

NIST Technical Note 1889v2

**CFAST – Consolidated Model of Fire
Growth and Smoke Transport
(Version 7)
Volume 2: User's Guide**

Richard D. Peacock
Paul A. Reneke
Glenn P. Forney

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NIST
**National Institute of
Standards and Technology**
U.S. Department of Commerce

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U.S. Department of Commerce
Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie May, Acting Under Secretary of Commerce for Standards and Technology and Acting Director

CFAST Developers

The Consolidated Model of Fire and Smoke Transport (CFAST) and Smokeview are the products of a collaborative effort led by the National Institute of Standards and Technology (NIST). Its developers and contributors are listed below.

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About the Developers

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Glenn Forney is a computer scientist in the Fire Research Division of NIST. He received a bachelor of science degree in mathematics from Salisbury State College and a master of science and a doctorate in mathematics from Clemson University. He joined NIST in 1986 (then the National Bureau of Standards) and has since worked on developing tools that provide a better understanding of fire phenomena, most notably Smokeview, an advanced scientific software tool for visualizing Fire Dynamics Simulation data.

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Kevin McGrattan is a mathematician in the Fire Research Division of NIST. He received a bachelor of science degree from the School of Engineering and Applied Science of Columbia University in 1987 and a doctorate at the Courant Institute of New York University in 1991. He joined the NIST staff in 1992 and has since worked on the development and validation of fire models, most notably the Fire Dynamics Simulator.

Walter Jones was a physicist at NIST (now retired). He received a bachelor of arts degree in physics from Oberlin College and a doctorate in physics from the University of Maryland. He was the original developer of the CFAST model. In addition to the development of fire models, he has worked on smart fire alarms and smoke control for naval vessels.

Disclaimer

The U. S. Department of Commerce makes no warranty, expressed or implied, to users of CFAST and associated computer programs, and accepts no responsibility for its use. Users of CFAST assume sole responsibility under Federal law for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analyses performed using these tools. CFAST is intended for use only by those competent in the field of fire safety and is intended only to supplement the informed judgment of a qualified user. The software package is a computer model which may or may not have predictive value when applied to a specific set of factual circumstances. Lack of accurate predictions by the model could lead to erroneous conclusions with regard to fire safety. All results should be evaluated by an informed user.

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Intent and Use

The algorithms, procedures, and computer programs described in this report constitute a methodology for predicting some of the consequences resulting from a prescribed fire. They have been compiled from the best knowledge and understanding currently available, but have important limitations that must be understood and considered by the user. The program is intended for use by persons competent in the field of fire safety and with some familiarity with personal computers. It is intended as an aid in the fire safety decision-making process.

Abstract

CFAST is a two-zone fire model capable of predicting the environment in a multi-compartment structure subjected to a fire. It calculates the time-evolving distribution of smoke and gaseous combustion products as well as the temperature throughout a building during a user-prescribed fire. This report describes the use of the model, including installing and running the software, the computer platforms upon which it is supported and examples to verify correct installation.

Acknowledgments

Continuing support for CFAST is via internal funding at NIST. In addition, support is provided by other agencies of the U.S. Federal Government, most notably the Nuclear Regulatory Commission Office of Nuclear Regulatory Research and the U.S. Department of Energy. The U.S. NRC Office of Nuclear Regulatory Research has funded key validation experiments, the preparation of the CFAST manuals, and the continuing development of sub-models that are of importance in the area of nuclear power plant safety. Special thanks to Mark Salley and David Stroup for their efforts and support.

Support to refine the software development and quality assurance process for CFAST has been provided by the U.S. Department of Energy (DOE). The assistance of Subir Sen and Debra Sparkman in understanding DOE software quality assurance programs and the application of the process to CFAST is gratefully acknowledged. Thanks are also due to Allan Coutts, Washington Safety Management Solutions for his insight into the application of fire models to nuclear safety applications and detailed review of the CFAST document updates for DOE.

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Chapter 1

Getting Started

The Consolidated Model of Fire and Smoke Transport (CFAST) is documented by four publications, this user's guide, a technical reference guide [1], a verification and validation guide [2], and a configuration management guide [3]. The technical reference guide describes the underlying physical principles, provides a comparison with other models, and includes an evaluation of the model following the guidelines of ASTM E1355 [4]. The model verification and validation guide documents verification and validation efforts for the model. The configuration management guide documents the processes used during the development and validation of the model. This user's guide describes how to use the model.

1.1 Installation

CFAST was designed primarily for a personal computer running Microsoft Windows. However, the source code is written in Fortran and can be run as a stand alone command line application that reads input data from a text file. Details of how one runs CFAST without the Windows-based graphical user interface are found in Appendix A. All of the files associated with CFAST can be obtained at:

<http://cfast.nist.gov>

The CFAST distribution consists of a self-extracting set-up program for Windows-based personal computers. After downloading the set-up program, double-clicking on the file's icon walks you through a series of steps for installation of the program. The most important part of the installation is the creation of a folder (C:\Program Files\CFAST by default) in which the CFAST executable files and supplemental data files are installed. Sample input files are found in the `Examples` folder.

CFAST input files are best created and run using a Windows-based input editor called CEdit. Sample input files are provided with the program for new users who are encouraged to first run the sample calculations before attempting to create an input file. To run the model, browse to the location of the CFAST sample input file (default location is in a folder called `Examples` in the installation folder, copy the file named `Users_Guide_Example.in` to a location of your choice and then double click on the copied file. This should open the file in the CFAST input editor, CEdit, as shown in Fig. 1.1. The simple test case can be run from the program menu by clicking

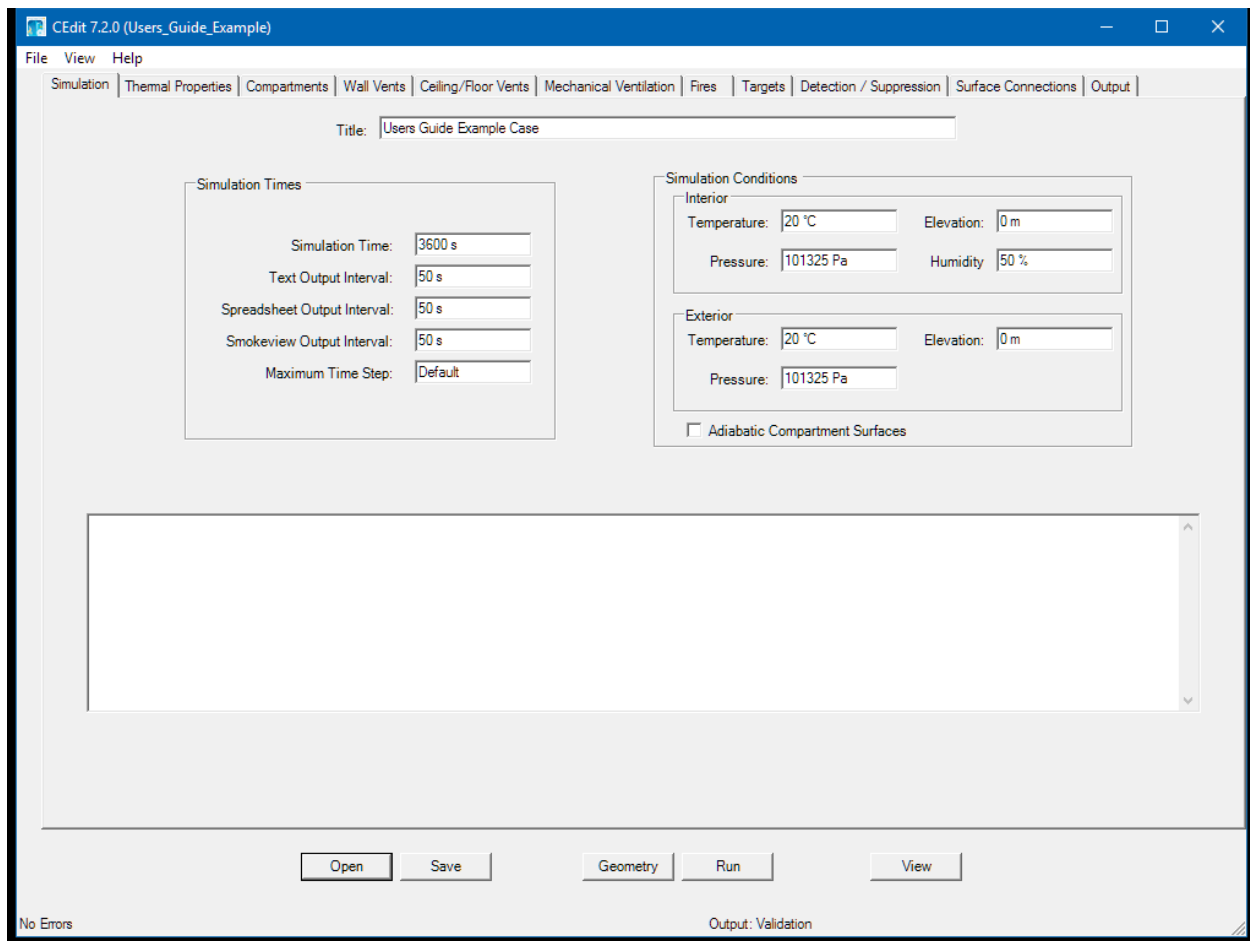


Figure 1.1: The Primary CFAST Input Page.

on the “Run” icon. The case should finish in a few seconds. To verify that the installation has been done correctly, the output of the model should appear as shown in Fig. 1.2.

1.2 Basic Features

The input parameters are organized via tabs near the top of the CEdit screen, as shown in Fig. 1.1.

Simulation Environment includes simulation time, specification of model outputs, and ambient conditions. Also included on the page are a constantly updated list of errors, warnings, and messages about the input file specification or model simulation.

Thermal Properties defines the thermal conductivity, specific heat, density, thickness and emissivity values for all materials and fuel sources to be used in a simulation.

Compartment defines the size, construction characteristics, and position of the compartments in a simulation.

Wall Vents define doors and windows.

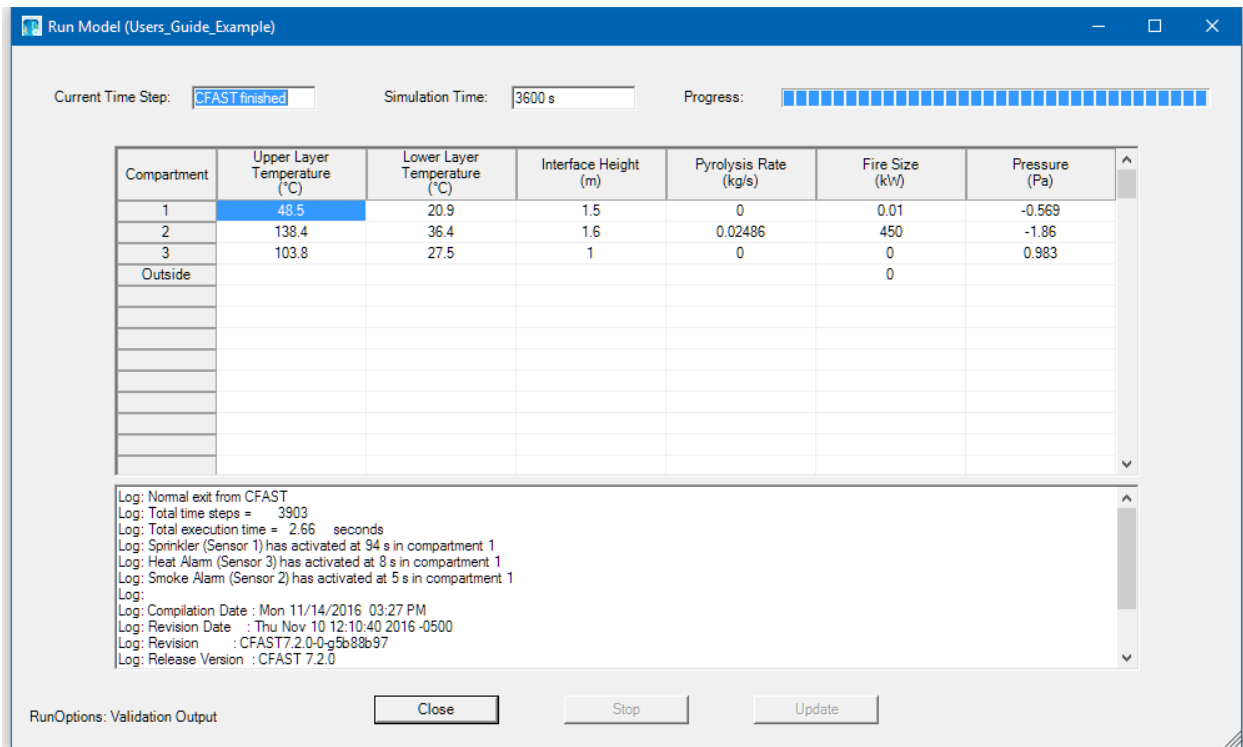


Figure 1.2: The Standard CFAST Output Screen.

Ceiling/Floor Vents define holes in the ceiling/floor.

Mechanical Ventilation defines forced air ventilation.

Fires include user specification of the initial fire source and any additional burning objects in one or more of the compartments of the simulation.

Targets provide the ability to calculate the temperature and net heat flux to objects placed and oriented arbitrarily in the structure.

Detection / Suppression defines any heat alarms and sprinklers in the compartments of the simulation.

Surface Connections allows for more detailed description of the connections between compartments in the simulation to better simulate the transfer of heat from compartment to compartment in the simulation.

Visualizations allows specification of one or more 2-D and 3-D visualizations to be added to the simulation for viewing with Smokeview. Note that these can require significant additional computational time than a basic CFAST simulation without visualizations.

1.3 The View Menu

The View menu allows you to view or print the input data file, output file (if the simulation has been run and a text output file generated) and the log file of the simulation. If one of the items does not exist on the user's hard disk, the selection is grayed out.

Select Engineering Units allows you to select the units for input and output. By default, most outputs are in S.I. units, with temperature in Celsius.

1.4 The Help Menu

The Help menu accesses this user's guide, the CFAST web site, or an about dialog box that displays the user license and version of the program.

Chapter 2

Simulation Environment

The Environment page defines the initial conditions and simulation time for the CFAST input file.

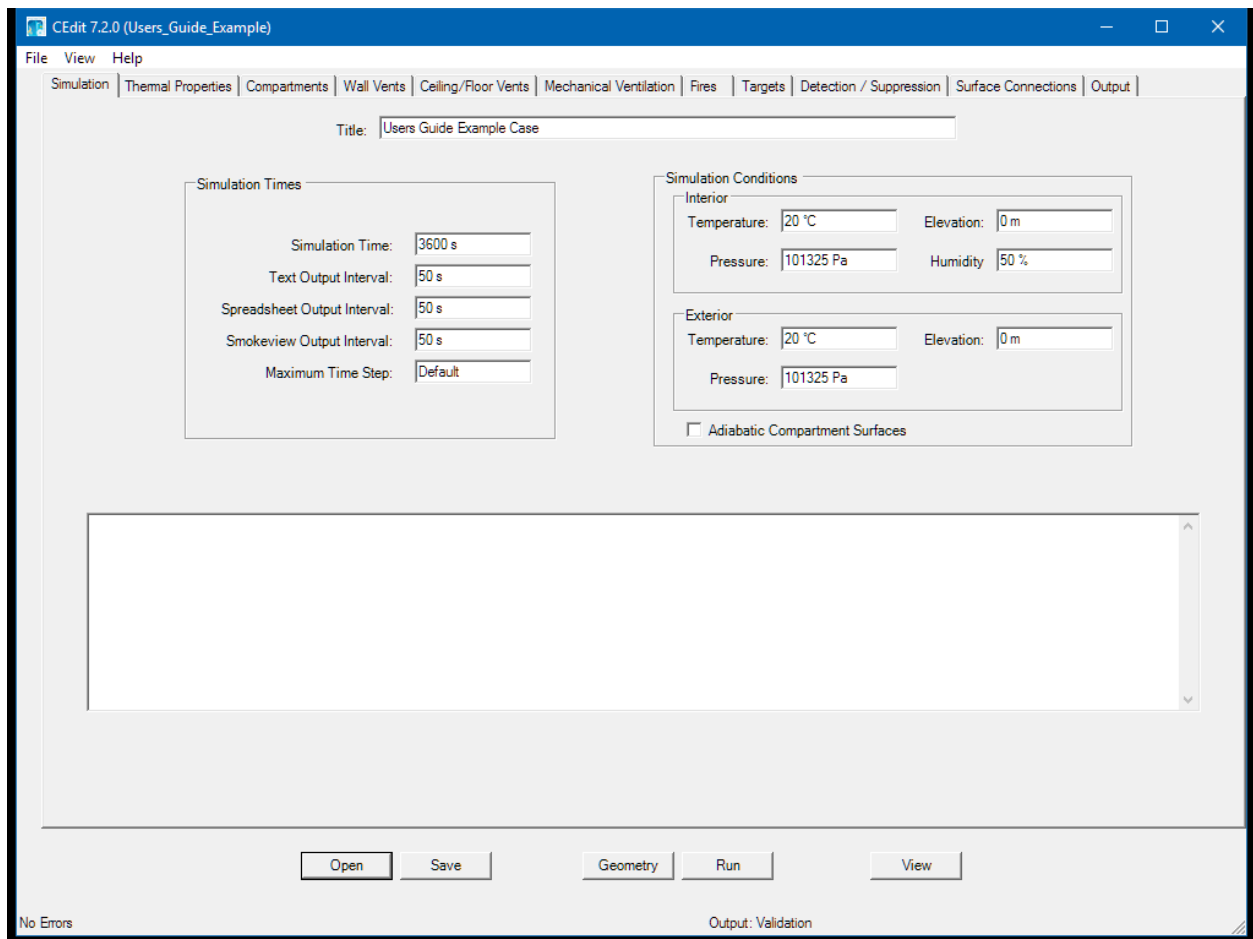


Figure 2.1: The CFAST Simulation Environment Tab.

2.1 Title

The first thing to do when setting up an input file is to give the simulation a title. The title is optional and may consist of letters, numbers, and/or symbols and may be up to 50 characters. All output files will be tagged with this character string.

2.2 Simulation Times

Simulation Time (default units: s, default value, 900 s): The length of time over which the simulation takes place. The maximum value for this input is 86400 s (1 day).

Text Output Interval (default units: s, default value, 50 s): The time interval between each printing of the output data. If equal to zero, no output values will appear.

Spreadsheet Output Interval (default units: s, default value, 10 s): CFAST can output the results of the simulation in a comma-delimited spreadsheet file. This parameter defines the time interval between these outputs. A value greater than zero must be used if the spreadsheet file is desired.

Smokeyview Output Interval (default units: s, default value: 10 s): CFAST can output a subset of the results in a format compatible with the visualization program Smokeyview. This input defines the time interval between outputs of the model results in a Smokeyview-compatible format. A value greater than zero must be used if the Smokeyview output is desired.

Maximum Time Step (default units: s, default value: 2 s): CFAST will automatically adjust the time interval for the solution of the differential equation set up or down so that the simulation is as efficient as possible within the pre-defined error tolerances. This parameter places a maximum value for the equation solver and can normally be left at the default value. In cases (which are hopefully rare) where the model fails to converge on a solution, this value can be reduced which often will allow the simulation to successfully complete.

2.3 Simulation Conditions

Ambient conditions define the environment at which the scenario begins. Initial pressures in a structure are calculated simply as a lapse rate (related to the height above sea level) based on the NOAA/NASA tables [5]. It is convenient to choose the base of a structure to be at zero height and then reference the height of the structure with respect to that height. The temperature and pressure must then be measured at that position. Another possible choice would be the pressure and temperature at sea level, with the structure elevations then given with respect to mean sea level. This is also acceptable, but somewhat more tedious in specifying the construction of a structure. Either of these choices works though, so long as they are consistent. Usually, the station elevation is set to zero and the pressure to ambient. The effect of changing these values is minor. Note that the equations implemented in the model are not designed to handle negative elevations and altitudes.

Temperature (default units: °C, default value: 20 °C): Initial ambient temperature inside or outside the structure at the station elevation.

Pressure (default units: Pa, default value: 101325 Pa): Initial values for ambient atmospheric pressure inside and outside the structure at the station elevation. The default value is standard atmospheric pressure at sea level.

Elevation (default units: m, default value: 0 m): The height where the ambient pressure and temperature are specified. This is the reference height for calculating the density of the atmosphere as well as the temperature and pressure inside and outside of the structure as a function of height.

Humidity (default units % RH, default value: 50 %): The initial relative humidity in the system, only specified for the interior. This is converted to kilograms of water per cubic meter as an initial condition for both the interior and exterior of the structure.

Adiabatic Compartment Surfaces When this box is checked, all of the compartment surfaces are assumed to be perfect insulators and the materials section of the compartments tab becomes grayed out. This feature is useful when designing an experiment in which it is safe to assume that there is no heat transfer to the walls of the compartments.

Chapter 3

Thermal Properties

The Thermal Properties page defines the thermal conductivity, specific heat, density, thickness and emissivity values for all materials and fuel sources that will be used in a simulation.

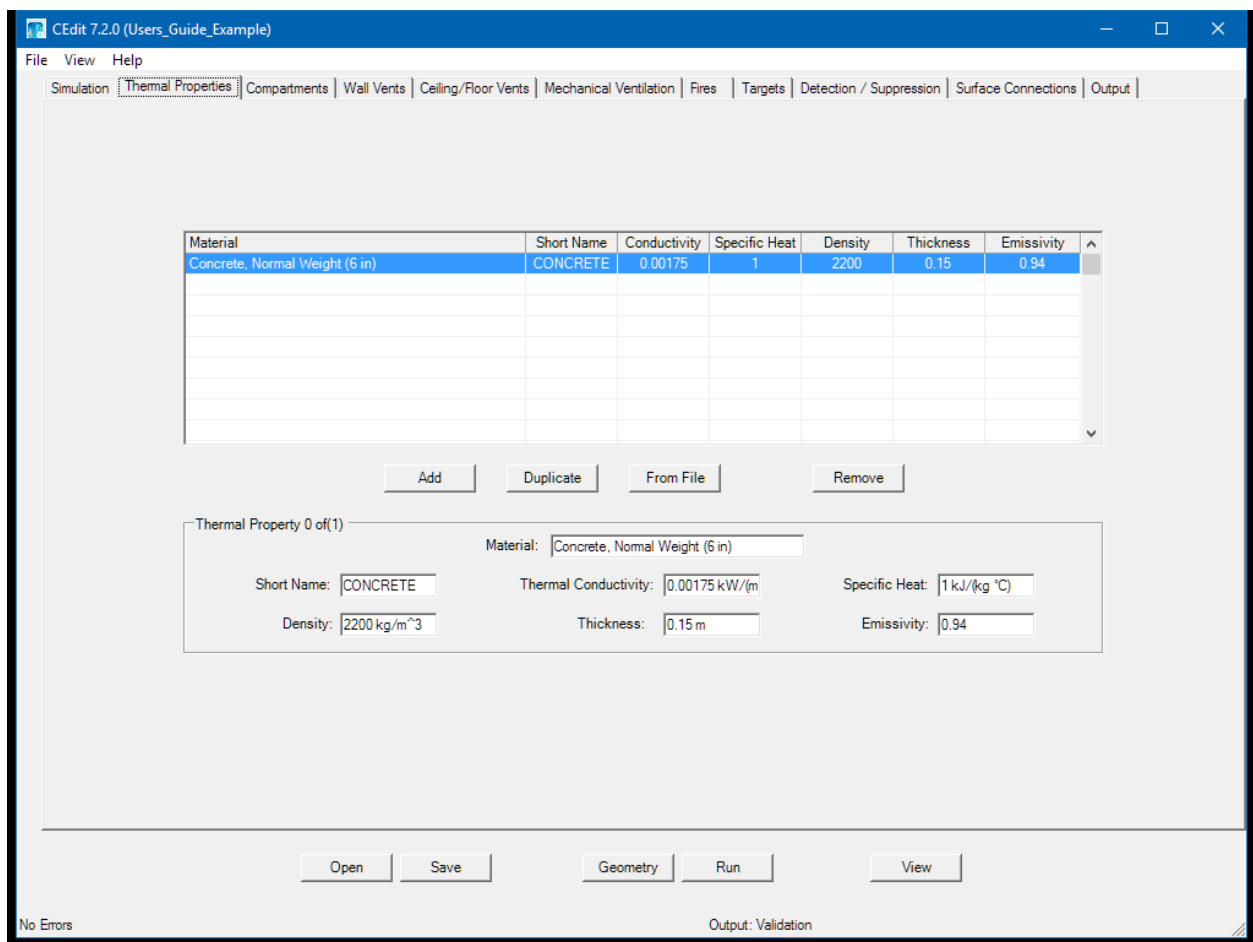


Figure 3.1: The CFAST Thermal Properties Tab.

3.1 Adding Thermal Properties

By default, CEdit does not include predefined thermal properties for compartment materials. Thus, the user needs to define materials for use within a specific simulation. These may be from other simulations or input directly from reference sources or test results. Clicking the 'Add' button and assigning values to the following list of properties will create a set of thermal properties associated with a material used in a compartment or a fuel source in a fire.

Material A descriptive name for the material.

Short Name A one-word (no more than 8 characters) **unique** identifier for the material. This identifier should not contain any spaces and is used in other CFAST inputs to identify the particular material referenced.

Thermal Conductivity (default value: none, default units: $\text{kW}/(\text{m}\cdot^{\circ}\text{C})$ / $\text{kW}/(\text{m}\cdot\text{K})$): Thermal conductivity for the material.

Specific Heat (default value: none, default units: $\text{kJ}/(\text{kg}\cdot^{\circ}\text{C})$ / $\text{kJ}/(\text{kg}\cdot\text{K})$): Specific heat for the material.

Density (default value: none, default units: kg/m^3): Density for the material.

Thickness (default value: none, default units: m): Thickness of the material. Note that if two materials with identical thermal properties but with different thicknesses are desired, two separate materials must be defined.

Emissivity (default value: 0.9, default units: none): Emissivity of the material surface. This is the fraction of radiation that is absorbed by the material.

3.2 Editing Thermal Properties

The 'From File' button allows you to insert thermal properties from existing CFAST input files to the current simulation.

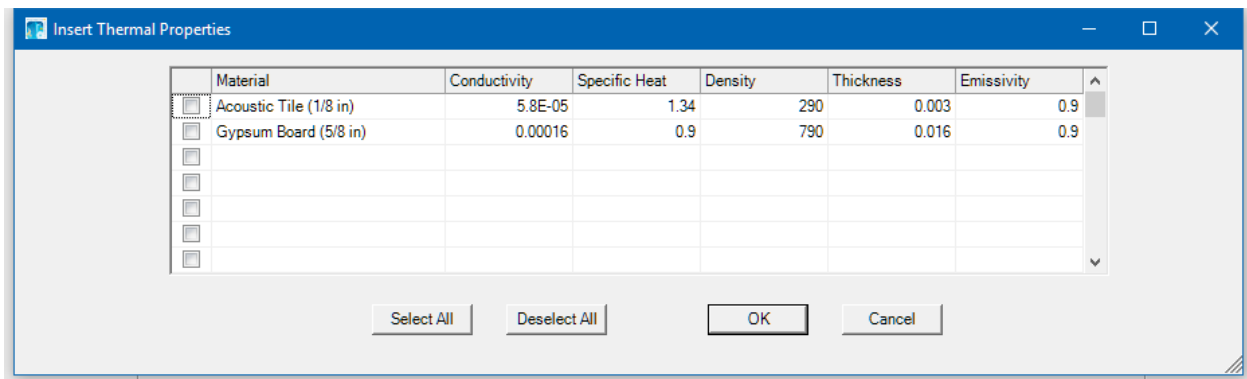


Figure 3.2: Inserting Thermal Properties in CFAST.

Chapter 4

Compartments

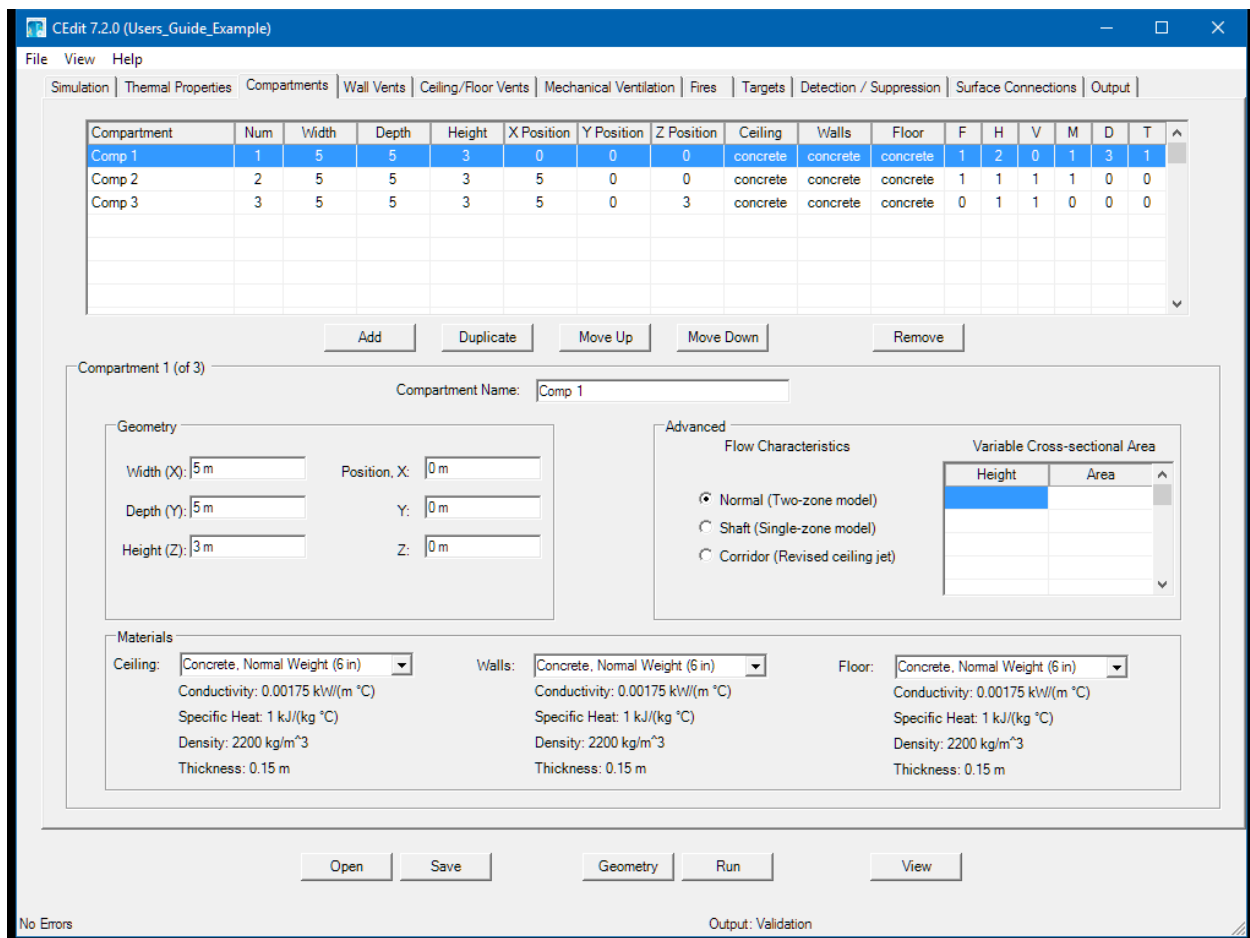


Figure 4.1: The CFAST Compartments Tab.

The Compartments page defines the size, position, materials of construction, and flow characteristics for the compartments in the simulation. Initially, only the simulation environment page and the 'Add' button on the compartment geometry and thermal properties pages are enabled; all

other pages are not available to the user for detailed inputs until a compartment has been added to the simulation.

In order to model a fire scenario, the size and position of each compartment in the structure must be specified. For a compartment, the width, depth, compartment height and height of the floor of the compartment provide this specification. The maximum number of compartments for version 7 is 100. The usual assumption is that compartments are rectangular parallelepipeds. However, the CFAST model can accommodate odd shapes as equivalent floor area parallelepipeds or with a cross-sectional area that varies with height.

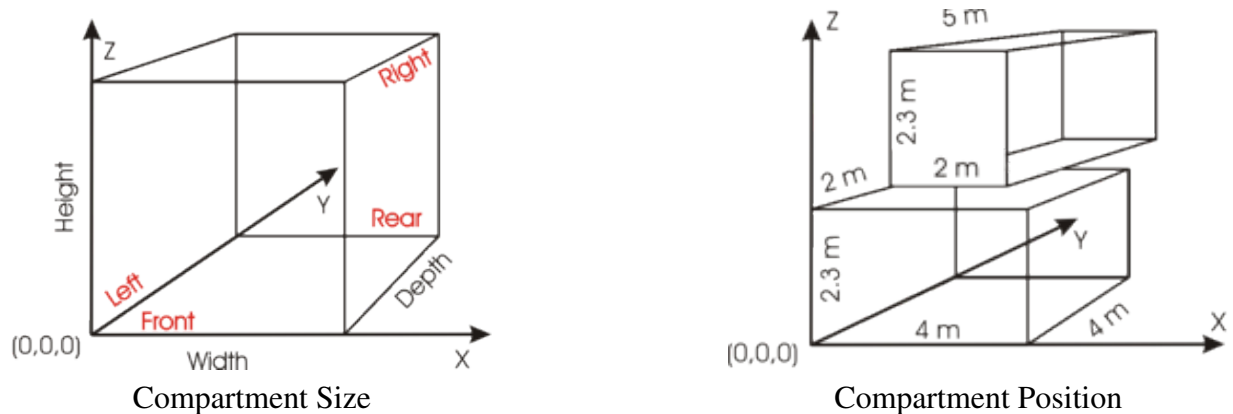


Figure 4.2: Compartment Orientation and Positioning in CFAST.

At least one compartment must be specified in the input file. There are no defaults for compartment size. There are defaults for absolute positioning (0,0,0). The fully mixed (single zone) and corridor models are turned off by default.

Compartments in CFAST are most typically defined by a width, depth, and height. If desired, compartments can be prescribed by the cross-sectional area of the compartment as a function of height from floor to ceiling for other shapes. The absolute position of the compartment with respect to a single structure reference point can be defined to ease visualization or to allow exact placement of vents and surfaces relative to other compartments in a detailed calculation. This specification is important for positioning the compartments for visualization in Smokeview.

Compartment Name: Compartments are identified by a unique alphanumeric name. This may be as simple as a single character or number, or a description of the compartment.

4.1 Geometry

Width specifies the width of the compartment as measured on the X axis from the origin (0,0,0) of the compartment.

Depth specifies the depth of the compartment as measured on the Y axis from the origin (0,0,0) of the compartment.

Height specifies the height of the compartment as measured on the Z axis from the origin (0,0,0) of the compartment.

Absolute Width Position (Position X) specifies the absolute x coordinate of the lower, left, front corner of the room. All absolute positions for all compartments must be greater than or equal to zero, i.e., negative numbers are not allowed for these inputs.

Absolute Depth Position (Position Y) specifies the absolute y coordinate of the lower, left, front corner of the room. All absolute positions for all compartments must be greater than or equal to zero, i.e., negative numbers are not allowed for these inputs.

Absolute Floor Height (Position Z) specifies the height of the floor of each compartment with respect to station elevation specified by the internal ambient conditions reference height parameter. The reference point must be the same for all elevations in the input data. For example, the two rooms in the sample to the right in figure 4.2 would be located at (0,0,0) and (0,2,2.3). All absolute positions for all compartments must be greater than or equal to zero, i.e., negative numbers are not allowed for these inputs.

4.2 Materials

To calculate heat loss through the ceiling, walls, and floor of a compartment, the properties of the bounding surfaces must be known. This includes the thermophysical properties of the surfaces and the arrangement of adjacent compartments if inter-compartment heat transfer is to be calculated.

The bounding surfaces are the ceilings, walls and floors that define a compartment. These are referred to as thermophysical boundaries, since each participates in conduction and radiation as well as defining the compartments, unless these phenomena are explicitly turned off.

The thermophysical properties of the surfaces which define compartments are described by specifying the thermal conductivity, specific heat, emissivity, density, and thickness of the enclosing surfaces for each material and then assigning the material to the ceiling, walls, and floor of a compartment. Thermal properties for materials are read from the CFAST input file. The thermophysical properties are specified at one condition of temperature, humidity, etc. Only a single layer per boundary is allowed (some previous versions allowed up to three).

Ceiling Material (default value: Gypsum Board): material name from the thermal properties data file used for the ceiling surface of the compartment.

Wall Material (default value: Gypsum Board): material name from the thermal properties data file used for the wall surfaces of the compartment.

Floor Material (default value: Off): material name from the thermal properties data file used for the floor surface of the compartment.

If the thermophysical properties of the enclosing surfaces are not included, CFAST will treat them as adiabatic (no heat transfer).

If a name is used which is not in the input file, the model should stop with an error message.

The back surfaces of compartments are assumed to be exposed to ambient conditions unless specifically specified (see the section on Surface Connections) to specify heat transfer connections between compartments).

4.3 Modeling a Compartment as a Tall Shaft or Long Corridor

For tall compartments or those removed from the room of fire origin, the compartment may be modeled as a single, well-mixed zone rather than the default two-zone assumption. A single zone approximation is appropriate for smoke flow far from a fire source, where the two-zone layer stratification is less pronounced than in compartments near the fire or in situations where the stratification does not occur. Examples are elevators, shafts, complex stairwells, or compartments far from the fire.

By specifying the compartment as a corridor, the ceiling jet temperature is calculated with a different empirical correlation that results in a somewhat higher temperature near the ceiling. This will impact, for example, detectors, sprinkler, and targets near the ceiling in corridors.

Normal (Two-zone model) Conditions in the compartment are calculated with the normal two-zone approach.

Shaft (Single-zone model) Conditions in the compartment are calculated as a single well-mixed zone.

Corridor (Revised ceiling jet) Conditions in the compartment are calculated with the normal two-zone approach. Ceiling jet temperatures in the compartment are calculated with a revised empirical correlation specific to corridors.

4.4 Defining Variable Compartment Area

The Compartment Geometry page includes two additional entries that may be used for defining compartment properties for spaces which are not rectangular in area. Values for a chosen compartment are entered in a spreadsheet.

Height Value(s) (default units: m, default values: none): Height off the floor of the compartment.

Area Value(s) (default units m^2 , default values: none): Cross-sectional area at the corresponding Height.

Once the total compartment volume is determined from the set of cross-sectional area and height inputs, an effective width and depth are calculated (maintaining the original user input for compartment height) so the compartment volume matches the actual total volume of the compartment. The aspect ratio (width/depth) is maintained.

Cross-sectional area values should be input in order by ascending height. If the first height value is not zero (i.e., at floor level), the cross-sectional area is assumed constant from the floor to the height specified in the first cross-sectional area value.

Similarly, if the last height value is not at the ceiling height, the cross-sectional area is assumed constant from the height specified in the last cross-sectional area value to the ceiling. Between any two adjacent cross-sectional area data values in the input list, the area is assumed to be a pyramidal section (which by definition maintains the same width to depth aspect ratio for the compartment from floor to ceiling).

CFAST uses the variable cross-sectional area inputs to determine the layer height. The equations solved by CFAST determine the volume of the upper layer. For a normal rectangular room, this corresponds directly to a layer height. For a variable cross-sectional area compartment, a numerical integration of the area inputs beginning at the ceiling is used to determine the height at which the upper layer occupies the calculated volume of the upper layer.

Chapter 5

Natural Ventilation

Natural ventilation can occur when two compartments are connected via open doorways or windows (**Wall Vents**); or when two compartments are connected via **Floor/Ceiling Vents**. If no vents are specified between two compartments, they are assumed to be isolated.

5.1 Wall Vents

Wall vents are doors or windows that connect compartments that physically overlap in elevation, or that connect to the outside. Horizontal flow connections may also be used to account for leakage between compartments or to the outdoors.

First Compartment First of the two compartments connected by a door or window.

Second Compartment Second of the two compartments connected by a door or window.

Sill (default units: m): Height of the bottom of the opening relative to the floor of the first compartment.

Soffit (default units: m): Height of the top of the opening relative to the floor of the first compartment.

Width (default units: m): The width of the opening.

Vent Offset (default units: m, Default value: 0 m): For visualization only, the horizontal distance between the near edge of the vent and the origin of the axis defined by the selected face (below) in the first compartment (Front and Rear are along the X-axis; left and right are along the Y-axis).

Face The wall on which the vent is positioned. Choices are Front, Rear, Right, Left and are relative to the X-Z plane.

Vents in CFAST can be opened or closed at user-specified times or by a user-specified target's surface temperature or incident heat flux. For time-based opening changes, the inputs are a series of time points and associated opening fractions from 0 (fully closed) to 1 (fully open).

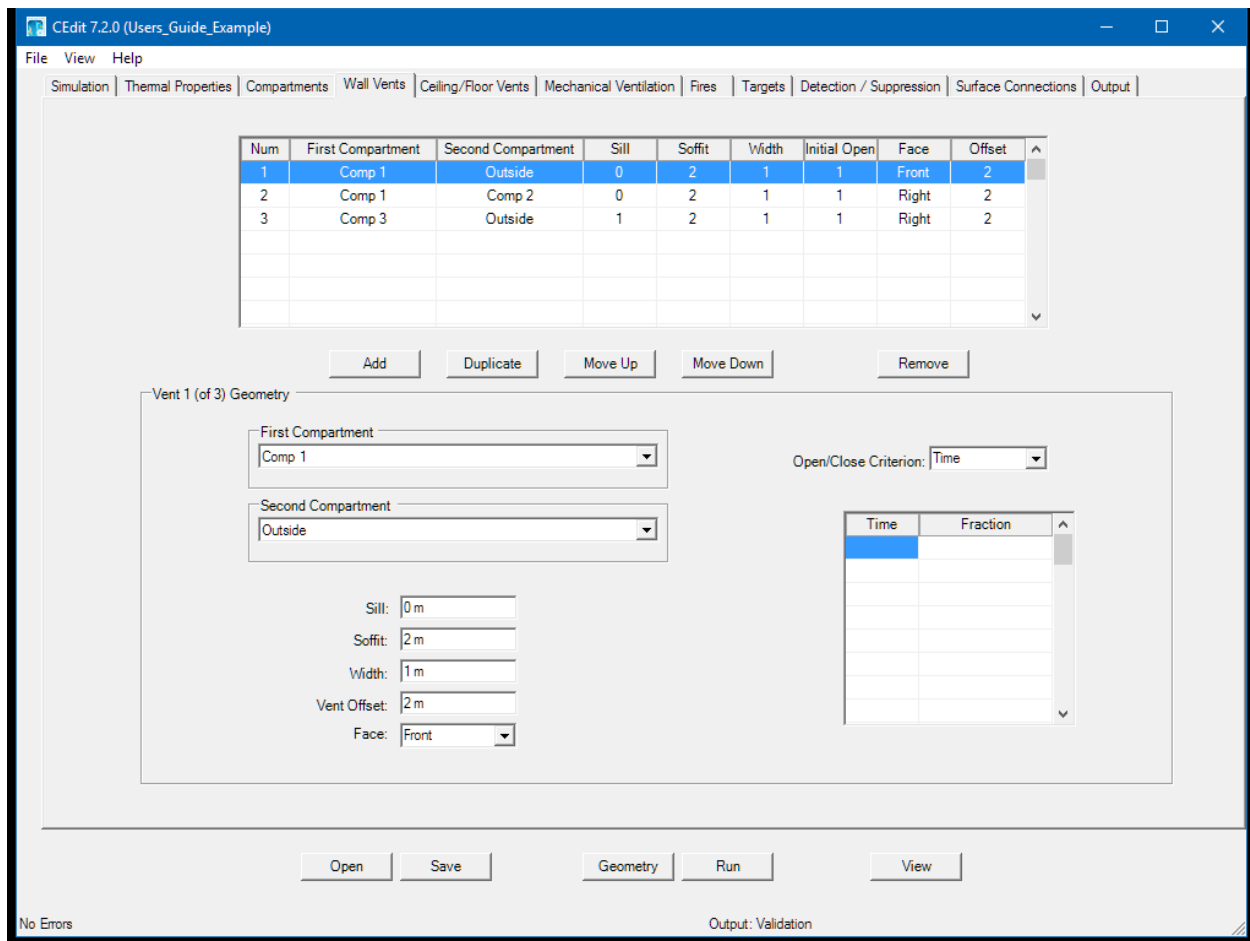


Figure 5.1: The CFAST Wall Vents Tab.

Time (default units: s, default values: 0): Time during the simulation at which to begin or end a change in the open fraction.

Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is closed, partially-open, or fully-open as the associated time point.

For condition-based opening changes, the inputs specify an associated target, trigger value, and vent opening fractions before and after the trigger value has been reached.

Set Point The critical value at which the vent opening change will occur. If it is less than or equal to zero, the default value of zero is taken.

Trigger Target User-specified target used to calculate surface temperature or incident heat flux to trigger a vent opening change. Target is placement is specified by the user as part of the associated target definition.

Pre-Activation Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is partially open at the start of the simulation.

Post-Activation Fraction (default value: 1, fully open): Opening fraction at the end of the simulation. The transition from the pre-activation fraction to the post-activation value is assumed to occur over one second beginning when the specified set point value is reached.

CFAST assumes a linear transition between time points. If the initial time specified for a time-changing opening fraction is non-zero, the vent is assumed to be open at the initial value of the opening fraction from the beginning of the simulation up to and including the time associated with the initial value of the opening fraction. If the final value of the opening fraction is less than the total simulation time, the vent is assumed to be open at the final value of the opening fraction from and including the time associated with the final value of the opening fraction until the end of the simulation.

5.2 Ceiling/Floor Vents

CEdit 7.2.0 (Users_Guide_Example)

File View Help

Simulation Thermal Properties Compartments Wall Vents **Ceiling/Floor Vents** Mechanical Ventilation Fires Targets Detection / Suppression Surface Connections Output

Num	Top	Bottom	Area	Shape
1	Comp 3	Comp 2	1	Round

Add Duplicate Remove

Vent 1 (of 1) Geometry

Top Compartment:

Bottom Compartment:

Open/Close Criterion:

Cross-Sectional Area:

Shape:

Vent Offset X:

Y:

Time	Fraction
0	0
100	0.5
500	1

Open Save Geometry Run View

No Errors Output: Validation

Figure 5.2: The CFAST Ceiling/Floor Vents Tab.

Examples of these openings are scuddles in a ship, or a hole in the roof of a residence. Connections can exist between compartments or between a compartment and the outdoors. Combined

buoyancy and pressure-driven flow through a vertical flow vent is possible when the connected spaces adjacent to the vent are filled with gases of different density in an unstable configuration, with the density of the top space larger than that of the bottom space. With a moderate cross-vent pressure difference, the instability leads to a bi-directional flow between the two spaces. For relatively large cross-vent pressure difference the flow through the vent is unidirectional.

Top Compartment The vent is located on the floor of this compartment.

Bottom Compartment The vent is located on the ceiling of this compartment.

Cross-sectional Area (default units: m^2)

Shape The shape factor changes the calculation of the effective diameter of the vent and flow coefficients for flow through the vent.

Vent Offset (default units: m, Default value: 0 m): For visualization only, the horizontal distances between the center of the vent and the origin of the X and Y axes in the first compartment (Front and Rear are along the X-axis; left and right are along the Y-axis). See figure 4.2 for axis position conventions in CFAST.

Vents in CFAST can be opened or closed at user-specified times or by a user-specified target's surface temperature or incident heat flux. For time-based opening changes, the inputs are a series of time points and associated opening fractions from 0 (fully closed) to 1 (fully open).

Time (default units: s, default values: 0): Time during the simulation at which to begin or end a change in the open fraction.

Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is closed, partially-open, or fully-open as the associated time point.

For condition-based opening changes, the inputs specify an associated target, trigger value, and vent opening fractions before and after the trigger value has been reached.

Set Point The critical value at which the vent opening change will occur. If it is less than or equal to zero, the default value of zero is taken.

Trigger Target User-specified target used to calculate surface temperature or incident heat flux to trigger a vent opening change. Target is placement is specified by the user as part of the associated target definition.

Pre-Activation Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is partially open at the start of the simulation.

Post-Activation Fraction (default value: 1, fully open): Opening fraction at the end of the simulation. The transition from the pre-activation fraction to the post-activation fraction is assumed to occur over one second beginning when the specified set point value is reached.

CFAST assumes a linear transition between time points. If the initial time specified for a time-changing opening fraction is non-zero, the vent is assumed to be open at the initial value of the open fraction from the beginning of the simulation up to and including the time associated with the initial value of the opening fraction. If the final value of the opening fraction is less than the total simulation time, the vent is assumed to be open at the final value of the opening fraction from and including the time associated with the final value of the opening fraction until the end of the simulation.

CFAST allows only a single connection between any pair of compartments included in a simulation because the empirical correlation governing the flow was developed using only a single opening between connected compartments.

Vertical connections can only be created between compartments that could be physically stacked based on specified floor and ceiling elevations for the compartments. Some overlap between the absolute floor height of one compartment and the absolute ceiling height of another compartment is allowed. However, whether the compartments are stacked or overlap somewhat, the ceiling/floor absolute elevations must be within 0.01 m of each other. The check is not done when the connection is to the outside.

Chapter 6

Mechanical Ventilation

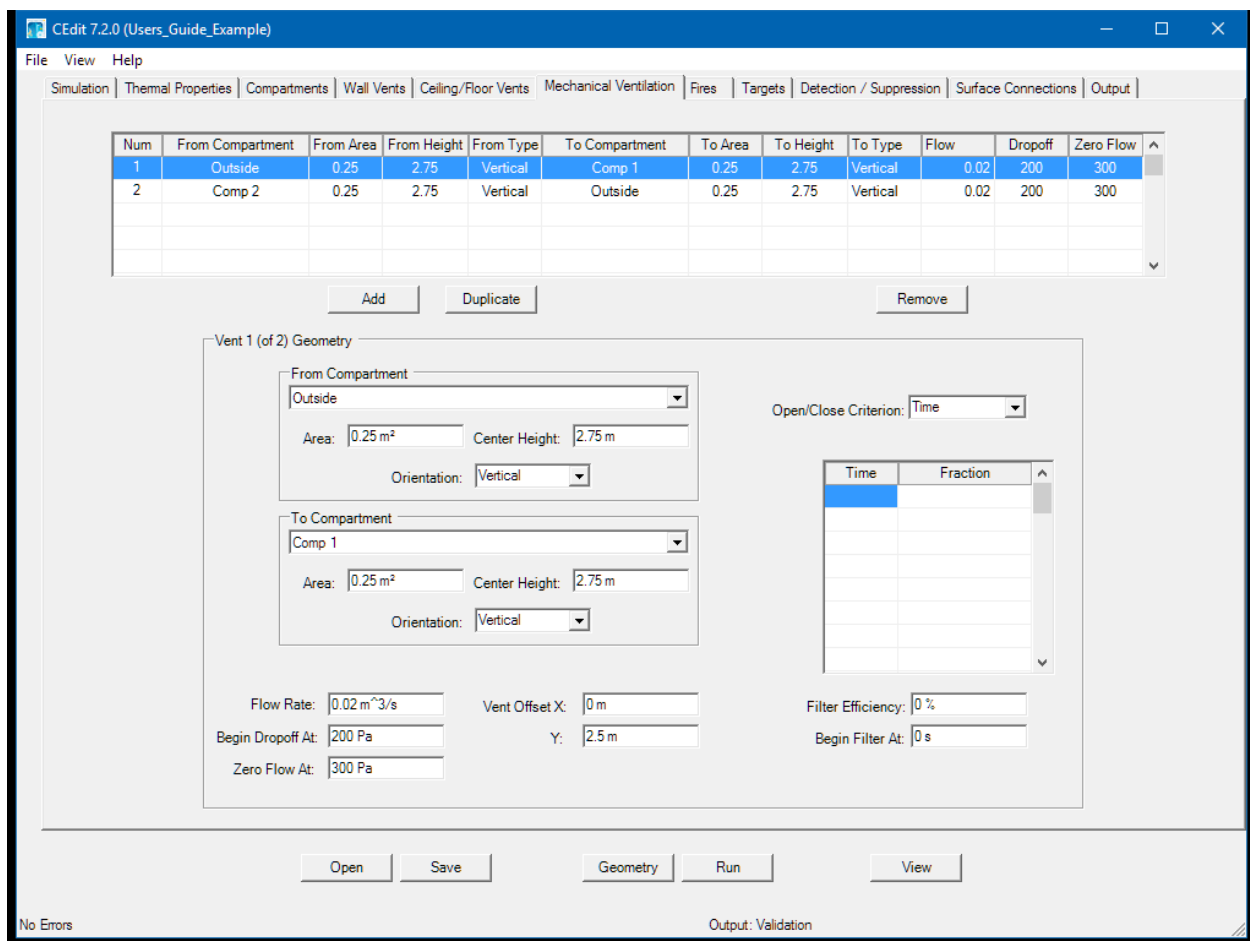


Figure 6.1: The CFAST Mechanical Vents Tab.

Fan-duct systems are commonly used in buildings for heating, ventilation, air conditioning, pressurization, and exhaust. Generally, systems that maintain comfortable conditions have either one or two fans. Residences often have a system with a single fan. Further information about these

systems is presented in Klote and Milke [6] and the American Society of Heating, Refrigerating and Air Conditioning Engineers Handbook [7].

The model for mechanical ventilation is based on the theory of networks and is based on the model developed by Klote [8]. This is a simplified form of Kirchoff's law which says that flow into a node must be balanced by flow out of the node. The equations used describe the relationship between the pressure drop across a duct, the resistance of a duct, and the mass flow. The pressure can be changed by conditions in a compartment, or a fan in line in the duct system. Resistance arises from the finite size of ducts, roughness on duct surfaces, bends and joints. In CFAST, default values are used for the duct properties, and thus mechanical ventilation connections are simply described by the connections to the two compartments and a fan whose throughput is a constant volumetric flow up to a user-specified pressure drop across the fan, dropping to zero at high backwards pressure on the fan.

6.1 Connections to Compartments

From Compartment The compartment from which the fan flow originates.

To Compartment The compartment to which the fan flow terminates.

Area (default units: m^2): Cross-sectional area of the opening.

Center Height (default units: m): Height of the midpoint of the duct opening above the floor.

Orientation A horizontal diffuser implies vertical flow through the ceiling or floor of the compartment. A vertical diffuser implies horizontal flow through a wall of the compartment.

Vent Offset (default units: m, Default value: 0 m): For visualization only, the horizontal distances between the center of the vent and the origin of the X and Y axes in the first compartment (Front and Rear are along the X-axis; left and right are along the Y-axis). See figure 4.2 for axis position conventions in CFAST.

6.2 Fans

CFAST does not include provisions for reverse flow through a fan, or a fan curve. Rather, you may specify a pressure above which the flow linearly decreases to zero.

Flow Rate (default units: m^3/s): Constant flow rate of the fan.

Begin Drop Off Pressure (default units: Pa, default value: 200 Pa): Above this pressure, the flow begins a drop-off to zero. A hyperbolic tangent function is used to ensure a smooth transition from full flow at the “Begin Drop Off Pressure” to zero flow at the “Zero Flow Pressure”.

Zero Flow Pressure (default units: Pa, default value: 300 Pa): The pressure above which the flow is zero.

Vents in CFAST can be opened or closed at user-specified times or by a user-specified target's surface temperature or incident heat flux. For time-based opening changes, the inputs are a series of time points and associated opening fractions from 0 (fully closed) to 1 (fully open).

Time (default units: s, default values: 0): Time during the simulation at which to begin or end a change in the open fraction.

Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is closed, partially-open, or fully-open as the associated time point.

For condition-based opening changes, the inputs specify an associated target, trigger value, and vent opening fractions before and after the trigger value has been reached.

Set Point The critical value at which the vent opening change will occur. If it is less than or equal to zero, the default value of zero is taken.

Trigger Target User-specified target used to calculate surface temperature or incident heat flux to trigger a vent opening change. Target is placement is specified by the user as part of the associated target definition.

Pre-Activation Fraction (default value: 1, fully open): Fraction between 0 and 1 of the vent width to indicate the vent is partially open at the start of the simulation.

Post-Activation Fraction (default value: 1, fully open): Opening fraction at the end of the simulation. The transition from the pre-activation fraction to the post-activation fraction is assumed to occur over one second beginning when the specified set point value is reached.

CFAST assumes a linear transition between time points. If the initial time specified for a time-changing opening fraction is non-zero, the vent is assumed to be open at the initial value of the open fraction from the beginning of the simulation up to and including the time associated with the initial value of the opening fraction. If the final value of the opening fraction is less than the total simulation time, the vent is assumed to be open at the final value of the opening fraction from and including the time associated with the final value of the opening fraction until the end of the simulation.

6.3 Filtering

For mechanical vents, there are two species that can be filtered out of the gas flow: soot and the user-defined trace species. Filters are applied only to fan openings. The fan must have been defined before the filter can be applied. Initially filtering is off.

Filter Efficiency (default units: %): Flow through mechanical vents may include filtering that removes a user-specified portion of soot and trace species mass from the flow through the vent. By default, there is no filtering applied; that is, all of the soot and trace species mass in the vent flow is passed through the vent. Within the user interface, this is specified as a filter efficiency of 0 %. If desired, you may specify the fraction of the soot and trace species mass to be removed as a percentage.

Begin Filtering At Time (default units: s): Time during the simulation at which the mechanical vent filtering begins.

If the simulation includes mechanical ventilation filtering, care should be taken in choosing trace species production rates to insure the production rate is small compared to the total pyrolysis rate since the filtering removes mass from the system. This will better allow appropriate conservation of mass in the solution of the system of differential equation. For large production rates of trace species, scaling factors can be used (e.g., divide by 1000) for the trace species production rate to reduce the relative magnitude compared to the pyrolysis rate. For analysis, the resulting trace species in compartments and filters can be converted back to original units multiplying by the scaling factor used.

Chapter 7

Fires

A fire in CFAST is specified via a time-dependent heat release rate. The specified heat of combustion is used to calculate the mass loss rate of fuel, from which the production rate of combustion products can be calculated using specified product yields. The heat release and the corresponding product generation rates go to zero when the lower oxygen limit is reached, and are replaced by the appropriate production rate of unburned fuel gas which is transported from zone to zone until there is sufficient oxygen and a high enough temperature to support combustion.

The model can simulate multiple fires in one or more compartments. These fires are treated as totally separate entities, with no interaction of the plumes. These fires can be ignited at a prescribed time, or when a corresponding target (see Chapter 8) reaches a specified temperature or heat flux.

The combustion model is defined by the following one-step reaction:



It is assumed that all the nitrogen and chlorine in the fuel are converted to HCN and HCl.

Two inputs on the Fire Tab are global, that is, they apply to all fires included in a simulation.

Lower Oxygen Limit (default units: %, default value: 10 %): In the CFAST model, a limit is incorporated by limiting the burning rate as the oxygen level decreases until a “lower oxygen limit” (LOL) is reached. The lower oxygen limit is incorporated through a smooth decrease in the burning rate near the limit. Normally, this value would not be changed by the user.

Gaseous Ignition Temperature (default units: °C, default value: ambient temperature plus 100 K): The lower temperature limit for burning unburned fuel gas generated in an oxygen-depleted compartment.

7.1 Adding Fires

Fires are added to the simulation by clicking on the **Add New** or **Add t²** button. The latter is useful because it has predefined quadratic growth rate options that are commonly used in fire analyses. See Section 7.3 for details. You may also **Duplicate** a listed fire, or select a fire **From File** of an existing case. For each fire, specify the following properties:

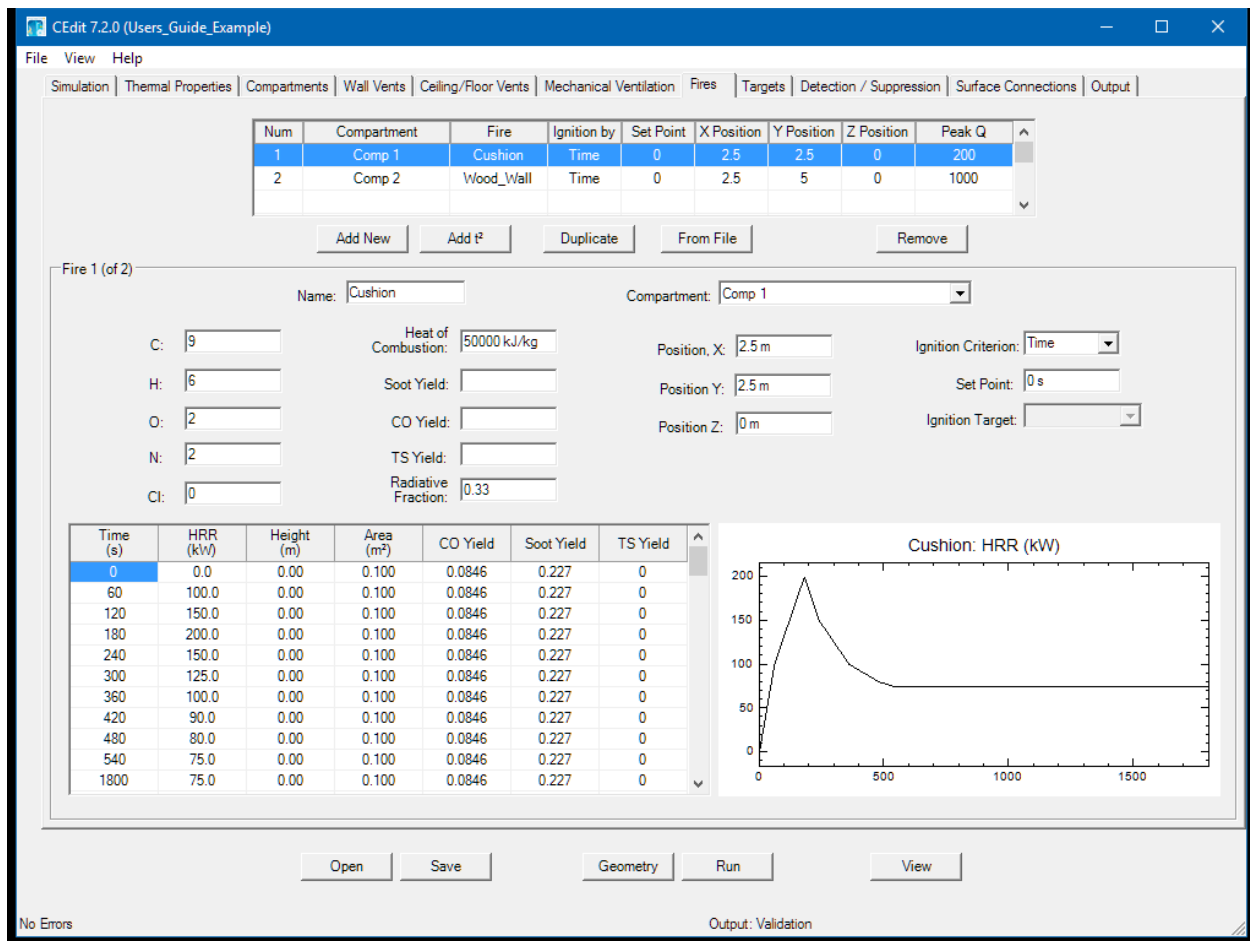


Figure 7.1: The CFAST Fires Tab.

Name The selected name must be unique (i.e., not the same as another fire in the same simulation).

Compartment where the fire occurs.

C, H, O, N, Cl The number of each atom in the fuel molecule. Burning fuels in CFAST are assumed to be hydrocarbon fuels that contain at least carbon and hydrogen and optionally oxygen, nitrogen, and chlorine. All of the specified nitrogen and chlorine is assumed to completely react to form HCN and HCl.

Heat of Combustion (default value: 50000 kJ/kg): The energy released per unit mass of fuel consumed.

Soot Yield (default value: 0 kg/kg): Mass of soot produced per unit mass of fuel consumed.

CO Yield (default value: 0 kg/kg): Mass of CO produced per unit mass of fuel consumed.

TS Yield (default value: 0 kg/kg): Mass of user-defined trace species per unit mass of fuel consumed. The trace species is transported along with the other products of combustion, but is

assumed not to take part in the combustion reaction and is assumed not to be a significant source of overall mass for the system mass balance. This implies that the production rate of trace species specified should be much smaller than the total specified pyrolysis rate.

Radiative Fraction (default value: 0.35): The fraction of the combustion energy that is emitted in the form of thermal radiation. Values for various fuels are suggested by Beyler [9].

Position X, Y, Z (default units: m, default value: compartment center): Position of the center of the base of the fire relative to the front lower left corner of the compartment.

Ignition Criterion The time of ignition can be controlled by a user-specified time, or by a user-specified target's surface temperature or incident heat flux.

Set Point The critical value at which ignition will occur. If it is less than or equal to zero, the default value of zero is taken.

Ignition Target User-specified target used to calculate surface temperature or incident heat flux to ignite fire. Target is typically placed at the base of the fire to be ignited.

7.2 Time-Dependent Properties

Following is a list of fire properties that can be specified as a function of time. The properties are linearly interpolated between specified points. If the simulation time is longer than the total duration of the fire, the final values specified for the fire are continued until the end of the simulation. Normal copy (Ctrl-C), cut (Ctrl-X), and paste (Ctrl-V) keyboard shortcuts work for data editing. In addition, Alt-Insert will insert a complete row above the currently-selected row in the spreadsheet and Alt-Delete will delete the current row in the spreadsheet.

Time (default units: s, default values: none): Time from ignition.

HRR (default units: kW, default values: none): Heat release rate of the fire.

Height (default units: m, default values: 0 m): Height of the base of the fire.

Area (default units: m², default values: 0.3 m²): Area of the base of the fire. The plume correlations used in CFAST generally regard the base to be circular. Do not set this value to zero because it is used in the various plume correlations.

CO, Soot, TS Yields (default units: kg/kg): Yields of carbon monoxide, soot, and trace species. The time-dependent values over-rides the constant values given above.

7.3 Special Topic: t-Squared Fires

Use the 'Add t²' button to create a new fire with a heat release rate that grows as a function of the time squared [10]:

$$\dot{Q}(t) = \dot{Q}_{\text{peak}} \left(\frac{t}{t_{\text{peak}}} \right)^2 \quad (7.2)$$

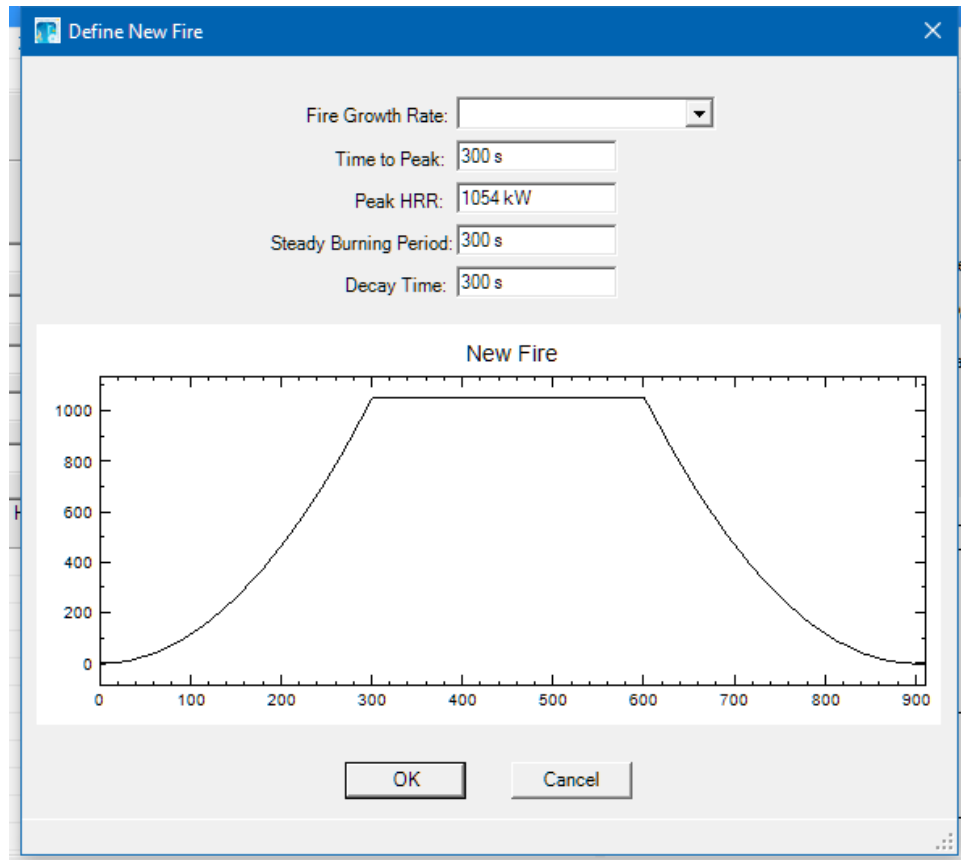


Figure 7.2: Inserting T-squared Fires in CFAST.

Fire Growth Rate A set of specific t-squared fires labeled slow, medium, fast, or ultra-fast such that the fire reaches 1054 kW (1000 BTU/s) in 600 s, 300 s, 150 s, and 75 s. A custom selection allows you to define any growth or decay rate desired.

Time to Peak (default units: s, default value: 300 s): The time for the fire to reach the peak HRR.

Peak HRR (default units: kW, default value: 1054 kW): The peak heat release rate of the t-squared fire.

Steady Burning Period (default units: s, default value: 300 s): Duration of time that the fire continues burning at the rate specified by the peak HRR.

Decay Time (default units: s, default value, 300 s): Duration of time for the fire to decay back to a zero value. Decay follows the inverse of the t-squared growth rate.

Chapter 8

Defining Targets

A target is any object in the simulation that can heat up via radiative and convective heat transfer. The heat conduction into the target is performed via a one-dimensional calculation in either cartesian or cylindrical coordinates.

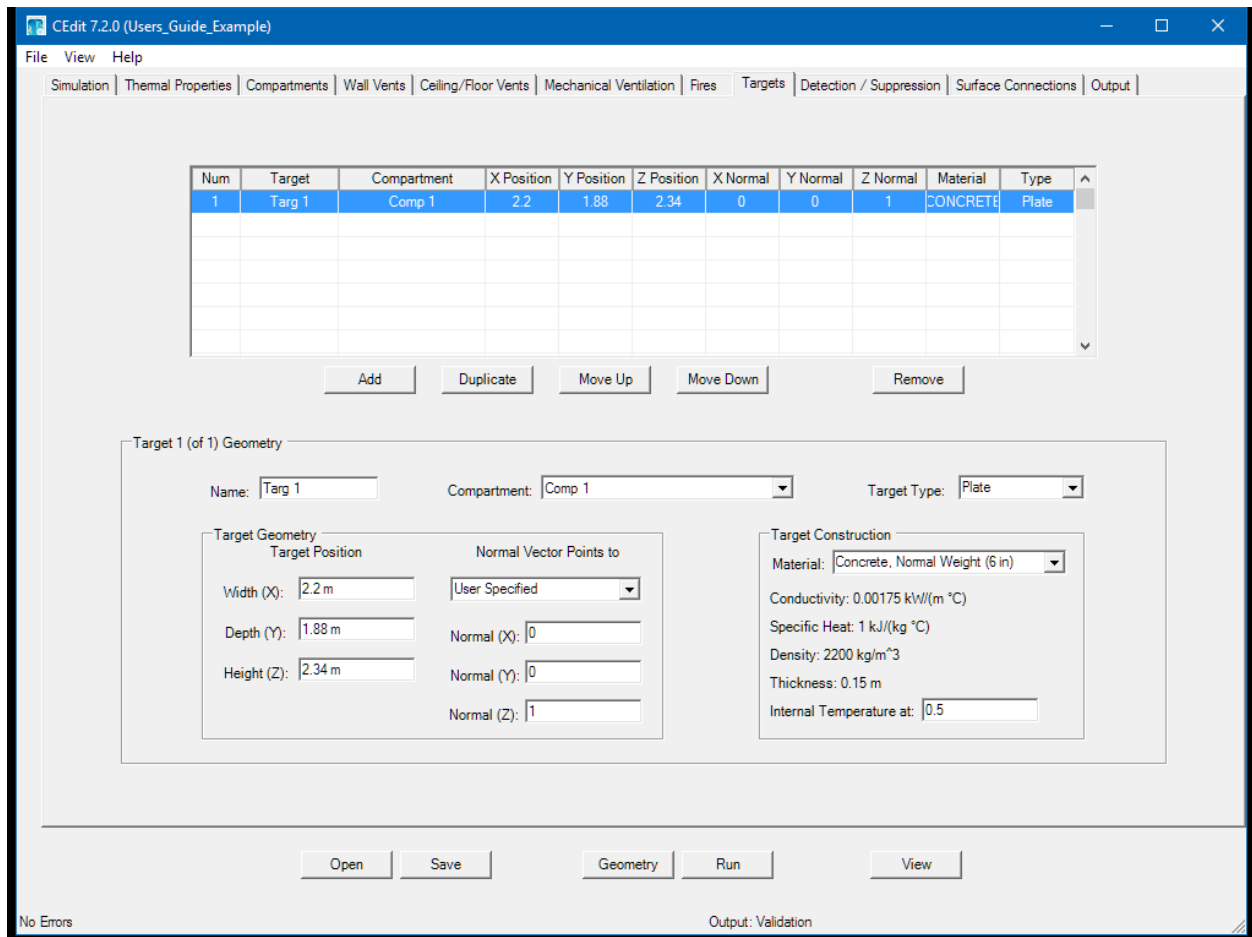


Figure 8.1: The CFAST Targets Tab.

Name The selected name must be unique (i.e., not the same as another target in the same simulation).

Compartment The compartment in which the target is located.

Target Type Specify Plate, or Cylindrical. For plate targets, CFAST solves a partial differential equation in cartesian coordinates, and for cylindrical targets, a partial differential equation in cylindrical coordinates.

Width (X) (default units: m): Distance from the left wall of the target compartment.

Depth (Y) (default units: m): Distance from the front wall of the target compartment.

Height (Z) (default units: m): Height of the target above the floor.

Normal Vector (X,Y,Z) : specifies a vector of unit length perpendicular to the exposed surface of the target. For example, the vector (-1,0,0) indicates that the target is facing the left wall. The vector (0,0,1) is facing the ceiling.

Material What the target is made of. Any existing material in the list of thermal properties may be used here. There can be only one material per target.

Internal Temperature at (default units: none, default value: 0.5): For each target, CFAST calculates the internal temperature at a number of node points within the target. By default, the reported internal temperature (in the printed and spreadsheet output) is the temperature at the center of the target, e.g., equidistant from the front and back faces of the target. This input allows the user to override this default position. The input represents the position as a fraction of the thickness from the front surface to the back surface of the material.

If the target is only needed to report the local gas temperature, which may include the plume or ceiling jet, then you may specify arbitrary properties and normal vector. The output spreadsheet file includes the local gas temperature in addition to the target temperature.

Chapter 9

Sprinklers and Detectors

Sprinklers and detectors are both considered detection devices by the CFAST model and are handled using the same inputs. Detection is based upon heat transfer to the detector. Fire suppression by a user-specified water spray begins once the associated detection device is activated.

The screenshot shows the CEdit 7.2.0 (Users_Guide_Example) software interface. The 'Detection / Suppression' tab is active. The table below lists the detection devices:

Num	Compartment	Type	X Position	Y Position	Z Position	Activation	RTI	Spray Density
1	Comp 1	Sprinkler	3	3	2.97	73.88892	100	7E-05
2	Comp 1	Smoke	2	2	2.97	23.93346	404	7E-05
3	Comp 1	Heat	2	2	2.97	30	5	7E-05

Below the table are buttons: Add, Duplicate, Move Up, Move Down, and Remove.

Alarm 1 (of 3)

Type: Sprinkler Compartment: Comp 1 Activation Temperature: 73.88892 °C
Activation Obscuration: 23.93346 %/m

Position

Width (X): 3 m
Depth (Y): 3 m
Height (Z): 2.97 m

RTI: 100 (m s)^{0.5}
Spray Density: 7E-05 m/s

Buttons at the bottom: Open, Save, Geometry, Run, View.

Status bar: No Errors Output: Validation

Figure 9.1: The CFAST Detection/Suppression Tab.

Type type of detector, select smoke detector, heat detector, or sprinkler.

Compartment the compartment in which the detector or sprinkler is located.

Activation Temperature (default units: °C, default value: dependent on type): the temperature at or above which the detector link activates.

Activation Obscuration (default units: %/m, default value: 23.93 %/m (8 %/ft)): the obscuration at or above which the detector link activates.

Width (X) Position (default units: m, default value: none): position of the object as a distance from the left wall of the compartment (X direction).

Depth (Y) Position (default units: m, default value: none): position of the detector or sprinkler as a distance from the front wall of the compartment (Y direction).

Height (Z) Position (default units: m, default value: none): position of the object as a distance from the floor of the compartment (Z direction).

RTI (default units: $(\text{m}\cdot\text{s})^{1/2}$, default value: none): the Response Time Index (RTI) for the sprinkler or detection device.

Spray Density (default units: m/s, default value: none): the amount of water dispersed by a sprinkler. The units for spray density are length/time, derived by dividing the volumetric flow rate by the spray area. The suppression calculation is based upon an experimental correlation by Evans [11].

Care should be taken when specifying detectors to activate based on smoke obscuration since the only calculation included in CFAST is a simple two-zone calculation of soot concentration that does not include the impact of an initial ceiling layer as is done for temperature-based calculations. Often, the activation of smoke alarms is simulated with a temperature-based criterion (in CFAST as a heat alarm), typically in the range of 5 °C to 10 °C above ambient. Davis and Notarianni studied the activation of heat and smoke alarms in small and large compartments [12]. They conclude that a temperature rise of approximately 5 °C corresponded to activation of ionization alarms for a range of fire sources and ceiling heights. The Nuclear Regulatory Commission includes a default value of 10 °C with an RTI value of 5 $(\text{m}\cdot\text{s})^{1/2}$ in NUREG-1805 [13].

Several cautions should be observed when using estimates of sprinkler suppression within the model: 1) The first sprinkler activated controls the effect of the sprinkler on the heat release rate of the fire. Subsequent sprinklers which may activate have no additional effect on the fire simulation. 2) The fire suppression algorithm assumes the effect of the sprinkler is solely to reduce the heat release rate of the fire. Any effects of the sprinkler spray on gas temperatures or mixing within the compartment are ignored. 3) The sprinkler always reduces the heat release rate of the fire. The ability of a fire to overwhelm an under-designed sprinkler is not modeled. 4) Since the dynamics of the sprinkler and direct effects of the spray on gas temperatures and velocities are not modeled, calculated times of activation of secondary sprinklers and / or detectors after the first sprinkler

is activated should be not be modeled since the impact of the first sprinkler on the activation of additional sprinklers is not included in the CFAST model.

Chapter 10

Surface Connections

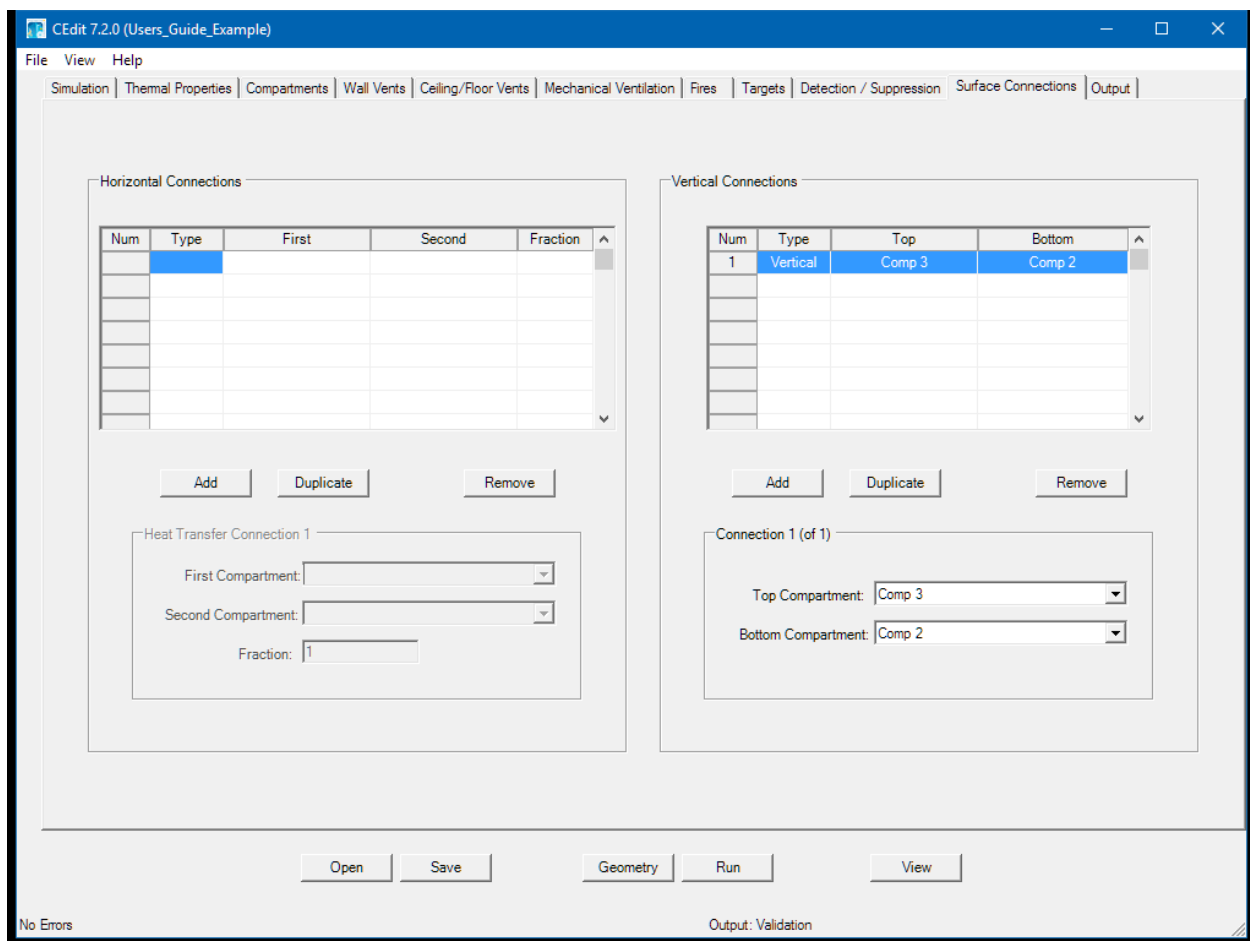


Figure 10.1: The CFAST Surface Connections Tab.

The Surface Connections page allows the user to define heat transfer between compartments in a simulation. Energy can be transferred from compartment to compartment through solid boundaries (walls, ceilings and floors) by means of conduction. The heat transfer between connected

compartments is modeled by setting the boundary condition for the outside surface of a compartment to the temperature of the outside surface of the connected compartment. As before, temperatures are determined by the solver so that the heat flux striking the wall surface (both interior and exterior) is consistent with the temperature gradient at that surface.

First Compartment First of the compartments whose walls are connected for horizontal heat transfer.

Second Compartment Second of the compartments whose walls are connected for horizontal heat transfer.

Fraction Specifies the fraction of the vertical surface areas of the compartments which are connected. The fraction specifies the fraction of the vertical surface area of the first compartment that connects the first and second compartment pair.

Top Compartment The top or first of the two compartments to be connected by a vertical heat transfer connection. The connection is through the floor of this compartment.

Bottom Compartment The bottom or second of the two compartments to be connected by a vertical heat transfer connection. The connection is through the ceiling of this compartment.

For horizontal heat transfer, you must include a connection for each compartment. For example, for a connection between compartment 1 and compartment 2, you must include a connection from 1 to 2 AND a connection from 2 to 1. For consistency, the fraction for each compartment needs to specify equal areas in the two compartments. Fractions for connections should add to unity. An error is generated if the fractions for a compartment add to greater than unity. If the fractions for a compartment add to less than unity, the remaining surface area will be assigned to be connected to the outdoors.

Chapter 11

Visualization

Calculated results from a CFAST simulation can be visualized using Smokeview [14]. This allows the user to see the compartment geometry and connections or view the results of the simulation visually. In addition to a simplified view of the layer temperatures and vent flows, more detailed estimates of gas temperature, gas velocity, vent flow velocity, target temperature, and detector status can be visualized.

11.1 Adding Visualizations

Visualization Type (default units: n/a, default value: 2-D): The type of visualization to be included. Choose from 2-D (a single plane slice of temperature at the position and axis specified), 3-D (a set of three animated slices whose position can be moved along its respective axis, or Isosurface (a fixed 3-D surface where the gas temperature is equal to the value specified. See the Smokeview documentation [14] for details on the use of Smokeview.

Compartment (default units: n/a, default value: All): Visualizations can be placed in a single compartment or at the same position and axis in all compartments.

Value (default units: m, default value: 0 m): Position along the specified axes where the slice is placed measured from the compartment origin for the selected axis (0,0,0 is the bottom left corner of the compartment. See page 14).

Axis (default units: n/a, default value: X-axis (Width)): Axis perpendicular to the specified slice. The slice is placed perpendicular to the selected axis (the Y-Z plane for the X-Axis; the X-Z plane for the Y-Axis, and the X-Y plane for the Z-Axis)

Temperature (default units °C, default value: none): Specified gas temperature for the selected isosurface.

Use the Add Defaults button to add a default set of visualizations for the current simulation. A slice file entry is created at the center of each compartment in the x (width) and y (depth) directions along with one near the ceiling in the z direction. A 3-D slice file entry is created for each compartment as well.

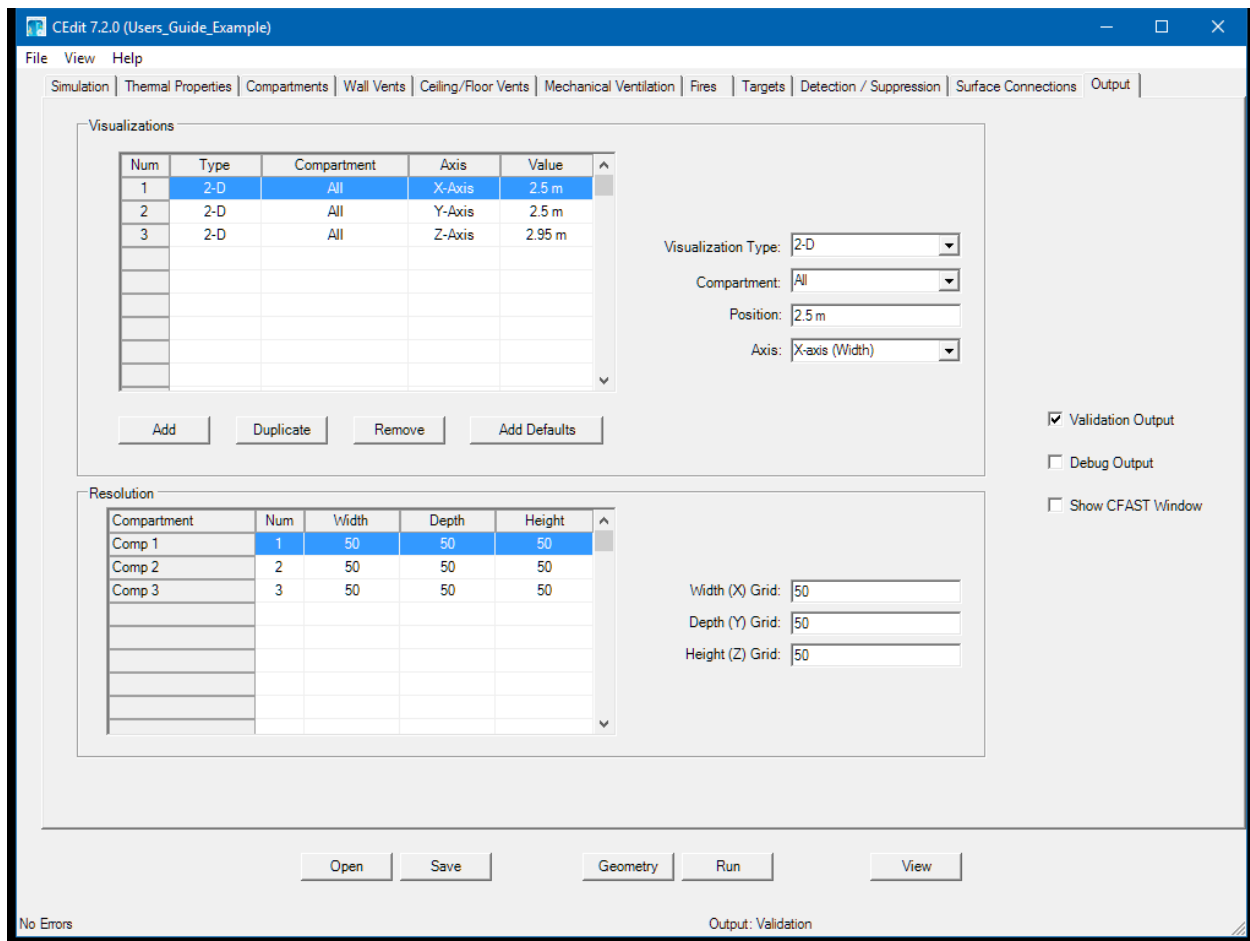


Figure 11.1: The CFAST Visualizations Tab.

11.2 Visualization Resolution

By default, slice files are generated with a grid of 50 data points in each direction for each compartment specified. If desired, the grid spacing can be adjusted up or down individually by compartment. Specifying a larger number of data points can *dramatically* slow program execution since the gas temperature and velocity are evaluated at each grid location every time a Smokeview output is specified. The default value should be appropriate for most simulations.

Width (X) Grid (default units: n/a, default value: 50): slices included along the X axis for each compartment are uniformly divided into the specified number of data points.

Width (Y) Grid (default units: n/a, default value: 50): slices included along the Y axis for each compartment are uniformly divided into the specified number of data points.

Width (Z) Grid (default units: n/a, default value: 50): slices included along the Z axis for each compartment are divided into the specified number of data points.

Sample visualizations are included below.

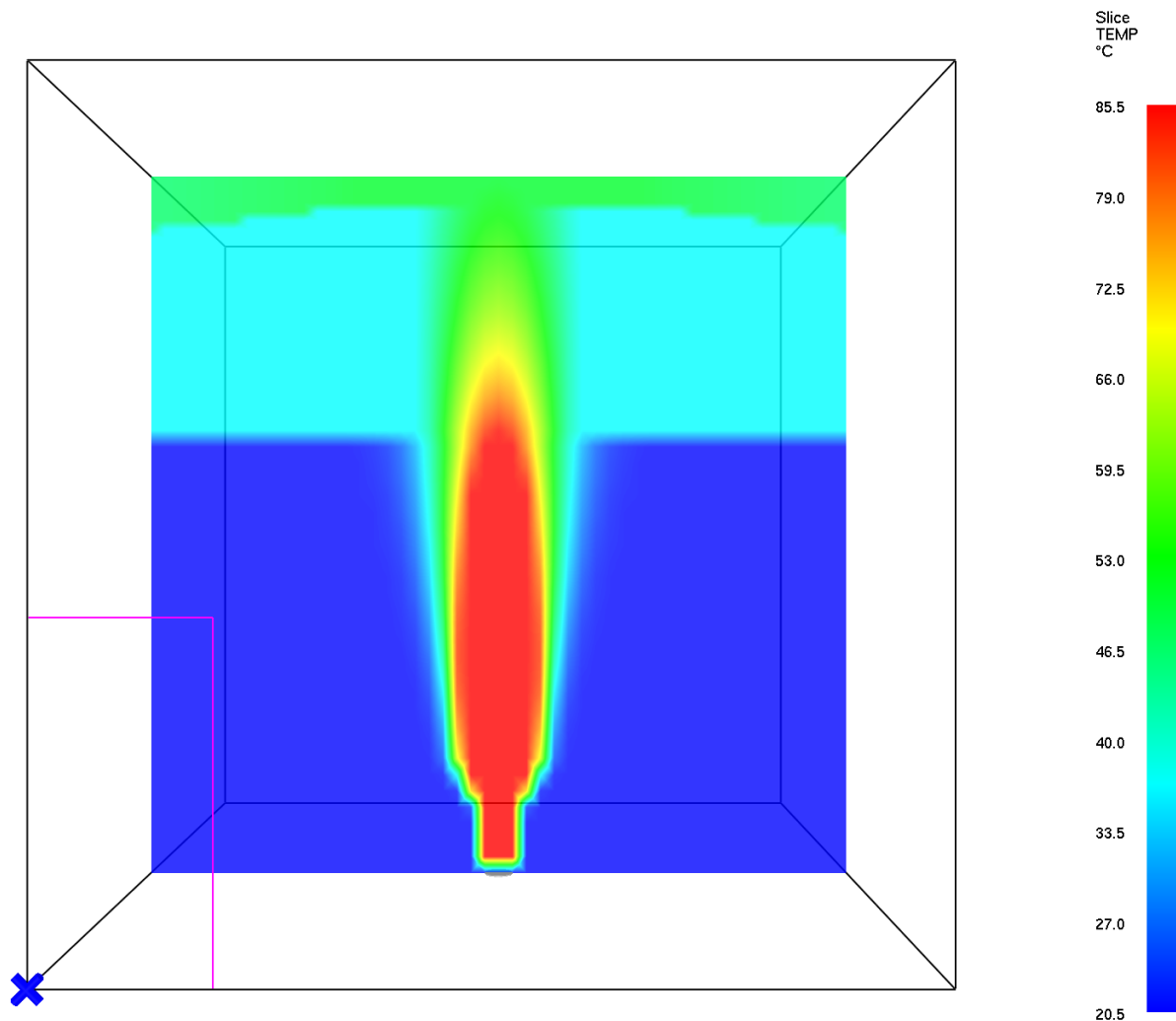


Figure 11.2: Smokeview Visualization of Gas Temperature with a Single Fire

11.3 Output Options

By default, CFAST generates a set of output files that includes a formatted readable output and a set of spreadsheet files. Options are available to modify the output files. The default output should be appropriate for most simulations.

CFAST Validation Output If checked, this item directs the CFAST model to output abbreviated headings for spreadsheet columns that are better for automated processing of the data.

Total Mass Output If checked, this item directs the CFAST model to replace the flow output with total mass flow through (mechanical) vents rather than the default flow rate values.

Debug Output If checked, CFAST will create a detailed output spreadsheet that contains values of all the solution variables at each successful solution time step. This file is typically only of use to model developers diagnosing a problem with the model.

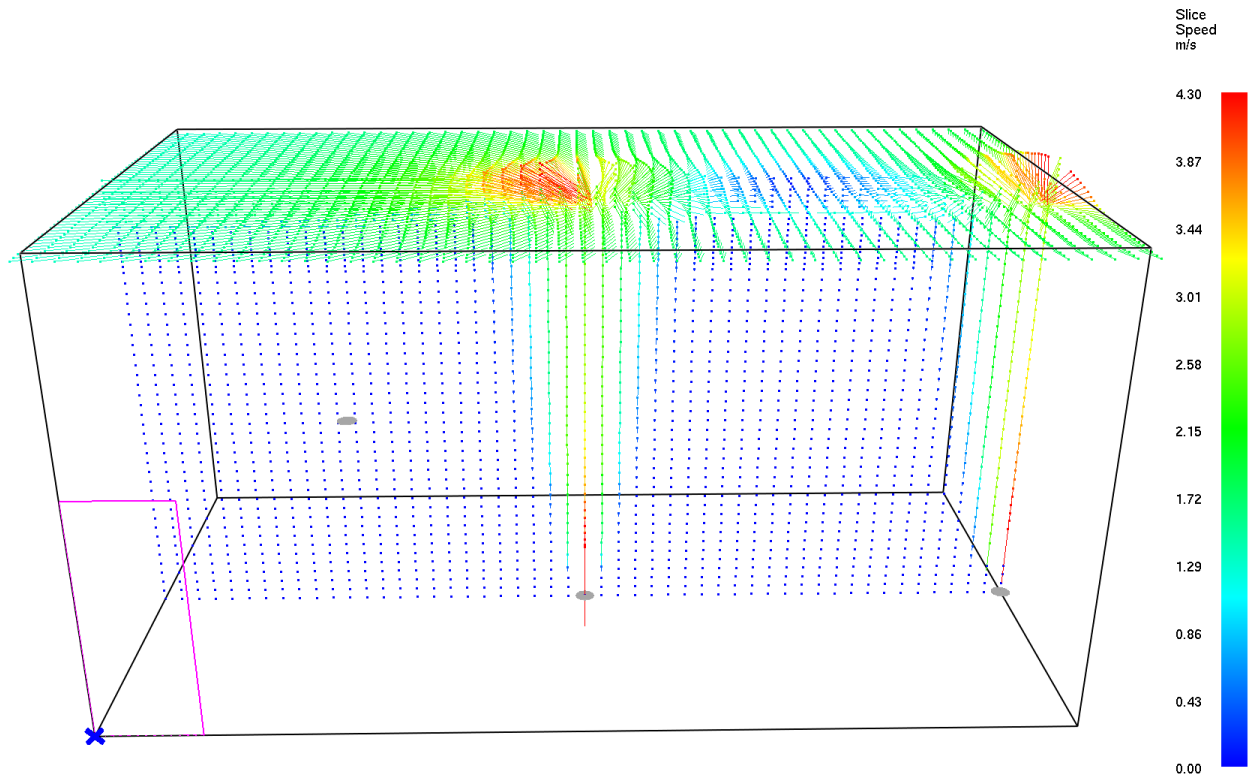


Figure 11.3: Smokeview Visualization of Gas Velocity with Two Fires

Show CFAST Window If checked, this item allows the user to see the windows command prompt that is used to execute the CFAST model when the Model Simulation, CFAST menu item is used. By default, this is not checked. Normally, this can be left unchecked. For troubleshooting, this can be selected to see additional details of the calculation as it progresses.

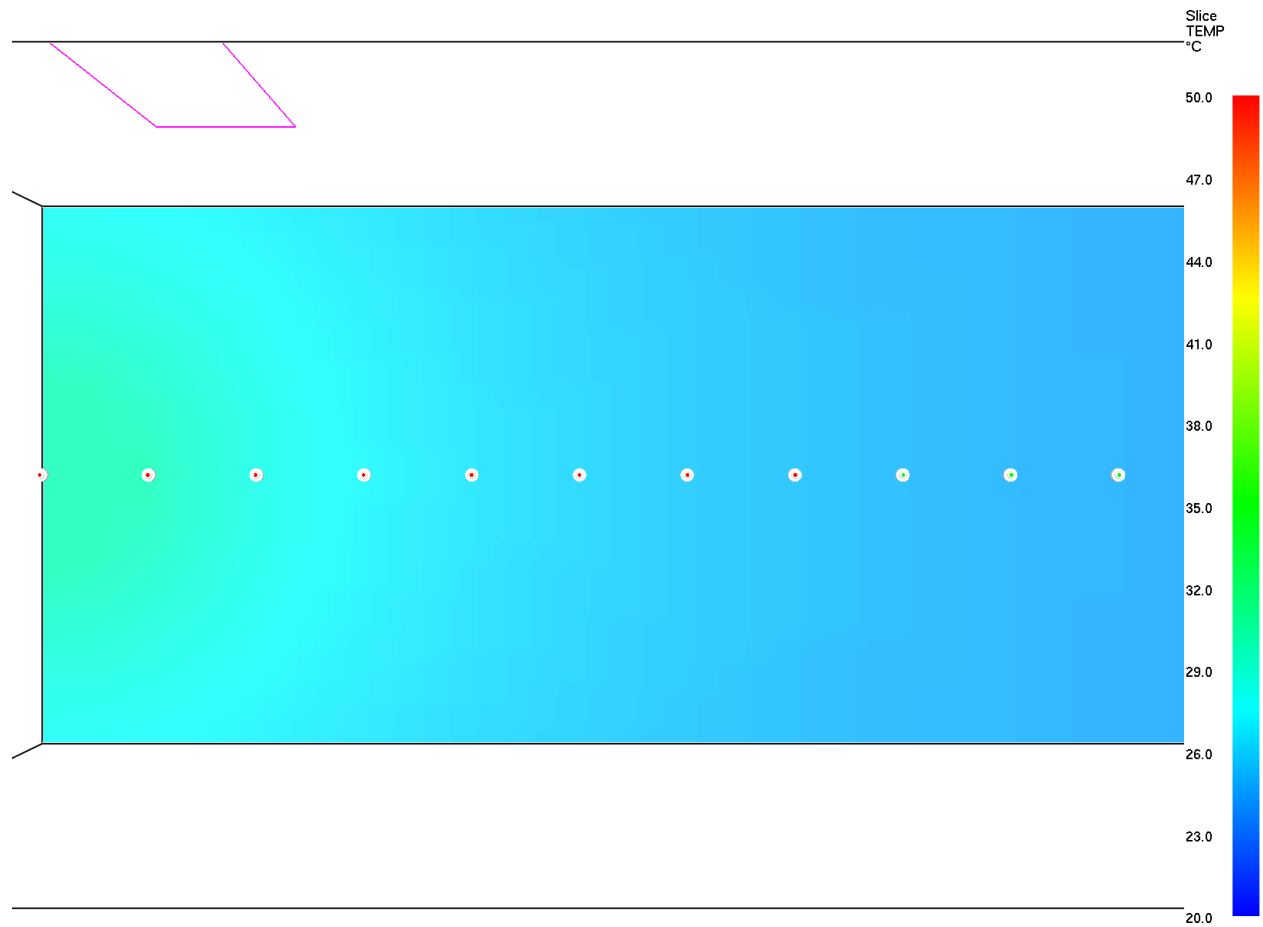


Figure 11.4: Smokeview Visualization of Detector Activation in a Corridor

Chapter 12

Output from CFAST

The output of CFAST includes the temperatures of the upper and lower gas layers within each compartment, the ceiling/wall/floor temperatures within each compartment, the visible smoke and gas species concentrations within each layer, target temperatures and sprinkler activation time. The amount of information can be very large, especially for complex geometries and long simulations.

12.1 Compact Output

The default output to the console is called the compact form, and shows the basic information about a scenario, including layer temperatures and the size of fires. Default text output provides a simple overview for the user to make sure the case runs as expected.

Time = 1800.0 seconds.

Compartment	Upper Temp. (C)	Lower Temp. (C)	Inter. Height (m)	Pyrol Rate (kg/s)	Fire Size (W)	Pressure (Pa)	Ambient Target (W/m^2)
1	113.4	33.3	1.4	1.393E-02	3.000E+05	-0.790	523.
Outside				0.00			

The first column contains the compartment number. On each row with its compartment number from left to right is the upper layer temperature, lower layer temperature, the height of the interface between the two layers, the total pyrolysis rate, and finally the total fire size. The only value given for the outside is the total heat release rate of fires venting to the outside.

12.2 Detailed Outputs

The following sections describe each of the outputs from the model. Each section refers to a specific part of the print out and appears in the order the output appears. A description of each option follows.

12.2.1 Output for Initialization

This option prints the initial conditions to the output before the actual run starts. This merely mimics the inputs specified by the user in the input data file. The initial conditions break down into seven sections. Each is described below with the section name. The following explanation uses the output from the case `Users_Guide_Example.in` which is included in the distribution. Please note, there are no mechanical ventilation, horizontal vents or detectors in this example, so the section discussing these phenomena are from additional data files.

Overview

The overview gives a general description of the case. The output is fairly self explanatory. “Doors, ...” is the total number of horizontal natural flow vent connections in all compartments of the simulation. “Ceil. Vents, ...” gives the total number of vertical natural flow vent connections in all compartments of the simulation. The last header on the line “MV Connections” has the total number mechanical flow connections to all compartments in the simulation. Times in these outputs come from the `TIMES` input. All times are in s.

CFAST

```
Version      : CFAST 7.2.0
Revision     : Gitv7.0.1-132-gf03a791
Revision Date : Tue Feb 2 12:54:53 2016 -0500
Compilation Date : Tue 02/02/2016 12:55 PM

Data file: C:\Users\rpeacoc\Documents\Visual Studio 2013\Projects\cfast\Bin\Data\Users\_Guide\_Example.in
Title: Users Guide Example Case
```

OVERVIEW

Compartments	Doors, ...	Ceil. Vents, ...	MV Connects
3	3	1	2
Simulation Time (s)	Output Interval (s)	Smokeview Interval (s)	Spreadsheet Interval (s)
3600	50	10	10

Ambient Conditions

This section, like the overview section, needs little elaboration. It gives the starting atmospheric conditions for the simulation both for outside and inside the structure. Data for these outputs come from the `TAMB` and `EAMB` inputs. Temperatures are in K, pressure in Pa, elevations in m, and wind speed in m/s. Wind Power is the dimensionless power law coefficient from the `WIND` input.

AMBIENT CONDITIONS

Interior Temperature (C)	Interior Pressure (Pa)	Exterior Temperature (C)	Exterior Pressure (Pa)
20.	101325.	20.	101325.

Compartments

The compartments section gives a summary of the geometry for the simulation. A simple table summarizes the geometry with compartments running down the page in numerical order. The various dimensions for each compartment are on the row with its compartment number. Two columns need explanation. The second to last column “Ceiling Height” gives the height of the ceiling relative to the station height in the Ambient Conditions section. Similarly the “Floor Height” refers to the height of the floor above the station height.

COMPARTMENTS

Compartment	Name	Width (m)	Depth (m)	Height (m)	Floor Height (m)	Ceiling Height (m)
1	Comp 1	5.00	5.00	3.00	0.00	3.00
2	Comp 2	5.00	5.00	3.00	0.00	3.00
3	Comp 3	5.00	5.00	3.00	3.00	6.00

Horizontal Natural Ventilation

This is the first table in the vent connections section. Each row in the table characterizes one vent. The first two columns contain the two compartments connected by the vent. Each vent is ordered first by the lower number of the two compartments and then the numeric order of the second compartment. The third column gives the vent number. Column four is the width of the vent. The next two columns report the sill and soffit height for the vent relative to the floor of the first compartment. The seventh and eighth columns have a second listing of the sill and soffit height, this time relative to the station height.

VENT CONNECTIONS

Horizontal Natural Flow Connections (Doors, Windows, ...)

From Compartment	To Compartment	Vent Number	Width (m)	Sill Height (m)	Soffit Height (m)	Open/Close Type (m)	Trigger Value (C/W/m^2)	Target	Initial Time (s)	Initial Fraction	Final Time (s)	Final Fraction
Comp 1	Outside	1	1.00	0.00	2.00	Time			0.00	1.00	0.00	1.00
Comp 1	Comp 2	1	1.00	0.00	2.00	Time			0.00	1.00	0.00	1.00
Comp 3	Outside	1	1.00	1.00	2.00	Time			0.00	1.00	0.00	1.00

From compartment, to compartment, vent number, width, sill height, and soffit height all come directly from the HVENT specifications in the input data file. Vent opening and closing information can be specified by time, by an associated time / fraction history by a RAMP input or by an associated target to trigger a change in the vent opening by temperature or heat flux.

Vertical Natural Ventilation

The first column is the upper compartment. The upper compartment is the compartment where the vent opens into the floor. The second column is the lower compartment where the vent is in the ceiling. Each vent connection between compartment pairs is also identified by a vent number index beginning with 1. The fourth column describes the shape of the vent, which can be either round or square. The fifth column gives the area of the vent. Vent opening and closing information can be specified by time, by an associated time / fraction history by a RAMP input or by an associated target to trigger a change in the vent opening by temperature or heat flux.

Vertical Natural Flow Connections (Ceiling, ...)

Top Compartment	Bottom Compartment	Vent Number	Shape	Area (m ²)	Open/Close Type	Trigger Value (C/W/m ²)	Target	Initial Time (s)	Initial Fraction	Final Time (s)	Final Fraction
Comp 3	Comp 2	1	Round	1.00	RAMP # 1						

Top compartment, bottom compartment, shape, and area come from the VVENT specifications in the input data file. Relative height is the height of the vent above the floor of the bottom compartment and absolute height is the height of the vent above the station elevation.

Mechanical Flow Connections

This section lists all connections to compartments and fans that connect between compartments. The table lists, in order, the compartments connected by the fan, a numeric index assigned to the fan beginning with 1. A fan actually draws air from the first or “from” compartment and pushes it to the second or “to” compartment. The fourth column is the cross-sectional area of the duct connection to the chosen compartment. Vent opening and closing information can be specified by time, by an associated time / fraction history by a RAMP input or by an associated target to trigger a change in the vent opening by temperature or heat flux.

FANS

From Compartment	To Compartment	Fan Number	Area (m ²)	Flowrate (m ³ /s)	Open/Close Type	Trigger Value (C/W/m ²)	Target	Initial Time (s)	Initial Fraction	Final Time (s)	Final Fraction
Outside	Comp 1	1	0.00	0.02	Time			0.00	1.00	0.00	1.00
Comp 2	Outside	2	0.00	0.02	Time			0.00	1.00	0.00	1.00

Ventilation Opening Ramp Specifications

Opening and closing of vents in CFAST can be specified by a series of times and opening fractions for a specified vent. By default, all vents are open at the beginning of a simulation and remain open throughout the simulation. With the RAMP input, the opening of a vent can change of time.

VENT RAMPS

Type	From Compartment	To Compartment	Vent Number		(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)	(s)
V	Comp 3	Comp 2	1	Time	0	100	500						
				Fraction	0.00	0.50	1.00						

Thermal Properties

The thermal properties section is broken into two parts. The first part is a table that lists the material for each surface of each compartment. The compartments appear as rows down the page in numerical order. From left to right next to the compartment number comes the material for the ceiling, wall and floor. The second part lists the properties of each material used in the simulation. For each listing of a material, the name is followed by the conductivity, specific heat, density, thickness and emissivity. In addition to materials for compartment surfaces, any thermal properties specified for targets are also listed (this may include thermal properties for gaseous materials specified as fire sources in a simulation).

THERMAL PROPERTIES

Compartment	Ceiling	Wall	Floor
Comp 1	CONCRETE	CONCRETE	CONCRETE
Comp 2	CONCRETE	CONCRETE	CONCRETE
Comp 3	CONCRETE	CONCRETE	CONCRETE

Name	Conductivity	Specific Heat	Density	Thickness	Emissivity
CONCRETE	1.75	1.000E+03	2.200E+03	0.150	0.940
DEFAULT	0.120	900.	800.	1.200E-02	0.900

Material choices of the ceiling, walls, and floors come from the CEILI, WALLS, and FLOOR specifications in the input data file. Units for thermal properties are standard S.I. units. For thermal conductivity, W/m K; for specific heat, J/kg K; for density, kg/m³; for thickness, m; emissivity is dimensionless.

Fires

The fire section lists all the information about the main fire and any object fires that might exist. All the information for each fire is listed separately. If there is a main fire, it comes first. Each fire listing has the same form. First is the name of the fire followed by a list of general information. Listed left to right is the compartment the fire is in, the type of fire, the initial x (width), y (depth), z (height) position of the fire, the relative humidity, the lower oxygen limit, and finally the radiative fraction for the fire.

A table of time history curves for the fire follows. The table contains all the time history curves for the fire. Each row on the table is a specific time given in the left most column. The rest of the columns give the values at that particular time. The column headers indicate each input quantity and correspond to specific keywords in the fire definition. The headings are defined as follows: ‘Mdot’ is pyrolysis rate; ‘Hcomb’ is the heat of combustion; ‘Qdot’ is the heat release rate; ‘Zoffset’ is height of the fire above the base z-position; ‘Soot’ is the fraction of the fuel mass converted to soot during combustion; ‘CO’ is the fraction of the fuel mass converted to carbon monoxide during combustion; ‘HCN’ is the fraction of the fuel mass converted to hydrogen cyanide during combustion; ‘HCl’ is the fraction of the fuel mass converted to hydrogen chloride during combustion; ‘CT’ is the concentration-time product; and ‘TS’ is the fraction of fuel mass converted to trace species during combustion.

FIRES

Name: bunsen Referenced as object # 1 Normal fire

Compartment	Fire Type	Position (x,y,z)			Relative Humidity	Lower O2 Limit	Radiative Fraction
Comp 1	Constrained	2.50	2.50	0.00	50.0	15.00	0.33

Chemical formula of the fuel

Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
1.000	4.000	0.000	0.000	0.000

Time (s)	Mdot (kg/s)	Hcomb (J/kg)	Qdot (W)	Zoffset (m)	Soot (kg/kg)	CO (kg/kg)	HCN (kg/kg)	HCl (kg/kg)	TS (kg/kg)
0.	0.0	5.00E+07	0.0	0.0	0.0	1.05E-03	0.0	0.0	0.0
60.	2.00E-03	5.00E+07	1.00E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0
120.	3.00E-03	5.00E+07	1.50E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0
180.	4.00E-03	5.00E+07	2.00E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0
240.	3.00E-03	5.00E+07	1.50E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0
300.	2.50E-03	5.00E+07	1.25E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0

360.	2.00E-03	5.00E+07	1.00E+05	0.0	0.0	1.05E-03	0.0	0.0	0.0
420.	1.80E-03	5.00E+07	9.00E+04	0.0	0.0	1.05E-03	0.0	0.0	0.0
480.	1.60E-03	5.00E+07	8.00E+04	0.0	0.0	1.05E-03	0.0	0.0	0.0
540.	1.50E-03	5.00E+07	7.50E+04	0.0	0.0	1.05E-03	0.0	0.0	0.0
1800.	1.50E-03	5.00E+07	7.50E+04	0.0	0.0	1.05E-03	0.0	0.0	0.0

Name: Wood_Wall Referenced as object # 2 Wall fire

Compartment	Fire Type	Position (x,y,z)			Relative Humidity	Lower O2 Limit	Radiative Fraction
Comp 2	Constrained	2.50	5.00	0.00	50.0	15.00	0.33

Chemical formula of the fuel				
Carbon	Hydrogen	Oxygen	Nitrogen	Chlorine
6.000	10.000	5.000	0.000	0.000

Time (s)	Mdot (kg/s)	Hcomb (J/kg)	Qdot (W)	Zoffset (m)	Soot (kg/kg)	CO (kg/kg)	HCN (kg/kg)	HCl (kg/kg)	TS (kg/kg)
0.	0.0	1.81E+07	0.0	0.0	2.00E-02	2.00E-02	0.0	0.0	0.0
8000.	5.52E-02	1.81E+07	1.00E+06	3.0	2.00E-02	2.00E-02	0.0	0.0	0.0

All of the inputs for the main fire come from the fire specifications in the input data file. Data for the object fire comes from the object data file included with the CFAST software. Units for most values are included in the output. Fire position is in m, relative humidity is in %, lower oxygen limit is in volume percent, and pyrolysis temperature is in K.

Targets

The entry for targets shows the orientation of additional targets specified in the data file. Targets explicitly specified in the data file are listed first in the order they are included in the data file. Each target is numbered based on the order of the target specifications in the input data file. The compartment number, position of the target within the compartment, direction of the front face of the target object expressed as a normal unit vector to the surface, and object material.

TARGETS

Target	Compartment	Position (x, y, z)			Direction (x, y, z)			Material
1 Targ 1	Comp 1	2.20	1.88	2.34	0.00	0.00	1.00	CONCRETE

All of the inputs for targets come from the TARGE command in the input data file. Direction is specified as a unit vector as described in the section on target input. Units for position and direction are all in m.

Detectors and Sprinklers

The entry for each detector or sprinkler shows the compartment and position of the device and its activation characteristics. For smoke detectors, activation is based on the smoke obscuration as the position of the detector; for heat detectors and sprinkler, the temperature of the detector.

DETECTORS/ALARMS/SPRINKLERS

Target	Compartment	Type	Position (x, y, z)			Activation Obscuration (%/m)	Temperature (C)	RTI (m s) ^{1/2}	Spray Density (m/s)
			(m)	(m)	(m)				
1	Comp 1	HEAT	2.50	2.50	2.97		73.89	100.00	

All of the inputs for detectors and sprinklers come from the DETEC command in the input data file. Units for position are all in m.

12.2.2 Output for Main Variables

The normal print out is the first information printed at each time interval. This information includes the layer temperatures, interface height, volume of the upper layer, layer absorption coefficients, and compartment pressure (relative to ambient).

Time = 3600.0 seconds.

Compartment	Upper Temp. (C)	Lower Temp (C)	Inter. Height (m)	Upper Vol (m ³)		Upper Absor (m ⁻¹)	Lower Absorb (m ⁻¹)	Pressure (Pa)
Comp 1	78.70	23.01	1.404	40.	(53%)	0.235	0.100	-0.430
Comp 2	176.5	44.97	1.495	38.	(50%)	0.240	9.153E-02	-1.49
Comp 3	104.3	27.58	1.248	44.	(58%)	0.241	9.556E-02	-0.336

The second table of the normal print out has information about the fires. In essence it is two tables joined. The first part lists information by fire. It starts with the main fire, if there is one, and then the object fires down the page. The fires are listed in the second column followed by the plume flow rate, the pyrolysis rate, the fire size, and flame height. The next three columns are then skipped. The next column with information is the amount of heat given off by each fire convectively, followed by the amount of heat given off radiantly. The last two columns give the total mass pyrolyzed and the amount of trace species produced. The second part starts after all the fires have been individually listed. It gives the totals for all fires in each compartment. The first column has the compartment number. The compartments start at one and are listed down the page in order. The third to fifth columns are the same as the first part except the values are totals for the compartment and not just for one fire. The sixth column has the total heat release rate that occurs in the upper layer. The next column has the same total in the lower layer. The eighth column has the total size of vent fires in the compartment.

FIRES

Compartment	Fire	Plume Flow Rate (kg/s)	Pyrol Rate (kg/s)	Fire Size (W)	Flame Height (m)	Fire in Upper (W)	Fire in Lower (W)	Vent Fire (W)	Convec. (W)	Radiat. (W)	Pyrolysate (kg)	Trace (kg)
	bunsen	8.571E-05	1.440E-07	7.20	0.00				4.82	2.37	1.02	0.00
	Wood_Wal	0.974	2.486E-02	4.500E+05	0.382				3.015E+05	1.485E+05	44.8	0.00
Comp 1		8.571E-05	1.440E-07	7.20		0.00	7.20	0.00				
Comp 2		0.974	2.486E-02	4.500E+05		0.00	4.500E+05	0.00				

Flame height is calculated from the work of Heskestad [15]. The average flame height is defined as the distance from the fuel source to the top of the visible flame where the intermittency is 0.5. A flame intermittency of 0.5 means that the visible flame is above the mean 50 % of the time and below the mean 50 % of the time.

12.2.3 Output for Wall Surfaces, Targets, and Detectors/Sprinklers

The printed output provides two tables displaying information about wall surface or target temperatures and fluxes, and heat detectors or sprinklers. The left most column specifies the compartment number; followed by four columns providing the temperatures of the bounding surfaces of the compartment in contact with the ceiling, upper wall surface (in contact with the upper layer gases), lower wall surface (in contact with the lower layer gases), and floor, in that order. Next comes information about targets in the compartment, with each target listed on a separate line. Information in the columns includes the surface temperature of the target, net heat flux to the target, and

the percentage of that net flux that is due to radiation from the fire, radiation from compartment surfaces, radiation from the gas layers, and convection from the gas surrounding the target. CFAST includes one target in the center of the floor for all compartments. Information on additional targets specified by the user in the input data file are also included, in the order specified in the input file.

For smoke detectors, heat detectors, and sprinklers, the temperature of the device, its current state (activated or not), and the nearby gas temperature and velocity are included.

SURFACES AND TARGETS

Compartment	Ceiling Temp. (C)	Up wall Temp. (C)	Low wall Temp. (C)	Floor Temp. (C)	Target	Gas Temp. (C)	Surface Temp. (C)	Internal Temp. (C)	Flux To Target (W/m^2)	Fire Rad. (W/m^2)	Surface Rad. (W/m^2)	Gas Rad. (W/m^2)	Convect. (W/m^2)
Comp 1	31.8	30.8	22.5	23.4	Targ 1	78.7	30.4	24.5	503.	0.00	341.	209.	347.
Comp 2	133.	61.8	86.2	51.3									
Comp 3	34.2	34.2	22.7	23.1									

DETECTORS/ALARMS/SPRINKLERS

Number	Compartment	Type	Sensor	Smoke	Vel (m/s)	Obs (1/m)	Activated
			Temp (C)	Temp (C)			
1	Comp 1	HEAT	7.757E+01	7.870E+01			YES

In all cases, the flux to/from a target is net radiation or net convection. That is, it is the incoming minus the outgoing. So while a target or object is heating, the flux will be positive, and once it starts to cool, the flux will be negative. Values for radiation from fires (fire rad.), radiation from surfaces (surface rad.), radiation from the gas layers (gas rad.), and convection from surfaces (convect) are expressed as the net flux to target (flux to target). Positive values indicate heat gains by the target and negative values indicate heat losses.

12.2.4 Output for Gas Species

The output has two tables displaying information about the amounts of species in each layer. The species information follows the normal print out. The first table gives species volume fractions for the upper layers of all the compartments and the second reports the same for the lower layers of all the compartments. Again the compartments are listed down the page and the information across the page. The species are each given in one of several different terms. Below each header are the units for the given value. Most of the headers are simply the chemical formula for the species being tracked (Elemental nitrogen, oxygen, carbon dioxide, carbon monoxide, hydrogen cyanide, hydrochloric acid, and water). However, several are not obvious. “TUHC” is the total unburned hydrocarbons or the pyrolyzed fuel that hasn’t burned yet. “OD” is the optical density, which is a measure of the amount of smoke. “TS” is trace species.

UPPER LAYER SPECIES

Compartment	N2 (%)	O2 (%)	CO2 (%)	CO (%)	HCN (%)	HCL (%)	TUHC (%)	H2O (%)	OD (1/m)	TS kg
Comp 1	76.7	17.8	2.24	4.617E-02	0.00	0.00	0.00	3.13	1.69	0.00
Comp 2	76.4	17.4	2.58	5.320E-02	0.00	0.00	0.00	3.43	1.53	0.00
Comp 3	76.5	17.4	2.52	5.205E-02	0.00	0.00	0.00	3.38	1.78	0.00

LOWER LAYER SPECIES

Compartment	N2 (%)	O2 (%)	CO2 (%)	CO (%)	HCN (%)	HCL (%)	TUHC (%)	H2O (%)	OD (1/m)	TS kg
Comp 1	78.3	20.4	7.400E-02	1.526E-03	0.00	0.00	0.00	1.23	6.656E-02	0.00

Comp 2	78.3	20.4	8.491E-02	1.751E-03	0.00	0.00	0.00	1.24	7.108E-02	0.00
Comp 3	78.4	20.5	4.208E-10	8.678E-12	0.00	0.00	0.00	1.16	3.726E-10	0.00

The report by species for are percent by volume. Optical depth per meter is a measure of the visibility in the smoke. This is covered in detail in the comment on visibility in the section on fires and species specification. Trace species (TS) is the total mass of the trace species that is present in the layer in kilograms. It is an absolute measure and not percent or density.

12.2.5 Output for Vent Flows

Information about vent flow is obtained by using this option. It includes a section detailing mass flow through horizontal, vertical, and mechanical vents. There are two forms for the vent flow. The first is flow through the vents as mass per second. The alternative, obtained with the total mass flow output option on the 'Run!,' 'Output Options' menu, gives the total mass which has flowed through the vent(s) and the relative mass of trace species divided by the total mass of trace species produced up to the current time.

The section for vent flow is titled "FLOW THROUGH VENTS (kg/s)." Because flow is always given in positive values, each vent is listed twice, once for flow going from compartment A to compartment B (labelled as "Flow relative to 'from'") and a second time for flow from B to A (labelled as "Flow relative to 'To'"). As the example below shows, the first column specifies the vent, including the type of vent (an "H" in this column stands for horizontal flow, such as through a doorway or window; a "V" here would mean vertical flow, such as through an opening in the ceiling, and an "M" stands for a mechanical ventilation connection) and the compartment from which the flow comes. The second column lists the name of the compartment. Up to six additional columns detail the flow at this vent. Flow into and out of the compartment through the vent in the upper and lower layers are included.

FLOW THROUGH VENTS (kg/s)

Vent	From/Bottom	To/Top	Flow relative to 'From'		Lower Layer		Flow Relative to 'To'		Lower Layer	
			Upper Layer Inflow	Upper Layer Outflow	Inflow	Outflow	Upper Layer Inflow	Upper Layer Outflow	Inflow	Outflow
H 1	Comp 1	Comp 2	0.2996E+00	0.5729E-02	0.1406E-01	0.9832E+00	0.1469E-02	0.2904E+00	0.9874E+00	0.2322E-01
H 2	Comp 1	Outside		0.2891E+00	0.9410E+00		0.2891E+00			0.9410E+00
H 3	Comp 3	Outside		0.6894E+00	0.1667E-01	0.1752E-01	0.7069E+00			0.1667E-01
V 1	Comp 2	Comp 3		0.6855E+00		0.1217E-02	0.6868E+00			
M 1	Outside	Comp 1				0.2391E-01	0.2391E-01			
M 3	Comp 2	Outside		0.1559E-01					0.1559E-01	

TOTAL MASS FLOW THROUGH MECHANICAL VENTS (kg)

To Compartment	Through Vent	Upper Layer		Lower Layer		Trace Species	
		Inflow	Outflow	Inflow	Outflow	Vented	Filtered
Comp 1	M Node 2	0.8585E+02		0.2200E+00			
Comp 2	M Node 3		0.6754E+02		0.4443E+00		
Outside	M Node 1				0.8607E+02		
	M Node 4			0.6798E+02			

An alternative printout is provided that shows total (mass) flow through vents. At present this is confined to mechanical ventilation (It applies only to vents which can be filtered, in this case mechanical ventilation). The last column is obtained by summing the outflow/inflow for each vent and then dividing that sum by the total trace species produced by all fires. For details on this value, see the section on output listing for fires.

12.3 Spreadsheet Output

CFAST can generate a number of output files in a plain text spreadsheet format. These files capture a snap shot of the modeling data at an instant of time. This instance is determined by the fourth entry on the TIMES line of the data file. *However*, there are events which can occur in between these reporting periods. Examples are the ignition of objects and the activation of detectors or sprinklers. These are *not* reported in these output files.

12.3.1 Primary Output Variables (project_n.csv)

There are two sets of information in this file. The first includes compartment information such as layer temperature. This is output by compartment and there are eight entries for each compartment plus a column that indicates the current simulation time:

Time (s)

Upper Layer Temperature (°C)

Lower Layer Temperature (°C)

Layer Height (m)

Upper Layer Volume (m³): total volume of the upper layer. This is just the floor area times the difference between the ceiling height and the layer height.

Pressure (Pa): pressure at compartment floor relative to the outside at the absolute height of the floor.

Ambient Temp Target Flux (W/m²): net heat flux to the center of the floor assuming the floor is at ambient temperature. This is largely useful to estimate the tenability of the compartment.

Floor Temp Target Flux (W/m²): net heat flux to the center of the floor.

HRR Door Jet Fires (W): total heat release rate of all door jet fires *adding* heat to this compartment.

The second set of information is for fires. There are seven entries per fire. This information is displayed for each fire :

Plume Entrainment Rate (kg/s): current mass entrained from the lower layer into the plume for this fire.

Pyrolysis Rate (kg/s): current rate of mass loss for this fire.

HRR (W): current total heat release rate for this fire. This is just the sum of the heat release rate for the lower layer and upper layer for this fire.

HRR Lower (W): current heat release rate for burning in the lower layer for this fire.

HRR Upper (W): current heat release rate for burning in the upper layer for this fire.

Flame Height (m): current calculated flame height for this fire.

Convective HRR (W): current rate of heat release by convection for this fire. The remainder is released by radiation to the surroundings.

Total Pyrolysate Released (kg): total mass released by the fire up to the current time.

Total Trace Species Released (kg): total mass of trace species released by the fire up to the current time.

12.3.2 Species Output (project_s.csv)

At present, there are nine outputs in this file: oxygen (O₂), carbon dioxide (CO₂), carbon monoxide (CO), hydrogen cyanide (HCN), hydrogen chloride (HCL), water vapor (H₂O), optical depth (OD), concentration-time dose (CT) and trace species (TS). This set of nine is enumerated for the upper and lower layer, and are done sequentially by compartment.

Time (s)

N₂ Upper/Lower Layer (mol %): nitrogen concentration in the upper (or lower) layer in the current compartment

O₂ Upper/Lower Layer (mol %): oxygen concentration in the upper (or lower) layer in the current compartment

CO₂ Upper/Lower Layer (mol %): carbon dioxide concentration in the upper (or lower) layer in the current compartment

CO Upper/Lower Layer (mol %): carbon monoxide concentration in the upper (or lower) layer in the current compartment (multiply by 10 000 to convert to ppm)

HCN Upper/Lower Layer (mol %): HCN concentration in the upper (or lower) layer in the current compartment (multiply by 10 000 to convert to ppm)

HCL Upper/Lower Layer (mol %): HCl concentration in the upper (or lower) layer in the current compartment (multiply by 10 000 to convert to ppm)

H₂O Upper/Lower Layer (mol %): water vapor concentration in the upper (or lower) layer in the current compartment

Optical Density Upper/Lower Layer (m⁻¹): optical density in the upper (or lower) layer in the current compartment

Trace Species Upper/Lower Layer (kg): total mass of trace species in the upper (or lower) layer in the current compartment

12.3.3 Vent Flow (project_f.csv)

The first columns in this file pertain to the horizontal flow through vertical vents such as windows and doors. There are two types of output, first to and from the outside, and second for interior compartments. The flow is broken down to flow in and out of the compartments. For flow to and from the outside (compartment N) there are two entries.

Time (s)

HVENT Inflow Vent # 1 Outside-1 (kg/s): mass flow into the current compartment through the current horizontal flow (door/windows) vent connected to the current compartment

HVENT Outflow Vent # 1 Outside-1 (kg/s): mass flow out of the current compartment through the current horizontal flow (door/windows) vent connected to the current compartment

The second set of columns pertain to the vertical flow through horizontal vents. There are two entries for each vent in each compartment, showing the total flow into or out of each vent in each compartment.

VVENT Inflow Vent # 1-Outside (kg/s): mass flow into the current compartment through the current vertical flow (ceiling/floor) vent connected to the current compartment

VVENT Outflow Vent # 1-Outside Vent Connection at Node 1-2 (kg/s): mass flow out of the current compartment through the current vertical flow (ceiling/floor) vent connected to the current compartment

The third set of columns pertain to the mechanical ventilation. Once again, there will be an entry for each node/compartment pair, showing the total flow into or out of the compartment through this node. In addition, the total amount of trace species through filters and captured on filters in mechanical ventilation connected to the compartment is included.

MVENT Inflow Vent Connection at Node 1-2 (kg/s): mass flow into the current compartment through the current mechanical flow (HVAC) vent connected to the current compartment

MVENT Outflow (kg/s): current mass flow out of the compartment through the current mechanical flow (HVAC) vent connected to the current compartment

MVENT Trace Species Flow Fan at Node 2 (kg/s): current total mass of trace species flowing through the filter at the fan in the current mechanical vent connected to the current compartment

MVENT Trace Species Filtered Fan at Node 2 (kg/s): total mass of trace species captured on the filter at the fan in the current mechanical vent connected to the current compartment

12.3.4 Surface and Target Temperature and Heat Flux (project_w.csv)

This file provides information on surface and target temperatures and flux, and reports on the current state of detectors and sprinklers (as a sub-set of detectors). The output is in three sections, one for wall surface temperatures, one for target temperature and heat flux, and one for detector/sprinkler temperature and activation. The first set of columns pertain to the temperature of compartment surfaces.

Time (s)

Ceiling Temperature (°C): temperature of the ceiling surface in the current compartment

Upper Wall Temperature (°C): temperature of the wall surface adjacent to the upper layer in the current compartment

Lower Wall Temperature (°C): temperature of the wall surface adjacent to the lower layer in the current compartment

Floor Temperature (°C): temperature of the floor surface in the current compartment

The second set of columns pertain to the user-defined targets included in the simulation.

Target Surrounding Gas Temperature (°C): gas temperature nearby the current target

Target Surface Temperature (°C): temperature of the surface of the current target

Target Center Temperature (°C): interior temperature of the current target

Target Total Flux (kW/m²): total net heat flux to the front surface of the current target

Target Convective Flux (kW/m²): convective heat flux to the front surface of the current target

Target Radiative Flux (kW/m²): total net radiative heat flux to the front surface of the current target

Target Fire Radiative Flux (kW/m²): radiative heat flux from fires to the front surface of the current target

Target Surface Radiative Flux (kW/m²): radiative heat flux from compartment surfaces to the front surface of the current target

Target Gas Radiative Flux (kW/m²): radiative heat flux from the upper and lower gas layers to the front surface of the current target

Target Radiative Loss Flux (kW/m²): radiative heat flux from the current target to surroundings at the calculated temperature of the target

Target Total Gauge Flux (kW/m²): total net heat flux to the front surface of the current target assuming the target radiative losses are at ambient temperature

Target Radiative Gauge Flux (kW/m²): total net radiative heat flux to the front surface of the current target assuming the target radiative losses are at ambient temperature

Target Radiative Loss Gauge Flux (kW/m²): radiative heat flux from the current target to surroundings assuming the target radiative losses are at ambient temperature

The third set of columns pertain to the detector/sprinkler output.

Sensor Temperature (°C): temperature of the current detector / sprinkler

Sensor Activation (none): indicator of activation of the current detector / sprinkler; takes a value of zero if the sensor has not activated and one if it has

Sensor Surrounding Gas Temperature (°C): gas temperature nearby the current detector / sprinkler. This is the ceiling jet temperature at the device location if the device is in the ceiling jet or the appropriate gas layer temperature if the device is lower in the compartment

Sensor Surrounding Gas Velocity (m/s): gas velocity nearby the current detector / sprinkler. This is the velocity of the ceiling jet at the device location if the device is in the ceiling jet or a default value of 0.1 m/s if the device is lower in the compartment

12.4 Error Messages

In some (hopefully rare) cases, a simulation will fail to complete. In those cases, an error message provides guidance to the user on possible reasons for the failure. The message will contain an error number which provides a reference to additional information from the table below. Most often, these errors result from improper information in the input data files. During initialization of the program for a simulation, CFAST may stop with an error message if the simulation cannot be initialized due to a missing or incorrect file specification. The error codes are as follows:

- 100** program called with no arguments (no input file)
- 101** internal error in fire input; code for a free burning fire should not be reachable
- 102** project file does not exist
- 103** total file name length including path is more than 256 characters
- 104** one of the output files is not accessible (for example, if a CFAST case with this name is already running)
- 105** error writing to an output file (openoutputfiles)
- 106** a system fault has occurred. Applies to all open/close pairs once the model is running
- 107** incompatible options
- 108** not currently used
- 109** cannot find/open a file
- 110** error in handling the status input/output

Error codes from 1 to 99 are from the routine which parses the input and will be reported in the .log file. The first set indicates a command with the wrong number of arguments. These errors indicate an error in a particular input command as follows:

- 1** TIMES command
- 2** TAMB command
- 3** EAMB command
- 4** LIMO2 command
- 5** THERMAL or FIRE commands
- 7** MAINF command
- 8** COMPA command
- 10** HVENT command

- 11** EVENT command
- 12** MVENT command
- 23** VVENT command
- 24** WIND command
- 25** INTER command
- 26** MVOPN command
- 28** MVDCT command
- 29** MVFAN command
- 32** OBJECT command
- 34** CJET and DETEC command
- 35** STPMAX command
- 37** VHEAT command
- 39** ONEZ command
- 41** TARGE command
- 46** HALL command
- 47** ROOMA command
- 51** ROOMH command
- 55** DTCHE command
- 56** SETP command
- 58** HHEAT command
- 65** HEATF command

The second set of errors related to parsing the input indicate specific errors with a command as follows:

- 9, compa** Compartment out of range
- 26, inter** Not a defined compartment
- 27, mvopn** Specified node number too large for this system
- 30, mvfan** Fan curve has incorrect specification

31, mvfan Exceeded allowed number of fans

33, object Object must be assigned to an existing compartment

35, detect Invalid DETECTOR specification

36, detect A referenced compartment is not yet defined

38, vheat VHEAT has specified a non-existent compartment

42, target Too many targets are being defined

43, target The compartment specified by TARGET does not exist

44, target Invalid TARGET solution method specified

45, target Invalid equation type specified in TARGET

49, rooma Compartment specified by ROOMA does not exist

52, roomh Compartment specified by ROOMH is not defined

53, roomh ROOMH error on data line

54, roomh Data on the ROOMA (or H) line must be positive

57, setp Trying to reset the SETP parameters

61, hheat HHEAT specification error in compartment pairs

62, hheat Error in fraction for HHEAT

63, object Fire type out of range

64, object The fire must be assigned to an existing compartment

66, heatf The heat source must be assigned to an existing compartment

67, mvent Compartment has not been defined

68, mvent Exceed one of the array bounds, ierror=68 (external), 69 (internal) and 70 (fan)

71, event Undefined vent type

72, inter Specification for interface height is outside of allowable range

73, inter Compartments must be defined in pairs

74, setp The requested SETP command does not exists

75, setp Incorrect file reference

76, setp Cannot read the parameter file

77, setp Unsupported parameter

Errors 400 and above are failures while the model is running. 610 through 685 are failures in the numerical routines; these are rarely seen, but typically result from an internal error in the model.

Chapter 13

Scenario and Software Limits

CFAST is intended for use with a wide variety of fire scenarios. A number of limits to the inputs in the software implementation of the model are noted below.

Maximum simulation time in seconds	86400
Maximum number of compartments	100
Maximum number of horizontal flow (door/window) vent connections that can be included in a single test case	2500
Maximum number of horizontal vent connections between a pair of compartments that can be included in a single test case	25
Maximum number of vertical flow (ceiling/floor) vent connections which can be included in a single test case	200
Maximum number of vertical vent connections between a pair of compartments that can be included in a single test case	1
Maximum total number of connections between compartments and mechanical ventilation systems which can be included in a single test case	200
Maximum number of fans that can be included in a single test cases	100
Maximum number of fires which can be included in a single test case	200
Maximum number of data points for a single fire definition	199
Maximum number of data points in a variable cross-sectional area definition for a single compartment	21
Maximum number of material thermal property definitions which can be included in a single thermal database file	125
Maximum number of targets which can be included in a single test case. In addition, the CFAST model includes a target on the floor of each compartment in the simulation and one for each object fire in simulation.	1000
Maximum number of detectors/sprinklers which can be included in a single test case.	1000

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Appendix A

Structure of the CFAST Input File

The purpose of this appendix is to describe the format of the text-based input file that is generated by the CEdit graphical user interface. A simple input file is listed below. The input values may be integers, real numbers, or text. The input file is a comma-separated ASCII text file and may be edited with a spreadsheet program or any text editor. It is possible to use a word processor but it is important to save the file in ASCII text format and not in a word processing format. Note that some word processors will save punctuation and other characters incorrectly for the simple ASCII text file used by CFAST. It is recommended that the input files be created with the input editor, CEdit, provided as part of the CFAST distribution. In addition to checking the input data for errors, it includes typical ranges for input values to assist in appropriate use of the model.

Each line of the input file consists of a label followed by one or more alphanumeric parameters associated with that input label, separated by commas. The label must always begin in the first space of the line and be in capital letters. Following the label, the values may start in any column, and all values must be separated by a comma. Values may contain decimal points if needed or desired. They are not required.

Inputs are in standard SI units. The maximum line length is 1024 characters, so all data for each keyword must fit in this number of characters.

```
VERSN,7,Users Guide Example Case
!!
!!Scenario Configuration
!!
TIMES,3600,50,50,50
EAMB,293.15,101325,0
TAMB,293.15,101325,0,50
!!
!!Material Properties
!!
MATL,CONCRETE,1.75,1000,2200,0.15,0.94,"Concrete, Normal Weight (6 in)"
!!
!!Compartments
!!
COMPA,Comp 1,5,5,3,0,0,0,CONCRETE,CONCRETE,CONCRETE,50,50,50
COMPA,Comp 2,5,5,3,5,0,0,CONCRETE,CONCRETE,CONCRETE,50,50,50
COMPA,Comp 3,5,5,3,5,0,3,CONCRETE,CONCRETE,CONCRETE,50,50,50
!!
```

```

!!Vents
!!
HVENT,1,4,1,1,2,0,2,,1,TIME,,,0,1,0,1,0,0
HVENT,1,2,1,1,2,0,0.5,,2,TIME,,,0,1,0,1,0,0
HVENT,3,4,1,1,2,1,0.5,,2,TIME,,,0,1,0,1,0,0
VVENT,3,2,1,1,1,TIME,,,0,0,100,0.5,2.5,1
MVENT,4,1,1,V,2.75,0.25,V,2.75,0.25,0.02,200,300,TIME,,,0,1,0,1,0,4
MVENT,2,4,2,V,2.75,0.25,V,2.75,0.25,0.02,200,300,TIME,,,0,1,0,1,5,4
RAMP,V,3,2,1,3,0,0,100,0.5,500,1
!!
!!Fires
!!
LIMO2,0.1
!!Cushion
FIRE,1,2.5,2.5,0,1,TIME,0,0,0,0,Cushion
CHEMI,9,6,2,2,0,0.33,5E+07
TIME,0,60,120,180,240,300,360,420,480,540,1800
HRR,0,100000,150000,200000,150000,125000,100000,90000,80000,75000,75000
SOOT,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227
CO,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557
TRACE,0,0,0,0,0,0,0,0,0,0,0,0
AREA,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1
HEIGH,0,0,0,0,0,0,0,0,0,0,0,0
!!Wood_Wall
FIRE,2,2.5,5,0,1,TIME,0,0,0,0,Wood_Wall
CHEMI,6,10,5,0,0,0.33,1.81E+07
TIME,0,8000
HRR,0,1000000
SOOT,0.015,0.015
CO,0.006171682,0.006171682
TRACE,0,0
AREA,0.05,9
HEIGH,0,3
!!
!!Targets and detectors
!!
DETECT,SPRINKLER,1,347.0389,3,3,2.97,100,1,7E-05
DETECT,SMOKE,1,23.93346,2,2,2.97,404,0,7E-05
DETECT,HEAT,1,303.15,2,2,2.97,5,0,7E-05
TARGET,1,2.2,1.88,2.34,0,0,1,CONCRETE,EXPLICIT,PDE,0.5,Targ 1
!!
!!Intercompartment heat transfer
!!
VHEAT,3,2
!!
!!Visualizations
!!
SLCF,2-D,X,2.5
SLCF,2-D,Y,2.5
SLCF,2-D,Z,2.95

```

A.1 COMPA

The COMPA keyword defines the size and location of all compartments in a simulation. The compartments are numbered internally as they are read in. The other key words which refer to compartment numbers then refer to these ordinals. Compartments must be defined before they are referenced by other commands. The arguments are

NAME Short description of the compartment.

WIDTH, DEPTH, HEIGHT size of the compartment.

X0, Y0, Z0 location of the lower left/front corner of the compartment.

CEILING, FLOOR, WALL compartment surface materials which must match a **SHORT NAME** for one of the defined material properties.

XGRID, YGRID, ZGRID grid spacing for slice and isosurface files for the compartment. These may be different for each compartment.

Example:

```
COMPA, hallway, 9.1, 5.0, 4.6, 0., 0., 0., CONCRETE, CONCRETE, CONCRETE, 50, 50, 50
```

A.2 DEADROOM

The DEADROOM keyword specifies a dead-end compartment, i.e., a compartment that is only connected to another compartment that in turn is not connected to the outside. Compartment pressure is not calculated for the dead-end room. Pressure for this room is assumed to be the same as that of the connected room.

COMPARTMENT compartment number of the dead-end room.

CONNECTED compartment number of the connected compartment.

Example:

```
DEADROOM, 2, 1
```

A.3 DETEC

The DETEC keyword is used for both detectors and sprinklers. Sprinklers and detectors are both considered detection devices and are handled using the same input keywords. Detection is based upon heat transfer to the detector. Fire suppression by a user-specified water spray begins once the associated detection device is activated. For the type of detector, use 1 for smoke detector and 2 for heat detector or sprinklers. If suppression is set to a value of 1, a sprinkler will quench the fire with the specified spray density of water. If turned off (a value of 0), the device is handled as a heat or smoke detector only - values entered for activation temperature, RTI, and spray density are ignored. The spray density is the amount of water dispersed by a water sprinkler. The units for spray density are length/time. These units are derived by dividing the volumetric rate of water flow by the area protected by the water spray. The suppression calculation is based upon an experimental

correlation by Evans, and depends upon the RTI, activation temperature, and spray density to determine the behavior of the sprinkler.

TYPE detector type.

COMPARTMENT compartment number where the detector is located.

TRIGGER activation value for the detector. For smoke detectors, this is obscuration; for heat detectors or sprinklers, this is temperature.

X, Y, Z detector location relative to the lower, left, front corner of the compartment.

RTI response time index (RTI) value for a sprinkler

SUPPRESSION set to 1 if suppression is activated

SPRAY DENSITY amount of water dispersed by the sprinkler

Example:

```
DETECT, 2, 1, 344.2, 1.5, 1.5, 2.29, 98, 1, 7.00E-05
```

A.4 DTCHE

The purpose of the DTCHE keyword is to prevent excessive computation with a very small time step. This often appears to users as though the program has frozen, when it is simply the set of equations has reached a point that requires very small time steps for the solver to converge. A negative entry on DTCHE turns off the time step checking algorithm. A positive value for the minimum time input sets the software for a maximum number of iterations below a minimum time step before producing an error and stopping.

TIME minimum time step for equation solver.

COUNT maximum number of iterations below minimum time step before program stops in error.

Example:

```
DTCHECK, 1.E-9, 100
```

A.5 EAMB

This keyword sets ambient conditions for the outside of the building. Temperatures are in Kelvin and pressure in Pascals. Default values for temperature and pressure are 20 °C, 101325 Pa, respectively.

TEMPERATURE ambient temperature outside the building. This is a constant throughout a simulation.

PRESSURE ambient pressure outside the building. This is a constant throughout a simulation.

Example:

A.6 EVENT

EVENT is used to open or close a vent or to change filtering. This replaces the earlier CVENT and applies to all vents for vertical flow (V), horizontal flow (H) mechanical flow (M), and filtering of mechanical ventilation (F). Except for filtering, this has been replaced with inputs on the appropriate vent command or by the RAMP command beginning in CFAST version 7.1.2.

TYPE Type indicates the vent type associated with this EVENT action. “H” indicates a horizontal flow event that changes the vent opening, “V” a vertical flow event, “M” a mechanical flow event, and “F” for filtering of mechanical ventilation flow.

FIRST compartment number of lower numbered (for wall vents), top (for ceiling/floor vents) or from compartment (for mechanical vents).

SECOND compartment number of higher numbered (for wall vents), bottom (for ceiling/floor vents) or to compartment (for mechanical vents).

ID vent number associated with the vent consistent with appropriate vent command.

TIME beginning time of vent opening or filter fraction change.

FRACTION final vent opening fraction or filter fraction.

DECAY time over which opening or filter transitions from its initial fraction to its final fraction.

Example:

```
EVENT, H, 1, 2, 1, 10., 0.3, 1
```

The convention for vent fractions is the 1 is 100 % open, and 0 is closed. Filtering applies only to trace species and particulate (soot) and only to mechanical ventilation vents. For filtering, 0 indicates no filtering and 1 indicates that all soot and trace species flowing through the fan is removed.

A.7 FIRE

The FIRE keyword places a fire into a compartment. The associated keywords CHEMI, TIME, HRR, SOOT, CO, TRACE, AREA, and HEIGH completely specify time-dependent properties the fire for the current fire. They must be included, in order, directly after the associated FIRE keyword input line

COMPARTMENT the compartment in which the fire is located.

X, Y, Z the width, depth, and height of the center of the base of the fire relative to the selected compartment.

PLUME a “1” as the fifth argument is required to maintain compatibility with older versions of the model. It is ignored by the current of the model.

TYPE fires can be initiated at a specific time, temperature or incident heat flux. Corresponding inputs are TIME, FLUX, or TEMP. IF FLUX or TEMP is specified, an existing, user-specified target specified in the TARGET field is used to determine the ignition time.

CRITERION is the initialing value for the current fire, either a time, temperature or incident heat flux as chosen above.

TARGET user-specified target associated with this fire and used to judge ignition by temperature or incident heat flux.

0,0 zeros are required in the ninth and tenth arguments to maintain compatibility with older versions of the model.

NAME user-specified name for the fire

Example:

```
!!Cushion
FIRE,1,2.5,2.5,0,1,TIME,0,0,0,0,Cushion
CHEMI,9,6,2,2,0,0.33,5E+07
TIME,0,60,120,180,240,300,360,420,480,540,1800
HRR,0,100000,150000,200000,150000,125000,100000,90000,80000,75000,75000
SOOT,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227,0.227
CO,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557,0.0845557
TRACE,0,0,0,0,0,0,0,0,0,0,0
AREA,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1,0.1
HEIGH,0,0,0,0,0,0,0,0,0,0,0
```

A.7.1 CHEMI

The CHEMI input defines the chemical formula of the burning material, the fraction of its heat given off by radiation, and its heat of combustion.

C,H,O,N,Cl defines the stoichiometry of the fuel as carbon, hydrogen, oxygen, nitrogen, and chlorine atoms.

CHIR radiative fraction for the fuel.

HOC heat of combustion of the fuel.

A.7.2 TIME

The TIME input defines a series of time points which correspond to entries on the other fire inputs HRR, SOOT, CO, TRACE, AREA, and HEIGH. These define the time-based variation of the fire size, fire area, and species yields for the specified fire.

T₁, T₂, T₃, ... , T_{N-1}, T_N time points

A.7.3 HRR

The HRR input defines a series of heat release rates which correspond to entries on the TIME input. These define the time-based variation of the fire size for the specified fire.

Q_1, Q_2, Q_3, ... , Q_N-1, Q_N time history of fire heat release rate at time points specified by the TIME keyword

A.7.4 SOOT, CO, TRACE

These three inputs define a series of species yields which correspond to entries on the TIME input. These define the time-based variation of the soot, carbon monoxide, and trace species yields for the specified fire.

S_1, S_2, S_3, ... , S_N-1, S_N time history of soot yields (kg of soot/kg fuel burned) at time points specified by the TIME keyword

CO_1, CO_2, CO_3, ... , CO_N-1, CO_N time history of carbon monoxide yields (kg of CO/kg fuel burned) at time points specified by the TIME keyword

TR_1, TR_2, TR_3, ... , TR_N-1, TR_N time history of trace species yields (kg of trace species/kg fuel burned) at time points specified by the TIME keyword

A.7.5 AREA

The AREA input defines a series of areas which correspond to entries on the TIME input. These define the time-based variation of the cross-sectional area of the base of the fire for the specified fire.

A_1, A_2, A_3, ... , A_N-1, A_N time history of the cross-sectional area of the base of the fire at time points specified by the TIME keyword

A.7.6 HEIGH

The HEIGH input defines a series of height values which correspond to entries on the TIME input. These define the time-based variation of the vertical position of the base of the fire (measured from the floor of the current compartment) for the specified fire. The height used at any time point during a simulation is taken to be the sum of the height (Z) input in the FIRE keyword and the interpolated value of the HEIGH curve at the current time.

H_1, H_2, H_3, ... , H_N-1, H_N time history of the cross-sectional area of the base of the fire at time points specified by the TIME keyword

A.8 HALL

This command invokes the corridor flow ceiling jet algorithm for the chosen compartment. More than one HALL keyword can be included in a simulation.

COMPARTMENT compartment number of compartment assigned as a hall.

Example:

HALL, 3

A.9 HHEAT

HHEAT, FIRST_COMPARTMENT, NUMBER_OF_PARTS, N PAIRS OF {SECOND_COMPARTMENT, FRACTION}

Used to allow heat conduction between pairs of compartments which have a contiguous vertical partition between them. There are two forms of this command. The first form is to use only a compartment number. In this case, CFAST will calculate the conductive heat transfer to all compartments connected to this compartment by wall vents. The second form specifies the compartments to be connected and what fraction of the compartment is connected to an adjacent compartment. This latter is particularly useful for rooms which are connected to adjacent rooms as well as hallways. The user of the model is responsible for the consistency of these pairings. The model does not check to insure that the specified compartment pairs are physically located next to one another.

FIRST first compartment of pairs connected for horizontal heat transfer

N number of compartments connected to first compartment

SECOND_1, FRAC_1, SECOND_2, FRAC_2, ... , SECOND_N, FRAC_N N pairs of compartments and wall surface fraction of the first compartment connected to that compartment. Fractions should add to unity.

Example:

```
HHEAT, 1, 1, 2, 0.5
```

specifies that compartment one has one connection to compartment two and the fraction of wall surface through which heat is transferred is one half of the wall surface of compartment one. The rest of compartment one is assumed connected to exterior ambient conditions.

A.10 HVENT

The HVENT keyword specifies a vent which allows horizontal flow of gases through wall vents such as doors and windows.

FIRST first compartment of pairs connected by a wall vent. First compartment must be a lower number than second compartment. Outside is indicated by the number of compartments plus one.

SECOND second compartment of pairs connected by a wall vent. First compartment must be a lower number than second compartment. Outside is indicated by the number of compartments plus one.

ID vent number associated with this vent. Vents connecting the same compartment pair are numbered beginning with 1.

WIDTH vent width.

SOFFIT top of the vent from compartment floor.

SILL bottom of the vent from compartment floor.

OFFSET1 horizontal location of vent on selected face in first compartment.

OFFSET2 not used

FACE wall within first compartment containing the vent. Numbered 1, 2, 3, or 4 for front, right side, back side, or left side, respectively.

TYPE vent openings can change at a specific time, temperature or incident heat flux. Corresponding inputs are TIME, FLUX, or TEMP. IF FLUX or TEMP is specified, an existing, user-specified target specified in the TARGET field is used to determine the ignition time.

CRITERION is the initialing value for the current vent, either a time, temperature or incident heat flux as chosen above.

TARGET user-specified target associated with this vent and used to judge vent opening or closing based on temperature or incident heat flux.

INITIALTIME for time-based vent opening change, the time that the change in vent opening begins. For times less than or equal to this time, the vent is open at the specified INITIALFRACTION.

INITIALFRACTION fraction from 0 to 1 that vent is open up to the time specified in INITIALTIME

FINALTIME for time-based vent opening change, the time that the change in vent opening ends. For times greater than or equal to this time, the vent is open at the specified FINALFRACTION.

FINALFRACTION fraction from 0 to 1 that vent is open beginning at the time specified in FINALTIME

Example:

```
HVENT, 1, 2, 1, 1, 2, 0, 2.5, 0, 1, TIME, , , 0, 1, 0, 1
```

A.11 ISOF

The ISOF command creates 3-dimensional animated contours of gas temperature in one or more compartments. For example, a 300 °C temperature isosurface is a 3-D surface on which the gas temperature is 300 °C. The output frequency of the slice files is controlled by the SMOKE-VIEW_OUTPUT_INTERVAL input on the TIMES input line. Note that 3-D isosurface files can be quite large if the output interval is small. Computational time can also increase significantly with specification of isosurface files.

VALUE gas temperature to be displayed as an isosurface

COMP_1, COMP_2, ... , COMP_N one or more compartment numbers. If no compartment number is included, all compartments in the simulation are assumed.

Example:

```
ISOF, 300, 1, 2  
ISOF, 600
```

The first example specifies a 300 °C temperature isosurface in compartments 1 and 2. The last example specifies 600 °C isosurfaces in all compartments.

A.12 LIMO2

This parameter is global and applies to all fires. The keyword sets the lower oxygen limit for combustion. See the technical reference manual for the meaning and implication of modifying this parameter. [1].

O2INDEX lower oxygen limit for combustion

Example:

```
LIMO2,0.1
```

A.13 MATL

This keyword defines the thickness and thermal properties for a single material that may be referenced as a compartment surface material, target material, or fire object. Each name must be unique within a single input file.

SHORT single word name for the material.

K thermal conductivity of the material.

C specific heat of the material.

RHO density of the material.

THICKNESS thickness of the material.

EMISS surface emissivity of the material.

LONG descriptive name for the material.

Example:

```
MATL, CONCRETE, 1.75, 1000, 2200, 0.15, 0.94, "Concrete, Normal Weight (6 in) "  
MATL, GLASSFB3, 0.036, 795, 105, 0.013, 0.9, "Glass Fiber, Organic Bonded (1/2 in) "
```

A.14 MVENT

This replaces the more complex mechanical ventilation commands with a constant flow fan connection. The original commands MVOPN MVFAN MVDCT and INELV are not supported in this version. The command specifies a pair of openings connected by a constant volume flow fan.

FIRST first compartment of pairs connected by a wall vent. First compartment must be a lower number than second compartment. Outside is indicated by the number of compartments plus one.

SECOND second compartment of pairs connected by a wall vent. First compartment must be a lower number than second compartment. Outside is indicated by the number of compartments plus one.

ID vent number associated with this vent. Vents connecting the same compartment pair are numbered beginning with 1.

ORIENTATION orientation of the diffuser grill for the vent in the first compartment. Vents may horizontal (H) or vertical (V). This effects the partitioning of flow between the layers in the compartment and the mechanical vent.

HEIGHT height of the center of the vent relative to the floor in the first compartment.

AREA cross-sectional area of the vent connection in the first compartment.

ORIENTATION2 orientation of the diffuser grill for the vent in the second compartment. Vents may horizontal (H) or vertical (V). This effects the partitioning of flow between the layers in the compartment and the mechanical vent.

HEIGHT2 height of the center of the vent relative to the floor in the second compartment.

AREA2 cross-sectional area of the vent connection in the second compartment.

FLOW fan flowrate from first compartment to second compartment.

PLOWER fan flow can reduce to zero if the back pressure on the system is too great. At pressures less than or equal to PLOWER, full flow specified is used.

PUPPER At pressures greater than or equal to PUPPER, flow is zero. Between PLOWER and PUPPER, flow transitions from full flow to zero flow.

TYPE vent openings can change at a specific time, temperature or incident heat flux. Corresponding inputs are TIME, FLUX, or TEMP. IF FLUX or TEMP is specified, an existing, user-specified target specified in the TARGET field is used to determine the ignition time.

CRITERION is the initialing value for the current vent, either a time, temperature or incident heat flux as chosen above.

TARGET user-specified target associated with this vent and used to judge vent opening or closing based on temperature or incident heat flux.

INITIALTIME for time-based vent opening change, the time that the change in vent opening begins. For times less than or equal to this time, the vent is open at the specified INITIALFRACTION.

INITIALFRACTION fraction from 0 to 1 that vent is open up to the time specified in INITIALTIME

FINALTIME for time-based vent opening change, the time that the change in vent opening ends. For times greater than or equal to this time, the vent is open at the specified FINALFRACTION.

FINALFRACTION fraction from 0 to 1 that vent is open beginning at the time specified in FINALTIME

OFFSETX distance in the x (width) direction to the center of the vent relative to the lower left front corner of the compartment

OFFSETY distance in the y (depth) direction to the center of the vent relative to the lower left front corner of the compartment

Example:

```
MVENT, 2, 4, 2, V, 2.75, 0.25, V, 2.75, 0.25, 0.02, 200, 300, TIME, , , 0, 1, 0, 1, 5, 4
```

A.15 ONEZ

For tall compartments or those removed from the room of fire origin, the compartment may be modeled as a single, well-mixed zone rather than the default two-zone assumption. A single zone approximation is appropriate for smoke flow far from a fire source where the two-zone layer stratification is less pronounced than in compartments near the fire. This is used in situations where the stratification does not occur. Examples are elevators, shafts, complex stairwells, and compartments far from the fire. More than one compartment may be specified by including multiple ONEZ keywords.

COMPARTMENT compartment number to be modeled as a single well-mixed zone.

Example:

```
ONEZ, 2
```

A.16 RAMP

The RAMP keyword specifies a time-varying opening for a wall, ceiling/floor, or mechanical vent.

TYPE Type indicates the vent type associated with this RAMP. “H” indicates a horizontal flow event that changes the vent opening, “V” a vertical flow event, and “M” a mechanical flow event.

FIRST compartment number of lower numbered (for wall vents), top (for ceiling/floor vents) or from compartment (for mechanical vents).

SECOND compartment number of higher numbered (for wall vents), bottom (for ceiling/floor vents) or to compartment (for mechanical vents).

ID vent number associated with the vent consistent with appropriate vent command.

N number of compartments connected to first compartment

TIME_1, FRAC_1, TIME_2, FRAC_2, ... , TIME_N, FRAC_N N pairs of time and opening fraction of the first compartment connected to that compartment. Fractions must be between 0 and 1.

Example:

```
RAMP, V, 3, 2, 1, 3, 0, 0, 100, 0.5, 500, 1
```

A.17 ROOMA and ROOMH

These key words allow the user to define non-rectangular rooms by specifying cross-sectional area as a function of height. One set of values is included for each compartment that has a variable cross-sectional area. The format in both cases is the key followed by an index of the number of values. These key words must be used in pairs.

COMPARTMENT compartment number to be modeled with variable cross-sectional area.

NUMBER number of area or height inputs.

AREA_1, AREA_2, ... , AREA_N horizontal cross-sectional area at heights specified by the corresponding ROOMH keyword.

HEIGHT_1, HEIGHT_2, ... , HEIGHT_N height of corresponding horizontal cross-sectional specified by the corresponding ROOMA keyword.

Example:

```
ROOMA 1      3      10.0  5.0  3.0
ROOMH 1      3      0.0   1.0  2.0
```

The example specifies that compartment 1 has a cross-sectional area of 10 m², 5 m² and 3 m² at elevations 0.0 m, 1.0 m and 2.0 m respectively.

A.18 SLCF

With Smokeview, CFAST can display animations of various gas phase quantities in a plane or volume in one or more compartments, depending on the inputs. For 2-D slices, the DOMAIN input is 2-D, followed by the selected plane (either X, Y, or Z), and a position within the compartment along the respective axis. For 3-D slices, the DOMAIN input 3-D is selected. One, several, or all compartments can be specified. As many SLCF commands as needed can be used in a CFAST input file. The output frequency of the slice files is controlled by the SMOKEVIEW_OUTPUT_INTERVAL input on the TIMES input line. Note that 3-D slice files can be quite large if the output interval is small. Computational time can also increase significantly with specification of detailed 3-D slice files.

DOMAIN either 2-D for a single slice of temperature data or 3-D for all three dimensions.

PLANE for 2-D slices, either X, Y, or Z specifying a slice perpendicular to the chosen plane.

POSITION distance along the selected axis relative to the compartment origin.

COMP_1, COMP_2, ... , COMP_N one or more compartment numbers. If no compartment number is included, all compartments in the simulation are assumed.

Example:

```
SLCF, 3-D, 1, 2, 3
SLCF, 2-D, X, 2.5, 3, 5
SLCF, 3-D
SLCF, 2-D
\
```

The first SLCF example specifies a 3-D slice file output for compartments 1, 2, and 3. The second SLCF example specifies a 2-d slice file output parallel to the X (depth) axis, 2.5 m from the axis origin in compartments 3 and 5. The last two examples specify default 3-D and 2-D slice file output for all compartments.

A.19 STPMAX

This specifies the largest time step that the model will take. The default value is one second. In most cases, the numerical routines adjust the time step appropriately; however, for long simulation times and slowly varying conditions, a larger value is appropriate. In cases where the fire height and vent soffits interact, the time step may need to be smaller.

STEP maximum time step.

Example:

```
STPMAX, 0.2
```

A.20 TAMB

This keyword sets ambient conditions for the inside of the building. For the internal ambient, relative humidity sets the initial water concentration in the ambient air. Temperatures are in Kelvin, pressure in Pascals, and relative humidity in percent. Default values for temperature, pressure, and relative humidity are 20 °C, 101325 Pa, and 50 %, respectively.

TEMPERATURE ambient temperature. Default is 20 °C.

PRESSURE ambient pressure. Default is 101325 Pa.

RH ambient relative humidity. Default value is 50

Example:

```
TAMB, 300, 101300, 50
```

A.21 TARGE

CFAST can track and report calculations of the net heat flux striking arbitrarily positioned and oriented targets and the temperature of these targets.

COMPARTMENT compartment number where the detector is located.

X,Y,Z location relative to the lower, left, front corner of the compartment.

NORMALX, NORMALY, NORMALZ normal vector from front surface of target.

MATERIAL material which must match a SHORT NAME for one of the defined material properties.

METHOD must be EXPLICIT.

EQUATIONTYPE PDE for cartesian coordinates or CYL for cylindrical coordinates.

INTERNALLOCATION fraction of depth into material at which internal temperature is reported. For center of material, a value of 0.5 is specified.

Example:

```
TARGET, 1, 2.2, 1.88, 2.34, 0, 0, 1, CONCRETE, EXPLICIT, PDE, 0.5, Targ 1
```

A.22 TIMES

Printed output will be on the screen or in a file named project.out. Five spreadsheet files are produced (project_n.csv, project_w.csv, project_f.csv, and project_s.csv, and project_m.csv).

SIMULATION total simulation time.

PRINT time interval for printed output.

SPREADSHEET time interval for spreadsheet output.

SMOKEVIEW time interval for smokeview output.

Example:

```
TIMES, 360, 120, 130, 140, 150,
```

A.23 VERSN

```
VERSN, version number, Title
```

This input must be the first line in a CFAST input and largely specifies a title for the simulation.

VERSION version of the model for this input file. Should be 7 for the current version.

TITLE short descriptive title for the simulation

Example:

```
VERSN, 6, "Simple test of the object file input"
```

A.24 VHEAT

```
VHEAT, FIRST_COMPARTMENT, SECOND_COMPARTMENT
```

Heat transfer between the ceiling and floor of specified compartments can be incorporated with the VHEAT key word. Ceiling to floor heat transfer occurs between interior compartments of the structure or between an interior compartment and the outdoors. The model checks to make sure

that the ceiling and floor are reasonably contiguous (within 0.01 m), and the assumption is made that this is true for the entire ceiling and floor.

TOP compartment number of top compartment connected for ceiling/floor heat transfer.

BOTTOM compartment number of bottom compartment connected for ceiling/floor heat transfer.

Example:

```
VHEAT, 1, 2
```

The floor properties of the top compartment (1 in this case) and the ceiling properties of the bottom compartment (2 in this case) must be defined by COMPA and included in the thermophysical file.

A.25 VVENT

This key word describes horizontal openings between compartments connected with a vent in the floor/ceiling between the compartments. Each VVENT line in the input file describes one floor/ceiling vent.

TOP top compartment of pairs connected by a ceiling/floor vent. Outside is indicated by the number of compartments plus one.

BOTTOM bottom compartment of pairs connected by a wall vent. ceiling/floor vent. Outside is indicated by the number of compartments plus one.

ID vent number associated with this vent. Vents connecting the same compartment pair are numbered beginning with 1.

area cross-sectional area of the vent.

SHAPE numerical input specifies either a circular (1) or square (2) vent.

TYPE vent openings can change at a specific time, temperature or incident heat flux. Corresponding inputs are TIME, FLUX, or TEMP. IF FLUX or TEMP is specified, an existing, user-specified target specified in the TARGET field is used to determine the ignition time.

CRITERION is the initialing value for the current vent, either a time, temperature or incident heat flux as chosen above.

TARGET user-specified target associated with this vent and used to judge vent opening or closing based on temperature or incident heat flux.

INITIALTIME for time-based vent opening change, the time that the change in vent opening begins. For times less than or equal to this time, the vent is open at the specified INITIALFRACTION.

INITIALFRACTION fraction from 0 to 1 that vent is open up to the time specified in INITIALTIME

FINALTIME for time-based vent opening change, the time that the change in vent opening ends. For times greater than or equal to this time, the vent is open at the specified **FINALFRACTION**.

FINALFRACTION fraction from 0 to 1 that vent is open beginning at the time specified in **FINALTIME**

OFFSETX distance in the x (width) direction to the center of the vent relative to the lower left front corner of the compartment

OFFSETY distance in the y (depth) direction to the center of the vent relative to the lower left front corner of the compartment

Example:

```
VVENT, 3, 2, 1, 1, 1, TIME, , , 0, 0, 100, 0.5, 2.5, 1
```


Appendix B

Running CFAST from a Command Prompt

The model CFAST can also be run from a Windows command prompt. CFAST can be run from any folder, and refer to a data file in any other folder. The fires and thermophysical properties have to be in either the data folder, or the executable folder. The data folder is checked first and then the executable folder.

```
[drive1:\][folder1\]cfast [drive2:\][folder2\]project
```

The project name will have extensions appended as needed (see below). For example, to run a test case when the CFAST executable is located in c:\firemodels\cfast7 and the input data file is located in c:\data, the following command could be used:

```
c:\firemodels\cfast7\cfast c:\data\testfire0 <<< note that the extension is optional.
```

Command line options

- -k - no interactive keyboard access
- -i - initialization only
- -c - compact output
- -f - full output (c and f are exclusive). Note the interaction of the f and c option. The default for the console output is /c. The default for the file output is /f. This default action can be overwritten by explicitly including the /f or /c option.
- -n - net heat flux option
- -v - validation output (outputs a modified set of spreadsheet files with different column headers designed to facilitate automated analysis of the output)