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*PF-4 Simulated Fire Accident Analysis
Filter-Spray Cool-Down System
Reevaluation Implications*

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PF-4 SIMULATED FIRE ACCIDENT ANALYSIS FILTER-SPRAY COOL-DOWN SYSTEM REEVALUATION IMPLICATIONS

by

B. W. White and W. S. Gregory

ABSTRACT

The Los Alamos National Laboratory PF-4 facility was designed with spray cool down systems within the building's ventilation systems. The Engineering and Safety Analysis Group was asked, in cooperation with ENG-8 and MST-8, to evaluate whether the spray cool-down systems still need to be classified as "safety class" systems. The study was performed using the FIRAC computer code. Given the fire source terms (hypothetical fire energy or time-temperature history), FIRAC can predict the pertinent transient flow parameters (pressures, flows, and temperatures) throughout a previously defined and selected fire zone.

A computer model for the study that had all of the main ventilation systems in the south half of the PF-4 facility was used. Because the most hazardous room is located in the 400 Section, all ventilation systems but the 400 Section's one were simplified. The impetus for simplification was to keep the computer model tractable, and this was possible with the following assumptions: the fire cannot spread from one room to another, all corridor connecting doors are closed and will not fail under the pressures generated by the fire, and the principal pathway for potential release is the ventilation system. All of the blowers continue to operate, and all fire retardant systems fail to operate during the fire. The ASTM time-temperature curve was the source for the burn-room temperature, and smoke injection was used as input as well. Five different computer runs were made using different combinations of source terms and heat transfer. A connection from the burn room to the glovebox ventilation system was created by burning the glovebox plastic shielding; it was modeled by a branch having an initial flow of 75 ft³/min.

In the calculations, the entire model pressurizes, and its temperature increases. In runs with smoke injection, any filters into which combustion-product-tainted air is drawn plug. This is especially true for the 400 Section. Filter plugging in this section helped to confine the combustion products to within the burn room and the room adjacent to it. For any of the runs, the temperatu

response of the nodes just before the 400 Section glovebox and "bleed-off" filters (the filters that prevent contamination releases to the outside environment) did not present temperatures high enough or long enough that the filter integrity would be challenged. This study supports the redesignation of the spray cool-down systems protecting the high efficiency particulate air filters.

I. INTRODUCTION

The PF-4 facility (which we refer to as PF-4) is a reprocessing plant for nuclear metals. It was constructed at Los Alamos in 1974, after the disastrous fire at the Rocky Flats Plant in 1969. As a result, many fire safety requirements were imposed on PF-4; one of these was the spray cool-down systems. These requirements were conceived, designed, and implemented with the knowledge and tools available at that time. However, with the further development of computer modeling, a design now can be tested thoroughly while it is still in development, or, as in this case, a previously designed facility can be tested under various hypothetical conditions.

One of the previous requirements was that spray cool-down systems had to be installed in front of the high-efficiency particulate air (HEPA) filters for ventilation systems that exhaust air into the environment and that recirculate the air in the laboratory. A spray cool-down system cools hot air that is delivered to a filter during a possible fire. It also will wash some of the combustion products from the incoming air, thereby preserving the established airflow. When a facility has a spray cool-down system with the appropriate redundancy, the system will have to be maintained and tested. Periodic testing of these systems is expensive and generates a considerable amount of waste, which then will have to be disposed. Therefore, it is prudent to use the tools available today to determine whether these systems must be classified so stringently. A significant amount of money could be saved if the spray cool-down systems were reclassified.

We used the FIRAC¹ computer code in this study. FIRAC is one of a family of lumped-parameter accident analysis codes² developed by the Los Alamos Engineering and Safety Assessment Group. FIRAC has been validated by various computer/experiment comparisons.^{3,4} PF-4 was divided into two fire zones. A computer model of one of the fire zones was developed using design flows. The computer model was run with different combinations of source terms.

This report has the following general structure after the introduction. A general description of the pressure zones, ventilation systems, and physical components is

given in Sec. II, Fire Zone. Section III, Computer Model, further describes the major fire zone components and how they were modeled. Section IV, Fire/Accident and Fire Source Terms, describes the accident scenario and includes a matrix of source term combinations. Section V, Results, has steady state results that validate the model and how the ventilation systems respond to the transient condition. The transient results are shown mainly with temperature and volume flow comparison of the different source terms.

II. FIRE ZONE

A fire zone for PF-4 will be either the north or the south half of the building. Each half is separated physically by an intersecting wall and air locks, so we assumed that combustion products from one side cannot contaminate the other. Because of the combustible gases that are used routinely (for example, chlorine, fluorine, and phosphine), the amount of nuclear material (plutonium), and the amount of combustible plastic shielding that are present, Room 429 of the 400 Section was determined by the TA-55 Facilities Management Group to present the greatest hazard. The 400 Section and Room 429 are located in the south half of PF-4; therefore, the computer model represents PF-4's south half.

The south half comprises two floors. The lower floor (the basement) houses the blowers, filters, and other equipment for the ventilation systems of this half. The upper floor (the first floor) is composed of the 300 and 400 Sections with an interconnecting corridor. Figure 1 shows a general floor plan of the first floor. Stairwells with normally closed doors connect the basement and the first floor. As can be seen from Fig. 1, the 300 and 400 Sections are subdivided into separate rooms. Not only are there interconnecting doorways between the corridor and the labs, but unlatched swing doors also connect adjacent labs. The swing doors can open in either direction. There are several separate, but still interconnected, ventilation systems in this fire zone that were designed to establish four different pressure zones. An example of the system interconnection is given below. The pressure zones have been organized further into regions. The different regions reflect the contamination likelihood during an accidental release. Table I lists the appropriate region grouping and the likelihood for contamination, and Table II depicts the different pressure zones and their prescribed pressures. The volume fluxes for each of the ventilation systems are shown in Table III, and Fig. 2 shows the main ventilation components of the fire zone.

Fig. 1.
PF-4 south half first floor plan.

TABLE I
FIRE ZONE REGIONS

Region	Constituents	Contamination Likelihood
1	Gloveboxes, tunnels	High
2	300 & 400 Sections, corridor	Medium
3	Basement	Low

TABLE II
PRESSURE ZONE DESCRIPTIONS AND PRESSURES

Zone	Description	Pressure (in. w.g.)
1	Gloveboxes	-0.80
2	Laboratories	-0.20
3	Corridor	-0.17
4	Basement	-0.11

TABLE III
VENTILATION SYSTEM VOLUME FLOW RATES

System	Volume Flow Rates (ft ³ /min)
Basement Supply	8000
Basement Exhaust	1700
300 Glovebox	2100
300 Recirculation	34000
400 Glovebox	2000
400 Recirculation	38000
Fresh air	11000
Bleed off	13000

Fig. 2.
PF-4 south half main ventilation components.

For each 300 and 400 Section on the first floor, there is a recirculation ventilation system in which approximately 90% of the air is recirculated. The remaining 10% is removed by the "bleed-off" ventilation system and then made up by the "fresh-air" system. This is an example of a designed system interconnection. The recirculated air is delivered to individual rooms by a single-manifold distribution-type system and exhausted by two parallel manifold systems. Another example of system interconnection is leak flow from one pressure region to another. All air entering or leaving, as well as the recirculated air in the fire zone, is filtered.

The basement has its own supply and exhaust system, but it is also the source of air for the glovebox systems for each of the sections. Air entering the glovebox ventilation systems from the basement is filtered not only upon exiting but upon entering as well. According to the model, the glovebox and the basement air are not recirculated, and although the glovebox systems are physically present in the 300 and 400 wings, they do not have ventilation connections to their respective sections.

Because of the designed pressure difference and the availability of physical pathways, leak flow does occur in the general direction from the basement through the corridor and into the 300 and 400 Sections. In fact, the leak flow from the corridor to the 400 Section is the supply mechanism for replacement or fresh air.

III. COMPUTER MODEL

The basic computer model depicts the fire zone under normal operating conditions without any connections to any other parts of the building. A modification of the base model was required to represent the burning and destruction of the plastic shielding on the gloveboxes in the burn room (Room 429). The following discussions and results are from the modified model, Model Iteration No. 6. The modification is covered in more detail in Sec. III. E.

The computer model has all but the 400 Section recirculation system greatly simplified. The 400 Section rooms have been grouped into 12 different rooms, and the 300 Section rooms have been lumped together. Simplifying kept the computer model tractable and was based on the following.

- The fire scenario was constrained to Room 429.
- All corridor connecting doors are closed and will not fail under the pressures generated by the fire.
- The principal pathway for potential release is the ventilation system.

Even with the simplifications, the base computer model has 101 nodes and 142 branches. A schematic of the computer model is shown in Fig. 3.

A. 300 and 400 Recirculation Systems

These systems are similar. Both have two blowers parallel-connected to ventilate all the rooms in their sections. The volume flow rate is 34 000 ft³/min for the 300 Section and 38 000 ft³/min for the 400 Section. The volume turnover rate for each section is approximately 7 times an hour. The construction of the supply and exhaust for each system is also similar. The recirculation system for each section supplies air to the individual rooms through a single supply manifold distribution network and draws the air out by two exhaust manifolds, with one exhaust manifold on the north side and the other exhaust manifold on the south side of each section. Also, a significant amount of air for each system is bled off by the "bleed-off" blower. Most of this air is bled off immediately after the parallel connected blowers' ducts have been joined into one duct. This will be shown later to be an important feature and will be discussed further in the bleed-off section (Sec. V.B.4).

The 400 recirculation system has blowers HV-807 and HV-808 connected in parallel to ventilate all the rooms in the 400 Section and a single room in the basement. The blowers are represented by Branches 21 and 25, respectively. The single basement room is the equipment storage room (Room 38). The rest of the discussion will focus on the 400 Section rooms, not the single basement room. Some of the rooms in the 400 Section were lumped together as a single room, leaving a total of 12 rooms. The rooms are supplied and exhausted by manifold-distribution-type duct work. Very little simplification was done on the supply side. Because the ducts leading into a room varied in size and had multiple outlets, an average of the sizes and a single outlet was used for each supply duct to a room. The rooms are exhausted by two manifolds, one on the north side and the other on the south side. Several rooms have multiple ducts leading to each of these manifolds. Both of these return manifolds connect at a plenum just before the recirculation filters and blowers. The exhaust duct work presented a case of parallel flow across the same pressure drop. This situation allows the use of hydrodynamic equations to find a single duct to replace those with parallel flow. The single duct exhausting each room was placed approximately in the middle of each room, and the two exhaust manifolds were modeled as one. Generally, branch numbers 19 through 90 are related to the 400 Section.

The 300 recirculation system has blowers HV805 and HV806 connected in parallel to ventilate all rooms in its section. These are represented by Branches 110

Fig. 3(a)
PF-4 south fire zone computer model flow network.

Fig. 3(c)
PF-4 south fire zone computer model flow network.

and 114, respectively. Because the focus of the study was the 400 Section, the 300 Section was grouped into a single room, and its ventilation system was likewise simplified. The 300 Section supply and exhaust manifolds are represented by a single branch for each. These are Branches 118 and 107, respectively. The 300 Section ventilation system includes Branches 107 through 119.

B. "Fresh-Air" System

The "fresh-air" system services both sections. Its main purpose is supply fresh air that has been bled off to the fire zone deliberately. The fresh air volume flow turn-over rate for the entire first floor is once every 45 min. This system's blower's volume flow rate is 11 000 ft³/min. Much of the fresh-air is delivered to the corridor, where it then leaks into the other sections as a result of pressure differences. In normal operating conditions, the air flows through the doorway cracks and into the each section's rooms. The 400 Section receives most of its fresh air in this manner, whereas the 300 Section has more than half of its fresh air delivered directly to it. Table IV has the fresh-air volume flow and percentages delivered to each of the sections. Based on the above information and because the study focused on the 400 Section, the fresh-air system was greatly simplified. The branch numbers related to fresh-air delivery number roughly from 1 to 18. Branch 3 represents the fresh-air blower (HV810). Branches 12–18 are the leak flow paths from the corridor to the 400 Section.

C. "Bleed-Off" System

The "bleed-off" system also services both sections, but it also draws air from the corridor and basement. The "bleed-off" blower (HV822) is rated at 13 000 ft³/min and is represented by Branch 96. A significant portion of air from both the 300 and 400 recirculation ventilation systems is bled off directly after each section's parallel blowers

TABLE IV
FRESH AIR VOLUME FLOW DELIVERED TO 300 AND 400 SECTIONS

Section	Flow (ft ³ /min)	Percentage
300	8000	72.6
400	3000	27.4

are connected. The 300 Section supplies most of the air for the "bleed-off" system. The computer model reflects the intricate connections to different areas within the fire zone. The "bleed-off" system includes branches 30, 91-97, and 99-104.

Air drawn into the bleed-off system from connections to different areas of the fire zone allows combustion-product-tainted air to be diluted. For the case of filter plugging, this dilution lengthens the time the bleed-off system can be effective. The 300 Section recirculation blowers contribute significantly to this dilution, especially after the 400 Section recirculation filters plug. Any fire-induced pressurization can be alleviated only through exhaust connections to the outside environment. This includes the bleed-off, basement exhaust, and two glovebox systems. The glovebox systems are included because their supply comes directly from the basement. The dilution and pressure alleviation will be discussed in the results section.

D. Basement Supply and Exhaust Systems

Both of these systems are quite simple; they are represented by Branches 128 through 136 in Fig. 3. The supply and exhaust blowers are blowers HV 841 and HV 829.

E. Glovebox Supply and Exhaust Systems

These systems have only exhaust blowers. The absence of pressurizing supply blowers helps to reduce the possibility of pressurizing the glovebox system relative to the laboratories. These have blowers HV 856 and HV 854, which are represented by Branches 126 and 140, respectively.

When some of the shielding plastic on some of the gloveboxes has melted, there is a direct connection from the burn room to the glovebox system, which is represented by Branch 142. An initial flow of 75 ft³/min was assigned to this branch. This connection altered the pressures and volume flow rates for the model, but these were not readjusted to reflect normal operating conditions.

F. Components

1. Blowers. A standard procedure in modelling a blower curve is to extend its range from the first quadrant to the second and fourth quadrants in a Cartesian coordinate system. The second and fourth quadrants represent the back-flow and outrunning regions of a blower curve, respectively. The pressures generated by a fire could induce back flow and outrunning conditions. Another standard procedure is to ensure

that the blower curve input into the computer code has only negative slopes. This is required by the numerics in the code.

These two standard practices require that a manufacture's blower curve be modified slightly. Most blower curves will have negative slope right of the operating point to the abscissa and will transgress to a line having no slope or positive slope to the left of the operating point. To extend the blower curve to the ordinate axis with small but still negative slope, a linear equation is fit to a few points to the left of the operating point. The linear equation provides the points needed for the negative slope after the original blower curve transgress to a positive slope.

A similar approach is used to extend the blower curve in the back flow and outrunning regions of a blower's operation. A linear equation is fit to the data points to the right of the blower's operating point and the equation then is used to provide data in the fourth quadrant. Data for the second quadrant are found by using the same slope of the line in the fourth quadrant but using the ordinate intersection stipulated by the blower curve extension from the operating point to the ordinate axis. The result of using the transformation method is that, for normal or near normal operation, the code will be using the data points from the manufacturer's blower curve; only in an extreme situation should the code use the extension points. All of the blower curves are shown in Appendix A. The above method is described in Ref. 1 and supported by tests.⁽⁵⁾

2. Filters. All of the filters are currently of the same type. However, the pressure drop across each is different. Table V lists the pertinent parameters and the filter type. Table VI shows the pressure drop and location for each filter. The pressure drops are representative of actual Δp 's and were calculated under steady-state conditions.

TABLE V
HEPA FILTER TYPE AND ASSOCIATED PARAMETERS

Maker	American Air
Efficiency	99.95
Design Flow	500.0 ft ³ /min
Laminar Coefficient	7.3×10^6
Turbulent Coefficient	10.5
Plugging Factor	1/64 1/kg

TABLE VI
FILTER LOCATION AND PRESSURE DROP

Location	Branch Number	Pressure Drop (in. w.g.) ^a
"Fresh-Air"	2	0.6
400 Recirculation	20	3.4
400 Recirculation	24	3.4
Room 432	63	0.6
Room 425-8	72	0.3
Room 409-15	81	0.8
"Bleed-Off"	95	2.4
300 Recirculation	109	3.9
300 Recirculation	113	3.9
400 GB Supply	122	0.04
400 GB Exhaust	125	6.4
Basement Supply	129	3.1
Basement Exhaust	134	0.3
300 GB Supply	98	0.03
300 GB Exhaust	139	7.3

^aThese values are at 18 s.

3. Swing Doors. Control dampers within a ventilation system can be used to regulate volume flow and/or pressure. The dampers were added near the burn room (Room 429). The swinging doors connecting Room 429 to Room 432 and Room 429 to Room 425-8 were modelled as control dampers. Modelling the swinging doors as dampers was only to allow for pressure release between rooms under normal operating conditions, not flow.

Table VII shows the input parameters required by the code. The parameters represent an estimate of how the control dampers should operate with the method of simulation in the computer code. Refer to Fig. 3 for branch and node locations. Room 429, Node 14, is the control node for the dampers. The pressure at the control node triggers a response from the control dampers. The response of the control damper is controlled by user-specified parameters, which are discussed below.

TABLE VII
CONTROL DAMPER INFORMATION

Brn. #	C Node	Pmin	Pmax	I Theta	D Theta	T Delay
105	14	-0.2	+0.2	0.0	1.0	0.1
106	14	-0.2	+0.2	0.0	1.0	0.1

The control dampers modelling the swing doors (Branches 105 and 106) have an initial blade angle of 0 degrees; they are closed. The parameter "dtheta" is the angle to which a damper opens if the pressure at the control node is above the pressure given by the parameter "pmax." The swing door dampers will open because their "dtheta" is positive. When the pressure of the control node gets below the value prescribed by the parameter "pmin," the dampers close and the swing doors will close. Therefore, the dampers have a specific operating range between +0.20 in. w.g. (pmax) and -0.20 in. w.g. (pmin). The parameter "tdelay" is the time that the pressure must remain above or below the limits of pmax and pmin before the damper will respond.

4. Particulate Deposition and Heat-Transfer Areas. Particulate deposition and heat transfer were calculated for branches near the burn room or that led to filters that are within the primary focus of the study. Table VIII shows the particulate deposition information, and Table IX shows the heat-transfer information.

TABLE VIII
BRANCH PARTICULATE DEPOSITION PARAMETERS

Branch Number	Duct Height (ft)	Floor Area (ft ²)
30	2.5	66.
39	2.8	66.
41	2.8	31.
43	2.8	5.
70	3.3	106.
76	3.3	92.
78	3.3	79.

TABLE IX
BRANCH HEAT-TRANSFER PARAMETERS

Branch Number	Diameter (ft)	Area (ft ²)	Wall Thickness (in.)
70	3.3	267	0.188
76	3.3	287	0.188
89	3.4	172	0.188
90	3.4	172	0.188
124	1.5	121	0.188

IV. FIRE/ACCIDENT SCENARIO AND FIRE SOURCE TERMS

We assumed that a fire has started in Room 429 through some accident. No details of how the initial accident happened will be given. Descriptions of this kind can be lengthy; therefore, Room 429 simply is ablaze. We assumed that all fire retardant systems (such as someone using a fire extinguisher or automatic fire suppressants being discharged) are nonexistent or inoperative. After the fire has started, it continues to burn, and all of the blowers remain operating during the fire. To simplify and clarify the fire modeling, ENG-8 proposed the use of the ASTM standard-time temperature curve, which is shown in Fig. 4. This curve and a modified ASTM temperature curve were used as input into the computer code to represent the burn room temperature. The modified ASTM time-temperature curve was used to study the possible decrease in pressure resulting from a decrease in temperature.

During a fire, smoke particles are produced that can be carried to a filter and plug it. A burn room smoke injection rate was calculated using methods described in the "Nuclear Fuel Cycle Accident Analysis Handbook" for the burning of polymethylmethacrylate (PMMA) in air having 21% oxygen. The calculated burning rate of the PMMA is 900 g/s, and the smoke production rate is 18.8 g/s. During some of the initial computer runs, the 18.8-g/s, smoke injection caused the filters to plug very quickly. To provide a more liberal case, only half of the above value, 9.4 g/s, was used later. Figure 5 shows the smoke injection rate time history.

Fig. 4.
Burn room time temperature curves.

Fig. 5.
Smoke injection rate.

Carbon monoxide also is produced in most incomplete combustion processes. Under the right conditions, carbon monoxide can burn rapidly enough to simulate an explosion. ENG-8 was concerned about this and asked that another computer run be made. This run was made with the modified ASTM time-temperature curve. The CO injection was calculated using the full amount calculated as prescribed in the above reference. This value had to be converted using the burn room temperature and pressure time histories and the ideal gas equation from grams per second to cubic feet per minute for input into the computer code. The combined production and injection rates are shown in Fig. 6. Five different computer runs were made with combinations of different temperature curves, smoke injection, and heat transfer. Table X is a matrix of combinations that defines the different runs.

V. RESULTS

A. Steady-State Condition (Model Validation)

For a model to be valid, it generally must exhibit the given design pressures and flows. Only the base model was validated. The base model does not have a connecting branch from Room 429 (Node 14) to the 400 Section glovebox (Node 84). The pressures and volume flows throughout the systems changed after this branch was

Fig. 6.
CO production and injection rates.

TABLE X
COMPUTER RUN DESCRIPTION MATRIX

Run Notation	Temp. Curve	Heat Transfer	Smoke Injec.
Trans 1	ASTM	No	No
Trans 2	ASTM	Yes	No
Trans3	ASTM	No	Yes
Trans 4 ^a	ASTM	Yes	Yes
Trans 5	Mod-ASTM	No	Yes

^aBecause of numerical instabilities, this run went only to approximately 27 min.

connected. Because this connection is hypothetical, the resulting pressures and flows were not rebalanced. The average per cent difference in pressures of the major rooms is -0.5%; the average per cent difference of all the branch volume flows, which range from 20 ft³/min to 37 000 ft³/min, is 5%. The comparisons are in Appendix B.

B. Transient

1. General. As mentioned in the previous section and illustrated by Table X, five different computer runs were made. Five runs also were made for the base model [that is, without the branch connecting Room 429 (Node 14) to the 400 Section glove-box (Node 84)]. The results of these model validation transient runs were compared and illustrated in an interim report given to MST-8 and ENG-8. Overall, the comparison showed that the base and modified models responded quite similarly. This comparison is in Appendix C.

The results of the varied model show that the general response of the entire fire zone is that it became pressurized and increased in temperature. Generally, the effects of the fire are greater for areas that are near and closely connected to the burn room. Room 425-8 (Node 15) and Room 432 (Node 11) are affected more by the fire than the basement (Node 8).

The response is categorized in terms of runs with and without smoke injection. In runs with smoke injection, the filters that drew smoke into them became plugged. The plugging varied for different filters, depending on the smoke concentration of the air being drawn into them. Temperature distribution and time history shape also were

affected by filter plugging because the volume flow rate varied with the plugging of certain filters.

During the first 10–20 min of the computer run, the temperature responses for the runs with and without smoke injection were similar. Both types of runs produced a large pressure pulse that was felt throughout the fire zone. An overview of the general response and some peak values are given in Appendix C. Further responses are reviewed by sections. Some of the sections will overlap.

2. 400 Recirculation System. Of all the ventilation systems, the 400 recirculation system is affected the most and in the shortest period of time. Figure 7 shows the volume flow response of Branch 32, which is the feeder duct to the supply manifold for the 400 Section. Without smoke injection, there is a general decline to approximately 25 000 ft³/min. As one can see from Fig. 7, the smoke dramatically affects the volume flow. The recirculation filters essentially are plugged within the first 10 min.

The temperature response of Node 23, the node just before the 400 recirculation filters, is shown in Fig. 8. Trans1 is a realistic case of a fire whose temperature constantly increases but has no smoke particles. Node 23's Trans1 response is as one expects it to be—it is also ever increasing. Trans3's results present a more realistic case with smoke injection but with the same temperature curve. Trans5 presents the most realistic case with smoke injection and the burn room temperature decreasing from the lack of air resulting from the filter plugging.

Fig. 7.
400 recirculation Branch 32 volume flow response.

Fig. 8.
400 recirculation filter Node 23 temperature response.

Both Trans3 and Trans5 follow similar curves until 25 min have passed; they peak about 270°F. Trans3's curve remains approximately at 270°F for the rest of the run, where the total run time is 90 min. At about the 25-min mark, the Trans5 curve decays until the 40-min mark, where it stays relatively constant. Trans3 remains at the high level because the 400 Section recirculation filters have essentially plugged and no cooler air gets there; the model does not have heat transfer at filter branches. The Trans5 curve declines because the burn room temperature declines, which also lowers the resulting high pressure produced in the burn room.

3. 400 Glovebox System. The next most affected ventilation system is the 400 Section glovebox system. Again, only the main branch and filter temperature are discussed. During the first 5 min, runs with and without smoke injection produce a sharp increase of volume flow, which is shown in Fig. 9. The runs without smoke injection show a stable air draw for the problem run time, but runs with smoke injection follow an exponential decay to about 120 ft³/min at 90 min.

The temperature response can be seen in Fig. 10. The temperature response of this section presents a more complicated situation. The Trans1 response curve increases temperature logarithmically, which levels out at about 50 min but never goes above 120°F. Trans1 does not have smoke injection and thus has no filter plugging. Trans3 does have smoke injection, and the filters in this section do plug. The Trans3

Fig. 9.
400 glovebox Branch 124 volume flow response.

Fig. 10.
400 glovebox exhaust filter Node 85 temperature response.

temperature response is such that the curve is ever increasing and almost has an exponential shape. At 90 min, the peak temperature is 155°F. The response to Trans5 is that the curve shape is similar to Trans1 but just barely gets above 100°F.

There is obviously some disparity here. The response differences result from the different burn room temperature curves combined with filter plugging. Trans3's curve shape is primarily a result of the fact that the burn room temperature does not decrease and the entire fire zone pressurizes. The increase in pressures results from the burn room temperature curves and from the fact that the supply blowers continue to pump air into the system even after some of the fire zone exhaust filters have plugged. This particular response will be discussed further in Sec. V.B.5.

4. "Bleed-Off" System. This system's response does not present anything unexpected. However, what is not readily apparent is the effect that the 300 recirculation has on this system. The bleed-off system gets a major portion of its air from high pressure points in both the 300 and 400 recirculation systems. This point for both is directly downstream, where each of the systems' parallel blowers are connected. During normal operating conditions, the 300 Section delivers approximately 8000 ft³/min and the 400 Section delivers 3000 ft³/min. After the 400 recirculation system plugs, pressures throughout the fire zone are determined from the temperature curve and the degree of filter plugging in other systems. Most of the combustion-product-tainted air that the "bleed-off" system draws will come directly from the 400 Section. Several rooms of the 400 Section are serviced directly by the "bleed-off" system. One of these is Room 425-8 (Node 15), which is directly adjacent to Room 429 (Node 14) and is connected by a control damper that models the swing doors. Another source for the bleed-off system to draw large quantities of combustion-tainted air is its bleed-off connection at the recirculation blowers. This is possible after flow reversal in Branch 32, which is shown in Fig. 6. Essentially any air that is drawn from places other than the 400 Section helps to dilute the combustion tainted air, preserving the air draw by the "bleed-off" system. Figure 11 shows the volume flow response of the "bleed-off" system's Branch 104.

Figure 12 shows the "bleed-off" system's temperature comparison. As expected, Trans1's response is significantly higher than that of the other two. Without any filter plugging in Trans1, the hot air will follow the established flow distribution. Trans1's peak temperature is 194°F. Both the Trans3 and Trans5 curves peak at about 100°F, with Trans3's remaining constant and Trans5's decreasing to 80°F.

Fig. 11.
"Bleed-Off" Branch 104 volume flow response.

Fig. 12.
"Bleed-Off" filter Node 71 temperature response.

5. "Fresh-Air" System. The first floor corridor is part of the "fresh-air" system and is a connecting point between the 300 and 400 Sections; it also is the connecting between the basement and first floor. The pressure reaction (Fig. 13) and the volume flow response (Fig. 14) give a broad indication of the fresh-air system's response. Figure 13 shows the typical curve shape of the pressure response for the entire fire zone. The peak values of different sections of the fire zone will vary, but the general shape of the curve is the same. Figure 15 shows the temperature response of the corridor and the 300 Section. From Fig. 14 one can see that more air is delivered by the fresh-air blower in Trans1 than for runs with smoke injection. One would expect that the greater amount of fresh cool air that is delivered to the corridor and 300 Section would result in lower temperatures.

The volume flow response follows the corridor pressure's response. The higher the corridor pressure, the greater the impedance for delivery of fresh air. The drastic different temperatures are more a result from the relative pressure differences between the corridor and the burn room [Room 429 (Node 14)]. More hot air is forced into the corridor from the burn room for runs with smoke injection than for those without. This is shown in Fig. 16, which shows the volume response of Branch 14. Under normal operating conditions, Branch 14 represents the designed leak flow from the corridor to

Fig. 13.
Typical pressure response.

Fig. 14.
"Fresh-Air" Branch 4 volume flow response.

Fig. 15.
Corridor Node 9; 300 Section Node 73 temperature response.

Fig. 16.
Corridor/Room 429 leak flow Branch 14 volume flow.

Room 429. The resistance of the branch is set by the given designed pressure difference and the volume flow rate. Curves from Trans1, Trans3, and Trans5 are shown. Another important factor shown in this figure is that the volume flow for Trans5 is less than that for Trans3. Trans5 has the modified ASTM time temperature curve. Although Room 429's temperature is controlled by the above curve, the greater volume flow of Branch 14 will cool the burn room temperature if it does not cause the fire's burning rate to increase.

6. Basement Supply and Exhaust. This system's response also demonstrates the difference between runs with and without smoke injection and between Trans3 and Trans5. Trans1, which did not have any smoke injection, has the supply volume flow restricted during the pressure pulse and then increases to close to normal operating values. This can be seen in Fig. 17. The exhaust flow experiences an increase during the pulse and then only a slightly declines as shown in Fig. 18.

The Trans3 results show that the supply flow decreases during the pulse and momentarily increases after the pulse. After the momentary increase, the volume flow decreases until it is supplying less air than what is being exhausted. This means the exhaust blower, HV 829, is drawing from and being supplied by other areas within the fire zone.

Trans5 results show the same basic curve shapes for the supply and exhaust as demonstrated by Trans3's results. However, there is now more supply volume flow

Fig. 17.
Basement supply Branch 130 volume flow response.

Fig. 18.
Basement exhaust Branch 135 volume flow response.

than exhaust flow. This means that the modified ASTM time-temperature curve does create a more desirable and proper set of pressure balances. If the basement draws air from other regions within the fire zone, there is a greater likelihood of the basement having a higher degree of contamination, and although a fire of this magnitude and duration dictates that the structure has suffered extensive damage, maintaining the same pressure decrease from Region 3 to Region 1 would help with the clean-up efforts.

7. 300 Recirculation and Glovebox Systems. The 300 recirculation system and glovebox systems volume flows are virtually unaffected by the fire. The 300 Section temperature response was shown in Fig. 15. Figures 19 and 20 show the volume flow response for the recirculation and glovebox systems.

C. Overview

This section summarized the earlier sections and gave the peak values of all transient runs (1-5). Table XI is a summary of the volume flow response, and bar graphs of peak filter temperatures, the CO concentration in the burn room, and the regional peak temperatures for the different transient runs were given here. All of the trends can be seen in the above sections.

The burn room CO concentration represents the highest concentration of all the fire zones; for the most part, the other responses were an order of magnitude lower.

Fig. 19.
300 Section recirculation Branch 116 response.

Fig. 20.
300 glovebox Branch 138 volume flow response.

VI. DISCUSSION

We have discussed the results of our study of whether PF-4's spray cool down systems must be designated as safety class. The spray cool down systems were installed before computer codes such as FIRAC were developed. However, an entire fire zone and its ventilation systems can be modeled using FIRAC. FIRAC allows a modeler to determine the response of the interconnected systems, which we did for the PF-4 facility.

We selected a fire zone in PF-4 based on the location of the most hazardous room, which was determined on the basis that, during routine operations, it contained not only the greatest amount of fuel loading but also the room's operations presented the greatest likelihood of having an accident. Therefore, we selected Room 429. Chlorine, flourine, and phosphine, which are highly combustibile, are used routinely in this room. It also has a large amount of combustibile plastic shielding. The computer model and components were discussed in detail, and the computer model was shown to generally reflect the normal operating conditions of the fire zone.

Because any number of scenarios can describe how a fire starts, a scenario was not given; Room 429 simply was assumed to be ablaze. The burn room temperature was described by an ASTM time-temperature curve and a modified ASTM curve.

TABLE XI

SUMMARY OF VOLUME FLOW RESPONSE

Note: All values are approximate and have units of cfm

AREA	WITHOUT SMOKE INJECTION	WITH SMOKE INJECTION
400 Recirc.	Br 32 slow decay to 25000	Very sharp decline to approx. 1000 within first 10 min.
300 Recirc.	Br 116 flow is essentially not affected	
	<u>DURING PULSE</u>	<u>AFTER PULSE</u>
Fresh-Air	Restricted to 4500	Increases to nearly 10000
		<u>AFTER PULSE</u> Increase to 9300 then decays to 5300
Bleed-Off	Increase to 15500	Gradual decrease to 13600
		Sharp increase to 15500
Exponential decay to 2300		
Basement		
Supply	Decrease to 3400	Increase to 6900
		Decrease to 2000
Exhaust	Sharp increase to 2400	Decline to 2000
		Sharp increase to 2400
		Decrease to 2100 then increase to 2600
400 Glove Box	Supply and exhaust increase	Both follow same decline
		Supply and exhaust increase
		Both decay exponentially to -50 for supply and 120 for exhaust
300 Glove Box	Sharp increase to 2100	Gradual decay to 2000
		Sharp increase to 2100
		Decline to 2000 then increase to 2150

The modified curve was used to present the case of pressure rebalancing as a result of a decreasing burn room temperature curve. A smoke injection rate of 9.4 g/s also was used as input. This value is only half of the normal value from the burning rate of PMMA in 21% oxygen air (900 g/s). Five different runs were made using a combination of the above fire source terms and heat transfer. A sixth run was made to study carbon monoxide concentration; a CO production rate (g/s) was calculated from the above burning rate. The production rate was converted to an injection rate (ft³/min) using Trans5's burn room temperatures and pressures. Therefore, the CO concentrations were only for Trans5. Trans5 uses the modified ASTM time-temperature curve. The CO concentration shown in Fig. 21 indicates there should not be a problem of CO flashover.

The results of these runs for the entire fire zone were discussed in detail in earlier sections. The results were categorized broadly as runs with and without smoke injection and between Trans3 and Trans5 runs. Smoke injection caused the 400 Section recirculation filters to plug almost immediately. The 400 Section glovebox system and the "bleed-off" system filters eventually also plugged. The plugging rate of these filters was a lot less than that of the 400 Section recirculation filters. The "fresh-

Fig. 21.
Burn room CO concentration.

air" and basement ventilation systems were affected by the pressurization but not to the point of incapacitation. The 300 recirculation and glovebox systems were hardly affected.

Although the 400 Section filter temperatures were not the primary focus of the project, they also were studied. These filters trap contaminated products of combustion but are not the primary defense for environmentally contaminated releases. Obviously, runs without smoke injection allow the blowers of this section to draw significant amounts of hot air to the filters, increasing the temperature accordingly. These peak temperatures can be seen in Fig. 22. Because most of the air in the 400 Section is recirculated with a volume turnover rate of approximately 7 times an hour, heat transfer during the recirculation is important. The computer model has heat transfer only for the main branches leading in the recirculation system and in the main branches leading to environmental exhaust filters. As air is recirculated, it transfers heat to any surfaces it contacts. The model as stated above does not reflect this, but it does show significant peak temperature decreases for the runs with heat transfer. The heat transfer capability of the entire 400 Section would lower temperatures not only for the 400 Section recirculation filters but also for the "bleed-off" system. Adding heat transfer to every branch in the computer model would have lengthened the computer time astronomically and would have made the cost of the number of computer simulations that were run prohibitive. For burn room temperature curves, Trans5 with the

Fig. 22.
Transient run peak filter temperatures.

modified ASTM temperature curve presents the most realistic case, which produced a peak temperature of 272°F about 10 min into the run; the temperature started to decay after 15 min into the run. Trans4 (with the standard ASTM curve) produced a peak temperature for these filters of 162°F at approximately 7 min into the run and started to decay at 10 min into the run. Trans1 and Trans2 (with the standard ASTM temperature curve), with and without heat transfer, respectively, produced peak temperatures of 858°F and 541°F, respectively. These temperatures are at the end of the problem run time.

The plugging of the 400 Section filters helped confine any hot air in the burn room area, whereas runs without smoke injection and filter plugging allowed the hot air to be recirculated and distributed throughout the 400 Section and into the "bleed-off" system. For any of the runs, the temperature response of the nodes just before the 400 Section glovebox and "bleed-off" filters did not present temperatures high enough or long enough to challenge the filter integrity. These are the filters that prevent contamination releases to the outside environment. Figure 21 shows the peak temperatures for all of the filters from all of the transient runs. The trends of the temperature responses are given in Sec. V. B.

Wood-framed fire-resistant HEPA filters that are sealed with elastomeric adhesives can withstand 300°F temperature for 2 hours.⁽⁶⁾ The "Bleed-Off" and "400 Glove Box" exhaust filters reached peak temperatures of 194°F and 116°F, respectively. No consideration was given to any filter degradation by the process chemical fumes or fumes that could be produced in a fire.

When clean, HEPA filters can withstand 10 inwg pressure drop without structural damage or reduction in efficiency.⁽⁶⁾ Tests (7) have been done to find the structural limit of clean and loaded filters for tornado over pressurizations. These tests show loaded filters fail with smaller over pressurizations than clean filters. Minimum loaded-filter pressure drops for tornado before filter failure are 36 in. wg. For the most realistic case, Trans5, the "400 Glove Box" exhaust filter presents the highest pressure drop, which is 16.3 in. wg. But, even this case does not account for the filtering action of the demistor that is prior to the filter or material deposition in the "400 Glove Box" duct works.

As with every model, this model is an approximation. FIRAC is a lumped parameter computer code which implies that the temperature and other properties do not have any spacial variations within a room. Every value should then be viewed as an average. For instance, Figs. 23 and 24 show the peak temperatures of five zone regions. These then are average temperatures within each of those rooms or regions.

Fig. 23.
Trans 1-3 regional peak temperatures.

Fig. 24.
Trans 3-5 regional peak temperatures.

None of these temperatures are high enough to cause a component failure that could alter the ventilation systems.

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Although I have done most of the work, other people have contributed to this project, if only by reviewing the interim progress. During the beginning of the study Fritz Krause of the Engineering and Safety Analysis Group was working with me but had to take leave because of illness and has since died. Other people who have contributed include W. Wood, C. Smith, D. Davidson, J. Hatchell, L. Bartlien, W. Maraman, W. McNeese, J. Green, and A. Crawford.

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APPENDIX A
MODEL INPUT PARAMETERS

TABLE A-I
BRANCH LISTING

Br. No.	Up	Down	Given Flow (ft ³ /min)	Area (ft ²)	Length (ft)	Type	Resistance* [ln. w.g./ (ft ³ /min) ²]	Pres. Drop** (ln.w.g.)
1	1	2	11080	9.0	30.0	d	3.875 e-09	5.42 e-01
2	2	3	11080	24.3	8.0	f	5.415 e-05	5.76-e1
3	3	4	11080	6.3	4.0	b	N/A	-5.02 e+00
4	4	5	11080	3.4	140.0	d	1.550 e-08	2.11 e+00
5	5	73	5880	1.2	30.0	d	2.750 e-08	1.99 e+00
6	5	9	5020	3.1	20.0	d	8.000 e-08	1.97 e+00
7	5	13	180	0.444	20.0	d	6.000 e-05	1.98 e+00
8	9	73	2160	8.0	0.5	d	4.500 e-09	2.77 e-02
9	8	66	2070	1.4	20.0	d	4.500 e-10	1.47 e-03
10	8	9	310	2.5	10.0	d	7.000 e-07	5.69 e-02
11	9	67	100	0.087	18.0	d	2.750 e-05	4.37 e-01
12	9	10	475	1.0	0.333	d	8.000 e-08	2.30 e-02
13	9	13	238	0.75	0.333	d	3.052 e-07	1.54 e-02
14	9	14	475	1.0	0.333	d	8.000 e-08	2.52 e-02
15	9	16	237	0.75	0.333	d	3.500 e-07	2.28 e-02
16	9	17	475	1.0	0.333	d	8.000 e-08	2.38 e-02
17	9	18	475	1.0	0.333	d	8.000 e-08	2.29 e-02
18	9	20	475	1.0	0.333	d	8.000 e-08	2.87 e-02
19	22	23	18760	26.7	9.0	d	5.375 e-11	1.92 e-02
20	23	24	18760	128.7	28.0	f	1.800 e-04	3.41 e+00
21	24	25	18760	9.0	2.5	b	N/A	-6.95 e+00
22	25	29	18760	9.0	20.0	d	2.841 e-10	1.01 e-01
23	22	26	18760	26.7	9.0	d	5.375 e-11	1.92 e-02
24	26	27	18760	128	28.0	f	1.800 e-04	3.41 e+00
25	27	28	18760	9.0	2.5	b	N/A	-6.95 e+00
26	28	29	18760	9.0	3.0	d	2.841 e-10	1.01 e-01
27	29	30	37520	18.0	16.0	d	2.478 e-10	3.51 3-01

*These values are the same for both models.

**These values are at 18 s.

TABLE A-I (CONT)

Br. No.	Up	Down	Given Flow (ft ³ /min)	Area (ft ²)	Length (ft)	Type	Resistance* [in. w.g./ (ft ³ /min) ²]	Pres. Drop** (in. w.g.)
28	30	31	1900	1.7	64	d	4.000 e-07	1.51 e+00
29	31	22	1900	1.7	168	d	4.100 e-07	1.55 e+00
30	30	62	2660	9.0	4	d	3.500 e-07	2.43 e+00
31	30	32	32960	14.0	16	d	4.200 e-10	1.76 e-01
32	32	38	32960	15.0	14	d	4.200 e-10	4.61 e-01
33	33	10	1825	1.8	32	d	1.800 e-07	6.28 e-01
34	33	11	1555	1.4	56	d	2.500 e-07	6.39 e-01
35	34	33	3380	2.4	9	d	4.000 e-10	4.57 e-03
36	34	12	685	0.6	36	d	1.250 e-06	6.34 e-01
37	35	34	4065	2.9	22	d	5.000 e-10	8.22 e-03
38	35	14	3295	2.5	36	d	5.500 e-08	6.43 e-01
39	36	35	7360	5.0	26	d	4.750 e-10	4.93 e-02
40	36	14	3295	2.5	36	d	5.800 e-08	6.92 e-01
41	37	36	10655	6.3	11	d	4.000 e-10	4.50 e-02
42	37	15	975	0.88	38	d	7.000 e-07	7.43 e-01
43	38	37	11630	6.3	16	d	7.000 e-10	2.24 e-01
44	38	16	120	0.095	10	d	7.000 e-05	9.59 e-01
45	38	39	21210	10.5	14	d	9.000 e-11	1.10 e-01
46	39	17	2975	2.4	36	d	8.000 e-08	8.50 e-01
47	39	40	18235	9.5	24	d	4.500 e-11	3.36 e-02
48	40	17	2975	2.4	36	d	7.500 e-08	8.17 e-01
49	40	41	15260	9.5	32	d	2.000 e-11	4.63 e-03
50	41	18	1425	1.39	22	d	3.600 e-07	8.11 e-01
51	41	42	13835	8.0	16	d	6.447 e-11	1.22 e-02
52	42	18	4025	3.3	36	d	4.500 e-08	7.99 e-01
53	42	43	9810	6.0	26	d	6.800 e-11	6.41 e-03
54	43	19	755	0.78	60	d	2.500 e-06	8.02 e-01
55	43	44	9055	6.0	17	d	3.700 e-10	3.10 e-02
56	44	20	4465	3.5	36	d	3.600 e-08	7.67 e-01
57	44	45	4590	3.1	38	d	4.750 e-10	6.31 e-02
58	45	20	3805	3.5	36	d	4.800 e-08	7.04 e-01
59	45	21	785	0.6	24	d	9.900 e-07	7.02 e-01
60	10	49	2300	1.146	26	d	1.040 e-07	7.26 e-01

TABLE A-I (CONT)

Br. No.	Up	Down	Given Flow (ft ³ /min)	Area (ft ²)	Length (ft)	Type	Resistance* [ln. w.g./ (ft ³ /min) ²]	Pres. Drop** (ln.w.g.)
61	11	46	875	1.046	15	d	8.000 e-07	6.93 e-01
62	11	47	680	0.914	4	d	8.000 e-08	6.24 e-02
63	47	48	680	0.914	2	f	9.000 e-04	5.99 e-01
64	48	46	680	0.914	9	d	7.000 e-08	3.11 e-02
65	46	49	1570	4.972	20	d	9.000 e-09	2.22 e-02
66	12	49	1103	0.761	25	d	5.600 e-07	7.24 e-01
67	13	12	418	2.0	0.333	d	5.000 e-08	9.03 e-03
68	49	50	4973	8.364	26	d	5.750 e-10	1.37 e-02
69	14	50	7028	2.983	15	d	9.500 e-09	7.37 e-01
70	50	53	12001	8.364	32	d	9.000 e-11	1.26 e-02
71	15	51	320	0.667	4	d	2.300 e-06	2.48 e-01
72	51	52	320	0.667	2	f	9.000 e-04	2.89 e-01
73	52	53	320	0.667	9	d	2.000 e-06	2.06 e-01
74	15	53	884	1.169	15	d	9.200 e-07	7.44 e-01
75	16	15	257	1.0	0.333	d	8.000 e-08	8.41 e-03
76	53	54	13205	8.364	28	d	5.500 e-10	9.38 e-02
77	17	54	6425	2.979	15	d	1.325 e-08	8.45 e-01
78	54	57	19630	8.264	24	d	3.940 e-10	1.60 e-01
79	18	57	4565	2.54	15	d	4.000 e-08	1.01 e+00
80	18	55	1360	1.32	4	d	3.000 e-08	1.07 e-01
81	55	56	1360	1.32	2	f	5.600 e-04	7.54 e-01
82	56	57	1360	1.32	9	d	8.000 e-08	1.45 e-01
83	58	57	10065	8.364	29	d	8.000 e-11	8.33 e-03
84	19	58	775	0.922	15	d	1.750 e-06	9.88 e-01
85	20	19	20	2.0	0.333	d	1.000 e-07	3.68 e-03
86	59	58	9330	8.364	43	d	1.200 e-09	1.07 e-01
87	20	59	8545	3.531	15	d	7.700 e-09	8.84 e-01
88	21	59	785	1.05	15	d	1.375 e-06	8.87 e-01
89	57	60	35620	9.17	16	d	6.000 e-11	7.72 e-02
90	60	22	35620	9.17	16	d	3.000 e-10	3.86 e-01
91	15	70	50	0.087	18	d	1.000 e-04	3.46 e-01
92	16	69	100	0.087	18	d	7.000 e-05	5.79 e-01
93	9	67	220	0.087	18	d	1.350 e-06	4.37 e-01

TABLE A-I (CONT)

Br. No.	Up	Down	Given Flow (ft ³ /min)	Area (ft ²)	Length (ft)	Type	Resistance* [ln. w.g./ (ft ³ /min) ²]	Pres. Drop** (ln.w.g.)
94	61	70	9560	7.94	20	d	2.000 e-09	1.87 e-01
95	71	63	13000	11.7	10	f	1.769 e-04	2.38 e+00
96	63	64	13000	10.4	5	b	N/A	-9.15 e+00
97	64	65	13000	13.9	30	d	6.000 e-10	1.04 e-01
98	66	72	2070	9	2	f	1.800 e-05	3.45 e-02
99	67	68	320	0.349	16	d	1.000 e-06	1.20 e-01
100	8	68	360	1.227	10	d	4.750 e-06	6.14 e-01
101	68	69	680	1.069	40	d	9.000 e-08	4.47 e-02
102	69	62	730	1.396	20	d	4.000 e-07	2.50 e-01
103	70	62	9610	12.5	10	d	5.000 e-09	4.74 e-01
104	62	71	13000	12.5	20	d	3.250 e-08	5.64 e+00
105	14	15	22	2.0	0.333	v	2.000 e-08	5.97 e-03
106	14	11	15	2	0.333	v	2.000 e-08	8.47 e-03
107	73	6	33780	9.17	30	d	1.000 e-10	7.77 e-01
108	6	74	16890	26.7	9	d	2.000 e-11	5.51 e-03
109	74	75	16890	128.7	28	f	2.345 e-04	3.90 e+00
110	75	76	16890	9.0	2.5	b	N/A	-7.07 e+00
111	76	80	16890	9.0	11.5	d	8.000 e-10	2.18 e-01
112	6	77	16890	26.7	9	d	2.000 e-11	5.51 e-03
113	77	78	16890	128.7	28	f	2.345 e-04	3.90 e+00
114	78	79	16890	9.0	2.5	b	N/A	7.07 e+00
115	79	80	16890	9.0	11.5	d	8.000 e-10	2.18 e-01
116	80	81	33780	18.0	16	d	2.750 e-10	3.00 e-01
117	81	61	4710	7.9	3	d	9.500 e-08	2.03 e+00
118	81	73	29070	10.0	40	d	2.000 e-09	1.87 e+00
119	73	61	3330	4.0	30	d	1.000 e-08	1.63 e-01
120	8	61	1520	1.07	50	d	6.000 e-08	2.47 e-01
121	8	82	2000	1.4	20	d	4.500 e-10	2.11 e-03
122	82	83	2000	9.0	2	f	1.800 e-05	3.65 e-02
123	83	84	2000	1.4	50	d	1.330 e-07	6.46 e-01
124	84	85	2000	1.8	50	d	4.500 e-07	1.92 e+00
125	85	86	2000	9.0	2	f	3.125 e-03	6.39 e+00

TABLE A-I (CONT)

Br. No.	Up	Down	Given Flow (ft ³ /min)	Area (ft ²)	Length (ft)	Type	Resistance* (In. w.g./ (ft ³ /min) ²)	Pres. Drop** (In. w.g.)
126	86	87	2000	0.35	2.5	b	N/A	-9.27 e+00
127	87	88	2000	1.8	20	d	4.000 e-08	1.64 e-01
128	7	89	8000	4.9	20	d	5.450 e-09	4.63 e-01
129	89	90	8000	24.3	8	f	3.970 e-04	3.11 e+00
130	90	91	8000	6.3	4	b	N/A	-3.77 e+00
131	91	8	8000	3.0	30	d	1.835 e-09	3.17 e-01
132	8	92	1740	2.0	20	d	1.500 e-07	4.69 e-01
133	92	93	1740	2.0	20	d	6.500 e-07	1.88 e+00
134	93	94	1740	9.0	2	f	2.000 e-04	3.42 e-01
135	94	95	1740	3.3	4	b	N/A	-2.83 e+00
136	95	96	1740	3.3	20	d	8.000 e-09	2.30 e-02
137	72	97	2070	1.4	50	d	1.500 e-07	6.40 e-01
138	97	98	2070	1.8	50	d	5.500 e-07	2.08 e+00
139	98	99	2070	9.0	2	f	3.750 e-03	7.25 e+00
140	99	100	2070	0.35	4	b	N/A	-1.03 e+01
141	100	101	2070	1.8	20	d	4.000 e-08	1.47 e-01
142	14	84	75	0.5	15	d	9.000 e-05	

**TABLE A-II
NODE LISTING**

Node	Volume (ft³)	Flow Area (ft²)
2	187.2	16.7
3	109.7	15.3
4	250.6	4.9
5	340.4	3.4
6	675.6	26.7
8	553800.0	36920.0
9	28400.0	2840.0
10	10560.0	704.0
11	9840.0	656.0
12	6093.8	406.3
13	1125.0	75.0
14	46462.5	3097.5
15	11062.5	737.5
16	1912.5	127.5
17	43365.0	2891.0
18	39825.0	2655.0
19	11062.0	737.5
20	60982.5	4065.5
21	4950.0	330.0
22	675.6	26.7
23	1912.0	77.7
24	1803.3	68.5
25	101.3	9.0
26	1912.0	77.7
27	1803.3	68.5
28	24.8	9.0
29	247.5	18.0
30	380.7	16.0
31	15360.0	384.0
32	217.0	14.5
33	151.0	2.4
34	63.8	2.7

TABLE A-II (CONT)

Node	Volume (ft³)	Flow Area (ft²)
35	187.8	4.0
36	190.9	5.7
37	119.3	6.3
38	231.7	12.8
39	275.0	10.0
40	353.5	9.5
41	252.7	8.8
42	262.0	7.0
43	341.5	6.0
44	237.6	4.3
45	201.6	3.1
46	69.5	5.0
47	4.6	0.9
48	5.0	0.9
49	207.3	6.7
50	278.4	8.4
51	3.3	0.7
52	3.7	0.7
53	271.5	8.4
54	262.1	8.4
55	6.6	1.3
56	7.3	1.3
57	300.9	8.4
58	314.9	8.4
59	248.5	8.4
60	146.7	9.2
61	149.5	7.9
62	216.5	7.4
63	84.4	10.4
64	442.8	13.9
66	11.8	5.2
67	7.9	0.2
68	36.4	0.9

TABLE A-II (CONT)

Node	Volume (ft³)	Flow Area (ft²)
69	36.9	0.9
70	221.4	10.2
71	183.5	12.1
72	44.0	5.2
73	241755.0	16117.0
74	1912.0	77.7
75	1803.3	68.5
76	63.1	9.0
77	1912.0	77.7
78	1803.3	68.5
79	63.1	9.0
80	247.5	18.0
81	379.9	16.0
82	11.8	5.2
83	44.0	5.2
84	24175.0	1612.0
85	99.0	5.4
86	9.4	4.0
87	36.4	1.5
89	146.2	14.6
90	109.8	15.3
91	102.6	4.7
92	30.0	2.0
93	69.5	6.2
94	6.6	6.2
95	29.7	3.3
97	24175.0	1612.0
98	99.0	5.4
99	9.4	4.0
100	36.4	1.5

Fig. A-1.
400 recirculation HV 807 and 808 blower curves.

Fig. A-2.
300 recirculation HV 805 and 806 blower curves.

Fig. A-3.
"Fresh-Air" HV810 blower curve.

Fig. A-4.
"Bleed-Off" HV 822 blower curve.

Fig. A-5.
Basement supply HV 841 blower curve.

Fig. A-6.
Basement exhaust HV 841 blower curve.

Fig. A-7.
400 glovebox HV 856 blower curve.

Fig. A-8.
300 glovebox HV 854 blower curve.

APPENDIX B
MODEL VALIDATION PARAMETERS

TABLE B-I
PRESSURE COMPARISON

Node	Given Pressure (in. w.g.)	Calculated Pressure (in. w.g.)	% Difference
8	-0.11	-0.11466	4.24
73	-0.2	-0.19925	-0.38
9	-0.17	-0.17159	0.94
31	-0.11	-0.10911	-0.81
10	-0.2	-0.19456	-2.72
11	-0.202	-0.20527	1.62
12	-0.2	-0.19605	-1.98
13	-0.185	-0.18703	1.10
14	-0.197	-0.1968	-0.10
15	-0.203	-0.20278	-0.11
16	-0.2	-0.19437	-2.82
17	-0.2	-0.19542	-2.29
18	-0.2	-0.19445	-2.78
19	-0.205	-0.20398	-0.50
20	-0.2	-0.2003	0.15
21	-0.2	-0.19751	-1.25
84	-0.8	-0.79946	-0.07
97	-0.8	-0.79026	-1.22

TABLE B-II
VOLUME FLOW COMPARISON

Branch No.	Given Flow (ft ³ /min)	Calculated Flow (ft ³ /min)	% Difference
1	11080	10973.00	-0.97
2	11080	10989.00	-0.82
3	11080	11011.00	-0.62
4	11080	10848.00	-2.09
5	5880	5828.4	-0.88
6	5020	4915.3	-2.09
7	180	180.8	0.44
8	2160	2286.2	5.84
9	2070	1915.00	-7.49
10	310	283.58	-8.52
11	100	113.06	13.06
12	475	419.08	-11.77
13	238	197.6	-16.97
14	475	439.09	-7.56
15	237	227.51	-4.00
16	475	426.87	-10.13
17	475	418.11	-11.98
18	475	468.54	-1.36
19	18760	18957.00	1.05
20	18760	18959.00	1.06
21	18760	19166.00	2.16
22	18760	18755.00	-0.03
23	18760	18957.00	1.05
24	18760	18959.00	1.06
25	18760	19166.00	2.16
26	18760	18755.00	-0.03
27	37520	37521.00	0.00
28	1900	1898.6	-0.07
29	1900	1907.3	0.38
30	2660	2625.00	-1.32
31	32960	33043.00	0.25

TABLE B-II (CONT)

Branch No.	Given Flow (ft³/min)	Calculated Flow (ft³/min)	% Difference
32	32960	33055.00	0.29
33	1825	1832.2	0.39
34	1555	1545.5	-0.61
35	3380	3377.3	-0.08
36	685	676.48	-1.24
37	4065	4053.9	-0.27
38	3295	3275.2	-0.60
39	7360	7327.4	-0.44
40	3295	3272.9	-0.67
41	10655	10597.00	-0.54
42	975	985.35	1.06
43	11630	11579.00	-0.44
44	120	112.5	-6.25
45	21210	21420.00	0.99
46	2975	3100.3	4.21
47	18235	18325.00	0.49
48	2975	3129.5	5.19
49	15260	15198.00	-0.41
50	1425	1449.1	1.69
51	13835	13750.00	-0.61
52	4025	4050.1	0.62
53	9810	9701.6	-1.10
54	755	556.89	-26.24
55	9055	9144.2	0.99
56	4465	4530.00	1.46
57	4590	4616.3	0.57
58	3805	3828.00	0.60
59	785	788.86	0.49
60	2300	2255.8	-1.92
61	890	904.87	1.67
62	680	665.63	-2.11
63	680	665.72	-2.10

TABLE B-II (CONT)

Branch No.	Given Flow (ft³/min)	Calculated Flow (ft³/min)	% Difference
64	680	666.93	-1.92
65	1570	1573.7	0.24
66	1103	1057.6	-4.12
67	418	379.59	-9.19
68	4973	4893.2	-1.60
69	7028	6963.8	-0.91
70	12001	11868.00	-1.11
71	320	320.91	0.28
72	320	321.14	0.36
73	320	321.43	0.45
74	884	881.72	-0.26
75	257	253.57	-1.33
76	13205	13075.00	-0.98
77	6425	6675.2	3.89
78	19630	19768.00	0.70
79	4565	4586.2	0.46
80	1360	1345.9	-1.04
81	1360	1346.1	-1.02
82	1360	1349.2	-0.79
83	10065	10225.00	1.59
84	775	739.21	-4.62
85	20	180.81	804.05
86	9330	9480.2	1.61
87	8545	8670.7	1.47
88	785	790.47	0.70
89	35620	35932.00	0.88
90	35620	35948.00	0.92
91	50	56.993	13.99
92	100	86.87	-13.13
93	220	232.86	5.85
94	9560	9683.7	1.29
95	13000	13426.00	3.28

TABLE B-II (CONT)

Branch No.	Given Flow (ft³/min)	Calculated Flow (ft³/min)	% Difference
96	13000	13524.00	4.03
97	13000	13153.00	1.18
98	2070	1915.8	-7.45
99	320	346.15	8.17
100	360	358.21	-0.50
101	680	705.15	3.70
102	730	792.27	8.53
103	9610	9746.6	1.42
104	13000	13197.00	1.52
105	22	18.445	-16.16
106	15	21.966	46.44
107	33780	33221.00	-1.65
108	16890	16625.00	-1.57
109	16890	16626.00	-1.56
110	16890	16830.00	-0.36
111	16890	16466.00	-2.51
112	16890	16625.00	-1.57
113	16890	16626.00	-1.56
114	16890	16830.00	-0.36
115	16890	16466.00	-2.51
116	33780	32955.00	-2.44
117	4710	4601.00	-2.31
118	29070	28400.00	-2.30
119	3330	3514.00	5.53
120	1520	1539.00	1.25
121	2000	2032.2	1.61
122	2000	2030.00	1.50
123	2000	2028.8	1.44
124	2000	2033.1	1.66
125	2000	2044.7	2.24
126	2000	2093.2	4.66
127	2000	2026.8	1.34

TABLE B-II (CONT)

Branch No.	Given Flow (ft³/min)	Calculated Flow (ft³/min)	% Difference
128	8000	7821.8	-2.23
129	8000	7830.5	-2.12
130	8000	7905.6	-1.18
131	8000	7817.4	-2.28
132	1740	1698.1	-2.41
133	1740	1700.3	-2.28
134	1740	1710.00	-1.72
135	1740	1711.8	-1.62
136	1740	1697.1	-2.47
137	2070	1917.7	-7.36
138	2070	1921.00	-7.20
139	2070	1932.9	-6.62
140	2070	1983.3	-4.19
141	2070	1915.3	-7.47

APPENDIX C

BASE MODEL (MODEL ITERATION #5) PLOTS

The base computer model has the notation of Iter 5 or I5, and the model variation has the notation Iter 6 or I6. Figure C-1 shows the average peak pulse pressures of all the transient runs for each model. Unless otherwise noted, the 400 east wing has all of the values, for example, Room 429 and adjacent rooms with the swing doors modeled as control dampers in that section, averaged. This section can be compared with the overview section.

Fig. C-1.
Model variation peak pressure comparison.

Fig. C-2.
Trans 1 peak temperature comparison.

Fig. C-3.
Base model filter temperatures.

END

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