INTRODUCTION TO

FAN IMPLEMENTATION FOR STAIRWELL EVACUATION

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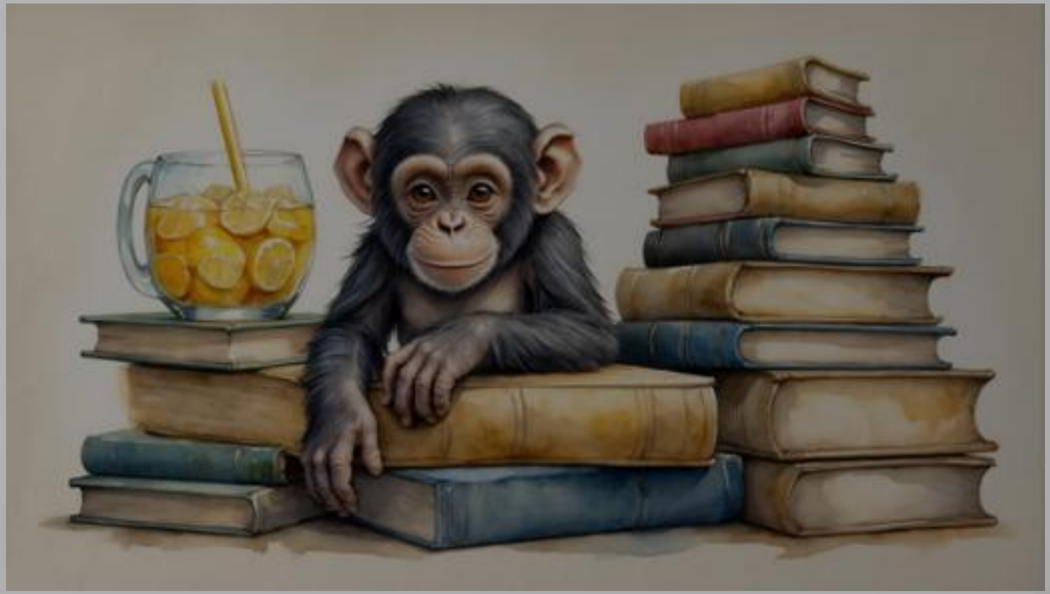
Presented by: Michael Hadlock

KNOWLEDGE IS POWER

It is our goal to provide in-depth knowledge of PPV fan implementation to the industry in a simple and understandable manner.

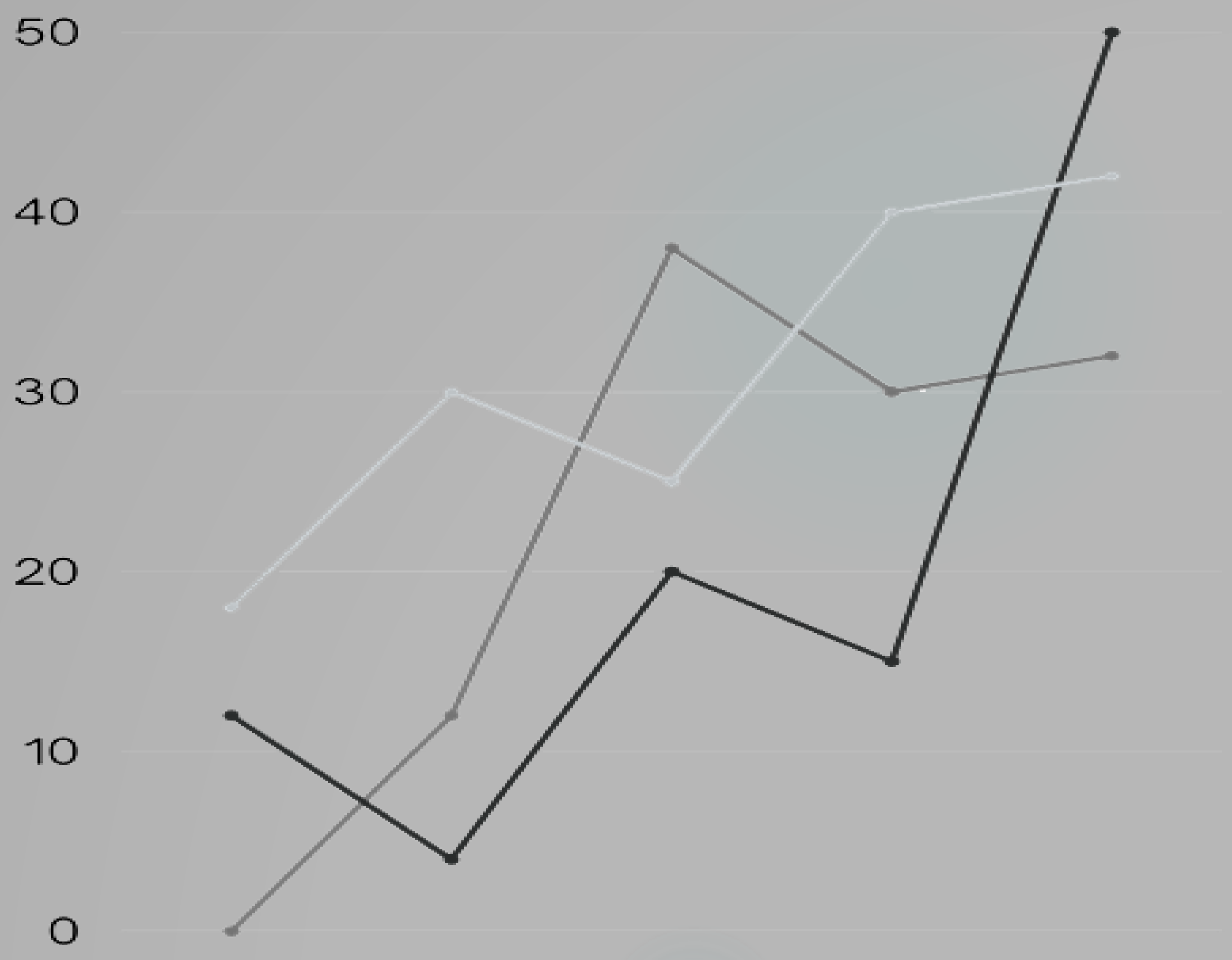
With this information firefighters and planners will be able to make better decisions in the field because they are operating from a standpoint of predictive modeling and knowledge.



Fundamentals:

Today we will show you the fundamentals of PPV fan performance and how it will impact your expected results.

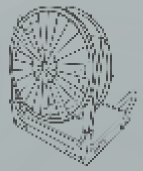
Utilizing these fundamentals, we will analyze the response of the system to identify where issues may occur.

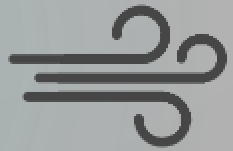


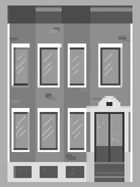
THE PLAYERS

When analyzing fan performance, we will break the system down into individual systems.

The combination of these three systems will define our outcome.


THE FAN


THE AIRSTREAM


THE STRUCTURE

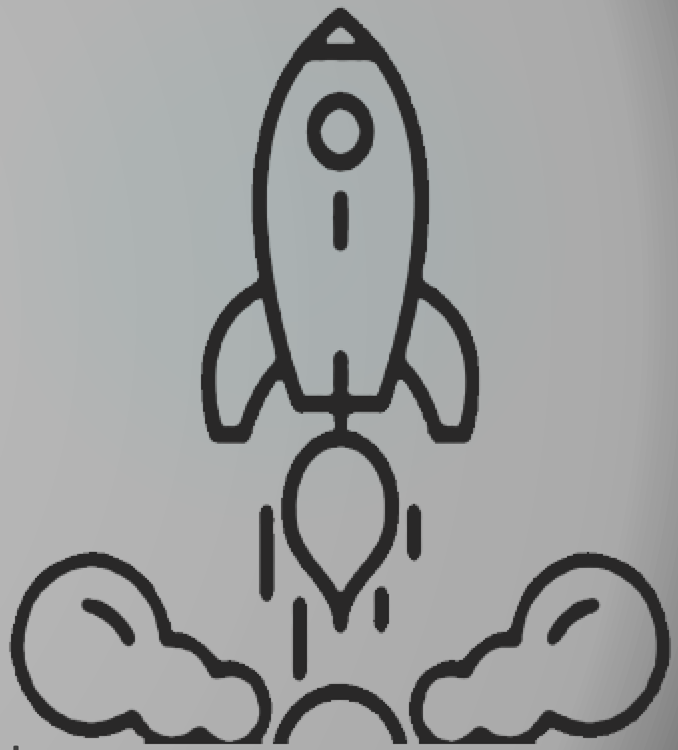
SYSTEM 1: THE FAN

THE FAN: THRUST & MOMENTUM

- When analyzing a fan, we are interested in the **momentum** the fan will induce into the airstream.

- **Airstream momentum can be measured from Thrust.**
  - Thrust is an equal and opposite reaction to the momentum induced into the airstream.
  - We can identify the momentum of the airstream by calculating or measuring the thrust generated by the fan.

- Think of momentum as a **Force** made up of components:
  - The components of momentum are volume (mass) and velocity. (Note that mass is simply volume X density.)

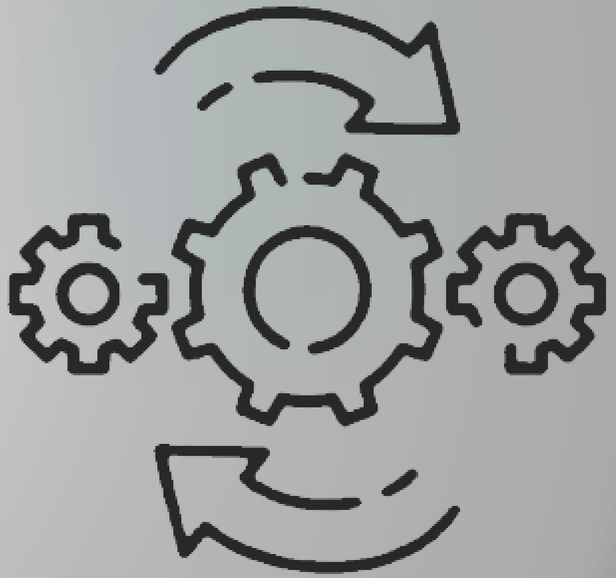


THE FAN: THRUST & MOMENTUM

Momentum/Thrust defines the true Potential of the airstream and later will be used to calculate the pressure and response in a building.

Primary <u>**FAN**</u> variables for airstream Thrust/Momentum

1. Fan Size (blade/airstream size)
2. Power
3. Efficiency
    - For simplicity we will assume the fan design/efficiency is constant.



Therefore, as we adjust fan size, we will need to change power to maintain the same thrust/momentum.

THE FAN: THRUST & MOMENTUM

EXAMPLE:

These fans have the same potential performance with 8.93lbs of thrust.

- 24” @ 750W =8.93lbs thrust
- 18” @ 1000W =8.93lbs thrust
- 12” @ 1500W =8.93lbs thrust

Fan Size Inches	Power Watts
24	750
THRUST - LBS	8.927

Note:
Both fan size and power have an impact on thrust.
As we adjust fan size, we will need to change power to achieve the same thrust/momentum.

SYSTEM 2: THE AIRSTREAM

THE AIRSTREAM: ENTRAINMENT

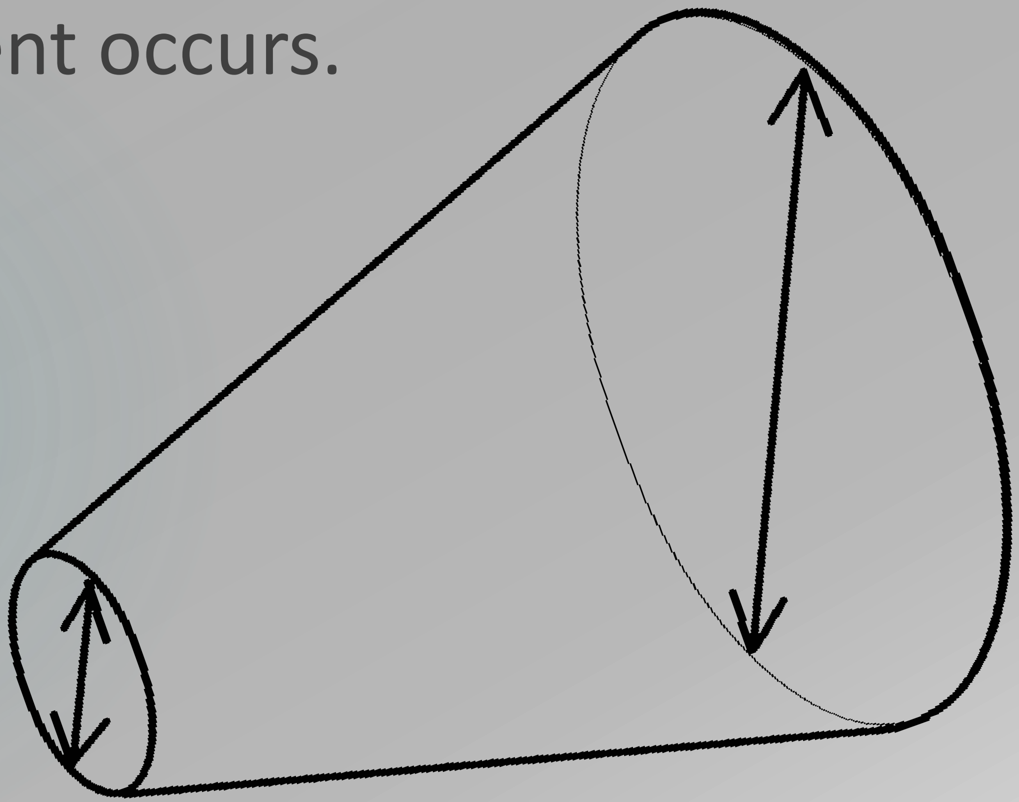
- As the airstream travels it will entrain air, this simply means that air will be pulled into and accumulate in the airstream.

- There are different types of entrainment that affect the rate at which entrainment occurs.
  - Venturi
  - Viscous Drag
  - Turbulent mixing

- As the fan is set back from the door the airstream will have a longer distance to entrain air.

THE AIRSTREAM: ENTRAINMENT

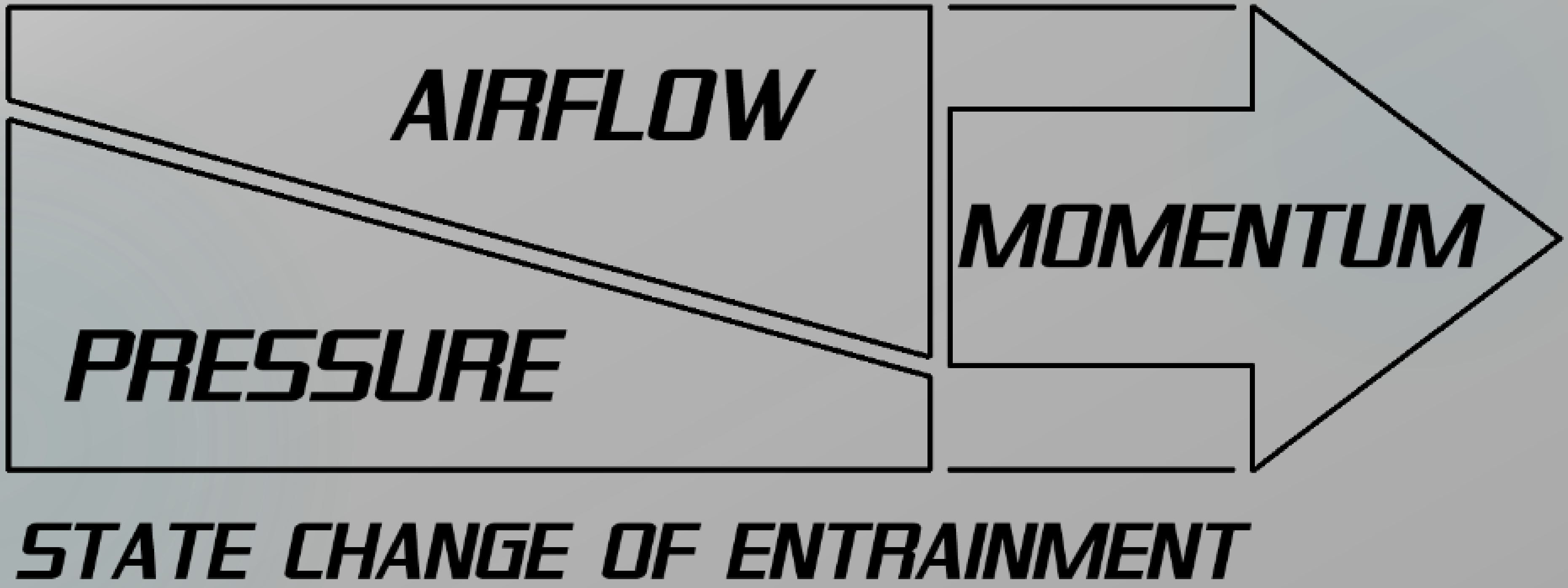
The airstream will grow in size and change state as entrainment occurs.



- Entrainment causes the airstream to transition "states"
  1. Exit State: Low volume high speed (pressure).
  2. Transition State: High volume low speed (pressure).

THE AIRSTREAM: STATE CHANGE

Airstream momentum corresponds to a combination of airstream volume and pressure at different states.



While momentum stays constant, the airflow and pressure will change as air is entrained into the airstream.

THE AIRSTREAM: ENTRAINMENT

Rate of Entrainment:

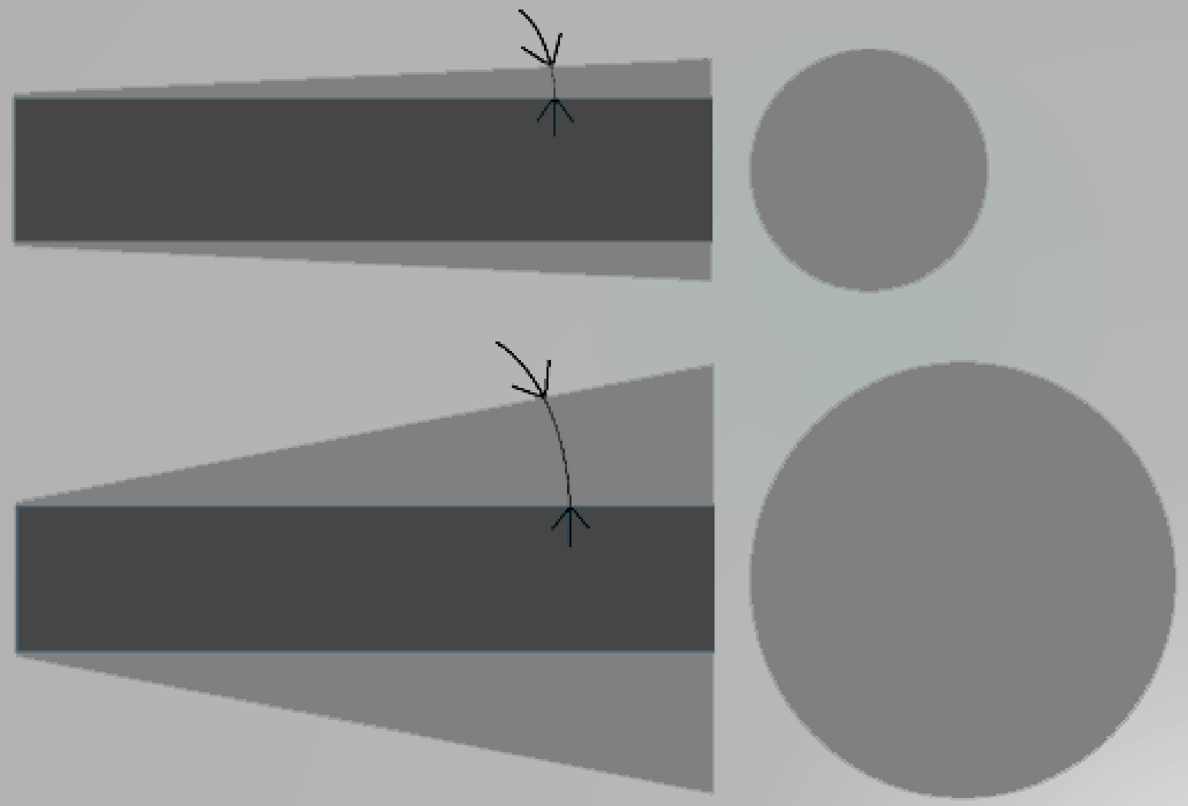
We will used the expansion angle to define the rate of entrainment.

Setback:

As the fan is set back from the door the airstream will have a longer distance to entrain air.

Total entrainment:

The combination of the expansion angle and setback will define how much air is entrained.



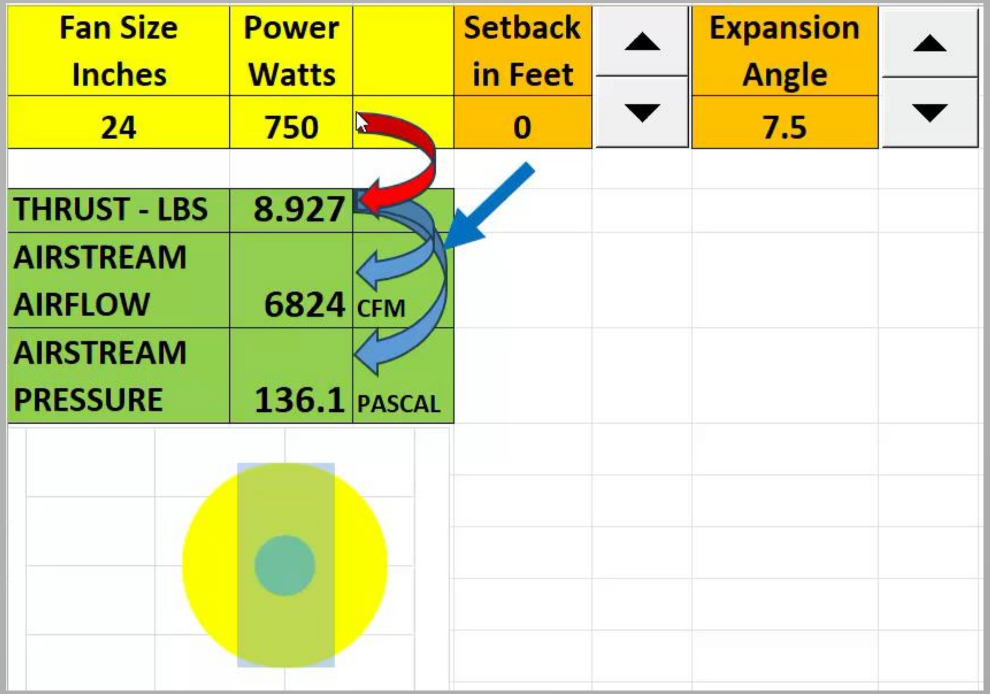
THE AIRSTREAM: MOMENTUM & STATE

Examples expanded:

First, we will show how the CFM and pressure changes as is entrained and the flow state of the airstream changes. Increasing volume, decreasing pressure.

Next, we will hold Thrust = 8.93 lbs. When the state is equal, all three systems will have the same flow and pressure.

- 24”: 750W/0ft/X-deg. : 6825CFM/136 pascal
- 18”: 1000W/1.9ft/7.5-deg. : 6825CFM/136 pascal
- 12”: 1500W/3.8ft/7.5-deg. : 6825CFM/136 pascal



The combination of airstream momentum and state will define how the airstream will interact with the structure.

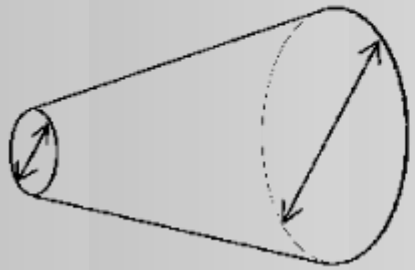
AIRSTREAM → STRUCTURE

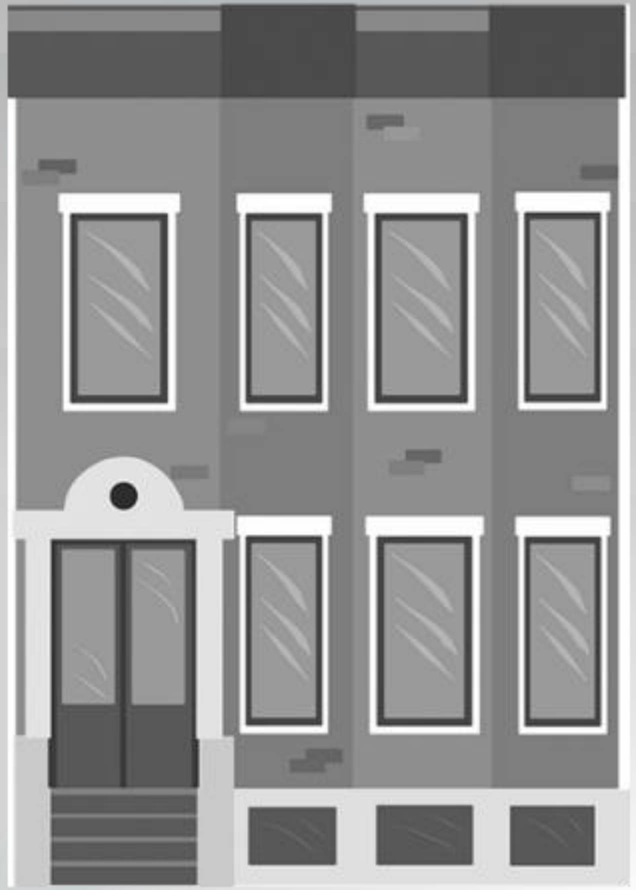
The fan will induce momentum into the airstream.

Entrainment results in a change of state of the airstream.

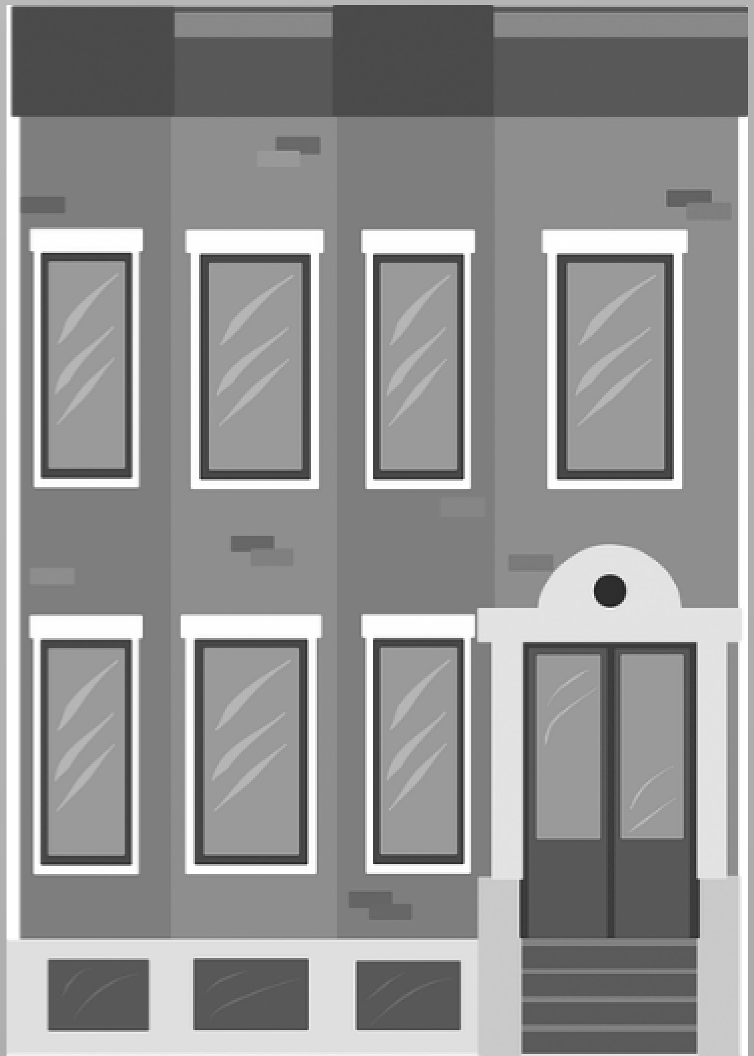
As the airstream entrains air it will expand and increase in volumetric flow. As volumetric flow increases, the pressure of the airstream will decrease.

The combination of airstream momentum and state will define how the airstream will interact with the structure.





SYSTEM 3: THE STRUCTURE



THE STRUCTURE: INLET & OUTLET

We will analyze Entrance Performance: and Outlet Flow independently.

Entrance Performance:

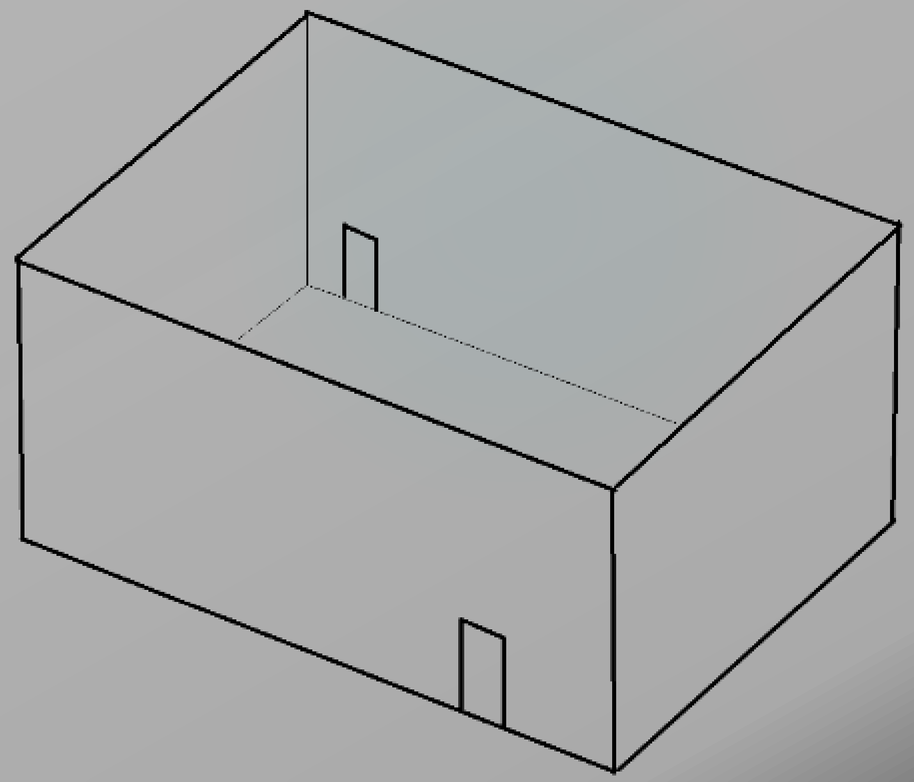
We will generate a performance fan curve based on the the airstream state, airstream thrust/momentum and entrance door size.

This is like an AMCA flow/pressure plot, but we will vary the fan entrainment and door size.

Outlet Flow:

We will also generate an outlet flow curve.

Flow will exit the structure based on the pressure in the structure, number and size of the openings and flow restrictions. For simplicity, we will model this as single exit door with a standard discharge coefficient.



SYSTEM 3: THE STRUCTURE

System Plot:

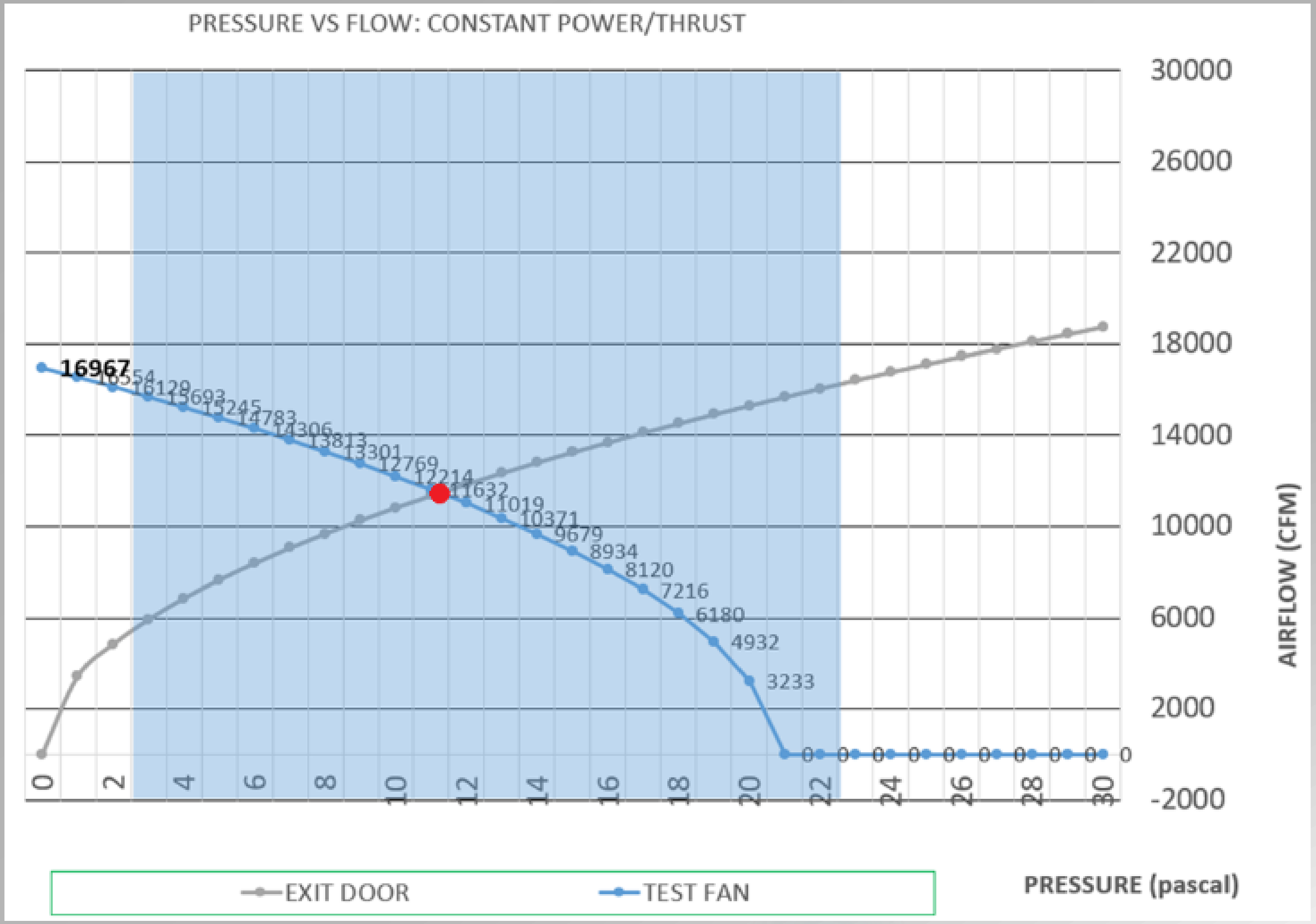
The fan curve is shown in blue; the exit flow in grey.

Both plots provides the flow relative to pressure.

The fan performance flow curve and outlet flow curve will cross. This is shown with a red dot.

This is the predicted “real world” operating point of the system.

Note: The AMCA value listed by manufacturers is depicted by the bold value.



The Structure: System Response

System Response:

With the system variables established, we can analyze how the system will change as the variables are adjusted. This information will help us understand the response of the system.

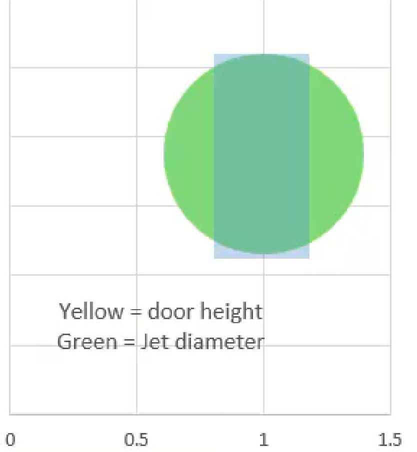
THE STRUCTURE: SYSTEM RESPONSE

- Case study 1: The Fan, Thrust Adjustment (Power only, size constant.)
  - Adjusting the power and thrust of the fan we can see how the volume and pressure change accordingly.
    - 24”: 750W/0ft/X-deg.   =8.93lbs
    - 24”: 1000W/0ft/X-deg. =10.81lbs
    - 24”: 1500W/0ft/X-deg. =14.17lbs

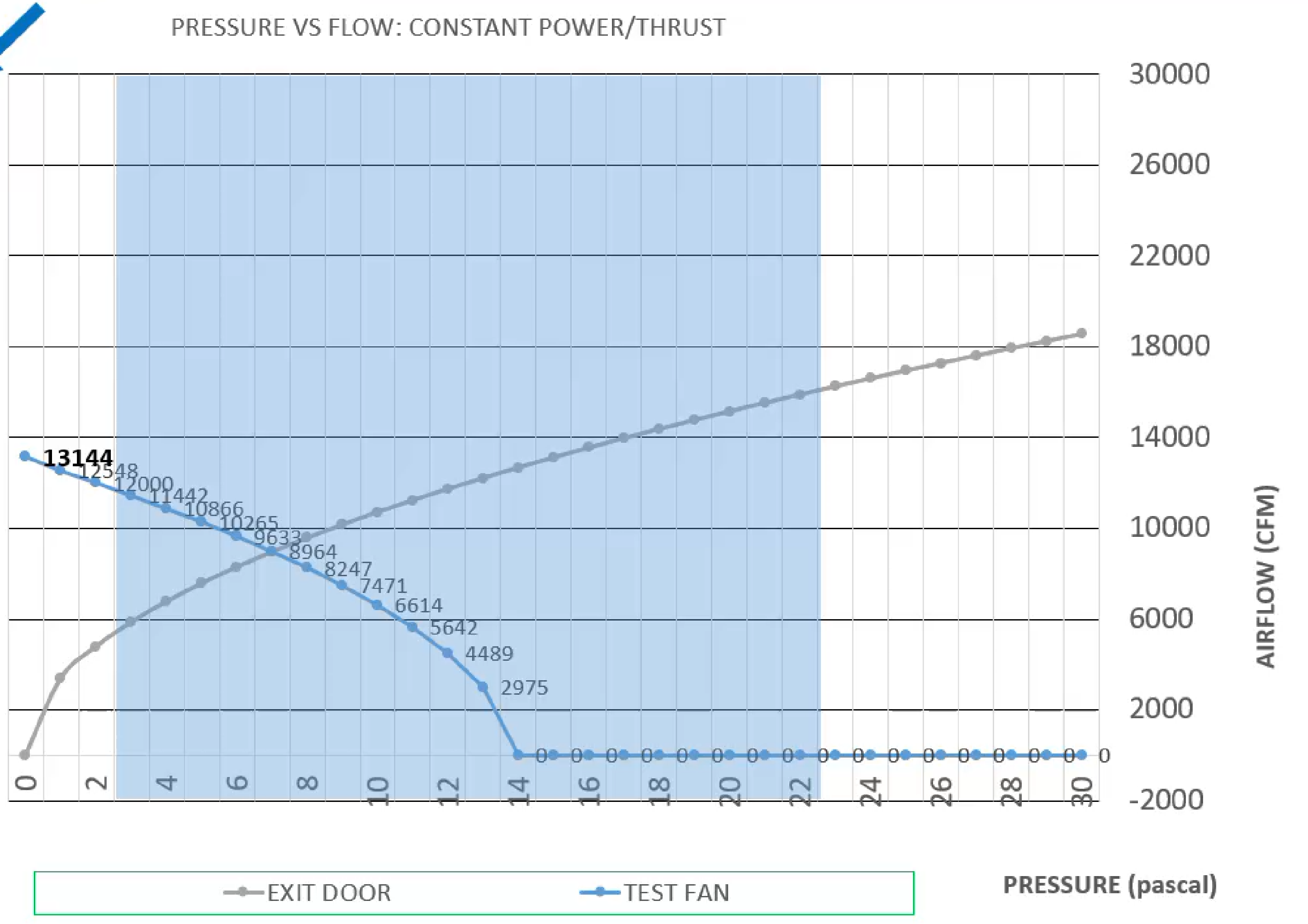
THE STRUCTURE: CASE STUDY 1, POWER/THRUST

Fan Size Inches	Power Watts		Setback in Feet	Expansion Angle
24	750		10	12

THRUST - LBS	8.927	
AIRSTREAM AIRFLOW	21330	CFM
AIRSTREAM PRESSURE	13.93	PASCAL



BATTERY SIZE	440 WH
RUN TIME	35.2 MIN
ENTERANCE	
DOOR WIDTH	38 IN
DOOR HEIGHT	75 IN
EXIT DOOR	
DOOR WIDTH	38 IN
DOOR HEIGHT	75 IN



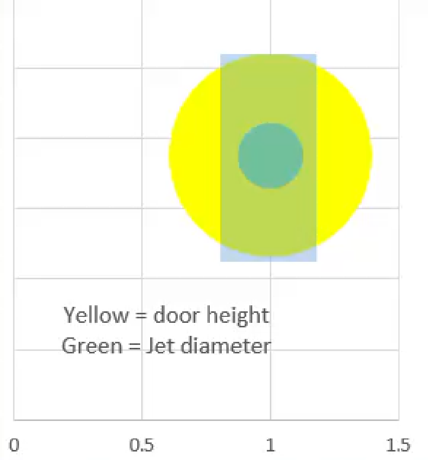
THE STRUCTURE: SYSTEM RESPONSE

- Case study 2: The Airstream, Entrainment Adjustment
  - Adjusting the setback and entrainment of the fan we can see how the volume and pressure change accordingly.
  - Note: When the entrainment covers the door, the plot changes from concave to convex.

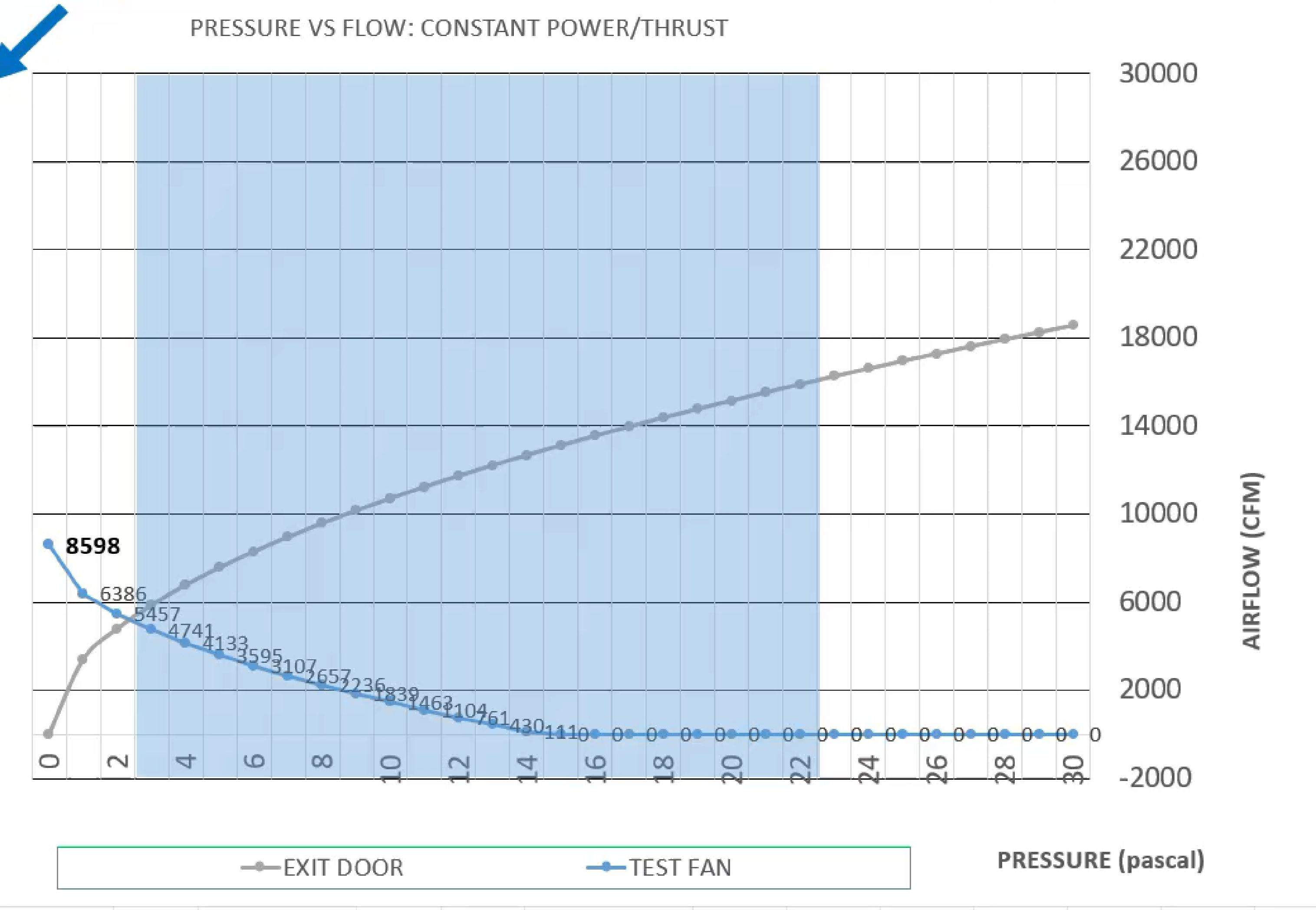
THE STRUCTURE: CASE STUDY 2, ENTRAINMENT

Fan Size Inches	Power Watts	Setback in Feet	Expansion Angle
24	1500	0	12

THRUST - LBS	14.17	
AIRSTREAM AIRFLOW	8598	CFM
AIRSTREAM PRESSURE	216	PASCAL



BATTERY SIZE	440 WH
RUN TIME	17.6 MIN
ENTERANCE	
DOOR WIDTH	38 IN
DOOR HEIGHT	75 IN
EXIT DOOR	
DOOR WIDTH	38 IN
DOOR HEIGHT	75 IN



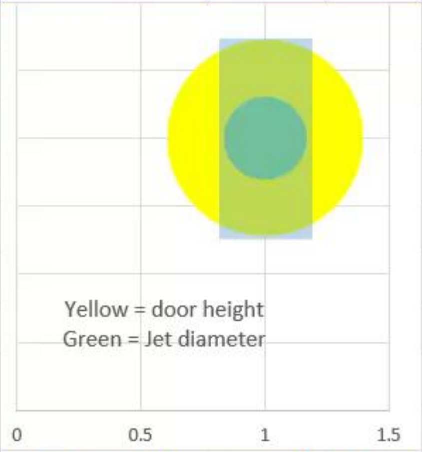
THE STRUCTURE: SYSTEM RESPONSE

- Case study 3: Structure, Door Size Adjustment
  - Adjusting the inlet door size we can see how the volume and pressure change accordingly.
    - Adding an air curtain will highly impact the pressure a fan can generate
  - Adjusting the outlet door size we can see how the volume and pressure change accordingly.
    - Increasing the size or number of exit doors will affect both the flow and pressure of the system.
  - Note where the curves cross. This operating point can be highly influenced as noted above.

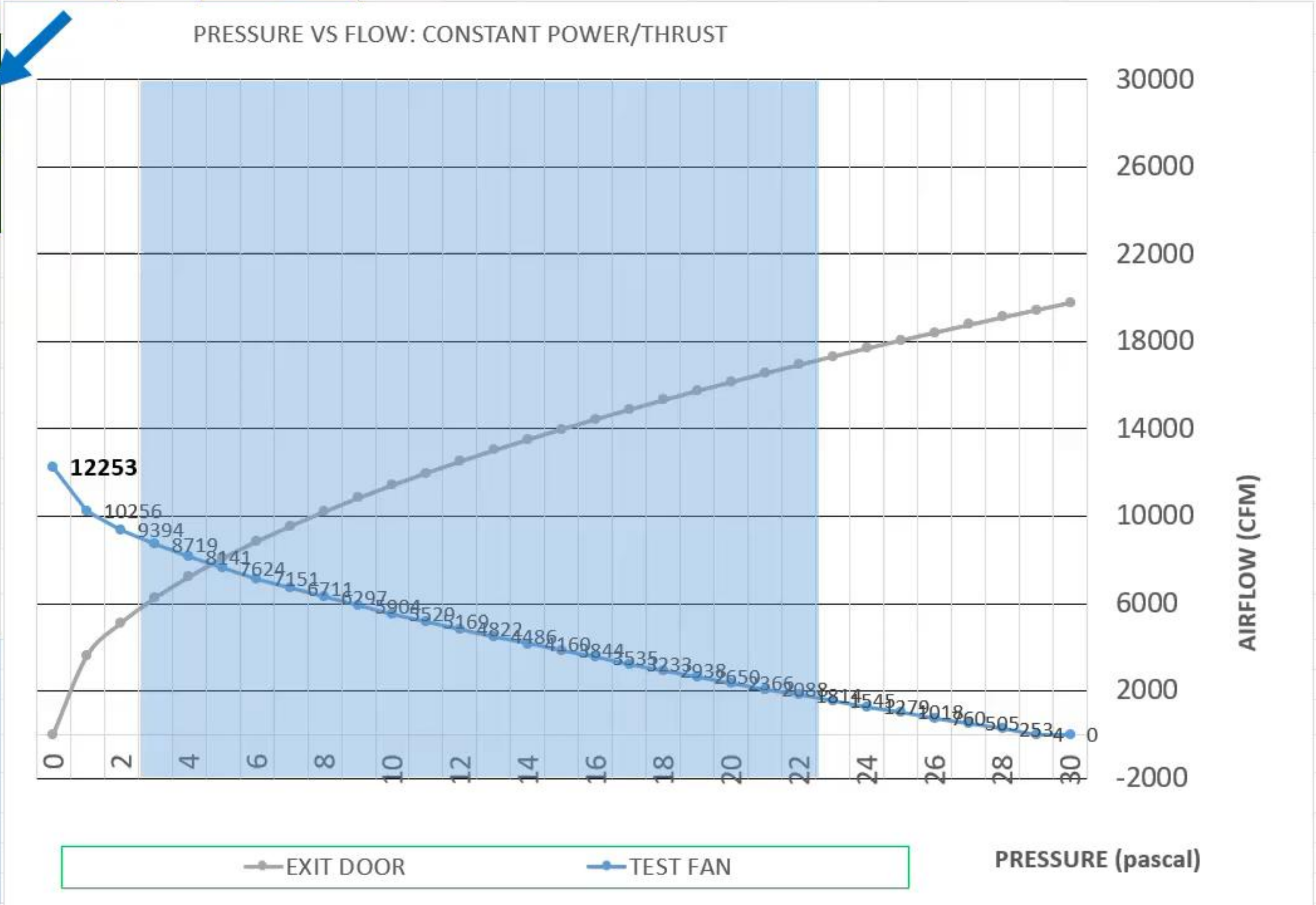
THE STRUCTURE: CASE STUDY 3, STRUCTURE

Fan Size Inches	Power Watts	Setback in Feet	Expansion Angle
24	1500	2	12

THRUST - LBS	14.17	
AIRSTREAM AIRFLOW	12253	CFM
AIRSTREAM PRESSURE	106.3	PASCAL



BATTERY SIZE	440 WH
RUN TIME	17.6 MIN
ENTERANCE	
DOOR WIDTH	38 IN
DOOR HEIGHT	80 IN
EXIT DOOR	
DOOR WIDTH	38 IN
DOOR HEIGHT	80 IN



THE STRUCTURE: STAIRWELL EVACUATION

- Predictive modeling will allow us to study the response of different system configurations relative to different fire pressure and structure variables. Optimizing these models can then be used to guide further research and field responses.
- Consideration of environmental conditions:
  - Referencing research studies on how much pressure a fire generates will provide a goal to achieve sufficient fan, airstream and structure performance.
  - Releasing pressure from the space the fire is in would reduce the driving pressure required by the fan to hold smoke back.
- Planning escape route processes with limit air escape will maintain pressure and reduce the potential for smoke to enter the stairway.

THE STRUCTURE: STAIRWELL EVACUATION

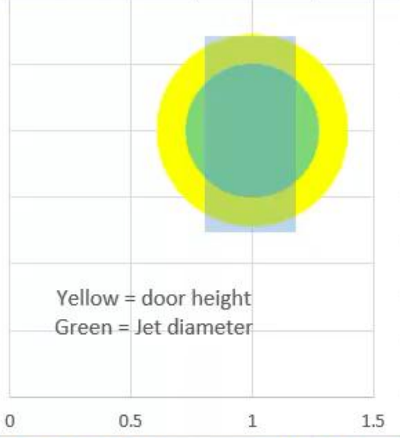
- Fire Pressure: Pressure from a fire will drive smoke into a stairwell. Our goal is to overpressure the fire or minimize the pressure differential between the stairwell and the fire.
  - Utilizing a fan to pressurize a stairwell will reduce pressure differential between the fire and the stairwell.
  - Releasing pressure from the floor level with the fire will reduce smoke driven into the stairwell.

THE STRUCTURE: SYSTEM RESPONSE

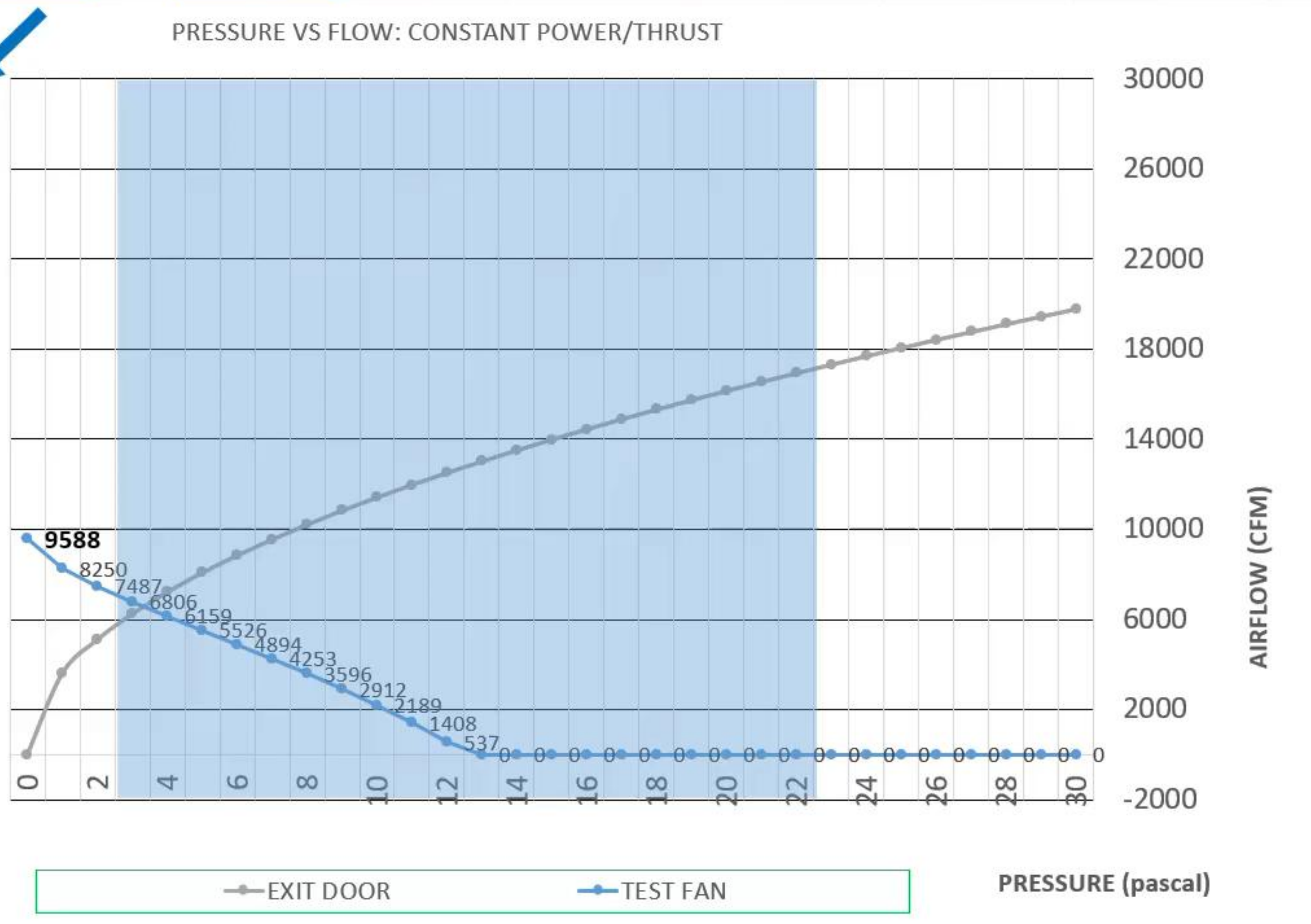
18-Inch Battery Operated Jet Fan

Fan Size Inches	Power Watts		Setback in Feet	Expansion Angle
18	440		15	6

THRUST - LBS	5.164	
AIRSTREAM AIRFLOW	12076	CFM
AIRSTREAM PRESSURE	14.54	PASCAL



BATTERY SIZE	440 WH
RUN TIME	60 MIN
ENTERANCE	
DOOR WIDTH	38 IN
DOOR HEIGHT	80 IN
EXIT DOOR	
DOOR WIDTH	38 IN
DOOR HEIGHT	80 IN

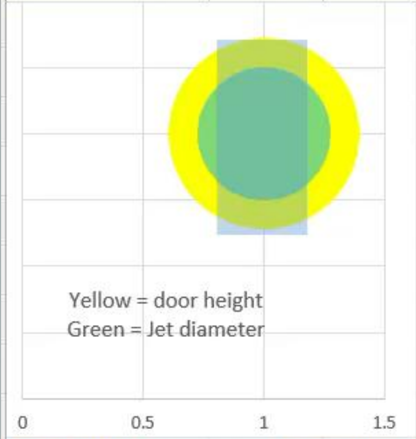


THE STRUCTURE: SYSTEM RESPONSE

24-Inch Battery Operated High Flow Jet Fan

Fan Size Inches	Power Watts		Setback in Feet	Expansion Angle
18	440		15	6

THRUST - LBS	5.164	
AIRSTREAM AIRFLOW	12076	CFM
AIRSTREAM PRESSURE	14.54	PASCAL



BATTERY SIZE	440 WH
RUN TIME	60 MIN
ENTERANCE	
DOOR WIDTH	38 IN
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EXIT DOOR	
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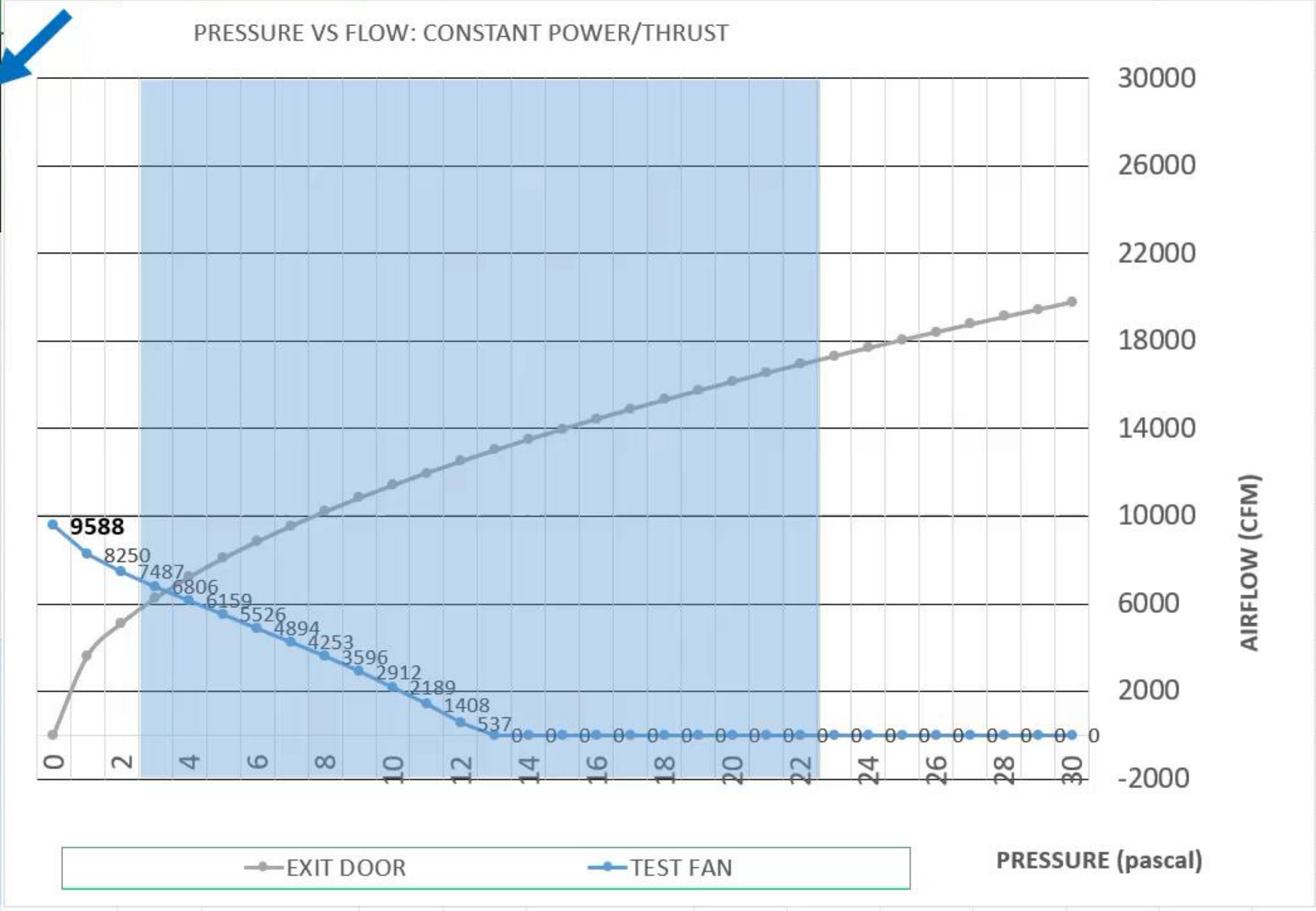

OTHER CONSIDERATIONS

- Utilization of gasoline driven fans provides a significant advantage over battery operated fans due to increased power, but results in high CO levels in the stairwell.
- Battery operated fans provide a clean alternative for stairway pressurization, but the performance of the fan must be considered relative to the overall system.

THE STRUCTURE: STAIRWELL EVACUATION

- The outlines presented do not provide a final solution but rather a process of evaluation. Our goal is to provide a model to help us further understand the potential and limitations of fan implementation for stairwell evacuation.
- Understanding limitations of the system through analysis will allow us to adjust, conduct further research, and prepare accordingly.
- Armed with knowledge we can respond smartly.

Thank you for your time and consideration of this topic