Technical Conference on the NIST Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Project #4: Investigation of Active Fire Protection Systems
Smoke Control Systems Sub-Task (NCSTAR 1-4D)

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NIST

NIST WTC Investigation
Project #4: Investigation of Active Fire Protection Systems Smoke Control Systems Sub-Task

Purpose:

Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.

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Goals and Objectives:

1) Document the design and installation of the smoke management systems installed in WTC 1, 2, and 7 and compare the designs to applicable code and standards requirements (Task 1).
2) Document the normal operation of the fully functional smoke management systems, and its potential effect on smoke conditions in WTC 1 and 2 on September 11, 2001 (Task 2).

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Approach:

- Identify applicable code requirements with respect to smoke management systems.
  - **NCSTAR 1-1D Report**
- Describe operation of smoke management systems.
  - **Building operations manuals (NIST Document Resource Center)**
  - **Port Authority input**
- Evaluate system performance on September 11, 2001.
  - **Actions of emergency response personnel**
  - **Damage to system components**
- Evaluate potential smoke management system effectiveness.
  - **Use CONTAM building airflow model to evaluate multiple smoke management system approaches for various design fire scenarios.**

Task 1: Summary of Installed Smoke Management Features in WTC 1 and 2

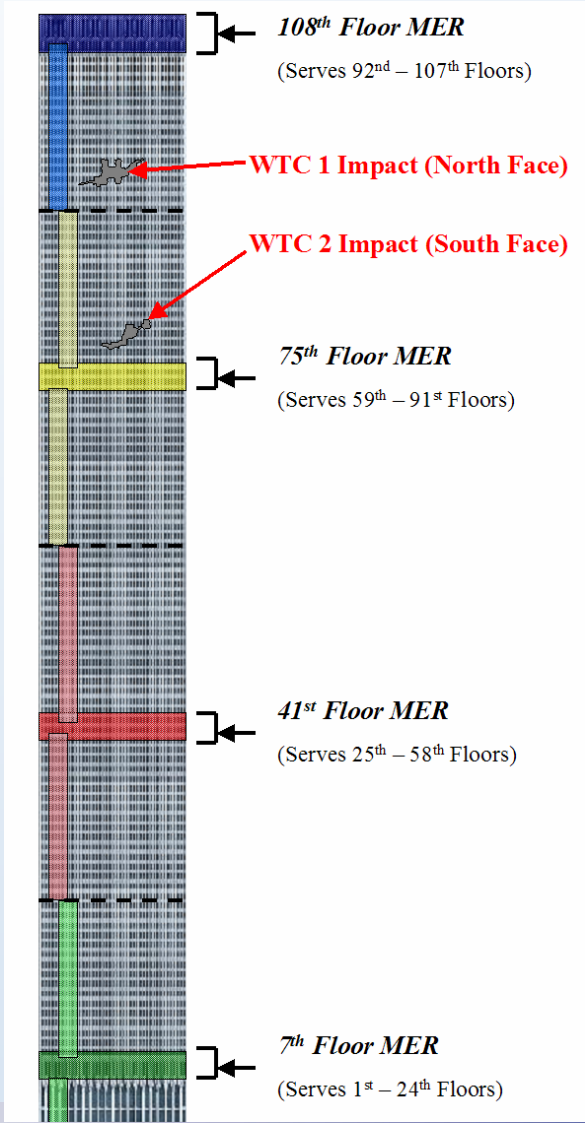
- WTC 1 and 2 provided with the means for accomplishing a smoke purge from each HVAC zone in the building.
- Fire dampers required at all duct openings into vertical shaft enclosures and at penetrations of fire resistance rated floors and ceilings.
- Provision of multiple fire compartments on each floor of the building (not required once sprinklers were installed). [LL#5, 1973]
- One or more smoke shafts by which smoke could be mechanically vented to the outdoors. In lieu of smoke shafts stairs could be provided with stair pressurization. [LL#5]
  - **Pilot study performed between 1976 and 1979 to evaluate feasibility of providing stair pressurization systems in WTC 1 and 2.**
  - **LL#86 (enacted in 1979) exempted buildings from smoke shaft/stair pressurization requirement if they were sprinklered throughout.**
  - **Stair pressurization systems never installed in WTC 1 and 2.**

Task 1: Summary of Installed Smoke Management Features in WTC 7

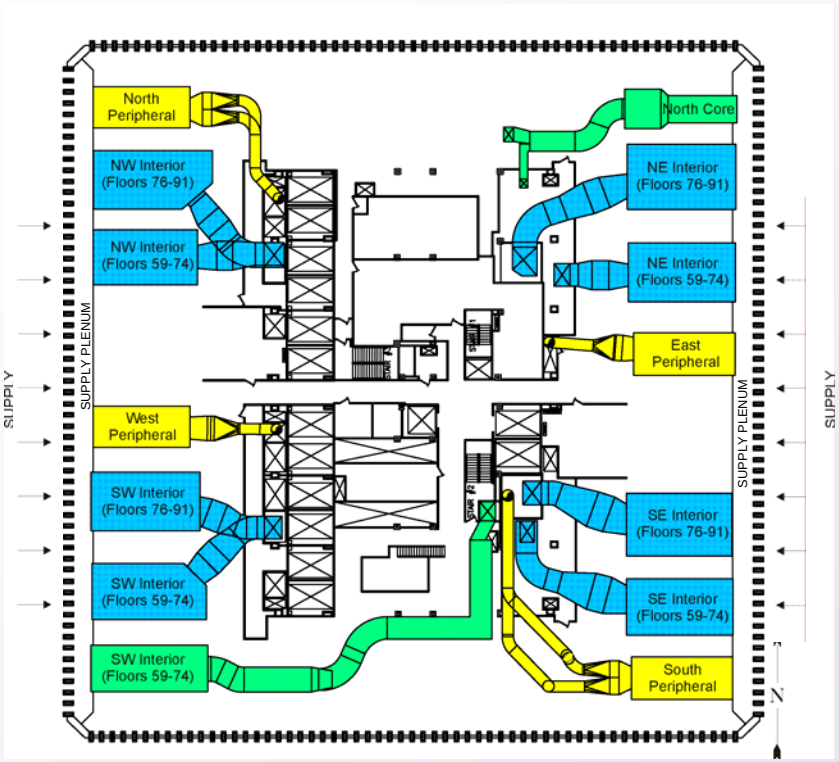
- Fire dampers required at all duct openings into vertical shaft enclosures and at penetrations of fire resistance rated floors and ceilings.
- Combination fire/smoke dampers or an independent smoke damper at fire resistance rated penetrations.
- A mechanical means to exhaust 6 air changes per hour, or 1 cfm/ft^2 from the largest floor of the building.
  - **Smoke purge quantities found to be not consistent with minimum value specified by code (48,000 cfm). Low on floors up to 23rd floors (36,000 cfm). High on renovated upper floors of the building (84,000 cfm).**
- Emergency power system having the capacity to operate life safety related equipment, including smoke purge equipment.
- No evidence found to show smoke purge utilized on 9/11/01. Since building was evacuated, systems had minimum effect on occupants/emergency responders.

WTC 1 and 2 – Building Ventilation Systems

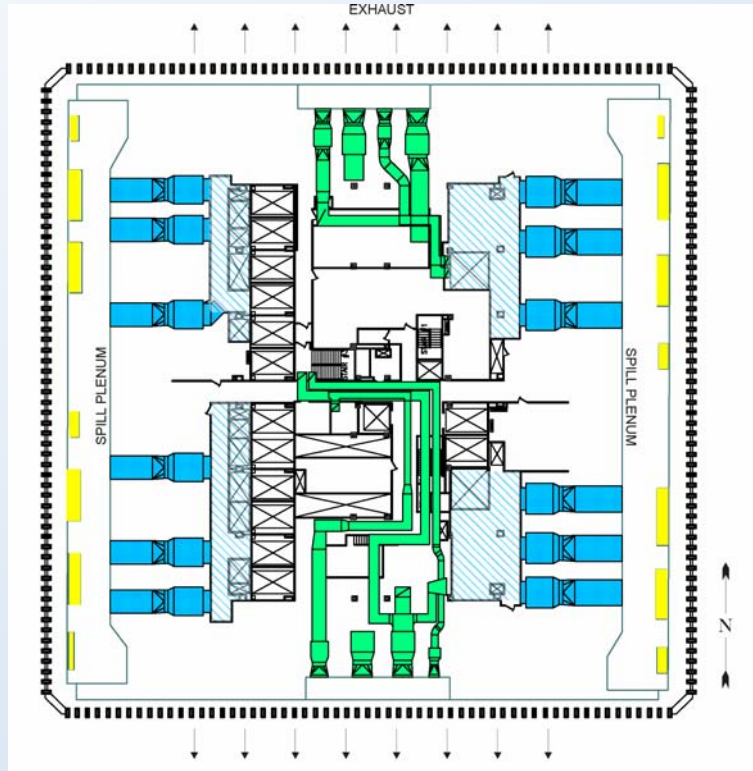
- Each tower had four two-level mechanical equipment rooms.
- Four major HVAC zones within each building.



WTC 1 and 2 – Building Ventilation Systems

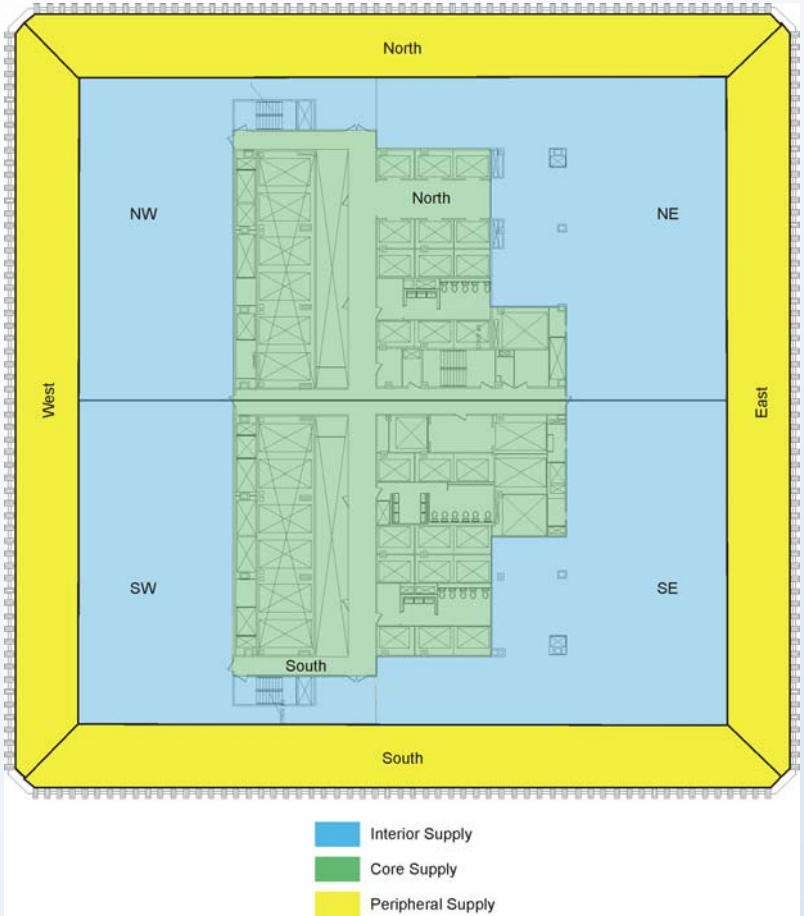


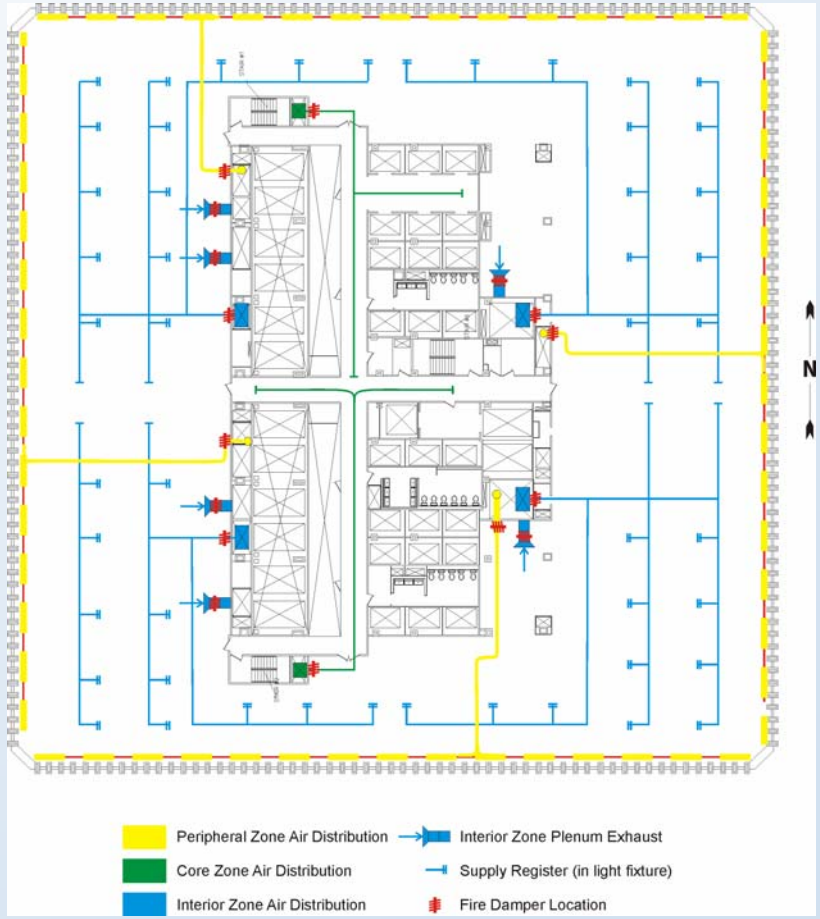
MER – Lower Level



MER – Upper Level

WTC 1 and 2 – Building Ventilation Systems





WTC 1 and 2 – Smoke Management System Sequence of Operations

- Fire Safety Plan for WTC 1 and 2 (PANYNJ 1999) defines use of smoke purge "after a fire has been extinguished". Operation could be achieved by aligning equipment from within an individual MER or from a central control panel located in the Operations Control Center (OCC) – B1 level of WTC 2.

- WTC Instruction Manual No. 23, *Operation and Maintenance of Fire Protection Systems (PANYNJ 1986) documents sequence of operations as follows ->*

Towers A and B
Interior Areas
<u>Note:</u> Only the Fire Safety Director on duty may request smoke purge.
In the event of smoke in an interior tenant's space involving personnel evacuation, the smoke purge procedure to be used is as follows:
1. Secure all fans in the pertinent MER. **2. Set all quadrant Normal/Purge/Reset switches to the Purge position.** **3. Start all return air fans.** **4. Start MER exhaust fan(s), if necessary.**
Tower Core
1. Secure all fans in the pertinent MER. **2. Set all quadrant Normal/Purge/Reset switches to the Purge position.** **3. Start all return air fans.** **4. Open Men's and Ladies' Room doors on the floors involved, and start the relevant toilet exhaust fan(s).**

WTC 1 and 2 – Smoke Management System Sequence of Operations

- PANYNJ was asked to clarify the operation of the smoke purge sequence. The response was as follows:

  "If fans were still operating, as would often be the case, the engineer at FDNY direction would key over to purge mode. This would sequence spill dampers to open 100 %. In addition, building operating procedure during a purge was to run the interior supply fans for purging [the] affected quadrant. During purge, the interior fan's outside supply air dampers would go to 100 % open…. Core fans would not normally operate during a smoke purge unless conditions warranted and requested by FDNY."

- PANYNJ stated that WTC Instruction Manual No. 23 had not been updated after the 1993 bombing and did not always reflect the most current fire protection system configuration.
- Accounts of February 13, 1975 fire on 11th floor of WTC 1 document the "smoke purge" sequence as the core being pressurized and the office spaces being exhausted. The accounts further state that the smoke purge sequence for the HVAC zone containing the fire floor was initiated during the fire.

WTC 1 and 2 – Evaluation of Smoke Management System Performance on September 11, 2001

Actions of Emergency Response Personnel

- WTC fire safety director on duty on September 11, 2001 stated that no recommendation was given on his part to initiate a smoke purge sequence, nor was smoke purge performed to his knowledge.
- No record was found of FDNY personnel having initiated a smoke purge sequence in WTC 1 or WTC 2.

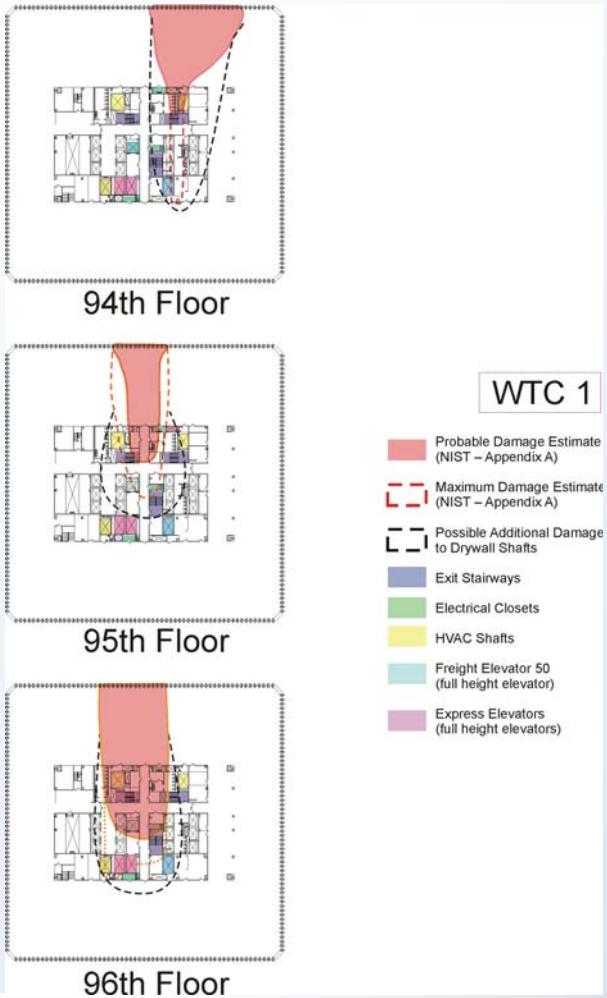
WTC 1 and 2 – Evaluation of Smoke Management System Performance on September 11, 2001

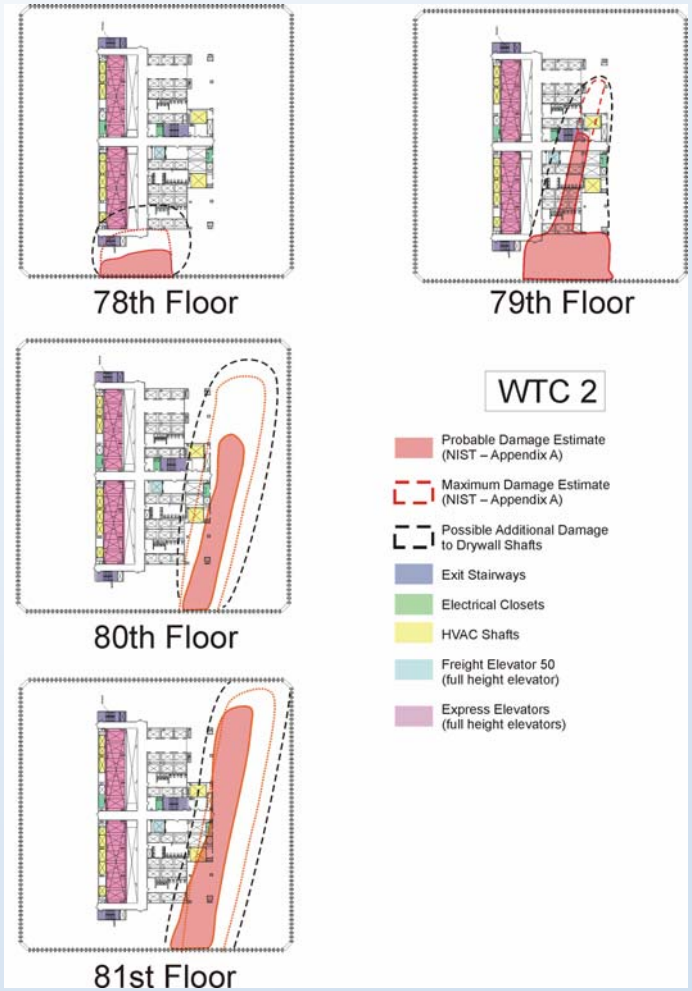
Damage to System Components

- While the extent of damage to individual floors of WTC 1 and 2 may never be known, the potential damage can be estimated based on the results of engineering analysis and observations of people within the buildings.
- Numerous accounts are available documenting the damage to the three stair shafts in each building and extensive damage to core areas, where HVAC and electrical system components were located.
- Extensive damage to HVAC ductwork systems was evident as was the loss of electrical power. HVAC systems in WTC 1 and 2 were not provided with emergency power.

WTC 1 and 2 – Evaluation of Smoke Management System Performance on September 11, 2001

Damage to System Components





WTC 1 and 2 – Evaluation of Smoke Management System Performance on September 11, 2001

Damage to System Components

WTC 1 and 2 – Evaluation of Smoke Management System Performance on September 11, 2001

Damage to System Components

WTC 1 and 2 – Evaluation of Potential Smoke Management System Effectiveness

- The CONTAM building airflow and contaminant dispersal model (developed by NIST) was used to evaluate how various smoke management system configurations might have performed on September 11, 2001.
- The performance of these systems for other hypothetical fire scenarios in high-rise buildings was also evaluated.
- Performance criteria – creation of pressure differential between smoke zones.
- Smoke management approaches evaluated:
  - **Smoke Purge**
  - **Core Pressurization**
  - **Building Pressurization**
  - **Sandwich Pressurization**
  - **Zoned Smoke Control with Stair Pressurization**
- High-rise fire scenarios evaluated:
  - **Sprinklered Fire**
  - **Full-Floor Burnout**
  - **Two-Floor Fire**
  - **9/11/01 Fire Scenario (No shaft damage)**
  - **9/11/01 Fire Scenario (Shaft damage assumed)**

WTC 1 and 2 – Evaluation of Potential Smoke Management System Effectiveness

Conclusions:

- The *smoke purge* system installed in WTC 1 and 2 would only have been effective in containing smoke from a sprinklered fire.
- The *zoned smoke control with stair pressurization* approach would be effective for typical high-rise fire scenarios but may be impacted by stack effect in tall buildings such as WTC 1 and 2.
- None of the postulated smoke management approaches would have been effective for the September 11, 2001 impact scenario.

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Findings:

1) The smoke management systems in WTC 1 and WTC 2, which provided the capability for a manual smoke purge within an individual HVAC zone on a quadrant-by-quadrant basis, were not initiated on September 11, 2001.
2) Had the smoke purge sequence been initiated in WTC 1 or WTC 2, it is unlikely the system would have functioned as designed, due to loss of electrical power and/or damage to the HVAC shafts and other structural elements in the impact zone.
3) Provision of active smoke management systems and/or combination fire/smoke dampers was not required by the 1968 BCNYC or retroactive provisions in the various local laws enacted after WTC 1 and WTC 2 were constructed for existing high-rise buildings provided with automatic sprinklers throughout.

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Findings:

4) None of the potential smoke management system configurations evaluated in this report would have provided sufficient pressure differentials to contain smoke for the postulated aircraft impact damage scenarios, even if these systems were capable of operation after the building sustained damage from the aircraft impact.

5) The *smoke purge* sequence in existence on or before September 11, 2001, would have been expected to be capable of limiting the spread of smoke from the zone of fire origin only for fire scenarios in which the sprinkler system was operational and controlled the fire. Other smoke management strategies capable of being implemented using the existing WTC 1 and WTC 2 ventilation systems may also have been capable of controlling smoke from the postulated full-floor burnout and two-floor fire scenarios evaluated in this report had these strategies been identified and implemented into the sequence of operations.

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Findings:

6) During the events occurring on September 11, 2001, stair pressurization would have been ineffective in improving conditions for occupants trying to exit the building.

7) Installation of combination fire/smoke dampers in HVAC ductwork, which was not required in WTC 1 or WTC 2, would have acted to slow the development of hazardous conditions on the uppermost floors of the building, but would likely not have had a significant effect on the ability of occupants to egress the building due to the impassibility of the exit stairways.