FDIC 2005

Testing Tactics Scientifically: PPV in Residential Structures

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Class Outline

- Austin Fire Department (AFD) close calls
- Ventilation principles and case studies
- Positive pressure ventilation research by AFD/UT
- Scientific principles and results of the research
- Tactical application of scientific results

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AFD Close Calls

- Between 1998 and 2003 the Austin Fire Department experienced FIVE near death fire related events at three incidents

1. 903 E. Riverside Drive (Two Firefighters)
2. 2213 S. Lakeshore Drive (Two Firefighters)
3. 837 E. Oltorf Street

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Common Incident Factors

- All Firefighters were hospitalized with thermal and/or smoke related injuries
- All were minutes or possibly seconds from death
- **Proper ventilation** could have prevented these injuries

4

Common Fire Characteristics

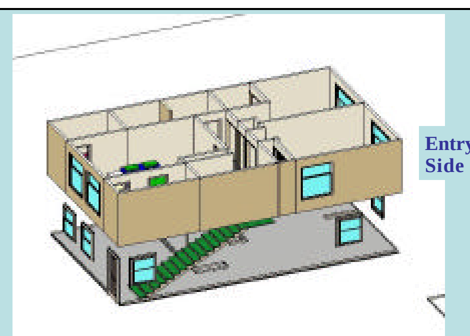
- **All fires were in a <u>ventilation</u> controlled state at the time of the event**
- **All were located in residential structures**
- **All fires were located on the second floor**
- **All were either <u>unventilated</u> or <u>ventilated</u> improperly**

AFD Recommendations from 2213 S. Lakeshore

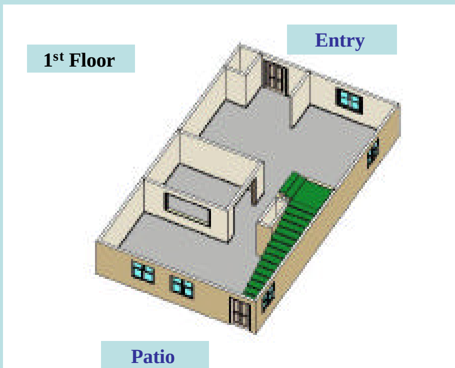
- Formal Investigations indicated that AFD needed:
  - Additional fireground training with an emphasis on **ventilation tactics and procedures**
  - Change from a “policy” based system to a “guideline” based system
  - The need to develop and review new fireground tactics

Investigative Results from the 837 E. Oltorf Incident

- On August 22, 2003 at 02:41 Engine 6 responded to a Heavy Box Alarm at 837 East Oltorf Street. Engine 6.
- All occupants were out of the structure.
- The second floor fire was in a ventilation-controlled state with no visibility and moderate to high heat (at least 500-600° F at waist level at the doorway of fire room).



Fire room: top of the stairs, first door on the left. Room where Engine 6 LT lost air: top of the stairs, first room on the right



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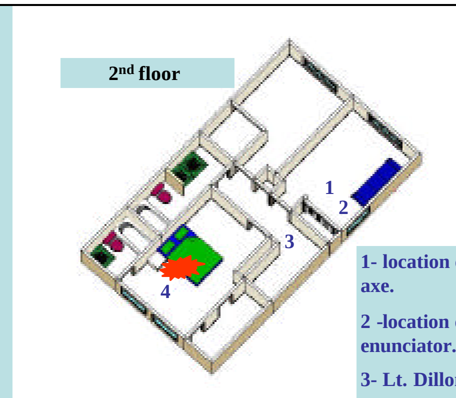

1- location of dropped axe.

2 -location of voice enunciator.

3- Lt. Dillon found.

4- Fire Origin

Stairway Engine 6 ascended to make fire attack
Open door where Engine 6 LT removed

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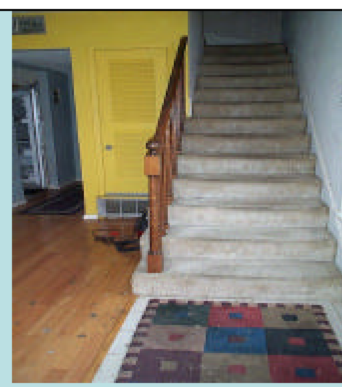

Looking up attack stairwell.

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Looking up attack stairwell.

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Fire room, first door to the left (cannot see in this photo). Door at end of hall is where Engine 6 Firefighter advanced. Engine 6 LT advanced into room on the right.

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Where Engine 6 LT ran into closet door. Engine 6 LT lost consciousness inside closet for 5 to 30 seconds, then regained consciousness and collapsed in hall at end of rug in doorway. Fire room directly across hall, stairway through the door just to the left.

Point of Origin

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Fire room. Window vented from the outside with pike pole

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Investigative Results from the Oltorf Incident

- The Engine 6 Lieutenant was transported to the hospital and treated for smoke inhalation.
- Doctor providing treatment stated that the Lieutenant was within 30 seconds of the injuries being fatal.
- The Engine 6 Lieutenant was treated and released the next day. Several days later the Engine 6 Lieutenant was readmitted to the hospital and treated for chemical burns to the lungs.
- The Engine 6 Lieutenant was released back to active duty after three weeks and has made a full recovery.

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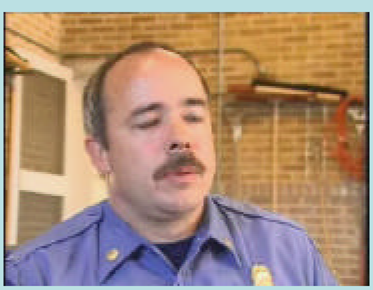
Lt. Dan Dillon Video



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Issues Relevant to this Incident

- Engine 6 Lieutenant experienced a sudden and complete loss of air.
- Ventilation was not coordinated with fire attack. Engine 6 fire attack team, along with all other crews operating on the interior, entered a fire building in a ventilation-controlled state before the structure was effectively ventilated.
- The Engine 6 fire attack team became separated in an IDLH atmosphere while attempting to locate the fire.

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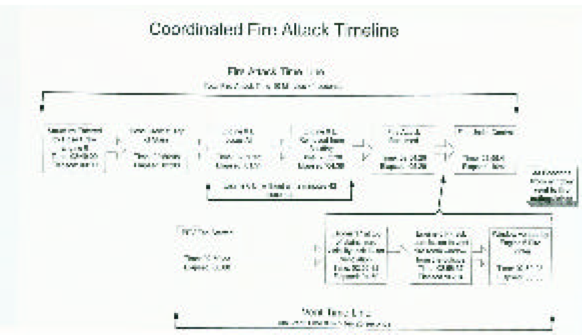

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Ventilation Principles and Case Studies

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Why Ventilate?

- Smoke is Fuel
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- Smoke is Fuel

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Would you fight a fire in a house filled with Propane?

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Propane Vs. Smoke
Smoke is Fuel

Propane
- Flammable Range 2.1-9.6%
- Ignition Temperature 920-1120 °F

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Propane Vs. Smoke
Smoke is Fuel

Propane
- Flammable Range 2.1-9.6%
- Ignition Temperature 920-1120 °F

Smoke / CO
- Flammable Range 12.5-74%
- Ignition Temperature 1128 °F

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Ventilation Controlled Fires Create Smoke that is Fuel!

- Most fires are ventilation controlled on arrival.
- Firefighter vent practices (or lack of) can change a ventilation controlled fire to a rapid fire progression (flashover,backdraft, etc.).
- AFD has had 5 close calls in ventilation controlled fires over the past 6 years

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Ventilation-Controlled
What does this mean?

- Speed and extent of fire is regulated by the air that can be supplied by the compartment openings
- Less than 21% oxygen: oxygen deprived combustion process produces 2 to 5 times the amount of carbon monoxide than in a balanced reaction.
- Less than 13% oxygen: under-ventilated fire conditions, flaming ceases, smoldering combustion occurs

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WARNING!!!
When firefighters arrive, most fires will be in a ventilation-controlled state.

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Ventilation-Controlled Compartment Fires Facts

- High production of flammable gases
- Containment of heat
- Containment of flammable gases
- Only needs more air for the fire to rapidly progress into flashover conditions
- Fire poised for a rapid change

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Ventilation Controlled Case Studies

This is an Emerging National Problem!

1. Washington DC under-ventilated fire flashover kills two firefighters
2. Ohio flashover kills a firefighter
3. Illinois backdraft kills two firefighters
4. Massachusetts flashover kills a firefighter

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Smoke Explosion, Flashover, or Backdraft?

- Terms often used interchangeably
- Definitions similar and overlap
- It is not important to debate the definitions: They are generally rapid fire progressions caused by ventilation controlled fires.
- Firefighter deaths and injuries are many times caused by firefighter ventilation practices.

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UT/AFD Research

Using PPV to mitigate ventilation controlled fire dangers in single family dwellings.

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What Did We Know About PPV?

- PPV has been in existence for over 30 years.
- Marketed as a tool to increase FF/Victim Safety
- Large difference of opinions across the Fire Service as to its benefits
- Untested. Very few studies conducted on the cost/benefit of this tactic.
- It is claimed that PPV could help reduce the chance of "extreme fire behavior" caused by fires in a ventilation controlled state.
- **If not understood and used improperly, PPV can be harmful.**

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AFD/UT Fire Tactics Research Group

- Recognized a lack of scientific based research in ventilation tactics particularly positive pressure
  - Most tactics have been based on anecdotal evidence
  - There is a great variance in opinion as to how positive pressure impacts a ventilation controlled fire
    - Firefighter safety
    - Victim tenability
    - Impact on fire spread/growth
  - Very few research studies have been performed on the effects of positive pressure ventilation

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Existing Studies

- Svensson (Swedish Rescue Services, 2001 & 2002)
  - PPV increases mass burning rates
  - Temperatures increase downstream of fire and decrease upstream
  - Delays in attack of fire after application of PPV may induce fire spread
  - Application of Positive Pressure without Ventilation created worse conditions
- Ingason & Fallberg (Swedish Nat'l Testing & Research Inst., 2002)
  - Overpressures of 1-6 Pascals.
  - Flow patterns in rooms were mapped and showed jetting flows
- Ziesler, Gunnerson, & Williams (Univ. of Central Florida, 1992-1994)
  - Primary show positive benefits of PPV (reduced temperatures, improved visibility, no spread of heat)
- National Research Council of Canada (2002, high-rise buildings)
- Technical Research Center of Finland (VTT) (2000)

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PPV Studies

- Structures involved were single family dwellings.
- Test burns were conducted over a two year period.
- Focus was the effect of PPV on the fire environment.
- Effect on victim environment downwind of PPV.

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Fire Room

- Fire room hardened by adding more sheet rock

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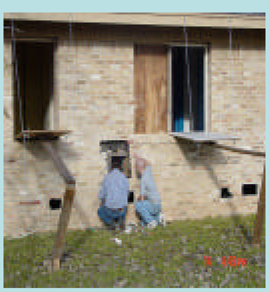
Fire Room Exterior



- Cut ports for video
- Install vent opening system: “Articulated Flying Buttress”.

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Victim Room

- Cut holes for cameras
- Remove windows and replace with plywood
- Cover closet to simplify modeling
- Insert Dummy

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Temperature

- 40 channels of type K thermocouples were used.
- copper wire was used to take signal from exterior of house to data shed.

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Data Acquisition

- Data acquired by computer.
- Video and Infrared movies

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Fuel

- 12 Polyurethane foam pads.
- Fuel load approximates total heat release of heavily loaded room contents fire (2.4 MW).

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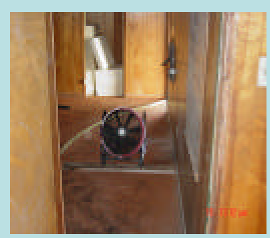
Air Flow

- Two Fans used:
  an 18” and a 24”
  18”: 6500 CFM
  24”: 9130 CFM

- Fan placed at attack entrance: typically placed at the front door of the house



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Live Fire Video

Hallway

Vent Window

Victim Room (video camera)

Victim Room (TIC)

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Scientific Principles and Results of the Research

Not Tactics!

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Physics of PPV
How does PPV work?

- The heat layer affects rapid fire progression
- Pressure created by PPV
  (Is "positive pressure" a correct term?)
- Fan characteristics (Fan is a Pump)
- Typical house flow resistances (Friction Loss)
- Trade-offs in applying PPV

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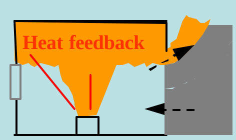
How heat layer effects rapid fire progression.

There is a competition between heat release rate and heat losses. Heat release rate is tied to the heat feedback. Heat losses can be tied to the convection of the hot upper layer out of the compartment.



To prevent rapid fire progression, take away the heat feedback and increase the heat losses by blowing the products out of a vent.

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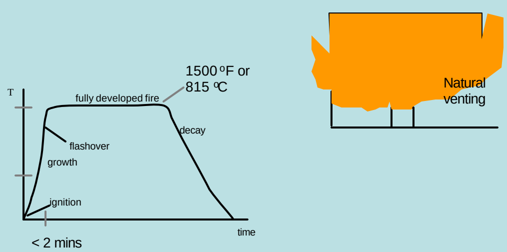
Fire Dynamics 101

Fires are generally modeled as having three distinctive phases: growth phase, fully developed phase and decay phase.



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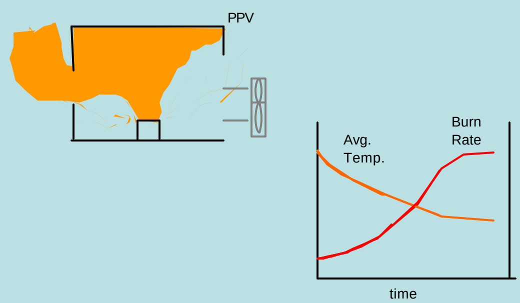
PPV pushes the heat layer out and decreases the average temperature even when the burning rate increases



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Review #1
When Fire is Ventilation Controlled:

- This is when we normally arrive.
- Heavy smoke is produced creating limited visibility.
- The heat layer increases off gassing (CO) faster than the fire itself.
- Conditions poised to change rapidly.
- Venting the hot products makes entry safer.

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Swedish Studies

Swedish study of Ingason and Fallberg measured static pressures and flow patterns

- PPV produces pressures less than **1/100th of 1 PSI**
- Flow velocities and patterns show **jet like regions** (Jet Stream) with secondary flows (recirculation regions).
- Velocities are typically in **2.2 mph to 8.8 mph** range.

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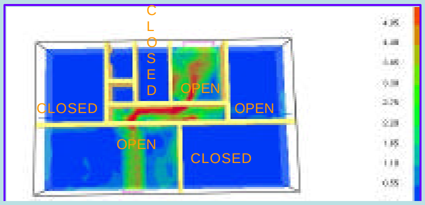
Cold Flow Contours of Air Speed

Fire Room Vented



•PPV does not "pressurize" the entire structure
•PPV develops a "Jet Stream" from the entrance to the exit opening.

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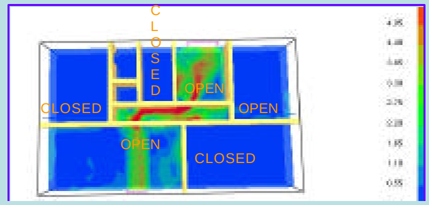
Cold Flow Contours of Air Speed

Fire Room Vented



•PPV does not "pressurize" the entire structure
•PPV develops a "Jet Stream" from the entrance to the exit opening.

Fire corridor- All of the compartments that contain fire or are connected to the fire room though open doorways.

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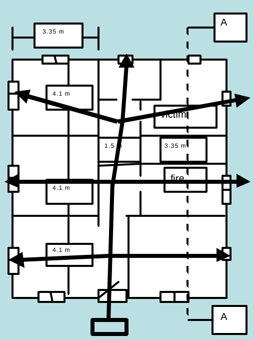
House Layout & Friction Loss

•PPV uses a fan (positive pressure source) to exhaust smoke, flammable gases, and high temperature gases from a structure fire.
•The fan characteristics (pump) and the resistance network (friction loss) will determine the flow characteristics.
•The flow rate at the fire compartment determines if PPV is a net positive or negative.
•Big flow good, small flow could be bad.



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Review #2

- PPV creates very little pressure, normally just a fraction of a PSI.
- Instead of pressurizing the entire building, the fan creates a "Jet Stream" from entrance to exit.
- A fan is like a pump - A fire is like a pump.
- Opening too many windows can cause small flow.
- Big flow is good, small flow could be bad.
- PPV overcoming winds: Vendors say 35 MPH, but Tests show 8.8 MPH.

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Trade-offs in Applying PPV

- Benefits
  - Clears attack corridor of smoke, gases, and high temperatures
    - Less likely extreme fire behavior
    - Faster path to fire compartment
    - Safer attack scenarios
- Costs
  - Possible spread of fire to non-connected areas.
  - Possible increase in burning rate of fire
  - Possible hazard to victims downstream of ventilation path

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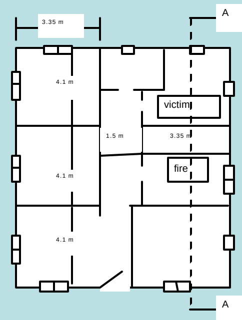
PPV in House 1



Austin Fire Department performed PPV tests in geometry shown at left.

Detailed simulations were performed for the entire house to examine the effect of ventilation on a single room.

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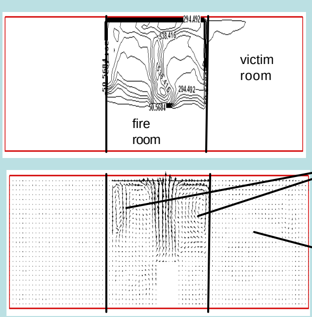
Natural Burn Fire Room Slices



Temperature and velocity vector plots in the fire room without venting

Roll-up vortices are clearly identifiable

No visible mixing in victim room

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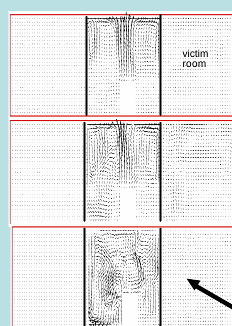

(a)

(b)

(c)

Effects of <u>fire room</u> venting and positive pressure on velocity vectors is clearly seen in:

Figure (a) prior to venting (40 seconds)

Figure (b) at initiation of venting (80 seconds)

Figure (c) during PPV (120 seconds)

No visible mixing in victim room

Notice the increased mixing in the fire room

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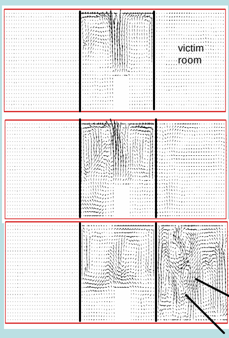
Effects of victim room venting and positive pressure on velocity vectors is clearly seen in:



(a) **Figure (a) prior to venting (40 seconds)**

(b) **Figure (b) at initiation of venting (80 seconds)**

(c) **Figure (c) during PPV (120 seconds)**

Visible Mixing is victim room

Notice the increased mixing in the victim room

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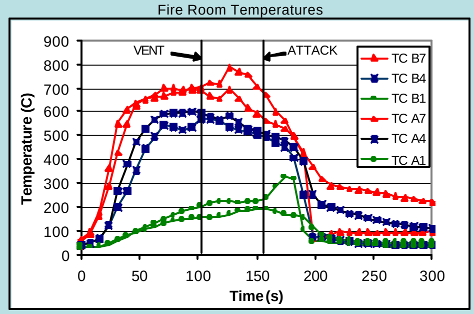
Natural Ventilation of Fire Room
Fire Room Temperatures



Fire room temperatures are shown on two thermocouple trees (A and B) at three elevations (7ft, 4ft, and 1ft) for a test with venting of the fire room but no fan.

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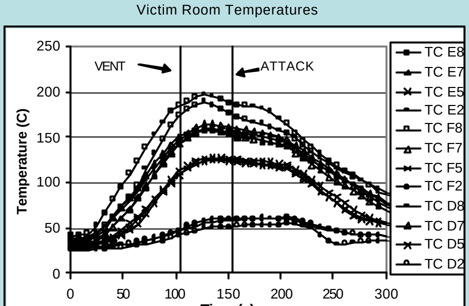
Natural Ventilation of Fire Room
Victim Room Temperatures



Victim room temperatures are shown on three thermocouple trees (E, F, and D) at four elevations (8ft, 7ft, 5ft, and 2ft) for fire room venting with no fan.

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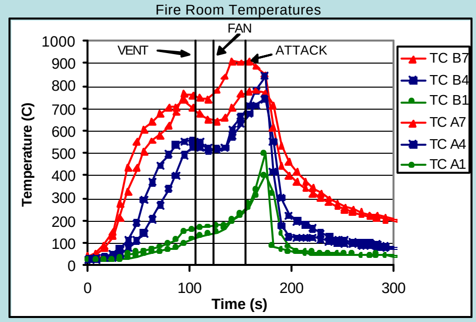
18" Fan with Fire Room Vent
Fire Room Temperatures



Fire room temperatures are shown on two thermocouple trees (A and B) at three elevations (7ft, 4ft, and 1 ft) for a test with positive pressure ventilation .

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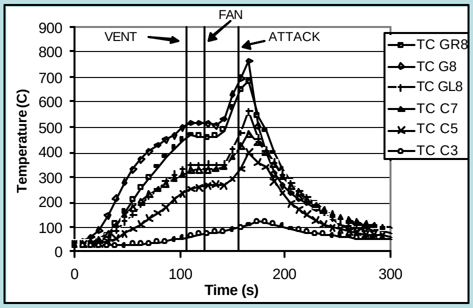
18" Fan with Fire Room Vent
Hallway Temperatures



Hallway temperatures are shown on a thermocouple tree (C) at three elevations (8ft, 5ft, and 3 ft) and at three 8ft elevation hallway ceiling measurement points (GR, G, and GL) for a test with positive pressure ventilation.

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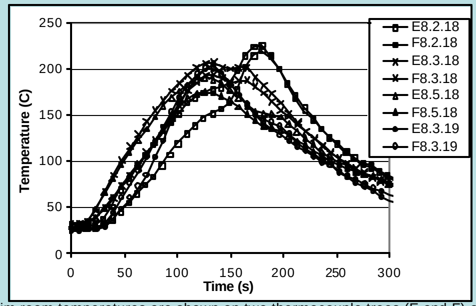
Fire Room Ventilation with 18" Fan (4 cases)
Victim Room Temperatures



Victim room temperatures are shown on two thermocouple trees (E and F) at the highest elevation (8ft) for four fire room ventilation with 18" fan cases.
***Average maximum temperature of 200 ºC.**

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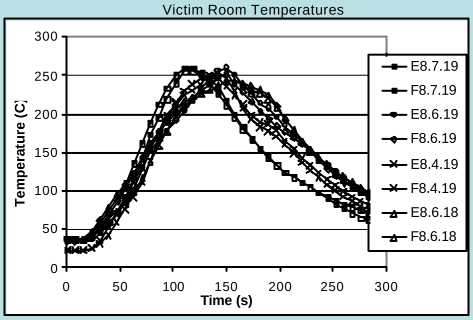
3 Victim Room Ventilation Cases and 1 Large Fan Fire Room Vent Case
Victim Room Temperatures



Victim room temperatures are shown on two thermocouple trees (E and F) at the highest elevation (8 ft) for three victim room ventilation cases and one fire room ventilation case (24" fan and low wind).
***Average maximum temperature of 250 ºC.**

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Thermal Impact on Victim Condition

We see that the peak temperature measured near the ceiling of the room is approximately 200 ºC. For a radiatively black surface at 200 ºC transmitting heat to a body at 25ºC, the radiative heat flux is approximately 2.4 kW/m².

ASTM F1939-99a provides the Stoll and Chianta* time criterion for a second degree burn from a radiative heat flux source as

$$q = 1.1971 t^{-0.7087}$$

Where the heat flux is in calories/(cm²s). We can easily invert this to find that in approximately 73 seconds a person could receive a second degree burn from a 2.4 kW/m² radiative source.

For the 250 ºC case we calculate a radiative heat flux of 3.8 kW/m2 which represents an approximately 50 % larger heat flux and a 50% decrease in the time required to get a second degree burn (38 seconds vs. 73 seconds).

Stoll, A.M., and Greene, L.C., "Relationship Between Pain and Tissue Damage Due to Thermal Radiation", Journal of Applied Physiology, Vol. 14, 1959, pp. 373-382

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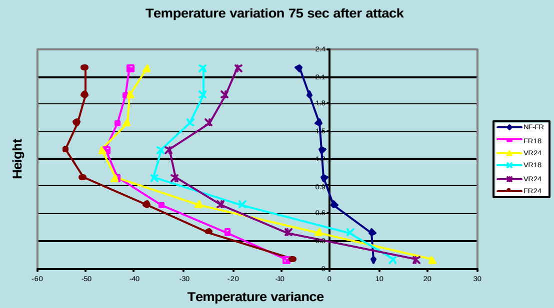
Victim Room Temperatures



Temperatures increase at the lower levels associated with PPV and victim room venting.

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Review #3

- Correctly Venting Fire Room
  - PPV is more effective than natural horizontal ventilation
    - Temperature slightly increases with natural ventilation at victim level
    - Temperatures reduce with PPV at victim level
- Incorrectly Venting Victim Room
  - Victims downwind of the PPV do experience an increase in temperature but the increase is small, survivable and temporary

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Tactical Application of Scientific Results

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Ventilation can be Confusing

- Positive Pressure Ventilation
- Negative Pressure Ventilation
- Horizontal Ventilation
- Vertical Ventilation
- Mechanical Ventilation
- Natural Ventilation
- Hydraulic Ventilation
- Vent for Life, Vent for Fire

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Vertical Ventilation is the Most Effective Form of Ventilation If…

- It can be performed safely
- It can be performed timely
- Vertical Ventilation should be strongly considered on:
  - Heavily smoke charged, larger, commercial structures
  - Heavily involved balloon framed structures

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If Vertical Ventilation is Not Performed

- UT/AFD studies prove that horizontal ventilation with PPV at single family dwelling fires is effective
- Firefighters must know how and why to employ horizontal PPV tactics correctly

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Ventilation Reasons

- Vent for Fire: Venting to assist the fire attack effort
- Vent For Life: Venting as you search for Firefighter safety and to reduce thermal and toxic damage to victims.
- How can we perform both of these ventilation tactics with PPV?

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Vent for Fire, Vent for Life

- Think of the fire building as a series of compartments that can be separated or connected by the existing doors.
- **Fire corridor**- All of the compartments that contain fire or are connected to the fire room though open doorways.

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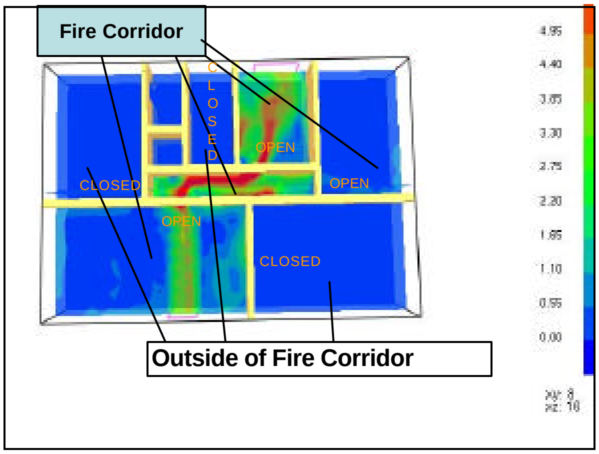

Properly Venting for Fire

- **Coordinated Fire Attack SOG (90/10 rule)**
  - **Hot Lap and Ventilation**
    - **Locate Fire – Determine Risk**
    - **Determine Vent Opening Location, close to fire**
    - **Determine when to make vent – Coordinate; Do not vent until attack crew is ready to move in**
  - **Fire Attack**
    - **Employ PPV before entry**
    - **Observe effects**
    - **Make Fire Attack**

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Properly Venting for Fire

– **Other Tactical Functions**
- **Must ensure "Vent for Life", Laddering, and/or Additional Forcible Entry do not negatively effect ventilation**
- **Backup Team must wait until entry of Fire Attack Team**

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How Can The Effectiveness Of PPV Be Assessed?

- After PPV is applied to the entrance of the attack corridor, observe the direction of the smoke flow.
- If the smoke flow is toward the fire room vent opening, PPV is effective.
  - Prevailing winds are not overcoming fan.
  - Added oxygen is not increasing burning rate enough to create ceiling jet.
  - There is a clear path from entrance to vent exit.
- Continually observe smoke flows as you advance down the attack corridor.

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How Can The Effectiveness Of PPV Be Assessed?

- If the smoke and fire gases are still moving toward you:
  - Prevailing winds may be overcoming fan, possibly making the entrance corridor unsafe for entry.
  - Fire behavior may have rapidly increased making entry risky.
  - A change of tactics may be required.

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Rules for Effective PPV

- **Must** have an exit before positive pressure is applied
- **Must** have attack corridor integrity. Too many vent exits can adversely effect PPV effectiveness
- **Should** know the fire location and make the exit vent as close to the fire as possible
- **Must** assess direction of smoke flow in the fire attack corridor to assess effectiveness of PPV.
- **Never** direct a hose stream into the exit vent

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Benefits of Effective PPV

- Heat and smoke are removed before the firefighters enter the area
- The chance of rapid fire progression due to ventilation-controlled fire is reduced
- The officer knows the location of the fire and the layout of the building
- Visibility is improved
- Search can be performed faster and safer
- In general, Firefighter safety is enhanced.

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TIC Video

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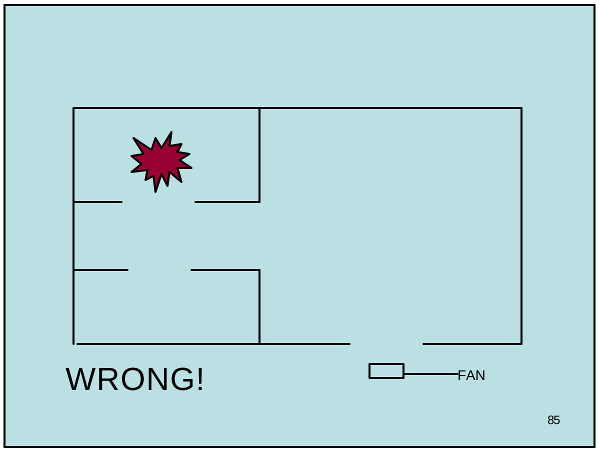
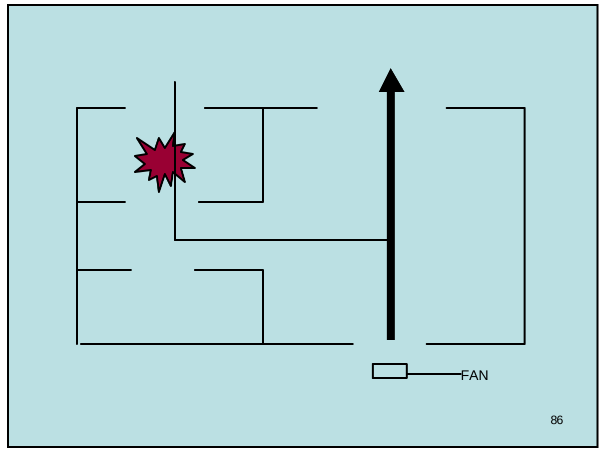

WRONG!
FAN
85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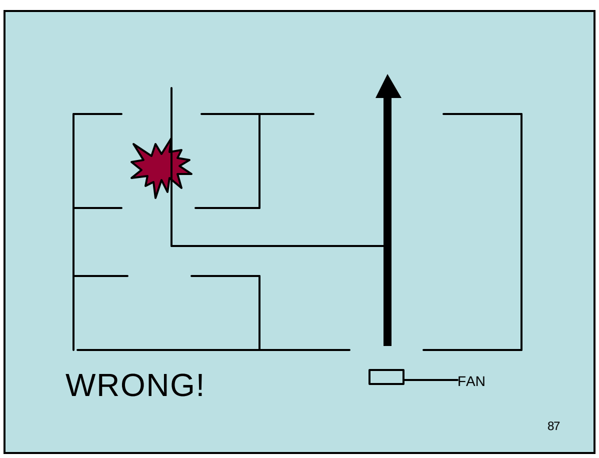
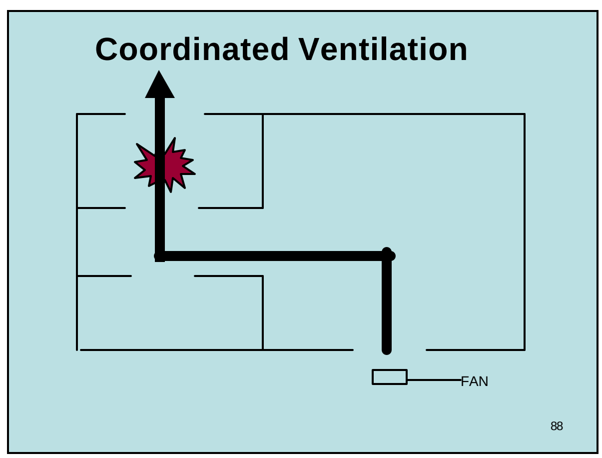
86


WRONG!
FAN
87


Coordinated Ventilation
FAN
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Venting for Life

- Breaking windows in the fire corridor will affect (either positively and negatively) ventilation conditions.
- Research from the UT/AFD PPV studies indicates that, all things being equal, small pressure differences caused by breaking a window in a fire corridor causes the smoke and heat to start moving in that direction.

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Venting for Life

- Therefore, if while searching you remove a window in the fire corridor to release heat and smoke to improve your conditions (Vent for Life), the opposite effect may be realized.
- Many Firefighters that are killed or injured in extreme fire behavior, the event was caused by their own ventilation practices!

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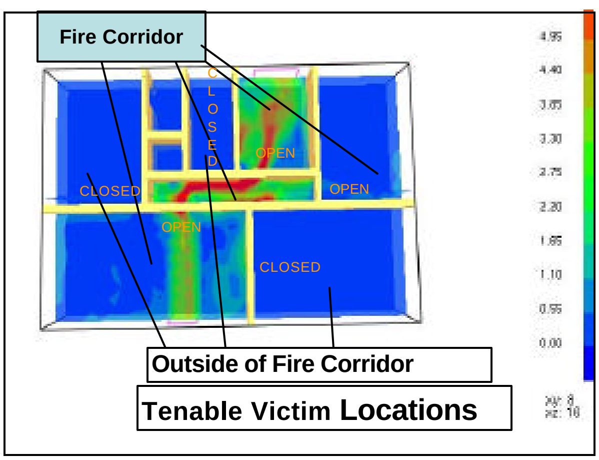

Properly Venting for Life

- Separate a compartment from the fire corridor by closing a door (door control).
- Now the heat layer is no longer racing into the room, windows can now be safely removed, if necessary

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Properly Venting for Life

- Break or open windows… If you cannot see your exit, break the window! Your life is more valuable than a window.
- When leaving the room, the door should remain shut.
- This will ensure that "vent for life" actions do not effect ventilation efforts in the fire corridor.

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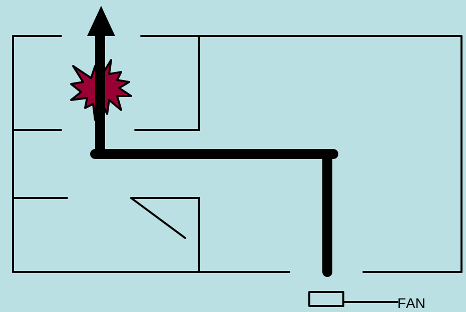
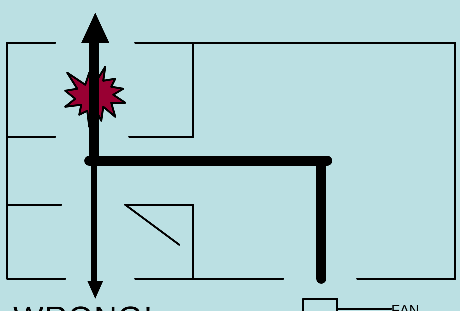
Coordinated Ventilation



94



WRONG!
Door Open

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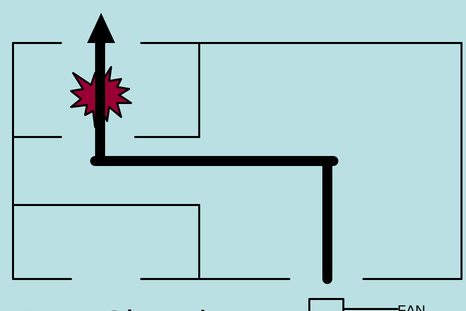
Coordinated Ventilation



Door Closed

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Benefits of Venting for Life

- Creates an environment safer for both the victims and searchers.
  - Increases visibility and improves victim tenability
  - Allows for secondary egress
  - Helps the searches re-orient themselves by looking outside the window
  - Indicates to the Outside Truck / RIC their location

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All Fire Tactics Should Be Selected, Assessed, and, if Necessary, Altered.

- The tactic should not be selected routinely, rather should be selected to solve the problems the fire is presenting.
- After selected, the tactic should be assessed for effectiveness.
- The tactic should be changed if it proves to be ineffective.

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Final Review

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Final Review

- Understand the dangers of Ventilation Controlled Fires.
  - A ventilation controlled fire creates smoke that is fuel
  - This smoke can cause rapid fire progression
  - This smoke can cause zero visibility
  - Rapid fire progression and zero visibility can kill firefighters

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Final Review

- Understand the importance of proper ventilation.
  - Proper ventilation can reduce the risk of rapid fire progression
  - Proper ventilation can increase visibility
  - Proper ventilation can save firefighter lives

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Final Review

- Understand how to perform proper ventilation.
  - Venting for Fire makes fire attack safer
  - Venting for Life makes searching safer
  - UT/AFD research has shown that PPV is effective in single family dwelling fires
  - UT/AFD studies recommend using a coordinated PPV fire attack in single family dwelling fires
  - Coordinated PPV fire attack makes firefighters safer in single family dwelling fires

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Final Review

- To increase the occurrence of proper ventilation in your department.
  - Ventilation Training
  - Live Fire Training
  - Critique ventilation tactics during Post Incidents Reviews

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