space, the net heat exchange by convection is given by

$$\dot{q} = h\ (T_1 - T_2) \quad (5)$$

where h is the convective heat transfer coefficient. For free convection at the surface of a vertical surface (such as the wall, appliance, or protector surface), h can be found from the equations [35]

$$Nu_L = \frac{h\,L}{k} = \left[0.825 + \frac{0.387\, Ra_L^{1/6}}{\left[1 + (0.492/Pr)^{9/16}\right]^{8/27}} \right]^2 \qquad (6)$$

3.3 Conductive Heat Transfer

For solids, the net heat exchange by conduction is given by

$$\dot{q} = \frac{k}{L}\,(T_1 - T_2) \qquad (7)$$

While for some materials, the thermal conductivity, k, is a function of temperature, for most materials, the assumption that k is a constant leads to inconsequential loss in generality. For instance, for aluminum, the thermal conductivity changes by only 25% over a temperature range from -170°C to well over 2000°C

3.4 Solution of the Equations for an Arbitrary Protection System

At steady state, the heat transferred from the appliance to the outside, figure 2, is equal to the heat transferred through any element or group of elements within the system, or

$$\dot{q}_{TOTAL} = \frac{(T_S - T_O)}{R_{TOTAL}} = \dot{q}_i = \frac{(T_i - T_{i+1})}{R_i} \tag{8}$$

Equations (1), (5), and (7) can be expressed as in equivalent resistance forms as

(Conduction) $$R_i = \frac{L}{K} \tag{9}$$

(Convection) $$R_i = \frac{1}{h} \tag{10}$$

(Radiation) $$R_i = \frac{\frac{1 - \epsilon_1}{\epsilon_1} + \frac{1}{F_{12}} + \frac{1 - \epsilon_2}{\epsilon_2}}{\sigma \, (T_1^2 + T_2^2) \, (T_1 + T_2)} \tag{11}$$

For the current problem, these equations can be combined into two as

(Solids) $$R_i = \frac{L}{K} \tag{12}$$

(Airspaces) $$R_i = \cfrac{1}{\cfrac{1}{h} + \cfrac{\sigma\,(T^2 + T^2)\,(T + T)}{\cfrac{1-\epsilon_1}{\epsilon_1} + \cfrac{1}{F_{12}} + \cfrac{1-\epsilon_2}{\epsilon_2}}} \qquad (13)$$

Thus, the solution method with a given appliance temperature, T_S, and a given temperature of the surroundings, T_O, begins by assuming temperatures for the intermediate surfaces, calculating individual resistances from equations (12) and (13) to determine the total resistance, R_{TOTAL}, calculating the total heat flow rate from equation (8), and comparing the total heat flow rate to the individual heats. If the calculated individual rates are sufficiently close to the calculated total heat flow rate, the steady state solution has been obtained. If any of the individual heats are different from the total heat, new estimates for each of the intermediate temperatures are made and the process is repeated until sufficient agreement has been found. Reference [36] provides a number of methods for making best guess estimates for the next iteration toward the solution. For the current problem, a simple linear search is used where one variable at a time is changed until a local optimum is found.

A number of literature sources are available to allow determination of the physical data required for the input (for instance, for the thermal conductivity and emissivity). References [32] and [33] provide extensive listings of thermal and material properties for common materials.

4. COMPUTER IMPLEMENTATION OF THE MODEL

Included as Appendix A is a listing of the FORTRAN (written in ANSI standard FORTRAN 77) program implementing the model as described above. The general structure of the program is illustrated in figure 3.

Program input (detailed in Appendix B) takes the form of different key words with arguments to specify values which depend upon the key word. In most cases, the order of the key words is unimportant. A description of each of the input key words and values which go on the same line are presented below:

STOVE	<height> <width> <emissivity> <temperature>
AIRSPACE	<thickness> <emissivity>
FOR	<variable> = <lower> <upper> <increment>
XWALL	<x position>
YWALL	<y position>
PROTECTOR	<thickness> <height> <width> <k> <emissivity> <temperature>

A sample input for the program follows:

```
FOR:                TSTOVE = 473.15 673.15 10.
STOVE:              0.9 0.5 0.5 473.15
AIRSPACE:           0.91 0.9
ALUMINUM SHEET:     0.00254 3.0 3.0 177. 0.9
AIRSPACE:           0.0254 0.9
ALUMINUM SHEET:     0.00254 3.0 3.0 177. 0.9
AIRSPACE:           0.0254 0.9
GYPSUM WALLBOARD:   0.0127 3.0 3.0 0.17 0.9
F/G INSULATION:     0.0916 3.0 3.0 0.038 0.9
BRICK OUTSIDE:      0.0916 3.0 3.0 0.72 0.9
AIRSPACE:           273.15
END:
```

This input specifies a series of calculations to be done for a stove temperature ranging from 200°C to 400°C (473.15 to 673.15 K in the input above) for a wall protection system consisting of two aluminum sheets spaced 25 mm (0.00254 m in the input above) apart and placed 25 mm from an insulated outside wall of a house. A clearance of 0.91 m from the appliance to the first aluminum sheet is specified. A sample output from the program, using this sample data set, is presented in table 1. Calculated temperatures on all surfaces from the stove to the outdoors are shown along with the specified sizes and thermal properties of the materials used for the walls and protectors. Execution time, of course, depends upon the computer in use. On a typical desk top personal computer, execution of the above test case required less than 1.5 minutes.

5. COMPARISON OF THE MODEL PREDICTIONS WITH EXPERIMENTAL DATA

Figure 4 presents a comparison of calculated temperatures on the surfaces of wall protectors and on the surfaces of combustible walls with experimentally measured values taken from references [4] and [5]. To assess the predictive capabilities of the model, a range of conditions from the experimental studies were simulated. Wall materials used in these experimental studies ranged from uninsulated gypsum wallboard to a fully insulated stud wall with a brick facing on the exterior. A number of different wall protection methods were taken from reference [5], varying from a simple sheet metal protector to a sheet metal / insulation board / air space composite protector or a ventilated brick protector. A simple cross plot of the calculated values and the experimental values illustrates the agreement of the model's predictions with experimental data obtained in earlier studies. Agreement of the calculated values with the experimentally measured values, stated as

$$((T_{calculated} - T_{measured}) / T_{calculated}) * 100$$

with temperatures expressed in absolute, averaged within less than 1 percent. Individual agreement, however ranged from 5 percent low (calculated values lower than experimental) to 4 percent high. Much of the disparity in the comparison can be explained by the choice of ambient conditions for the experimental tests. All the data in the two reports were described in terms of temperature rise above ambient conditions. Since the experimental calculations are based upon absolute temperatures, some assumptions had to be made for the ambient temperatures in the surroundings during the tests. A variation in ambient temperature of 15°C could change the calculated surface temperatures on the wall surfaces by as much as ±10 percent. Thus, the agreement illustrated in figure 5 is excellent in light of the possible variation in the calculations depending upon the assumed ambient temperature.

6. MODEL CAPABILITIES AND EXAMPLES

A theoretical model for predicting the heat transfer between the appliance and the wall surfaces can be a useful tool not only in the design of appliances and wall protection devices but also in the design of future experiments to study clearances and reduced clearances for wood burning appliances. This section presents some examples of the use of the model in predicting temperatures and clearances from combustibles for both protected and unprotected wall surfaces.

6.1 Heat Transfer From Appliance to an Unprotected Wall

Figure 5 shows 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 an unprotected wall surface for appliance surface temperatures from 150 to 350°C. For these calculations, the outside air temperature (temperature of the surroundings) was assumed equal to 0°C. 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. 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 [22] of 50°C above room ambient temperature at a point on the wall directly centered behind the appliance. Since, in an earlier study [4], average appliance surface temperatures of about 200 °C were noted, a sufficient margin of safety is indicated for an appliance this size.

6.2 Heat Transfer From Appliance to a Sheet Metal Protected Wall

Figures 6 and 7 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. As before, 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 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 -- in fact, about the same as the case with no protection. 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.

6.3 Heat Transfer From Appliance to a Masonry Protected Wall

Figure 8 shows calculated wall surface temperatures as a function of appliance / wall clearance for the same 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. Again, the outside air temperature was assumed equal to 0°C. The wall protector consisted of a 92 mm thick solid brick wall 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 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 -- again not significantly lower than in wall surface temperatures than for the unprotected wall. Note, however, one of the major thermal characteristics of a masonry wall protection system -- high thermal mass -- is not accounted for in a steady state prediction.

7. USES FOR AND LIMITATIONS OF THE MODEL

A model was developed to predict temperatures on protected and unprotected wall surfaces exposed to heating from a (primarily) radiant heating appliance. A one-dimensional, steady state model of appliance / protector / wall heat transfer showed agreement within an average of less than 1 percent when compared to experimental results from earlier laboratory studies. A range of building materials typical of residential construction, along with a number of different wall protection methods were simulated in the comparison. As a guideline to the range of applicability of the model, the variations of the thermal properties used in the comparisons were

k:	0.038	to	177	W/m · K
ϵ:	0.1	to	0.9	
airspace thickness:	0.1	to	1.0	m
solid thickness:	0.0025	to	0.1	m

Improvements in the program implementation of the model are possible. The simple linear search for the solution of the equations is certainly not the most efficient method. A number of search methods have been described in the literature [36]. An n-dimensional simplex search where the next guess for a given variable depends upon the values of the other n-1 variables would improve the execution speed of the program. Additional improvements would be realized with any of a number of acceleration methods, also available in the literature [36]. Of course, a more complicated, harder to understand and modify program would result.

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Table 1. Sample Output From STOVE

DOUBLE ALUMINUM PLATE, ALL SURFACES PAINTED BLACK

NUMBER OF NODES IN CALCULATION: 10
POINT ON WALL: (X): 0.000 (Y): 0.000

SERIES OF CALCULATIONS FOR VARIABLE TSTOVE: 473.150 673.150 20.000

I	MATERIAL	HEIGHT (m)	WIDTH (m)	THICK (m)	EMISS	K (W/m·K)	TEMPERATURE (°C)
0	STOVE	0.50	0.50		0.90		200.00
1	AIRSPACE			0.91	0.90		
2	ALUMINUM SHEET	3.00	3.00	0.00	0.90	177.000	
3	AIRSPACE			0.03	0.90		
4	ALUMINUM SHEET	3.00	3.00	0.00	0.90	177.000	
5	AIRSPACE			0.03	0.90		
6	GYPSUM WALLBOARD	3.00	3.00	0.01	0.90	0.170	
7	INSULATION	3.00	3.00	0.09	0.90	0.038	
8	BRICK OUTSIDE	3.00	3.00	0.09	0.90	0.720	
9	AIRSPACE			0.00	1.00		0.00

0: STOVE / AIRSPACE
1: AIRSPACE / ALUMINUM SHEET
2: ALUMINUM SHEET / AIRSPACE
3: AIRSPACE / ALUMINUM SHEET
4: ALUMINUM SHEET / AIRSPACE
5: AIRSPACE / GYPSUM WALLBOARD
6: GYPSUM WALLBOARD / INSULATION
7: INSULATION / BRICK OUTSIDE
8: BRICK OUTSIDE / AIRSPACE
9: AIRSPACE

TSTOVE	(0) (°C)	(1) (°C)	(2) (°C)	(3) (°C)	(4) (°C)	(5) (°C)	(6) (°C)	(7) (°C)	(8) (°C)	(9) (°C)
473.150	200.0	33.1	33.1	31.6	31.6	30.1	29.3	3.1	1.7	0.0
493.150	220.0	38.7	38.7	37.0	37.0	35.3	34.4	3.6	2.0	0.0
513.150	240.0	44.7	44.7	42.8	42.8	41.0	39.9	4.2	2.3	0.0
533.150	260.0	51.1	51.1	49.0	49.0	47.0	45.7	4.7	2.6	0.0
553.150	280.0	57.8	57.8	55.6	55.6	53.4	51.9	5.4	2.9	0.0
573.150	300.0	64.8	64.8	62.5	62.5	60.1	58.5	6.0	3.2	0.0
593.150	320.0	72.2	72.2	69.7	69.7	67.2	65.4	6.7	3.6	0.0
613.150	340.0	79.9	79.9	77.3	77.3	74.6	72.6	7.4	3.9	0.0
633.150	360.0	87.8	87.8	85.1	85.1	82.3	80.1	8.1	4.3	0.0
653.150	380.0	96.0	96.0	93.2	93.2	90.3	87.8	8.8	4.7	0.0
673.150	400.0	104.3	104.3	101.5	101.5	98.5	95.8	9.6	5.0	0.0

Figure 1. Heat Transfer From Hot Appliance to Cooler Wall Surface

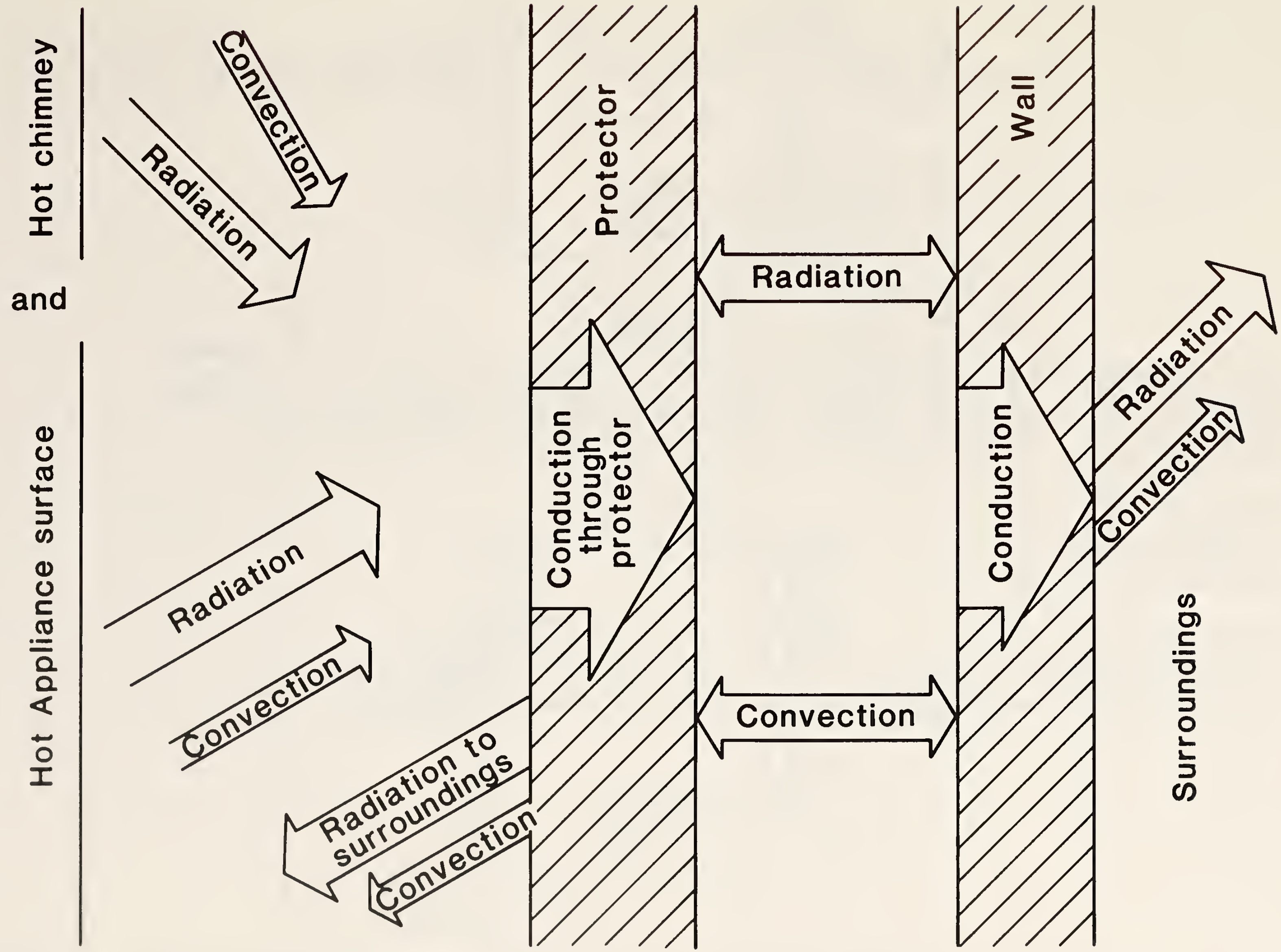


Figure 2. Node Model Representation of Stove / Protector / Wall System

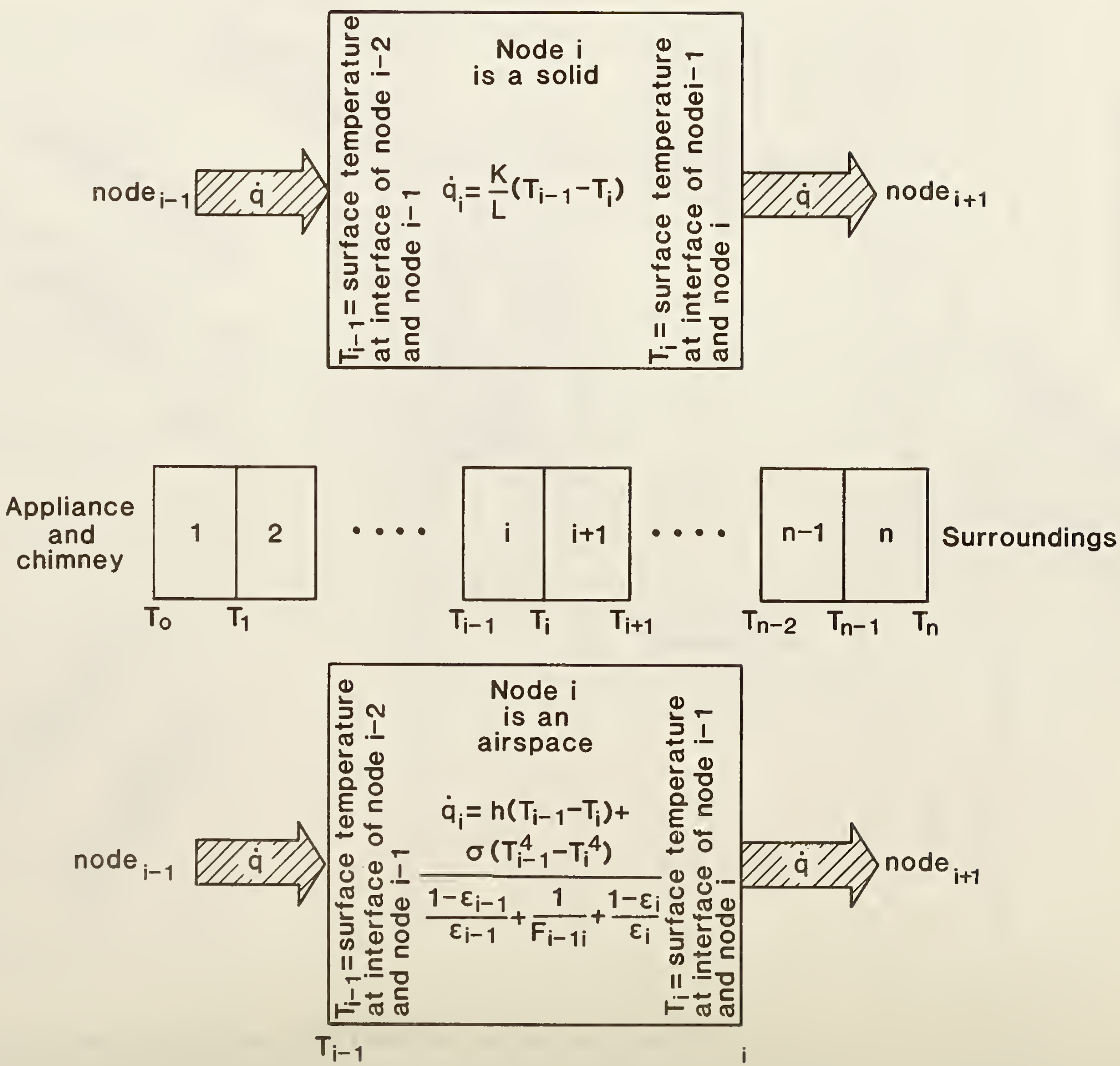


Figure 3.   Program Layout For Program STOVE

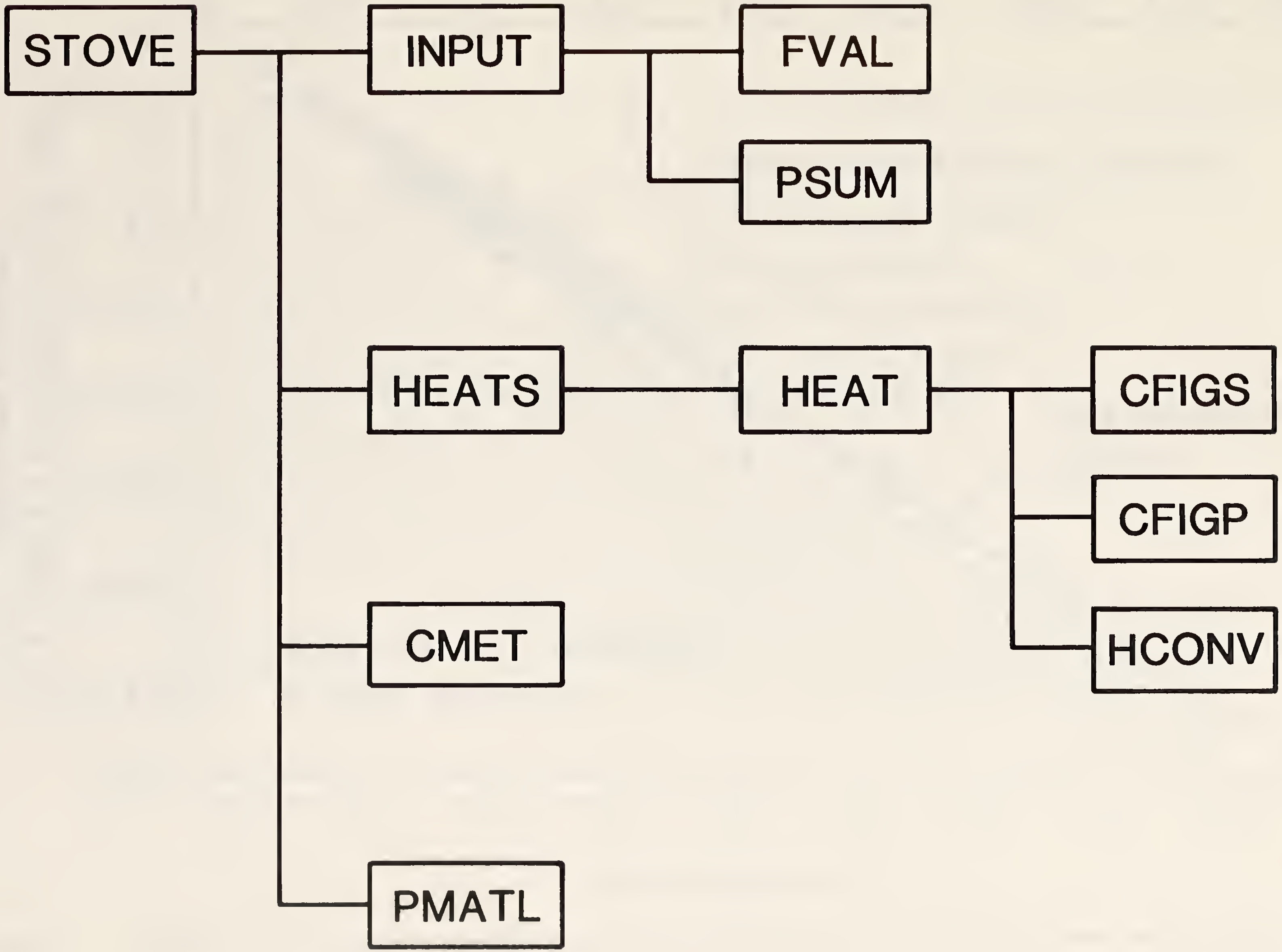


Figure 4. Comparison of Calculated Wall and Protector Surface Temperatures With Experimental Results

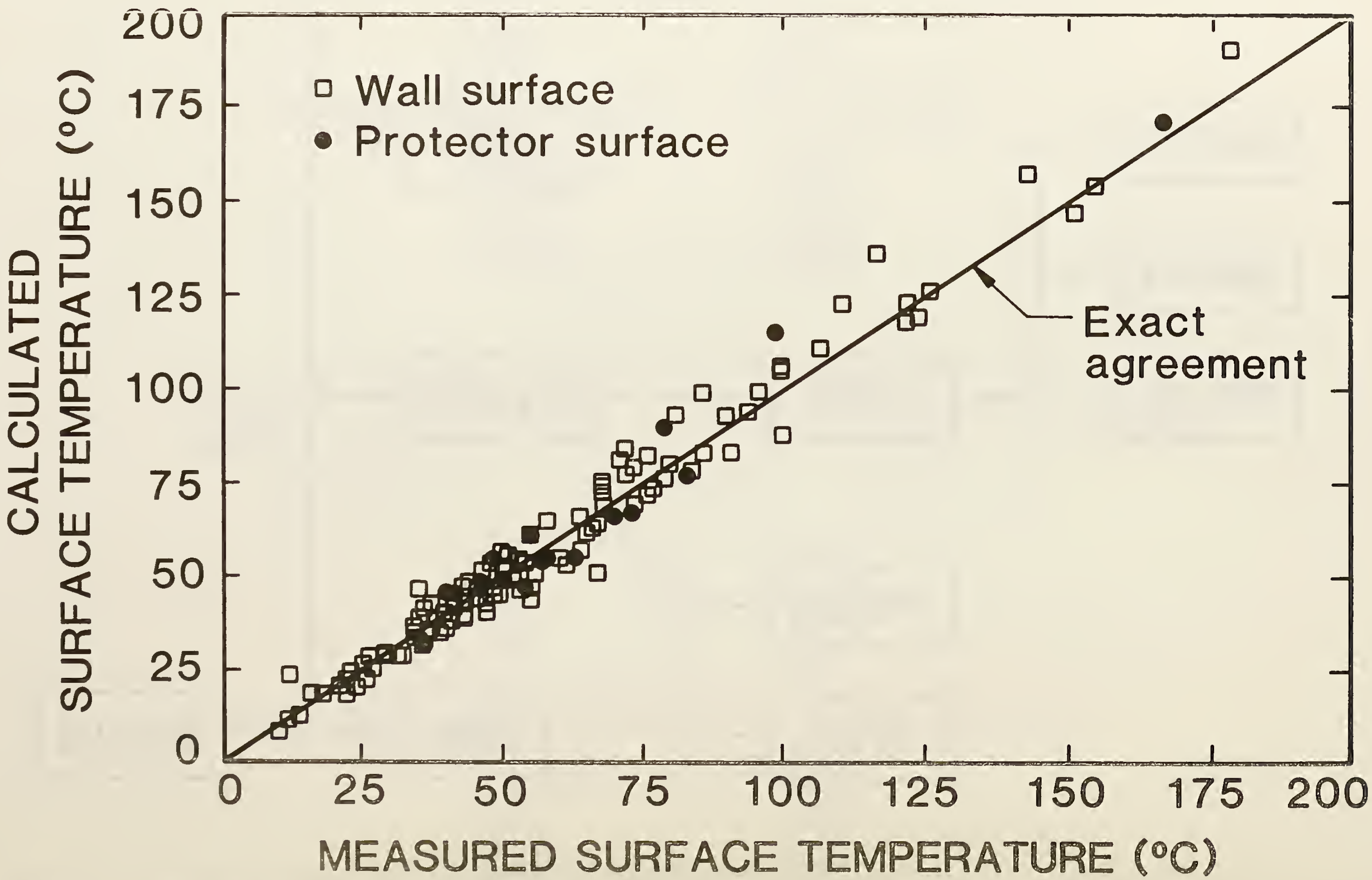


Figure 5. Predicted Wall Surface Temperatures for Heat Transfer From Appliance Surface to an Unprotected Combustible Wall Surface

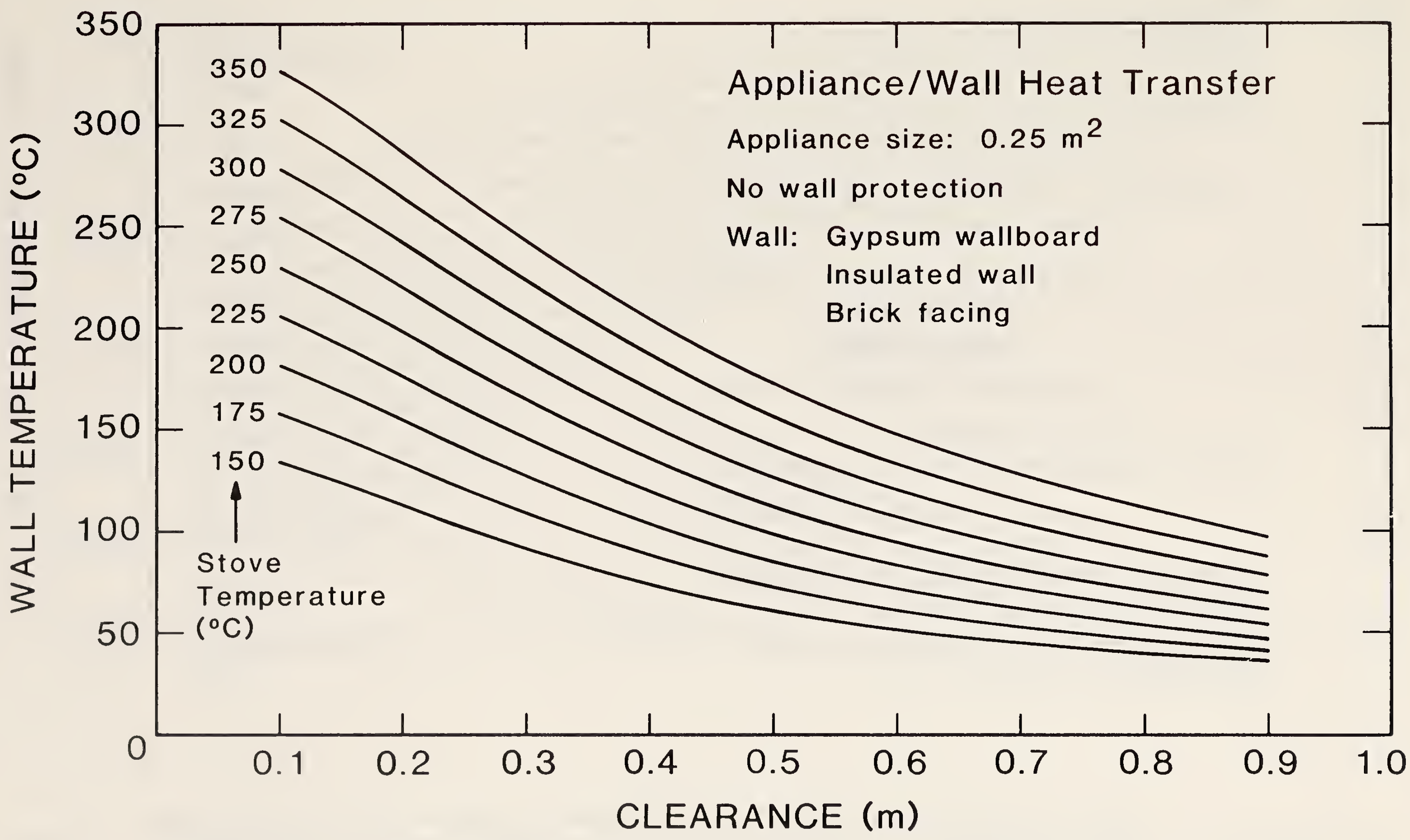


Figure 6. Predicted Wall Surface Temperatures for Heat Transfer From Appliance Surface to a Combustible Wall Protected With a Double Aluminum Sheet Wall Protector (Painted Black)

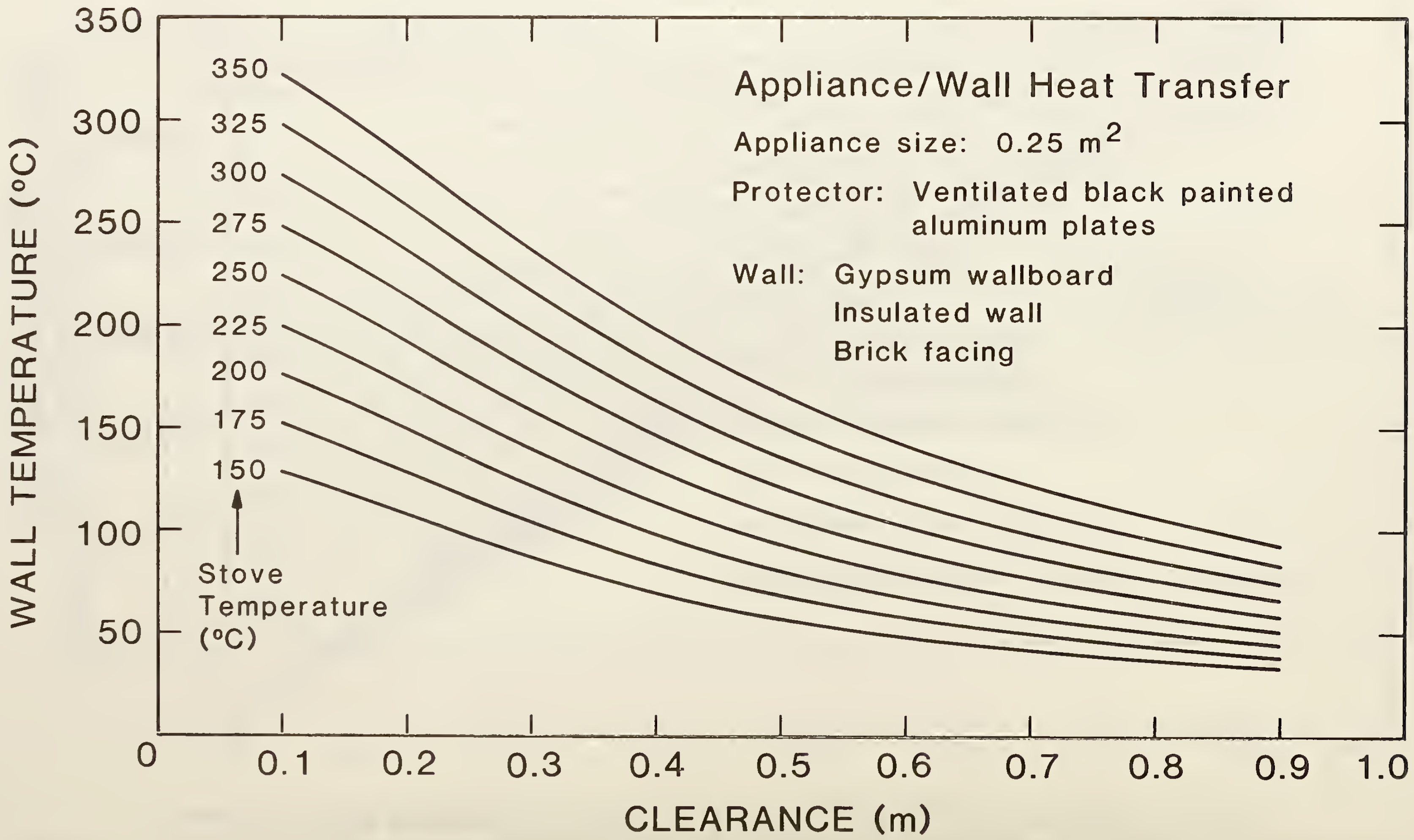


Figure 7. Predicted Wall Surface Temperatures for Heat Transfer From Appliance Surface to a Combustible Wall Protected With a Double Aluminum Sheet Wall Protector

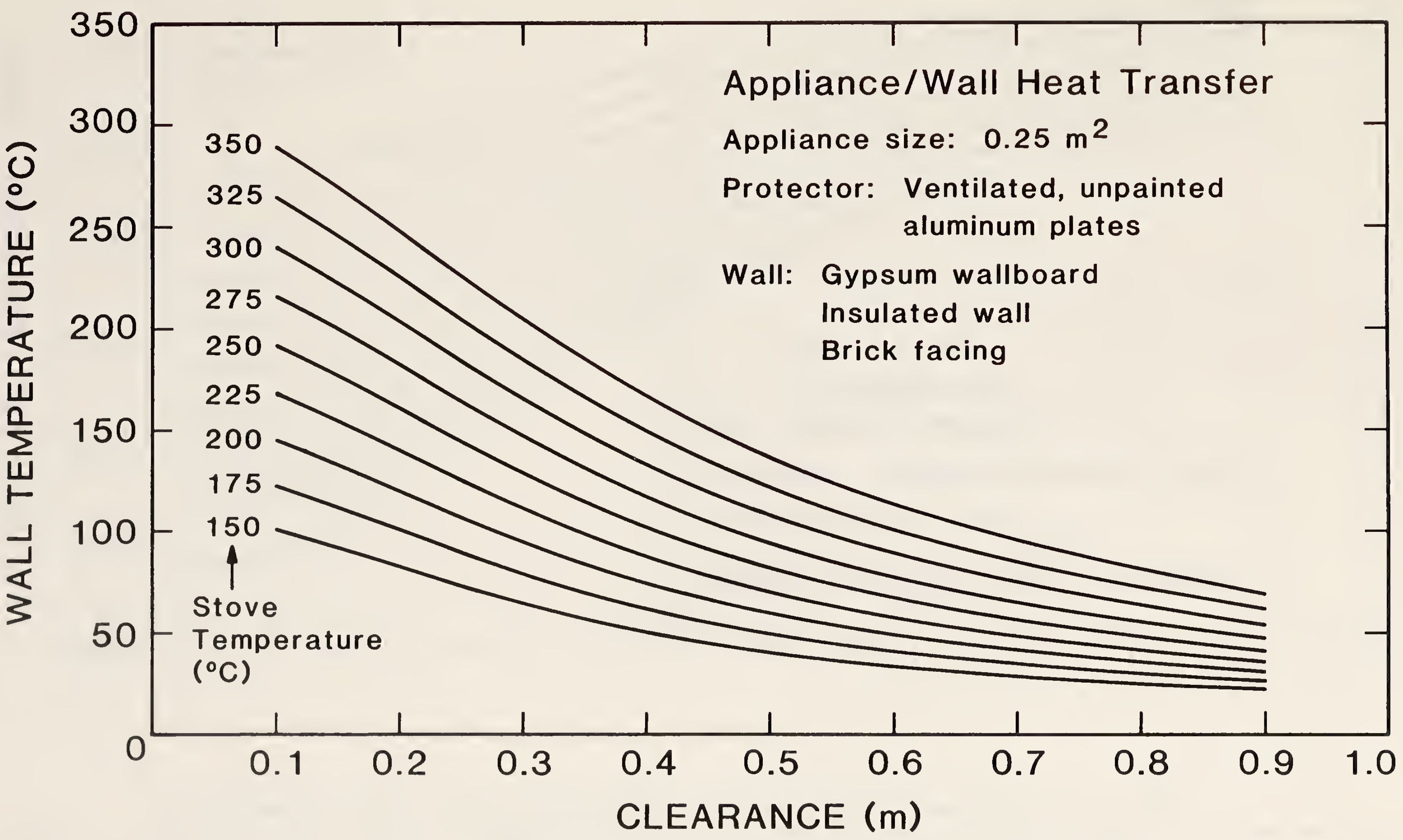
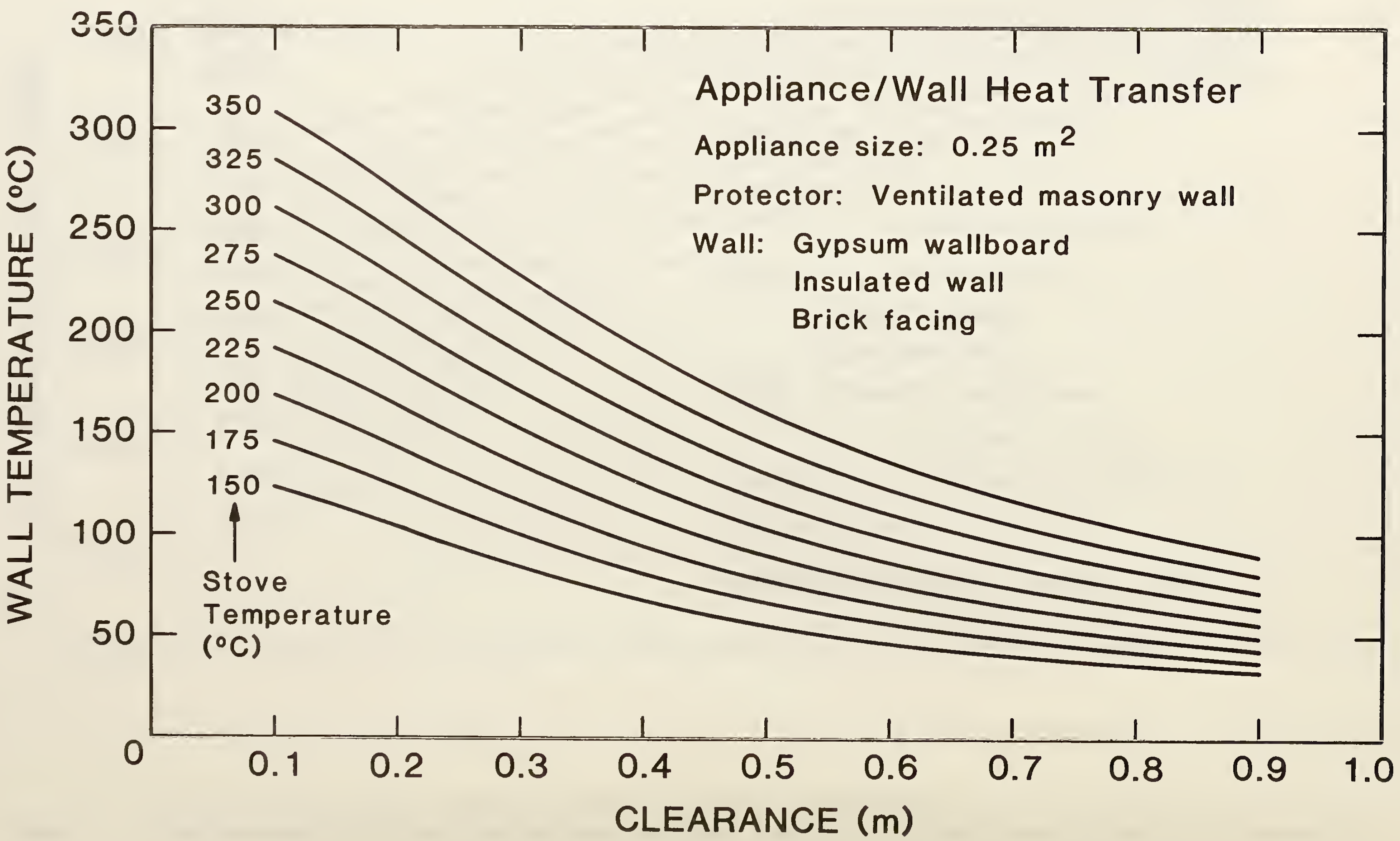


Figure 8. Predicted Wall Surface Temperatures for Heat Transfer From Appliance Surface to a Combustible Wall Protected With a Solid Masonry Wall Protector With A Ventilated Air Space



Appendix A: Program Listing of STOVE

```
      PROGRAM STOVE
C
C     @@@@@@@@
C     @@@@   @       @
C     @@@@       @@@@@@    @@@@@@    @@@  @    @@@@@@
C     @@@@@@@@    @@@@     @@@  @    @@@  @    @  @@@
C        @@@@    @@@@     @@@  @    @@@  @    @@@@@@
C     @   @@@@    @@@@     @@@  @     @@@@     @
C     @@@@@@@@    @@@@     @@@@@@      @@      @@@@@@
C
C
C   THIS PROGRAMS CALCULATES AN ENERGY BALANCE ON A STOVE / WALL SYSTEM
C   ASSUMING STEADY STATE CONDITIONS, WITH AN ARBITRARY NUMBER OF WALL
C   PROTECTORS BETWEEN THE STOVE AND THE WALL
C
      INCLUDE 'STOVE.CMN'
      CHARACTER CMET*5,PMATL*60,VERSN*7
      LOGICAL THRU1,NOTYET,THEEND
      DATA VERSN /'86.0108'/
C
C   INITIALIZE EVERYTHING TO DEFAULT CONDITIONS, READ INPUT FOR CASE
C
      QEPS=0.00001
      EPS=0.0001
      TSTEP1=2.
      TSTEP2=2.
10    CALL INPUT(THEEND)
      IF (.NOT. THEEND) THEN
        XSTOVE=WSTOVE/2.
        YSTOVE=0.
        IF (.NOT.FULPRT) THEN
          WRITE (6,11) (I,PMATL(MATL(I),MATL(I+1)),I=0,N-1),N,MATL(N)
          WRITE (6,12) VNAME,(I,I=0,N)
          WRITE (6,8) '          ',('  (°C) ',I=0,N)
          WRITE (6,8) ('————————',I=-1,N)
        END IF
        NCALCS=MAX(INT((VUPPER-VLOWER)/VINCR+0.5)+1,1)
        DO 100 ICALC=1,NCALCS
        VARVAL=VLOWER+VINCR*(ICALC-1)
C
C   SET NEXT VALUE OF VARIABLE TO BE INCREMENTED
C
        IF (IVAR.EQ.1) THEN
          XWALL=VARVAL
        ELSE IF (IVAR.EQ.2) THEN
          YWALL=VARVAL
        ELSE IF (IVAR.EQ.3) THEN
          T(0)=VARVAL
        ELSE IF (IVAR.EQ.4) THEN
          L(ISUB)=VARVAL
          IF (ISUB.EQ.1) ZSTOVE=VARVAL
        ELSE IF (IVAR.EQ.5) THEN
          WIDTH(ISUB)=VARVAL
          IF (ISUB.EQ.0) WSTOVE=VARVAL
          XSTOVE=WSTOVE/2.
        ELSE IF (IVAR.EQ.6) THEN
          HEIGHT(ISUB)=VARVAL
          IF (ISUB.EQ.0) HSTOVE=VARVAL
        ELSE IF (IVAR.EQ.7) THEN
          K(ISUB)=VARVAL
        ELSE IF (IVAR.EQ.8) THEN
          EMMIS(ISUB)=VARVAL
        END IF
C
C   INITIALIZE THE COUNTERS TO ZERO
C
        ITER=0
C
C   INITIALIZE TEMPERATURE GUESSES TO WORST CASE CONDITIONS
C
```

```
      DO 20 I=1,N-1
20    T(I)=T(N)
      TDIFF=T(0)-T(N)
      TGOAL=T(N)
C
C  DETERMINE NEXT GUESS FOR TEMPERATURES
C
      DO 30 I=1,N-1
30    T(I)=T(I)+TDIFF/N
C
C  CALCULATE TOTAL RESISTANCE AND HEAT FLOW FROM GUESSED TEMPERATURES
C
      CALL HEATS
40    INNER=0
C
C  CALCULATE WITH NEWLY GUESSED TEMPERATURES AND HEATS
C
      DO 60 I=1,N
      TINC=ABS(TDIFF/N/TSTEP1)
      TINCI=TINC
      QSIGN=DSIGN(1.D0,Q(I)-QTOTAL)
C
C GO THROUGH INNER ITERATION LOOP AT LEAST ONCE FOR SOME FORCED
C IMPROVEMENT
C
      THRU1=.FALSE.
50    IF (.NOT. (ABS((Q(I)-QTOTAL)/QTOTAL).LE.QEPS.AND.THRU1)) THEN
        INNER=INNER+1
        THRU1=.TRUE.
        IF (ABS((Q(I)-QTOTAL)/QTOTAL).GT.QEPS) NOTYET=.TRUE.
        IF (MATL(I).NE.'AIRSPACE') THEN
C
C  HEAT TRANSFER IS CONDUCTION, CALCULATE TEMPERATURE
C
          T(I)=T(I-1)-QTOTAL*R(I)
        ELSE
C
C  HEAT TRANSFER IS BY CONVECTION & RADIATION, SEARCH FOR TEMPERATURE
C
          T(I)=T(I)+QSIGN*TINC
C
C  RECALCULATE THE HEAT FLOW AND COMPARE TO TOTAL HEAT
C
          CALL HEAT(I)
          IF (DSIGN(1.D0,Q(I)-QTOTAL).NE.QSIGN) THEN
            TINCI=TINCI/TSTEP2
            TINC=TINCI
            QSIGN=DSIGN(1.D0,Q(I)-QTOTAL)
          ELSE
            TINC=TINC*2.
          END IF
          GO TO 50
        END IF
      END IF
C
C  RECALCULATE TOTAL HEAT WITH THE NEW TEMPERATURES AND PROCEED
C
      CALL HEATS
60    CONTINUE
C
C  IF DEBUG IS ON, PRINT OUT A SUMMARY OF THE ITERATION
C
      ITER=ITER+1
      IF (DEBUG.AND.NOTYET) THEN
        WRITE (6,7) ITER,INNER
        WRITE (6,'(1X,A,F7.2)') 'STOVE TEMPERATURE: ',T(0)-273.15
        WRITE (6,'(1X,A,F8.2,A,F8.3)') 'TOTAL HEAT: ',QTOTAL,
     2                                 '   TOTAL RESISTANCE: ',RTOTAL
        WRITE (6,3)
        DO 70 I=1,N
```

```
          IF (MATL(I).EQ.'AIRSPACE'.AND.I.EQ.1) THEN
            WRITE (6,5) MATL(I),T(I)-273.15,R(I),Q(I),CF(I)
          ELSE IF (MATL(I).EQ.'AIRSPACE'.AND.I.NE.1) THEN
            WRITE (6,1) MATL(I),T(I)-273.15,R(I),Q(I),H(I),CF(I)
          ELSE
            WRITE (6,2) MATL(I),T(I)-273.15,R(I),Q(I)
          END IF
70        CONTINUE
          TDIFF=T(N)-TGOAL
          WRITE (6,'(1X,A7,F10.3,A)') 'TDIFF: ',TDIFF,
     2                                CMET(TDIFF/TGOAL,EPS)
          WRITE (6,6) 'QMET:  ',(Q(I)-QTOTAL,
     2                CMET((Q(I)-QTOTAL)/QTOTAL,EPS),I=1,N)
        END IF
        TDIFF=T(N)-TGOAL
        T(N)=TGOAL
C
C   IF ANY OF THE INDIVIDUAL HEATS HAVEN'T CONVERGED ON THE FINAL VALUE,
C   CONTINUE WITH THE PROCESS UNTIL ALL ARE EQUAL
C
        NOTYET=.FALSE.
        DO 80 I=1,N
        IF (ABS((Q(I)-QTOTAL)/QTOTAL).GT.EPS) NOTYET=.TRUE.
80      CONTINUE
        IF (ABS(TDIFF)/TGOAL.GT.EPS) NOTYET=.TRUE.
        IF (NOTYET) GO TO 40
C
C   THE SOLUTION HAS BEEN FOUND, PRINT IT OUT
C
        IF (.NOT.FULPRT) THEN
          WRITE (6,9) VARVAL,(T(I)-273.15,I=0,N)
        ELSE
          WRITE (6,4) TITLE
          WRITE (6,'(1X,A,I3)') 'ITERATIONS: ',ITER
          WRITE (6,'(1X,3A,F8.3)') 'VARIED VARIABLE: ',VNAME,' = ',
     2                             VARVAL
          WRITE (6,'(1X,A,F7.2)') 'STOVE TEMPERATURE: ',T(0)-273.15
          WRITE (6,'(1X,A,F8.2,A,F8.3)') 'TOTAL HEAT: ',QTOTAL,
     2                                   '   TOTAL RESISTANCE: ',RTOTAL
          WRITE (6,3)
          DO 90 I=1,N
          IF (MATL(I).EQ.'AIRSPACE'.AND.I.EQ.1) THEN
            WRITE (6,5) MATL(I),T(I)-273.15,R(I),Q(I),Q(I)
          ELSE IF (MATL(I).EQ.'AIRSPACE'.AND.I.NE.1) THEN
            QCONV=(T(I-1)-T(I))/CONV(I)
            QRAD=(T(I-1)-T(I))/RAD(I)
            WRITE (6,1) MATL(I),T(I)-273.15,R(I),Q(I),QCONV,QRAD
          ELSE
            WRITE (6,2) MATL(I),T(I)-273.15,R(I),Q(I)
          END IF
90        CONTINUE
          WRITE (6,4) 'TEMPERATURES ARE OF COOLER SIDE OF NODE'
        END IF
100     CONTINUE
        GO TO 10
      END IF
      STOP
1     FORMAT (1X,A10,2X,F10.2,3X,F10.3,2X,F10.3,3X,F10.3,3X,F10.3)
2     FORMAT (1X,A10,2X,F10.2,3X,F10.3,2X,F10.3)
3     FORMAT ('0MATERIAL      TEMPERATURE   RESISTANCE    HEAT       CONV
     2ECTION    RADIATION',/)
4     FORMAT ('0',A)
5     FORMAT (1X,A10,2X,F10.2,3X,F10.3,2X,F10.3,16X,F10.3)
6     FORMAT (1X,A7,4(F10.3,A5,:),/,10(8X,4(F10.3,A5,:),/))
7     FORMAT ('0ITERATION: ',I3,'         INNER LOOP: ',I3)
8     FORMAT (' ',A10,20(A7,:))
9     FORMAT (' ',F10.3,20(F6.1,1X,:))
11    FORMAT ('0',/,20(' ',I6,':     ',A,/)/)
12    FORMAT (' ',A10,20('   (',I2,')',:))
      END
```

```
      SUBROUTINE INPUT (THEEND)
C
C      @@@@@@
C       @@@@                                        @
C       @@@@     @@@@@@    @@@@@@    @@@  @    @@@@@@
C       @@@@     @  @@@    @@@  @    @@@  @     @@@@
C       @@@@     @  @@@    @@@  @    @@@  @     @@@@
C       @@@@     @  @@@    @@@@@@    @@@  @     @@@@
C      @@@@@@    @  @@@    @@@       @@@@@@     @@@@
C                          @@@
C
C   PURPOSE:  INPUTS DATA DESCRIBING THE STOVE / WALL PROTECTION SYSTEM
C             TO BE MODELED
C
      INCLUDE 'STOVE.CMN'
      PARAMETER (NVAR=8)
      CHARACTER VAR(NVAR)*6,IN*80,KEYWD*80
      INTEGER VLEN(NVAR)
      LOGICAL THEEND,HAVEX,HAVEY
      DATA (VAR(I),VLEN(I),I=1,NVAR) /'XWALL ',5,'YWALL ',5,'TSTOVE',6,
     2 'THICK ',5,'WIDTH ',5,'HEIGHT',6,'K     ',1,'EMMIS ',5/
C
C   LOOK FOR A KEYWORD OR END OF FILE
C
      THEEND=.TRUE.
      HAVEX=.FALSE.
      HAVEY=.FALSE.
      TITLE='STOVE / WALL PROTECTOR HEAT TRANSFER MODEL'
      N=0
      IVAR=0
      VNAME=' '
10    READ (5,'(A80)',END=30) IN
      THEEND=.FALSE.
      IS=INDEX(IN,': ')
      IF (IS.GT.1) THEN
        KEYWD=IN(1:IS-1)
        IF (KEYWD.NE.'END') THEN
C
C   XWALL ... X POSITION OF POINT ON THE WALL
C
          IF (KEYWD.EQ.'XWALL') THEN
            ICHR=IS+2
            XWALL=FVAL(IN,ICHR)
            HAVEX=.TRUE.
C
C   YWALL ... Y POSITION OF POINT ON THE WALL
C
          ELSE IF (KEYWD.EQ.'YWALL') THEN
            ICHR=IS+2
            YWALL=FVAL(IN,ICHR)
            HAVEY=.TRUE.
C
C   AIRSPACE ... AN AIR SPACE BETWEEN TWO SOLID PROTECTORS
C
          ELSE IF (KEYWD.EQ.'AIRSPACE') THEN
            N=N+1
            MATL(N)='AIRSPACE'
            ICHR=IS+2
            V1=FVAL(IN,ICHR)
            V2=FVAL(IN,ICHR)
            V3=FVAL(IN,ICHR)
            IF (V2.EQ.0..AND.V3.EQ.0.) THEN
              T(N)=V1
              EMMIS(N)=1.0
              HEIGHT(N)=0.
            ELSE
              L(N)=V1
              EMMIS(N)=V2
              IF (EMMIS(N).EQ.0.) EMMIS(N)=1.0
              T(N)=V3
```

```
                HEIGHT(N)=HEIGHT(N-1)
                WIDTH(N)=WIDTH(N-1)
              END IF
C
C   STOVE ... THE HOT STOVE SURFACE
C
            ELSE IF (KEYWD.EQ.'STOVE') THEN
              MATL(0)='STOVE'
              ICHR=IS+2
              EMMIS(0)=FVAL(IN,ICHR)
              IF (EMMIS(0).EQ.0.) EMMIS(N)=1.0
              HEIGHT(0)=FVAL(IN,ICHR)
              WIDTH(0)=FVAL(IN,ICHR)
              T(0)=FVAL(IN,ICHR)
C
C   FOR ... SPECIFIES A SERIES OF CALCULATIONS TO BE DONE
C
            ELSE IF (KEYWD.EQ.'FOR') THEN
              IVAR=0
              ISUB=0
              DO 20 I=1,NVAR
              J=INDEX(IN,VAR(I)(1:VLEN(I)))
              IF (J.NE.0.AND.IN(J-1:J-1).EQ.' ') IVAR=I
20            CONTINUE
              IR=0
              ICHR=IS+2
              IF (IVAR.EQ.0) THEN
                WRITE (6,1) IN
                GO TO 10
C
C   IF IT'S A VARIABLE WITH SUBSCRIPT, MAKE SURE ONE'S THERE
C
              ELSE IF (IVAR.GE.4) THEN
                IL=INDEX(IN,'(')
                IR=INDEX(IN,')')
                IF (IL.EQ.0.OR.IR.EQ.0.OR.IL.GT.IR) THEN
                  WRITE (6,2) IN
                  GO TO 10
                END IF
                ISUB=FVAL(IN,ICHR)
              END IF
              ICHR=IR+1
              VLOWER=FVAL(IN,ICHR)
              VUPPER=FVAL(IN,ICHR)
              VINCR=FVAL(IN,ICHR)
              IF ((VLOWER.NE.VUPPER.AND.VINCR.EQ.0)
     2          .OR.(VLOWER.EQ.VUPPER.AND.VINCR.NE.0)
     3          .OR.(VUPPER.GT.VLOWER.AND.VINCR.LT.0)
     4          .OR.(VUPPER.LT.VLOWER.AND.VINCR.GT.0)) THEN
                WRITE (6,4) IN
                GO TO 10
              END IF
              VNAME=VAR(IVAR)
              VNAME(VLEN(IVAR)+1:VLEN(IVAR)+1+IR-IL)=IN(IL:IR)
C
C   DEBUG ... TURN DEBUG PRINT ON OR OFF
C
            ELSE IF (KEYWD.EQ.'DEBUG') THEN
              IF (INDEX(IN,'OFF').NE.0) DEBUG=.FALSE.
              IF (INDEX(IN,'ON').NE.0) DEBUG=.TRUE.
C
C   PRINTOUT ... SPECIFY LEVEL OF PRINTOUT
C
            ELSE IF (KEYWD.EQ.'PRINTOUT') THEN
              IF (INDEX(IN,'FULL').NE.0) FULPRT=.TRUE.
              IF (INDEX(IN,'FULL').EQ.0) FULPRT=.FALSE.
C
C   TITLE ... SPECIFY A TITLE FOR THE PRINTOUT
C
            ELSE IF (KEYWD.EQ.'TITLE') THEN
```

```
            TITLE=IN(IS+2:80)
C
C   IF IT'S NOT ONE OF THE RECOGNIZED KEYWORDS, ASSUME A SOLID PROTECTOR
C
          ELSE
            N=N+1
            ICHR=IS+2
            MATL(N)=IN(1:IS-1)
            L(N)=FVAL(IN,ICHR)
            HEIGHT(N)=FVAL(IN,ICHR)
            WIDTH(N)=FVAL(IN,ICHR)
            K(N)=FVAL(IN,ICHR)
            EMMIS(N)=FVAL(IN,ICHR)
            T(N)=FVAL(IN,ICHR)
            IF (L(N).EQ.0..OR.HEIGHT(N).EQ.0..OR.WIDTH(N).EQ.0..OR.
     2      K(N).EQ.0..OR.EMMIS(N).EQ.0.) THEN
              WRITE (6,3) IN
              N=N-1
              GO TO 10
            END IF
          END IF
          GO TO 10
        END IF
      END IF
C
C   DATA HAS BEEN READ IN, CHECK CONSISTENCY OF DATA INPUT
C
30    IF (THEEND) THEN
        RETURN
      ELSE IF (N.LE.1) THEN
        WRITE (6,*) 'DATA INPUT ERROR, TOO FEW NODES SPECIFIED.'
      ELSE
        IF (DEBUG.AND.IVAR.NE.0) THEN
          IF (IVAR.LT.4) THEN
            WRITE (6,5) VAR(IVAR),VLOWER,VUPPER,VINCR
          ELSE
            WRITE (6,6) VAR(IVAR),ISUB,VLOWER,VUPPER,VINCR
          END IF
        END IF
        DO 40 I=1,N
        IF (DEBUG) CALL PSUM(I)
        IF (MATL(I).EQ.'AIRSPACE') THEN
          IF ((L(I).LE.0..AND.I.NE.N).OR.(HEIGHT(I).LE.0..AND.I.NE.N)
     2 .OR.(HEIGHT(I).NE.0..AND.I.EQ.N).OR.EMMIS(I).LE.0.) THEN
            WRITE (6,'(1X,A,I3)') 'INCORRECTLY SPECIFIED AIR SPACE.',I
            STOP 'INPUT DATA ERRORS, AIR SPACE'
          END IF
        ELSE
          IF (L(I).LE.0..OR.HEIGHT(I).LE.0..OR.WIDTH(I).LE.0..OR.
     2    K(I).LE.0..OR.EMMIS(I).LE.0.) THEN
            WRITE (6,'(1X,A,I3)') 'INCORRECTLY SPECIFIED PROTECTOR.',I
            STOP 'INPUT DATA ERRORS, SOLID PROTECTOR'
          END IF
        END IF
40      CONTINUE
        IF (XWALL.LT.0..OR.YWALL.LT.0.) THEN
          WRITE (6,*) 'INCORRECTLY SPECIFIED POINT ON WALL.'
          STOP 'DATA INPUT ERRORS, XWALL & YWALL'
        END IF
        IF (T(0).LE.T(N)) THEN
          WRITE (6,*) 'INCORRECTLY SPECIFIED ENDPOINT TEMPERATURES.'
          STOP 'DATA INPUT ERRORS, T(0) & T(N)'
        END IF
        IF (T(0).LE.0..OR.WIDTH(0).LE.0..OR.HEIGHT(0).LE.0..OR.EMMIS(0)
     2  .LE.0.) THEN
          WRITE (6,*) 'INCORRECTLY SPECIFIED STOVE PARAMETERS.'
          STOP 'DATA INPUT ERRORS, STOVE'
        END IF
      END IF
      IF (MATL(N).EQ.'AIRSPACE') HEIGHT(N)=HEIGHT(N-1)
```

```
       ZSTOVE=L(1)
       HSTOVE=HEIGHT(0)
       WSTOVE=WIDTH(0)
C
C   IF NOT POSITION HAS BEEN SPECIFIED, USE MIDPOINT OF STOVE
C
       IF (.NOT. HAVEX) THEN
         XWALL=WSTOVE/2.
       END IF
       IF (.NOT. HAVEY) THEN
         YWALL=HSTOVE/2.
       END IF
C
C   IF NO INCREMENT HAS BEEN SPECIFIED, MAKE ONE UP
C
       IF (IVAR.EQ.0) THEN
         IVAR=1
         VLOWER=XWALL
         VUPPER=XWALL
         VINCR=1.0
       END IF
C
C   PRINT OUT A DESCRIPTION OF THE STOVE / WALL SYSTEM AS SPECIFIED
C
       WRITE (6,11) TITLE,N+1,XWALL,YWALL
       IF (IVAR.GT.0.AND.IVAR.LT.4) THEN
         WRITE (6,5) VAR(IVAR),VLOWER,VUPPER,VINCR
       ELSE IF (IVAR.GT.4) THEN
         WRITE (6,6) VAR(IVAR),ISUB,VLOWER,VUPPER,VINCR
       END IF
       WRITE (6,12)
       DO 50 I=0,N
       IF (I.EQ.0.OR.I.EQ.N) THEN
         IF (MATL(I).EQ.'STOVE') THEN
           WRITE (6,13) I,MATL(I),HEIGHT(I),WIDTH(I),EMMIS(I),T(I)-273.15
         ELSE IF (MATL(I).EQ.'AIRSPACE') THEN
           WRITE (6,14) I,MATL(I),L(I),EMMIS(I),T(I)-273.15
         ELSE
           WRITE (6,15) I,MATL(I),HEIGHT(I),WIDTH(I),L(I),EMMIS(I),K(I),
      2    T(I)-273.15
         END IF
       ELSE
         IF (MATL(I).EQ.'STOVE') THEN
           WRITE (6,13) I,MATL(I),HEIGHT(I),WIDTH(I),EMMIS(I)
         ELSE IF (MATL(I).EQ.'AIRSPACE') THEN
           WRITE (6,14) I,MATL(I),L(I),EMMIS(I)
         ELSE
           WRITE (6,15) I,MATL(I),HEIGHT(I),WIDTH(I),L(I),EMMIS(I),K(I)
         END IF
       END IF
50     CONTINUE
       RETURN
C
1      FORMAT ('0SYNTAX ERROR ON ''FOR'' STATEMENT, ILLEGAL OR NO VARIABL
      2E SPECIFIED.',/,' ',A79,//)
2      FORMAT ('0SYNTAX ERROR ON ''FOR'' STATEMENT, SUBSCRIPT REQUIRED FO
      2R VARIABLE SPECIFIED.',/,' ',A79,//)
3      FORMAT ('0SYNTAX ERROR ON STATEMENT, UNRECOGNIZED KEYWORD.',/,
      2 ' ',A79,//)
4      FORMAT ('0SYNTAX ERROR ON ''FOR'' STATEMENT, RANGE AND INCREMENT I
      2NCONSISTENT.',/,' ',A79,//)
5      FORMAT ('0SERIES OF CALCULATIONS FOR VARIABLE ',A,': ',3F10.3)
6      FORMAT ('0SERIES OF CALCULATIONS FOR VARIABLE ',A,'(',I2,
      2 '): ',3F10.3)
11     FORMAT ('1',A,//,
      2 ' NUMBER OF NODES IN CALCULATION: ',I2,/,' POINT ON WALL:  (X):',
      3 F10.3,T41,'(Y):',F10.3)
12     FORMAT ('0I   MATERIAL                 HEIGHT   WIDTH   THICK   EMISS
      2      K    TEMPERATURE',/,
      3         '                               (m)       (m)      (m)
```

```
     4   (W/m K)     (°C)',/,' ',78('-'),/)
13    FORMAT (1X,I2,2X,A,T26,1X,F6.2,T35,F6.2,T51,F6.2,T70,F7.2)
14    FORMAT (1X,I2,2X,A,T43,F6.2,T51,F6.2,T70,F7.2)
15    FORMAT (1X,I2,2X,A,T26,1X,4(F6.2,2X),F8.3,2X,F8.2)
      END
```

```
      DOUBLE PRECISION FUNCTION FVAL (IN,ICHR)
C
C     @@@@@@@@                        @@@
C     @@@@                            @@@
C     @@@@       @@@  @    @@@@@@     @@@
C     @@@@@@@@   @@@  @         @     @@@
C     @@@@       @@@  @    @@@@@@     @@@
C     @@@@        @@@@     @  @@@     @@@
C     @@@@         @@      @@@@@@     @@@
C
C   ARGUMENTS:  IN:     STRING CONTAINING (MAYBE) NUMBER
C               ICHR:   (INPUT) BEGINNING CHARACTER POSITION
C                       (OUTPUT) NEXT CHARACTER POSITION
C
C   PURPOSE:  DECODE NEXT NUMBER IN STRING AS A DOUBLE PRECISION VALUE
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER IN*(*),FORMAT*10
      IL=LEN(IN)
      IFIRST=ICHR
      DO 20 I=IFIRST,IL
      IF ((IN(I:I).GE.'0'.AND.IN(I:I).LE.'9').OR.IN(I:I).EQ.'.'
     2 .OR.IN(I:I).EQ.'+'.OR.IN(I:I).EQ.'-' ) THEN
C
C   THERE IS A NUMBER ON THE CARD, FIND OUT WHAT IT IS
C
        DO 10 J=I,IL
C
C   IF WE FIND THE END OF THE NUMBER, READ IT FROM THE LINE
C
        IF ((IN(J:J).LT.'0'.OR.IN(J:J).GT.'9').AND.IN(J:J).NE.'.'
     2 .AND.IN(J:J).NE.'+'.AND.IN(J:J).NE.'-' ) THEN
          WRITE (FORMAT,30) J-I
          READ (IN(I:J-1),FORMAT) VAL
          FVAL=VAL
          ICHR=J
          RETURN
        END IF
10      CONTINUE
C
C   IF WE GET TO THE END OF THE LINE WITHOUT FINDING END OF NUMBER,
C   JUST READ THE NUMBER
C
        WRITE (FORMAT,30) IL-I+1
        READ (IN(I:IL),FORMAT) VAL
        FVAL=VAL
        ICHR=J
        RETURN
      END IF
20    CONTINUE
C
C   IF NO NUMBER IS ON THE CARD, JUST RETURN A 0.
C
      FVAL=0.
      RETURN
C
30    FORMAT ('(F',I2.2,'.0)')
      END
```

```
      SUBROUTINE HEATS
C
C     @@@@   @
C     @@@@   @                           @
C     @@@@   @   @@@@@@    @@@@@@    @@@@@@    @@@@@@
C     @@@@@@@@   @  @@@           @     @@@@     @@@
C     @@@@   @   @@@@@@    @@@@@@     @@@@     @@@@@@
C     @@@@   @   @         @  @@@     @@@@        @@@
C     @@@@   @   @@@@@@    @@@@@@     @@@@     @@@@@@
C
C   ARGUMENTS:  NONE
C
C   PURPOSE:  CALCULATES TOTAL HEAT AND TOTAL RESISTANCE THROUGH WALL
C             PROTECTORS
C
      INCLUDE 'STOVE.CMN'
C
C   JUST SUM UP RESISTANCES TO MAKE UP TOTAL RESISTANCE
C
      RTOTAL=0.
      DO 10 I=1,N
      CALL HEAT(I)
10    RTOTAL=RTOTAL+R(I)
C
C   TOTAL HEAT IS JUST DELTA T / TOTAL RESISTANCE
C
      QTOTAL=(T(0)-T(N))/RTOTAL
      RETURN
      END
```

```
      SUBROUTINE HEAT(I)
C
C     @@@@   @
C     @@@@   @                          @
C     @@@@   @   @@@@@@    @@@@@@    @@@@@@
C     @@@@@@@@   @  @@@        @     @@@@
C     @@@@   @   @@@@@@    @@@@@@     @@@@
C     @@@@   @   @         @  @@@     @@@@
C     @@@@   @   @@@@@@    @@@@@@     @@@@
C
C   ARGUMENTS:    I:  ELEMENT NUMBER
C
C   PURPOSE:  CALCULATES HEAT THROUGH ELEMENT NUMBER I
C
      INCLUDE 'STOVE.CMN'
      DATA SIGMA / 5.67D-8 /
      IF (MATL(I).NE.'AIRSPACE') THEN
C
C   MATERIAL IS A SOLID, CONDUCTION ONLY
C
        R(I)=L(I)/K(I)
      ELSE IF (MATL(I).EQ.'AIRSPACE'.AND.I.EQ.1) THEN
C
C   MATERIAL IS AND AIRSPACE NEXT TO STOVE, CALCULATE FOR POINT ON WALL
C
        XNOTS=XWALL-(XSTOVE-WSTOVE*.5)
        YNOTS=YWALL-YSTOVE
        ZNOTS=ZSTOVE
        CF(I)=CFIGS(XNOTS,YNOTS,ZNOTS)-CFIGS(XNOTS-WSTOVE,YNOTS,ZNOTS)
     2        +CFIGS(XNOTS-WSTOVE,YNOTS-HSTOVE,ZNOTS)
     3        -CFIGS(XNOTS,YNOTS-HSTOVE,ZNOTS)
        RAD(I)=1./(CF(I)*SIGMA*EMMIS(I)*(T(I-1)**2+T(I)**2)
     2            *(T(I-1)+T(I)))
        RMTEMP=293.15
        RLOSS=(T(I-1)-T(I))/((T(I)**4-RMTEMP**4)*SIGMA*EMMIS(I)
     2        *(1-CF(I)))
        R(I)=1./(1./RAD(I)-1./RLOSS)
      ELSE IF (MATL(I).EQ.'AIRSPACE'.AND.I.NE.N) THEN
C
C   MATERIAL IS AN AIRSPACE, BUT NOT NEXT TO STOVE
C
        CF(I)=CFIGP(HEIGHT(I),WIDTH(I),L(I))
        H(I)=HCONV(T(I-1),T(I),HEIGHT(I))
        CONV(I)=1./H(I)
        RAD(I)=1./(CF(I)*SIGMA*EMMIS(I)*(T(I-1)**2+T(I)**2)
     2            *(T(I-1)+T(I)))
        R(I)=1./(1./CONV(I)+1./RAD(I))
      ELSE
C
C   MATERIAL IS AN AIRSPACE AND LAST ELEMENT ... THE GREAT OUTDOORS
C
        CF(I)=1.
        H(I)=HCONV(T(I-1),T(I),HEIGHT(I))
        CONV(I)=1./H(I)
        RAD(I)=1./(CF(I)*SIGMA*EMMIS(I)*(T(I-1)**2+T(I)**2)
     2            *(T(I-1)+T(I)))
        R(I)=1./(1./CONV(I)+1./RAD(I))
      END IF
      Q(I)=(T(I-1)-T(I))/R(I)
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION CFIGS (A,B,C)
C
C     @@@@@@@@    @@@@      @@@@
C     @   @@@@    @                       @
C     @   @@@@   @@@@@@     @@@@     @@@@@@    @@@@@@
C     @           @@@@      @@@@     @@@@@@    @@@
C     @   @@@@    @@@@      @@@@      @        @@@@@@
C     @   @@@@    @@@@      @@@@    @@@@@@@@      @@@
C     @@@@@@@@    @@@@      @@@@    @   @@@@   @@@@@@
C                                   @@@@@@@@
C
C   ARGUMENTS:    A:  WIDTH OF RECTANGLE
C                 B:  HEIGHT OF RECTANGLE
C                 C:  DISTANCE TO POINT OF CALCULATION
C
C   PURPOSE:  CALCULATES RADIATION CONFIGURATION FACTOR FOR A PLANE
C             ELEMENT TO A PLANE PARALLEL RECTANGLE.
C
C   SOURCE:  THERMAL RADIATION HEAT TRANSFER, SEIGEL & HOWELL.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      PI=3.14159
      X=A/C
      Y=B/C
      CFIGS=1./(2*PI)*(X/SQRT(1+X**2)*ATAN(Y/SQRT(1+X**2))
     2 + Y/SQRT(1+Y**2)*ATAN(X/SQRT(1+Y**2)))
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION CFIGP (A,B,C)
C
C      @@@@@@@@    @@@@      @@@@
C      @   @@@@    @                       @
C      @   @@@@   @@@@@@     @@@@     @@@@@@    @@@@@@
C      @           @@@@      @@@@     @@@@@@    @@@  @
C      @   @@@@    @@@@      @@@@       @       @@@  @
C      @   @@@@    @@@@      @@@@    @@@@@@@@   @@@@@@
C      @@@@@@@@    @@@@      @@@@    @   @@@@   @@@
C                                    @@@@@@@@   @@@
C
C   ARGUMENTS:    A:  WIDTH OF RECTANGLE
C                 B:  HEIGHT OF RECTANGLE
C                 C:  DISTANCE BETWEEN RECTANGLES
C
C   PURPOSE:  CALCULATES RADIATION CONFIGURATION FACTOR FOR TWO
C             IDENTICAL, PARALLEL, DIRECTLY OPPOSED RECTANGLES.
C
C   SOURCE:  THERMAL RADIATION HEAT TRANSFER, SEIGEL & HOWELL.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      PI=3.14159
      X=A/C
      Y=B/C
      CFIGP=2./(PI*X*Y)*(LOG(((1+X*X)*(1+Y*Y))/(1+X*X+Y*Y))**0.5 +
     2 X*SQRT(1+Y*Y)*ATAN(X/SQRT(1+Y*Y)) +
     3 Y*SQRT(1+X*X)*ATAN(Y/SQRT(1+X*X)) -
     4 X*ATAN(X) - Y*ATAN(Y))
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION HCONV(T1,T2,L)
C
C     @@@@   @
C     @@@@   @
C     @@@@   @   @@@@@@    @@@@@@    @@@@@@    @@@  @
C     @@@@@@@@   @  @@@    @@@  @    @  @@@    @@@  @
C     @@@@   @   @         @@@  @    @  @@@    @@@  @
C     @@@@   @   @  @@@    @@@  @    @  @@@     @@@@
C     @@@@   @   @@@@@@    @@@@@@    @  @@@      @@
C
C   ARGUMENTS:     T1:  TEMPERATURE OF HOTTER SURFACE
C                  T2:  TEMPERATURE OF COOLER SURFACE
C                  L:   HEIGHT OF SURFACES
C
C   PURPOSE:  CALCULATES FREE CONVECTION HEAT TRANSFER COEFFICIENT FOR
C             A VERTICAL SURFACE.
C
C   SOURCE:  FUNDAMENTALS OF HEAT TRANSFER, INCORPERA & DEWITT.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DOUBLE PRECISION K,NU,L,NUSELT
      DIMENSION C(3,5)
      DATA ((C(I,J),J=1,5),I=1,3) /
     2 -.381021E-2,  .132063E-3, -.117332E-6,  .687499E-10, -.127680E-13
     3,-.167333E-4,  .143076E-6, -.249135E-10, .781850E-13, -.127693E-16
     4,-.501195E-5,  .468550E-7,  .881329E-10,-.117315E-13,  .307192E-17
     5 /
      TF=(T1+T2)/2
      DELTAT=(T1-T2)
      K=C(1,1)+C(1,2)*TF+C(1,3)*TF*TF+C(1,4)*TF**3+C(1,5)*TF**4
      ALPHA=C(2,1)+C(2,2)*TF+C(2,3)*TF*TF+C(2,4)*TF**3+C(2,5)*TF**4
      NU=C(3,1)+C(3,2)*TF+C(3,3)*TF*TF+C(3,4)*TF**3+C(3,5)*TF**4
      PR=NU/ALPHA
      RA=9.8*(1./TF)*ABS(DELTAT)*L**3/(NU*ALPHA)
      NUSELT=(0.825+0.387*RA**(1./6.)/(1.+(0.492/PR)**(9./16.))
     2 **(8./27.))**2
      HCONV=NUSELT*K/L
      RETURN
      END
```

```
      CHARACTER*5 FUNCTION CMET(VALUE,EPS)
C
C     @@@@@@@@
C     @   @@@@                           @
C     @   @@@@  @@@@@@@    @@@@@@    @@@@@@
C     @         @ @ @@@    @  @@@     @@@@
C     @   @@@@  @ @ @@@    @@@@@@     @@@@
C     @   @@@@  @ @ @@@    @          @@@@
C     @@@@@@@@  @ @ @@@    @@@@@@     @@@@
C
C   ARGUMENTS:  VALUE:  NUMBER TO BE EVALUATED
C               EPS:    ACCEPTANCE CRITERION FOR VALUE
C
C   PURPOSE:  FUNCTIONS RETURNS A CHARACTER INDICATION OF WHETHER THE
C             VALUE IS WITHIN LIMITS.  USED FOR DEBUG PRINTOUT
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      IF (ABS(VALUE).LE.EPS) THEN
        CMET='(IN) '
      ELSE
        CMET='(OUT)'
      END IF
      RETURN
      END
```

```
      SUBROUTINE PSUM(I)
C
C     @@@@@@@@
C     @@@@   @
C     @@@@   @   @@@@@@    @@@  @   @@@@@@@
C     @@@@@@@@   @@@       @@@  @   @ @ @@@
C     @@@@       @@@@@@    @@@  @   @ @ @@@
C     @@@@          @@@    @@@  @   @ @ @@@
C     @@@@       @@@@@@    @@@@@@   @ @ @@@
C
C   ARGUMENTS:  I:  SURFACE NUMBER FOR SUMMARY PRINTOUT
C
C   PURPOSE:  PRINTS OUT ALL THE VARIABLES IN THE COMMON BLOCK.  USED
C             FOR DEBUG PRINTOUT.
C
      INCLUDE 'STOVE.CMN'
      WRITE (6,10) I,MATL(I),T(I),R(I),L(I),K(I),H(I),CF(I),EMMIS(I),
     2 Q(I),CONV(I),RAD(I),HEIGHT(I),WIDTH(I),XSTOVE,YSTOVE,ZSTOVE,
     3 WSTOVE,HSTOVE,XWALL,YWALL,RTOTAL,QTOTAL,N
      RETURN
C
10    FORMAT ('0CURRENT VALUES FOR SPACE ',I2,'    MATERIAL IS ',A,/,
     2 ' TEMPERATURE:',F10.3,T41,'RESISTANCE:',F10.3,/,
     3 ' THICKNESS:',F10.3,T41,'THERMAL CONDUCTIVITY:',E12.5,/,
     4 ' H:',F10.3,T41,'CONFIGURATION FACTOR:',F10.3,/,
     5 ' EMISSIVITY:',F10.3,T41,'INDIVIDUAL HEAT:',F10.3,/,
     6 ' CONV. RESISTANCE:',F10.3,T41,'RAD. RESISTANCE:',F10.3,/,
     7 ' HEIGHT:',F10.3,T41,'WIDTH:',F10.3,/,
     8 ' XSTOVE:',F10.3,T31,'YSTOVE:',F10.3,T61,'ZSTOVE:',F10.3,/,
     9 ' WSTOVE:',F10.3,T31,'HSTOVE:',F10.3,/,
     * ' XWALL: ',F10.3,T31,'YWALL: ',F10.3,/,
     1 ' RTOTAL:',F10.3,T31,'QTOTAL:',F10.3,T61,'N:     ',I10)
      END
```

```
      CHARACTER*60 FUNCTION PMATL(MATL1,MATL2)
C
C      @@@@@@@@                                  @@@
C      @@@@   @                           @      @@@
C      @@@@   @  @@@@@@@    @@@@@@    @@@@@@     @@@
C      @@@@@@@@  @ @ @@@         @     @@@@      @@@
C      @@@@      @ @ @@@    @@@@@@     @@@@      @@@
C      @@@@      @ @ @@@    @  @@@     @@@@      @@@
C      @@@@      @ @ @@@    @@@@@@     @@@@      @@@
C
C
C   ARGUMENTS:  MATL1:  DESCRIPTION OF MATERIAL CLOSER TO APPLIANCE
C               MATL2:  DESCRIPTION OF MATERIAL FURTHER AWAY FROM APPLIANCE
C
C   PURPOSE:  CREATES A CONCATENATED DESCRIPTION OF TWO MATERIALS FOR
C             PRINTOUT
C
      CHARACTER*40 MATL1,MATL2
      PMATL=MATL1
      DO 10 I=40,1,-1
      IF (MATL1(I:I).NE.' ') THEN
        PMATL(I+1:I+3)=' / '
        GO TO 20
      END IF
10    CONTINUE
      PMATL=' '
20    DO 30 I=40,1,-1
      IF (PMATL(I:I).NE.' ') THEN
        PMATL(I+2:60)=MATL2
        RETURN
      END IF
30    CONTINUE
      PMATL=MATL2
      RETURN
      END
```

```
C     COMMON BLOCK FOR PROGRAM STOVE
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
      PARAMETER (MAXPRO=20)
C
      DOUBLE PRECISION L,K
      CHARACTER MATL*40,VNAME*10,TITLE*80
      LOGICAL DEBUG,FULPRT
      COMMON /NSTOVE/ T(0:MAXPRO),R(0:MAXPRO),L(0:MAXPRO),K(0:MAXPRO),
     2 H(0:MAXPRO),CF(0:MAXPRO),EMMIS(0:MAXPRO),Q(0:MAXPRO),
     3 CONV(0:MAXPRO),RAD(0:MAXPRO),HEIGHT(0:MAXPRO),WIDTH(0:MAXPRO),
     4 XSTOVE,YSTOVE,ZSTOVE,WSTOVE,HSTOVE,XWALL,YWALL,RTOTAL,QTOTAL,N,
     5 IVAR,ISUB,VLOWER,VUPPER,VINCR,DEBUG,FULPRT
      COMMON /CSTOVE/ MATL(0:MAXPRO),VNAME,TITLE
C
```

Appendix B: Data Input for STOVE

The data input for stove takes the form of six different key words with arguments to specify values which depend upon the key word. In most cases, the order of the key words is unimportant, except as noted below. A description of each of the input key words and values which go on the same line are presented below:

STOVE	<height> <width> <emissivity> <temperature>
AIRSPACE	<thickness> <emissivity>
FOR	<variable> **=** <lower> <upper> <increment>
XWALL	<x position>
YWALL	<y position>
PROTECTOR	<thickness> <height> <width> <k> <emissivity> <temperature>

BOLDFACE type are required key words. Words in <brackets> specify numeric inputs as follows:

<emissivity> specifies the emissivity of the cooler surface of the material. If specified for an airspace, it is the emissivity of the surface adjacent to the airspace at the farther distance from the stove.

<height> specifies the height of the stove or protector in meters.

<increment> specifies the amount to increment the variable <variable> in the **FOR** statement for each calculation to be performed. The first calculation is done with <variable> equal to the value <lower>; the second calculation is done with <variable> equal to the value <lower> + <increment> and so forth until the value of <variable> is greater than or equal to the value of

<upper>. The units for the number are the same as those for the variable <variable>.

<k> specifies the thermal conductivity of the solid protector in W/m·K.

<lower> specifies the beginning value of the variable <variable> in the **FOR** statement for each calculation to be performed. The first calculation is done with <variable> equal to the value <lower>; the second calculation is done with <variable> equal to the value <lower> + <increment> and so forth until the value of <variable> is greater than or equal to the value of <upper>. The units for the number are the same as those for the variable <variable>.

<temperature> specifies the temperature of the stove surface, protector, or airspace in K. Temperatures are only specified for the stove surface (surface number 0) and for the outermost surface or airspace (surface number N).

<thickness> specifies the thickness of the material (for a protector) or the distance between surfaces (for an airspace).

<variable> specifies the variable to be incremented in each calculation to be done. The first calculation is done with <variable> equal to the value <lower>; the second calculation is done

with <variable> equal to the value <lower> + <increment> and so forth until the value of <variable> is greater than or equal to the value of <upper>. Legal variables which may be used are: T(0) -- the stove temperature, width(i), k(i), xwall, ywall, emissivity(i), height(i), l(i).

<width> specifies the width of the stove or protector in meters.

<x position> specifies the x position of the point on the wall at which the calculation is to done in meters.

<y position> specifies the y position of the point on the wall at which the calculation is to done in meters.

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STOVE: A Predictive Model for Heat Transfer from Solid-Fuel Appliances

5. AUTHOR(S)

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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)

A computer implementation of a model to predict temperatures on wall and wall protector surfaces exposed to the heating of an appliance such as a solid fuel heating appliance is described. A steady state heat transfer model with flexibility to describe a generalized method of protection for a combustible wall surface is presented along with a computer program implementing the model. Good agreement was found comparing the model predictions with data previously collected during full scale experiments conducted to evaluate the effectiveness of generic methods of wall protection in reducing temperatures on combustible wall surfaces. Extensive references of research related to solid fuel heating safety are included.

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

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

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