ASHRAE RP-1733

Develop Design Criteria for Psychrometric Air Sampler and Mixer Apparatus for Use in ASHRAE Test Standards

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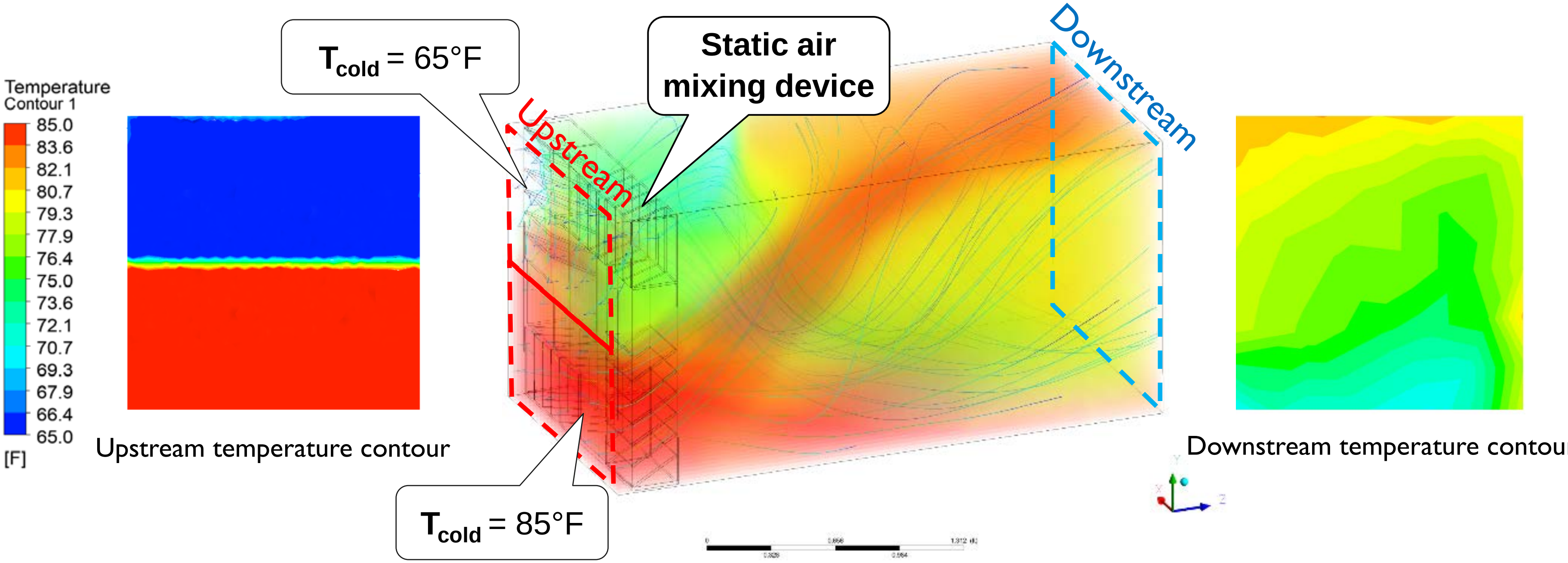
Agenda

1. Introduction
    I. Introduction
    II. Objectives
2. Progress Update
    I. Experimental Setup and Results
    II. Numerical Analysis and Results
3. Conclusion and Future Work
    I. Conclusion for Experimental Work
    II. Conclusion for CFD Work
    III. Future Work

Introduction

- Air mixer is a device to improve accuracy in measuring average air condition reducing non-uniformity
- The possible stratification of air streams is likely to cause many problems both in HVAC&R system control (e.g. economizers) and heat exchanger performance testing

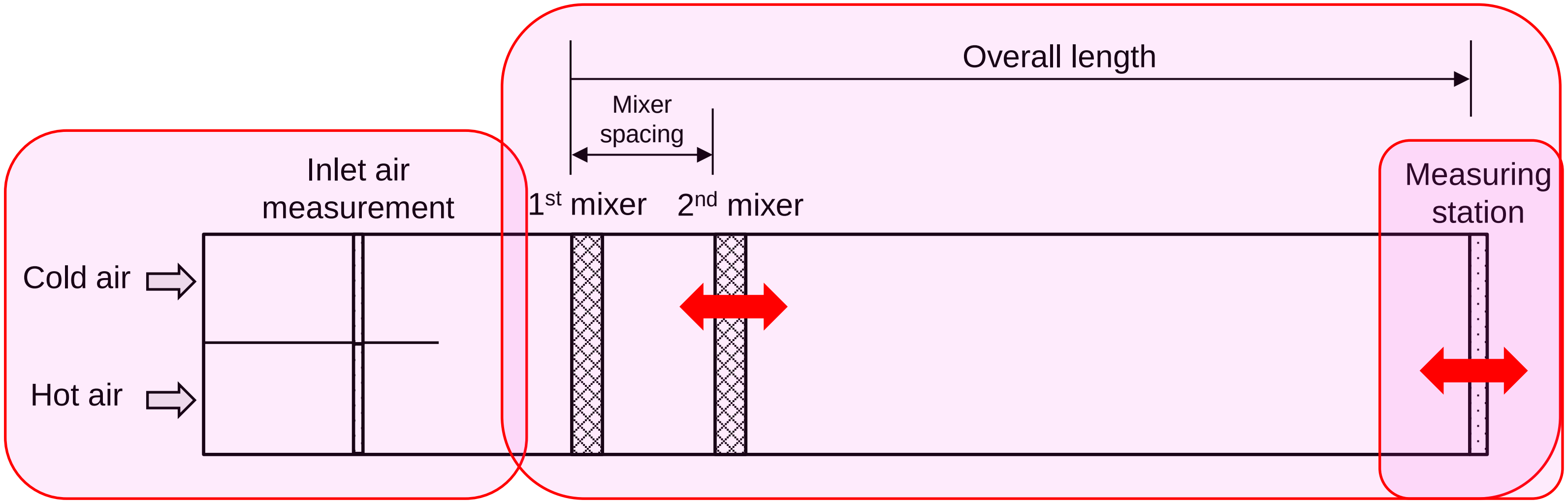


Objectives

1. Experimental investigation of the mixing performance of a pair of the mixers to better understand the effect of various parameters on it.
2. Numerical approach to predict the flow behavior based on louver angle configuration of the baseline mixer, as well as, several representative mixer geometries.
3. Provide design recommendations for air mixer geometry and configuration to obtain uniform air conditions.

Experimental Setup - Overview

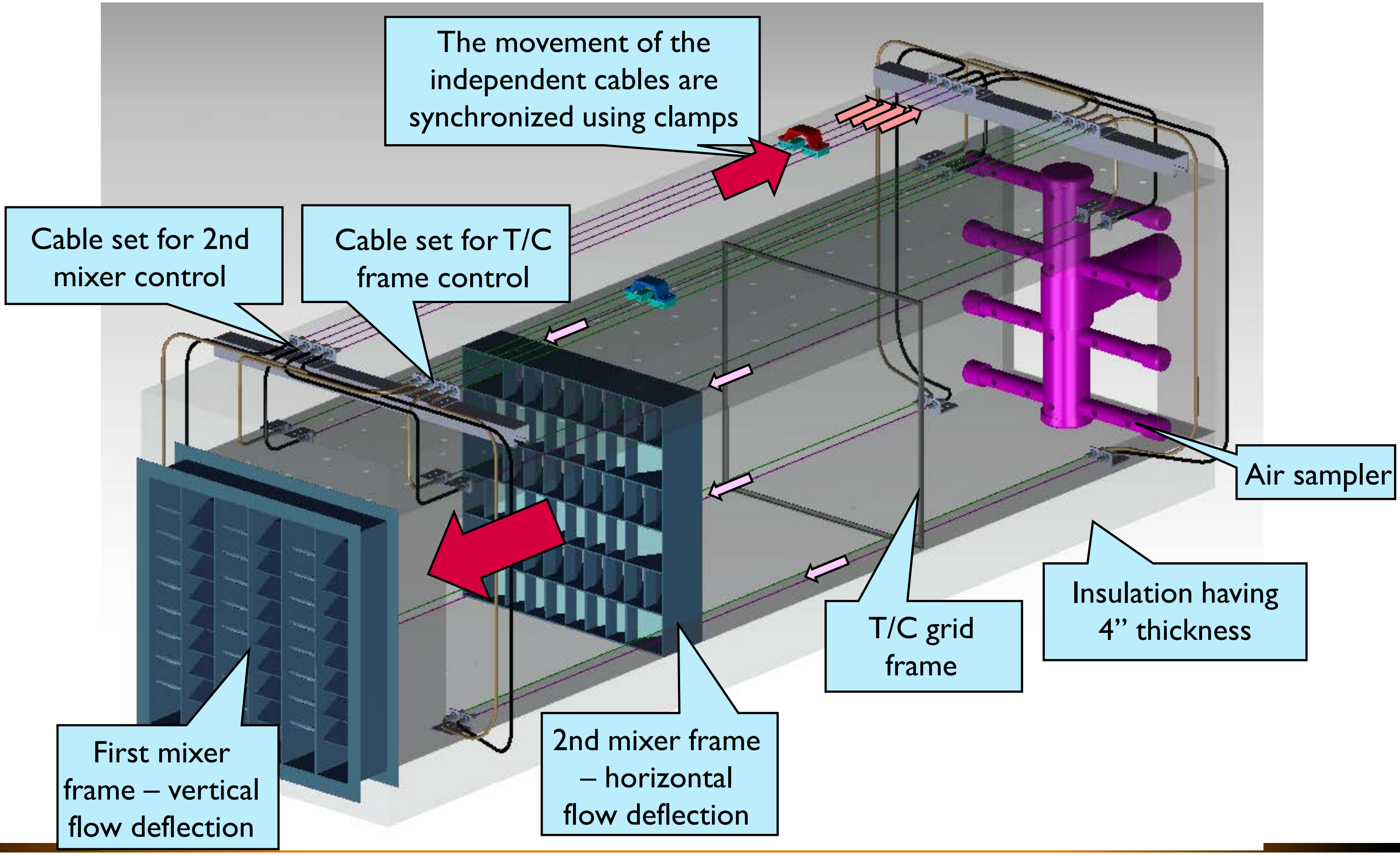
- Two inlets for air streams having different conditions. Flowrate at each inlet is controlled independently using PID controller implemented in LabVIEW.
- Adjustable mixer spacing and measuring station for various test conditions
- Air sampler and thermocouple grid allow to accurately measure the air conditions and mixing process.



Schematic of the experimental setup

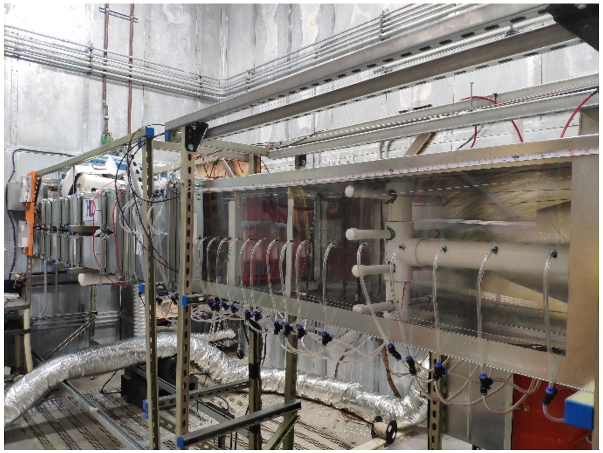
Experimental Setup – Test Section

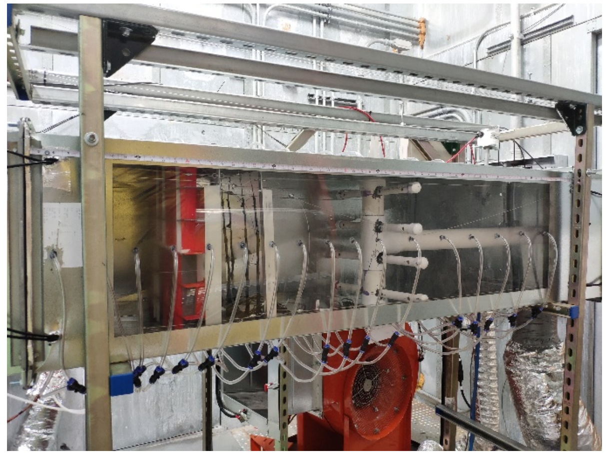
- Detailed schematic of the test section

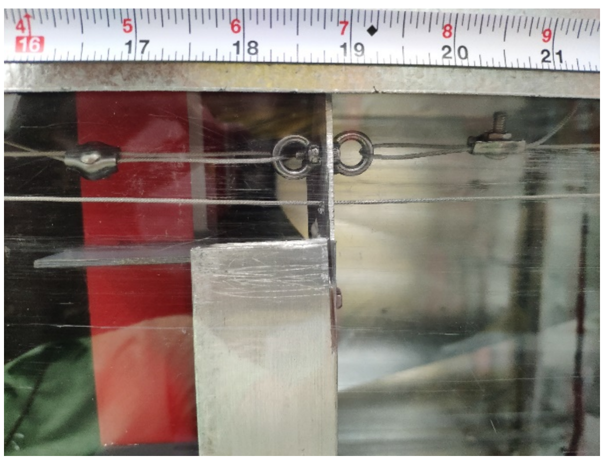


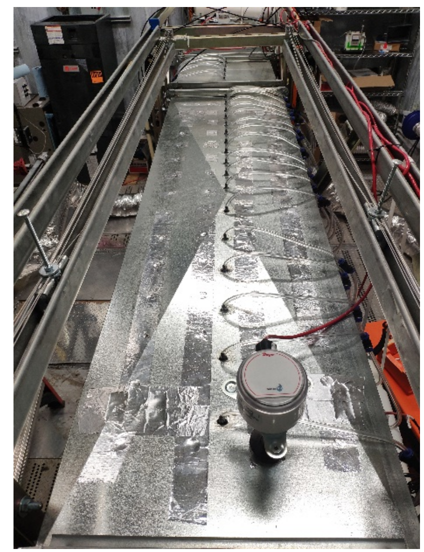
Experimental Setup – Test Section

- **Photos of the test section**



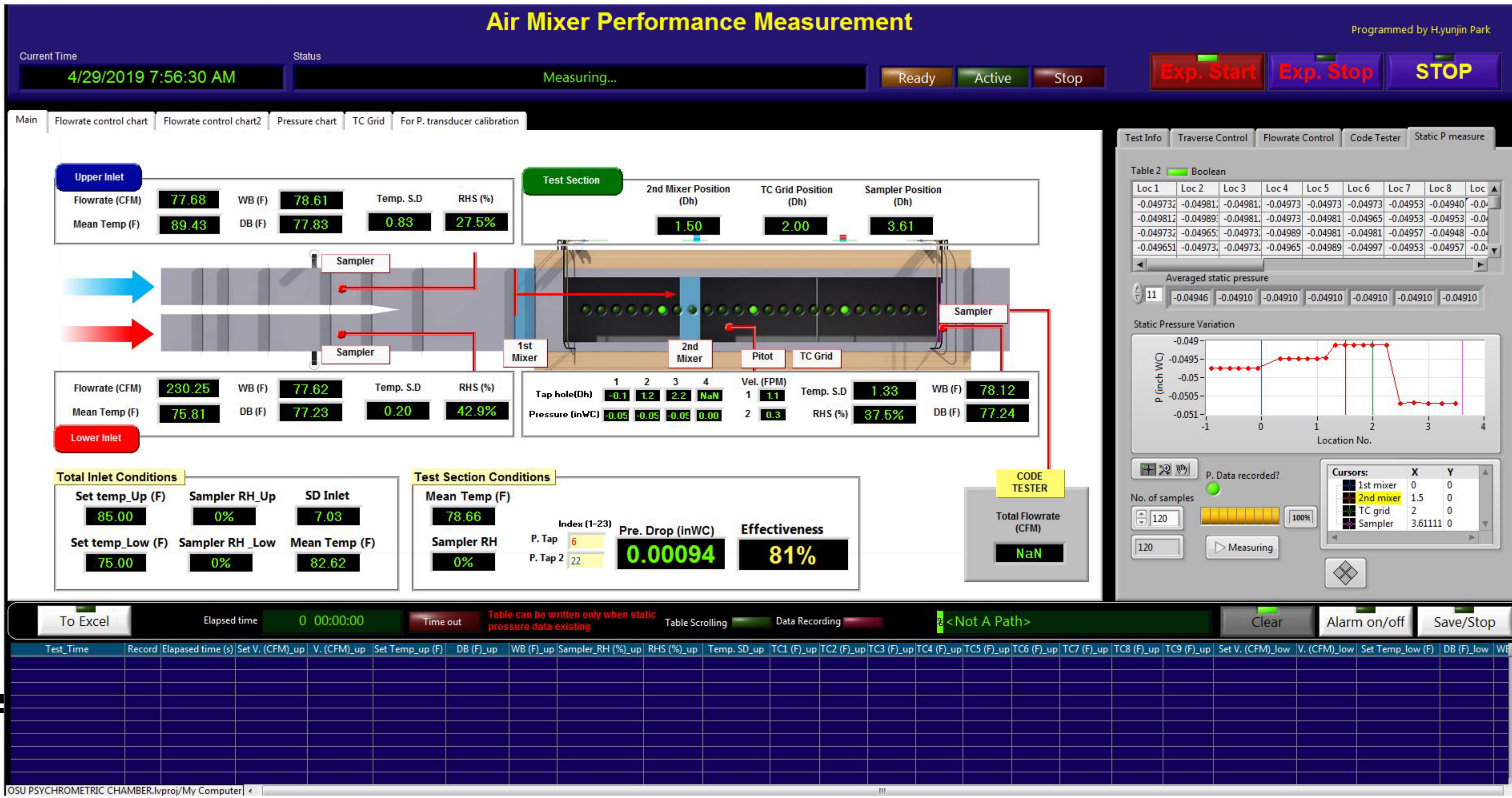






Experimental Setup – DAQ & Analysis

- A program developed to acquire and analyze the sensor signals using LabVIEW.
- The features include heat mapping to visualize temperature distribution in the test section, PID controller to adjust flowrate, and data template sheet with analysis results.



Experimental Setup – Test Conditions

- **Experimental conditions**

  A pair of baseline air mixer was considered to investigate the effects of total flowrate, flowrate ratio, mixer spacing, and overall length on mixing performance

#	Mixer spacing (D_h)	Overall length (D_h)	Temp. @ upper inlet (°F)	Flowrate @ upper inlet (CFM)	Vel. @ upper inlet (FPM)	Temp. @ lower inlet (°F)	Flowrate @ lower inlet (CFM)	Vel. @ lower inlet (FPM)	Total flowrate (CFM)
1	0.6	1.0	85	150	133.3	75	150	133.3	300
2		1.5							
3		2.0							
4		2.5							
5		3.0							
6		3.3							
7	1.0	1.5							
8		2.0							
9		2.5							
10		3.0							
11		3.3							
12	1.5	2.0							
13		2.5							
14		3.0							
15		3.3							
16	2.0	2.5							
17		3.0							
18		3.3							
19	1.5	2.0	85	100	88.9	75	100	88.9	200
20				200	177.8		200	177.8	400
21	1.5	2.0	85	225	200	75	75	66.7	300
22				75	66.7		225	200	300

Experimental Setup - Metric

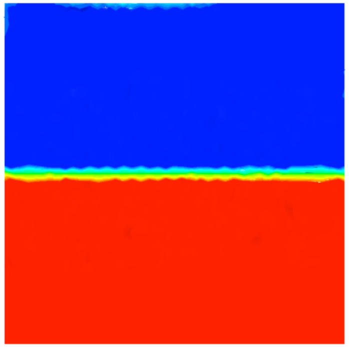
- **Metric for mixing effectiveness**

A metric (Faison et al, 1970) based on the average standard deviation of the upstream and downstream measurement was employed.

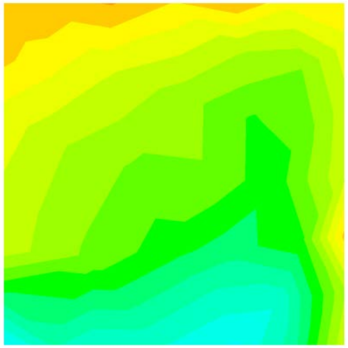
$$\varepsilon = \left(1 - \frac{s(\Delta T_{downstream})}{s(\Delta T_{upstream})}\right)$$

where:

$s(\Delta T_{upstream})$	Average standard deviation between temperature sample grid points prior to (upstream of) the first air mixer,
$s(\Delta T_{downstream})$	Average standard deviation between temperature sample grid points after (downstream of) the second air mixer, and
ε	Percent effectiveness.

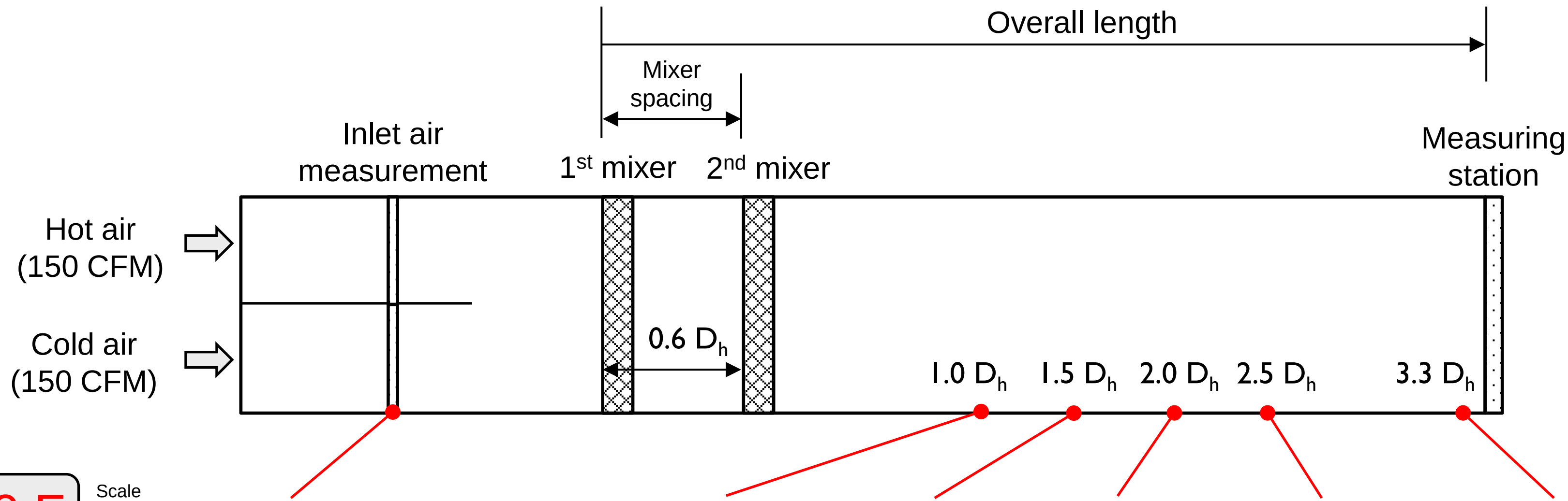


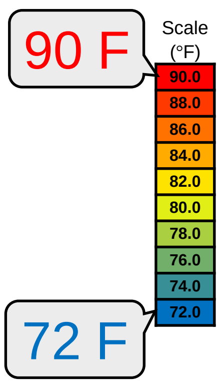
Upstream temperature contour



Downstream temperature contour

❑ Heat map showing temperature distribution at a cross-section





Upper inlet

88.52	88.95	88.59
88.37	89.18	88.31
88.41	88.59	87.38

Lower inlet

75.10	75.23	74.93
74.98	75.25	75.16
75.35	75.30	75.58

ε = 49.9%

85.98	86.64	81.23	82.86
78.09	82.29	77.78	79.18
77.58	82.73	77.98	79.33
76.20	76.75	75.63	76.33

ε = 60.0%

85.56	83.84	83.35	82.39
80.57	81.18	82.75	80.30
79.45	79.20	78.50	81.06
76.98	76.65	76.46	76.44

ε = 65.2%

84.44	84.04	83.35	82.34
82.04	82.20	80.90	82.21
80.48	80.57	77.75	80.46
77.90	77.62	77.24	77.65

ε = 69.7%

84.40	84.03	82.60	82.15
82.38	82.19	79.94	81.53
80.86	80.96	77.80	80.06
79.16	79.02	77.87	78.63

ε = 74.7%

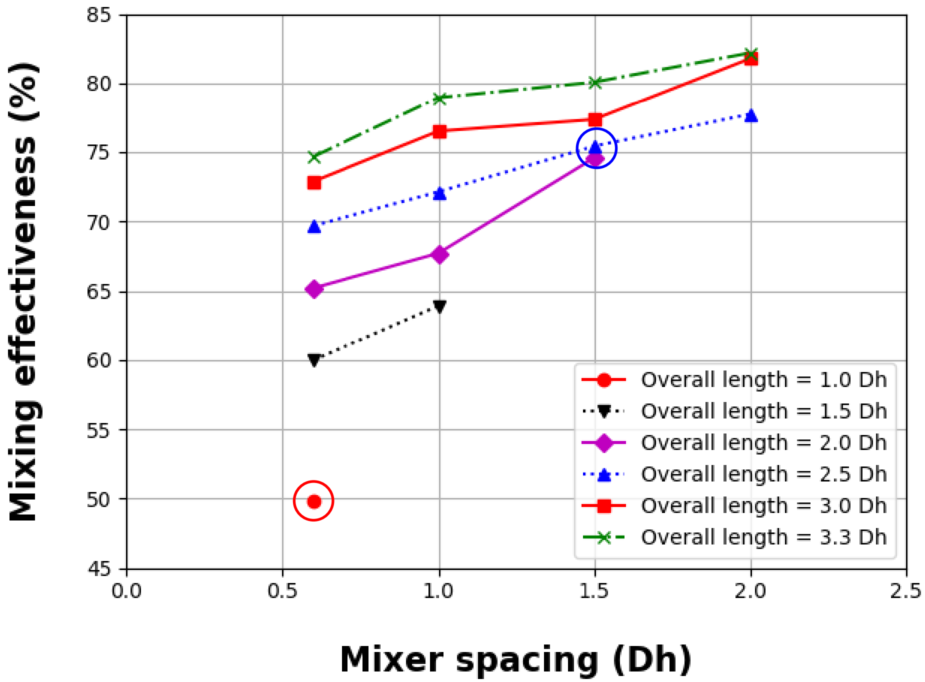
84.46	83.94	81.99	81.68
83.13	82.42	80.74	80.72
82.10	81.32	78.97	79.61
80.68	80.37	78.38	78.94

Experimental Results

❑ The effect of mixer spacing and overall length on effectiveness

- Flowrate at upper inlet: 150 CFM
- Flowrate at lower inlet: 150 CFM
- Temperature at upper inlet: ~89 F
- Temperature at lower inlet: ~75 F

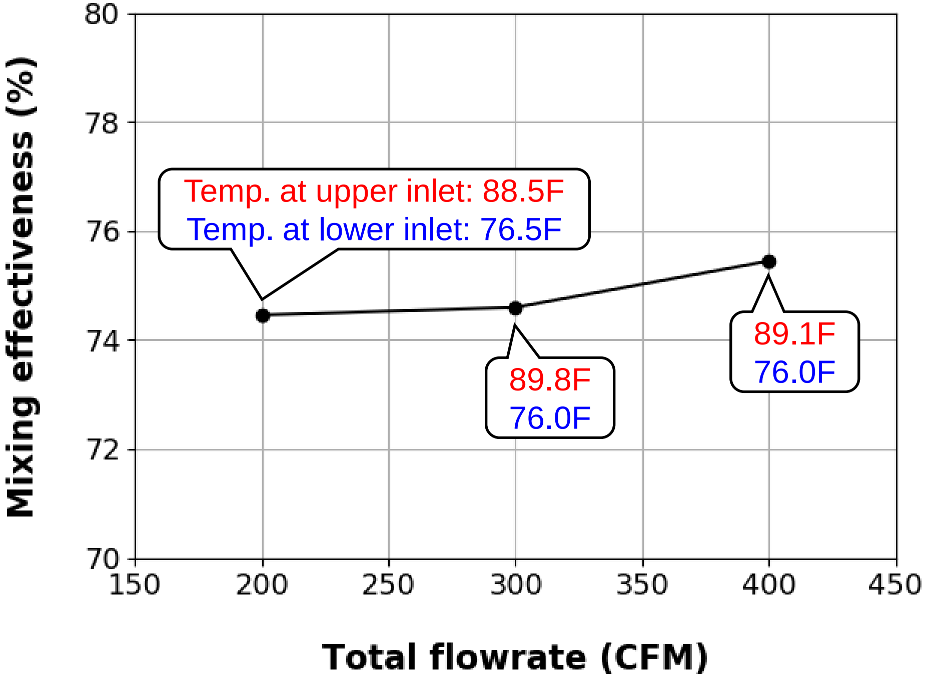
- The mixing effectiveness uncertainty is estimated at 1.7% based on 95% confidence level (mixer spacing of 0.6 D_h and overall length of 1.0 D_h).
- The uncertainty is also estimated at 1.5% for mixer spacing of 1.5 D_h and overall length of 2.5 D_h.



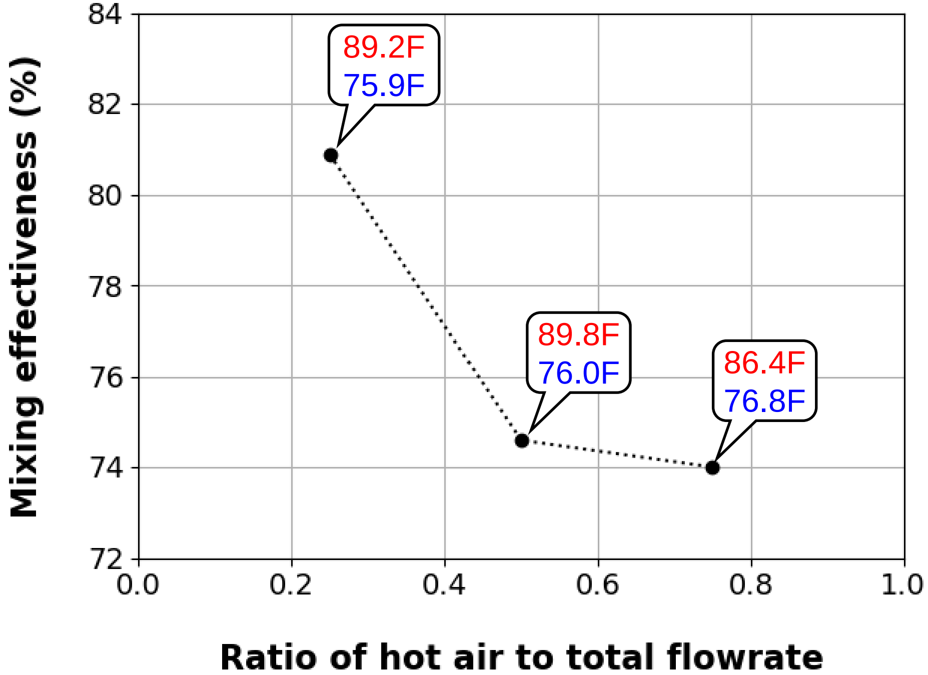
Variation of mixing effectiveness with different mixer spacing for overall length of 1.0, 1.5, 2.0, 2.5, 3.0, and 3.3 D_h

Experimental Results

- The effect of total flowrate and flowrate ratio between inlets on effectiveness



Variation of mixing effectiveness for different total flowrate with constant flowrate ratio of 0.5



Effect of the ratio of inlet flowrate on mixing effectiveness for total flowrate of 300 CFM

Numerical Analysis – CFD Setting

Objectives of Numerical Analysis

- Gain initial understanding of flow pattern caused by mixers prior to experimental study
- Predict flow characteristics and mixing performance with the use of candidate air mixers

Physics Setup

- Boundary conditions
  - i. Constant mass flow inlets
  - ii. Constant pressure outlet
  - iii. No-slip condition at wall surfaces
- Turbulence Model
  - i. k-ω turbulence model with y+ treatment for representative mixer geometries
  - ii. y+ less than or equal to 1 to resolve the viscous sublayer

Numerical Analysis – Metric

- Faison et al.'s metric, Eq. (1), used for experimental data used discrete measurement points
- Eq. (2), used for simulation data allows to consider all data in the cross-section, area weighted by mesh element area.

$$Mixing\ Effectiveness = \left(1 - \frac{S.D._{downstream}}{S.D._{upstream}}\right) \times 100 \qquad (1)$$

$$Standard\ Deviation\ of\ Temperature = \sqrt{\frac{\sum_i (\mathrm{T}_{f,i} - \bar{T})^2 A_{f,i}}{\sum_{i,} A_{f,i}}} \qquad (2)$$

where,

A_f : the face area of the cell,

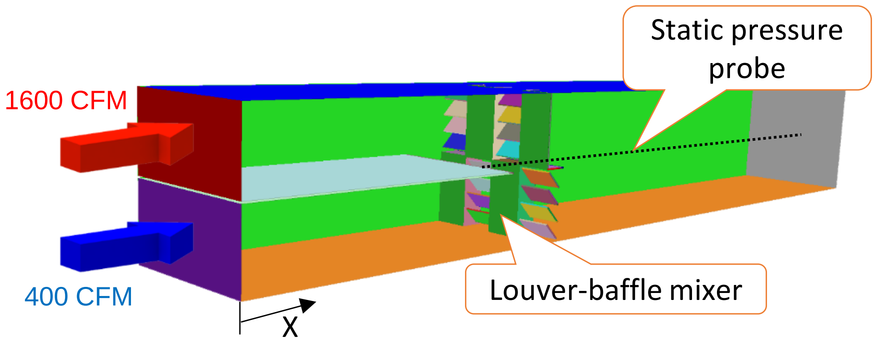
T_f : the average temperature of the cell,

$\bar{T}$: the mean temperature of the measuring plane,

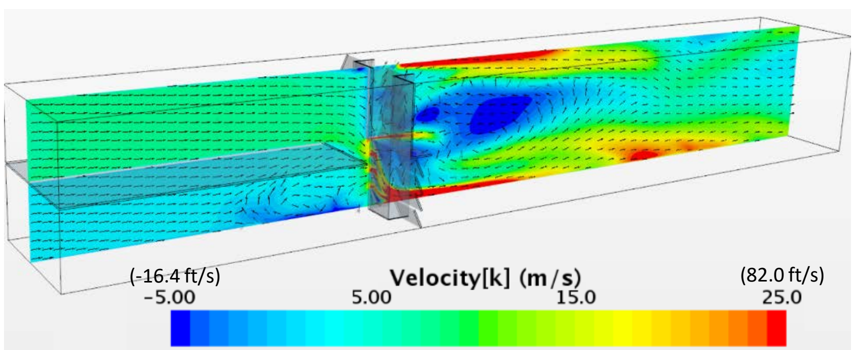
$S.D.$: the standard deviation.

Numerical Results: Louver-baffle Mixer

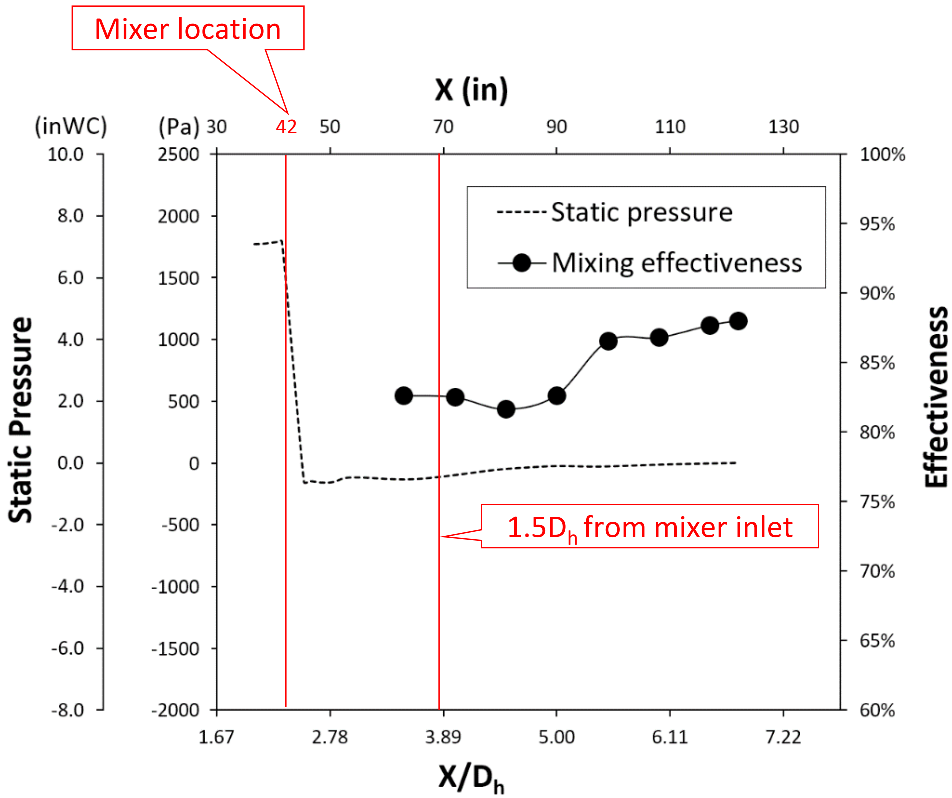
- Baffle supports generation of large vortices and accelerates flow, resulting in faster mixing.



Computational domain



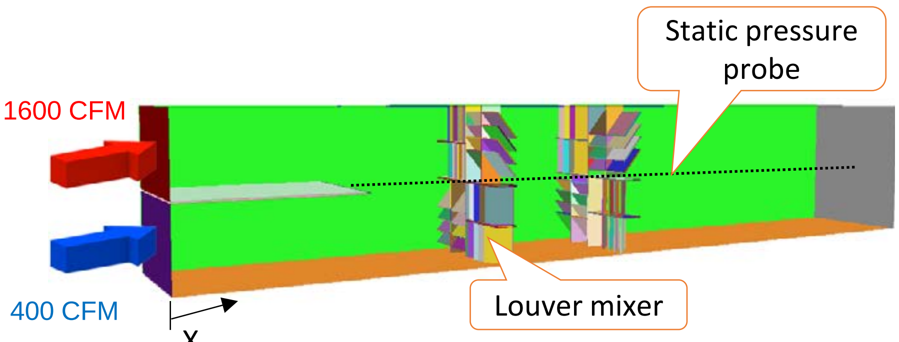
Velocity field color shows the velocity in x-direction



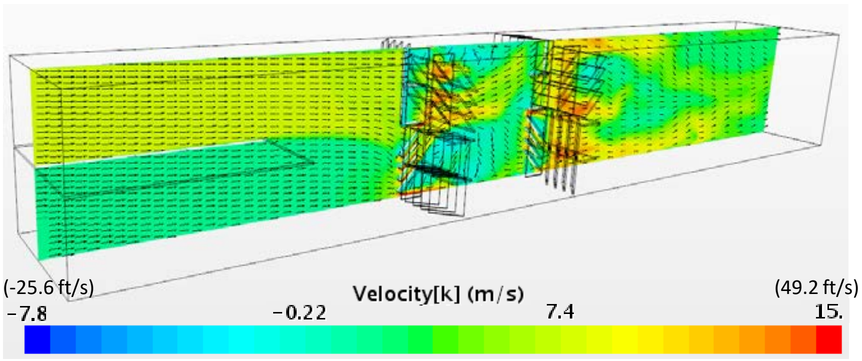
Variation of static pressure and effectiveness downstream of the duct with a louver-baffle mixer

Numerical Results: A Pair of Louver Mixer

- An orthogonal pair of louver mixers is used to enhance mixing effectiveness.



Computational domain



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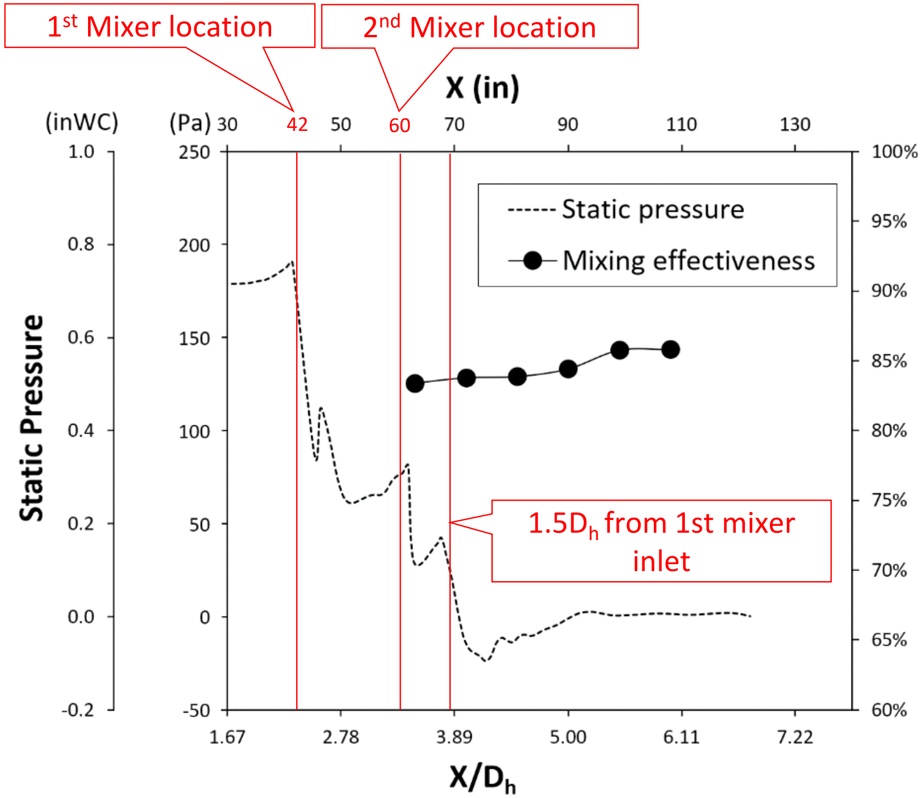
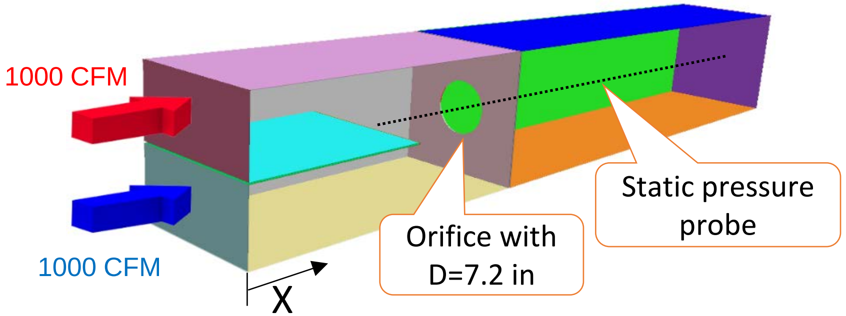


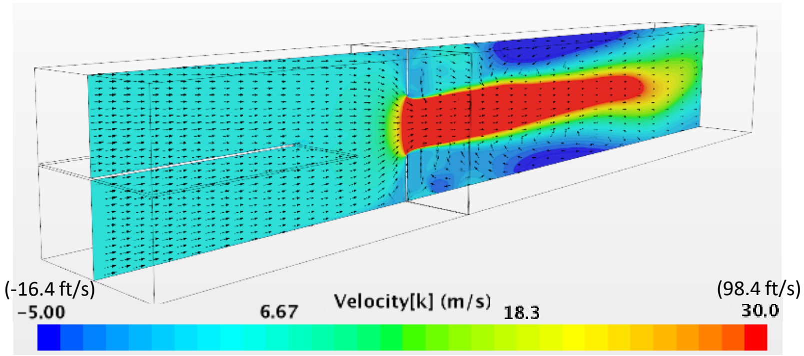
Variation of static pressure and effectiveness downstream of the duct with a louver mixer

Numerical Results: Orifice Mixer

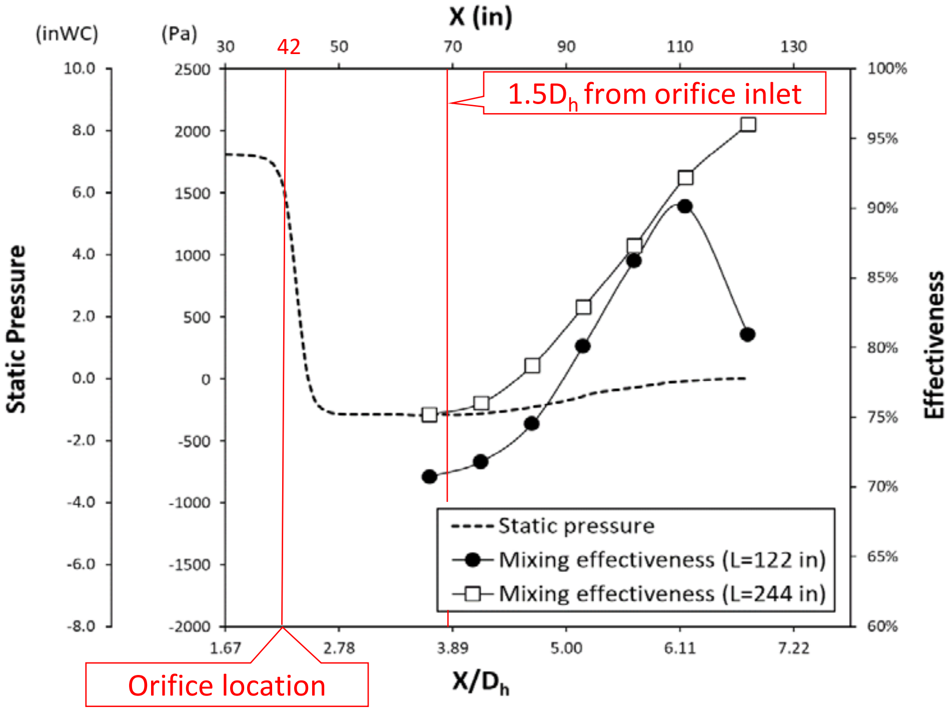
- Simple design allowing to easily fabricate it
- Orifice is used to increase the interface area between the cold and hot airstreams



Computational domain



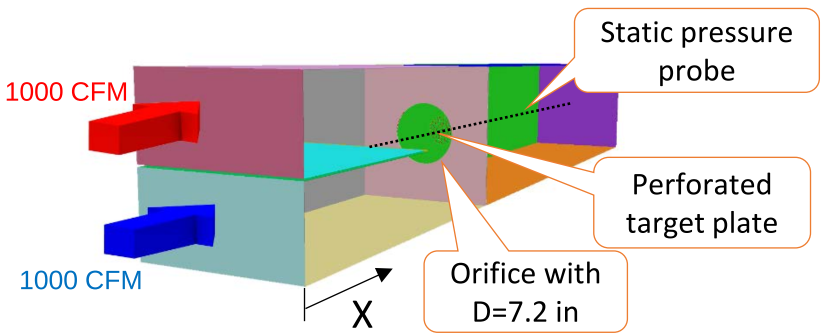
Velocity field color shows the velocity in x-direction



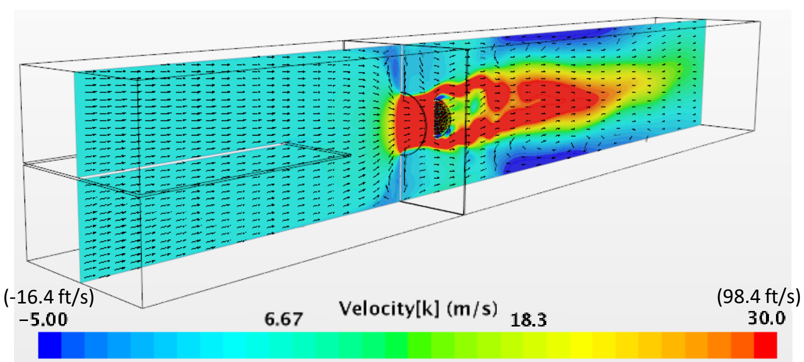
Variation of static pressure and effectiveness downstream of the duct with a orifice-target mixer

Numerical Results: Orifice-target Mixer

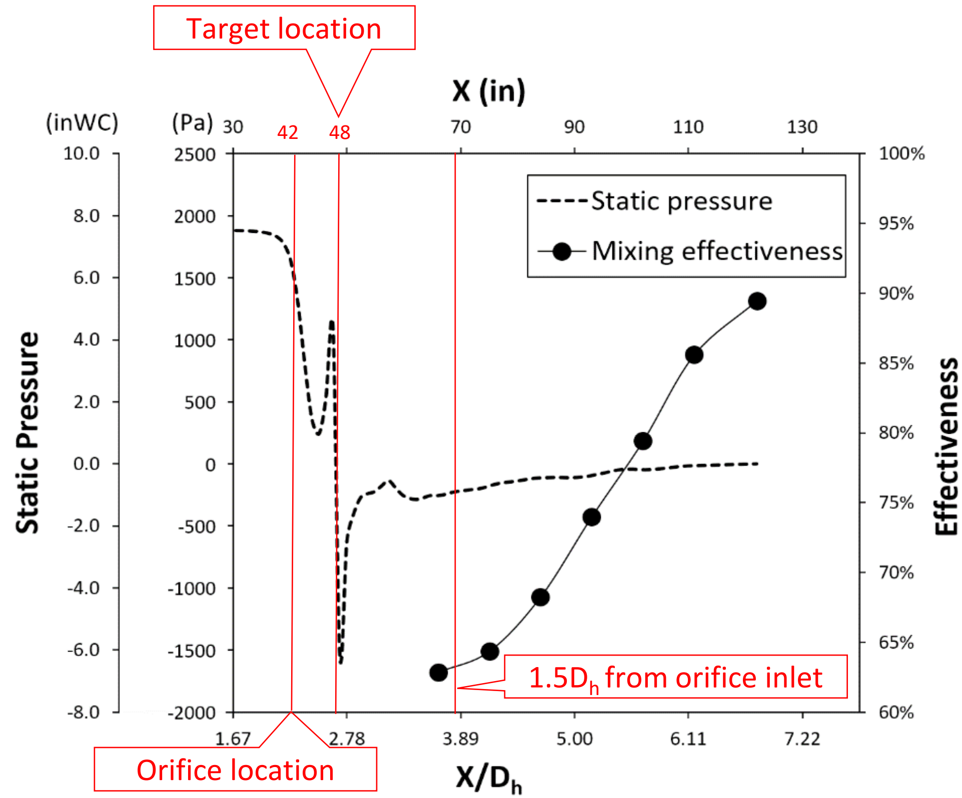
- Perforated target plate was applied to reduce velocity non-uniformity



Computational domain



Velocity field color shows the velocity in x-direction



Variation of static pressure and effectiveness downstream of the duct with a orifice-target mixer

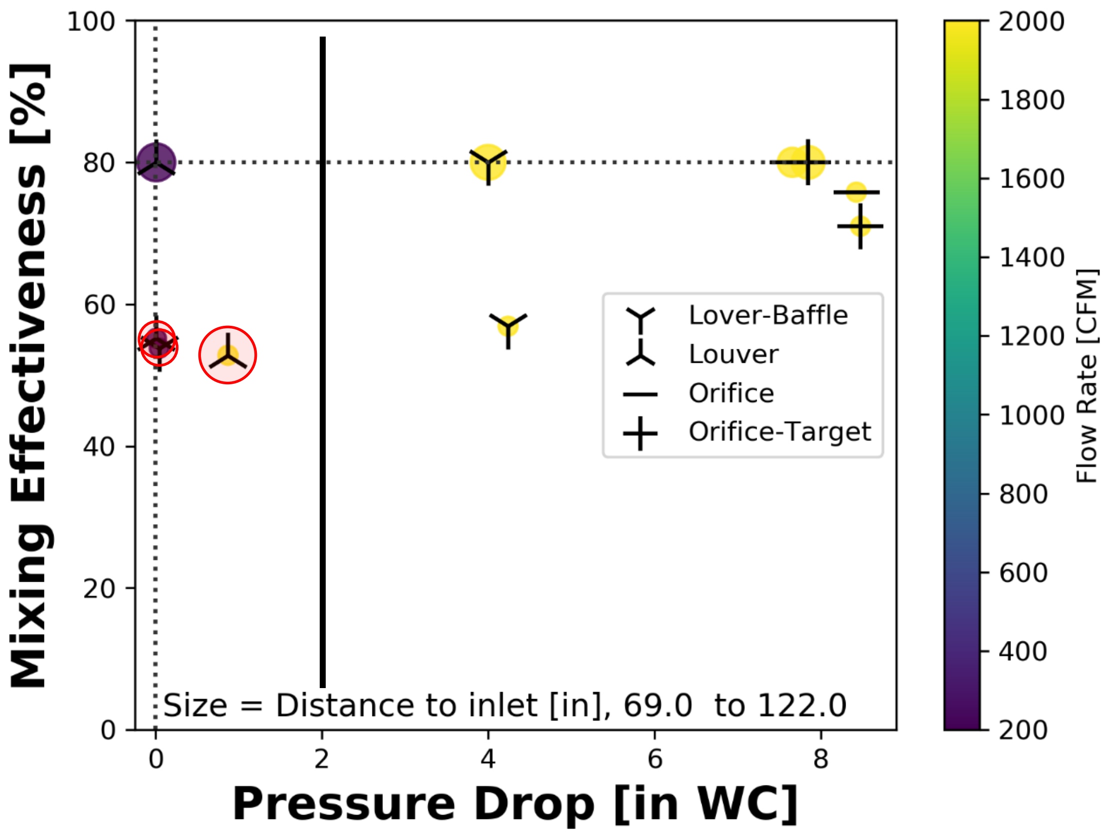
Numerical Results

❑ Conditions of variables

- A) Overall length for 80% mixing effectiveness
- B) Fixed length of 1.5Dh
- Total flowrate range:
  200 – 2,000 CFM (1:10)
- Ratio of hot air to total flowrate at inlet: 0.5

❑ Highlight

- For low flowrate, louver (pair) and louver-baffle (pair) mixers are acceptable for pressure drop constraint.
- For high flowrate, only louver mixer (⅄) is acceptable.



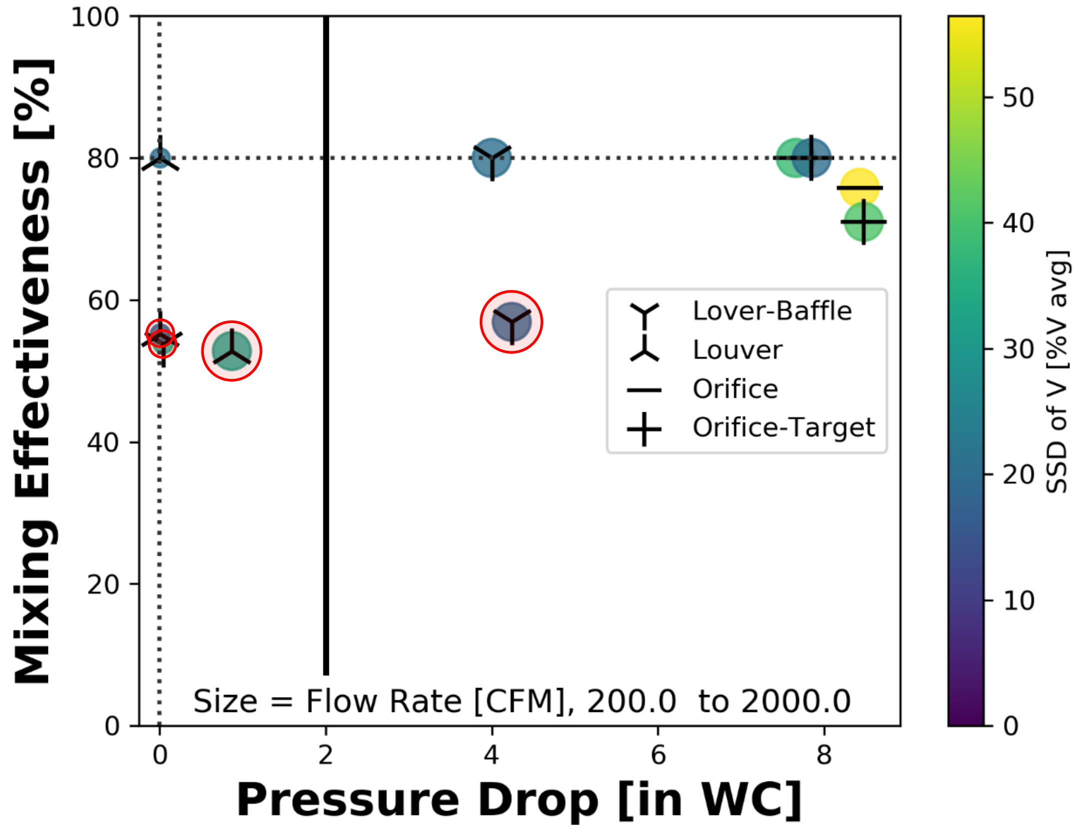
Numerical Results

❑ Conditions of variables

- Total length between 1st mixer inlet and measuring plane: 1.5 – 4.4 D_h
- Total flowrate range: 200 – 2,000 CFM (1:10)
- Ratio of hot air to total flowrate at inlet: 0.5

❑ Highlight

- For total flowrate range, louver mixer (⅄) is the best with low pressure drop, but higher SSD (Surface Standard Deviation) of velocity.
- Lower SSD of velocity with louver-baffle mixer (Y) for low flowrate, but the amount of pressure drop is more sensitive to flowrate.



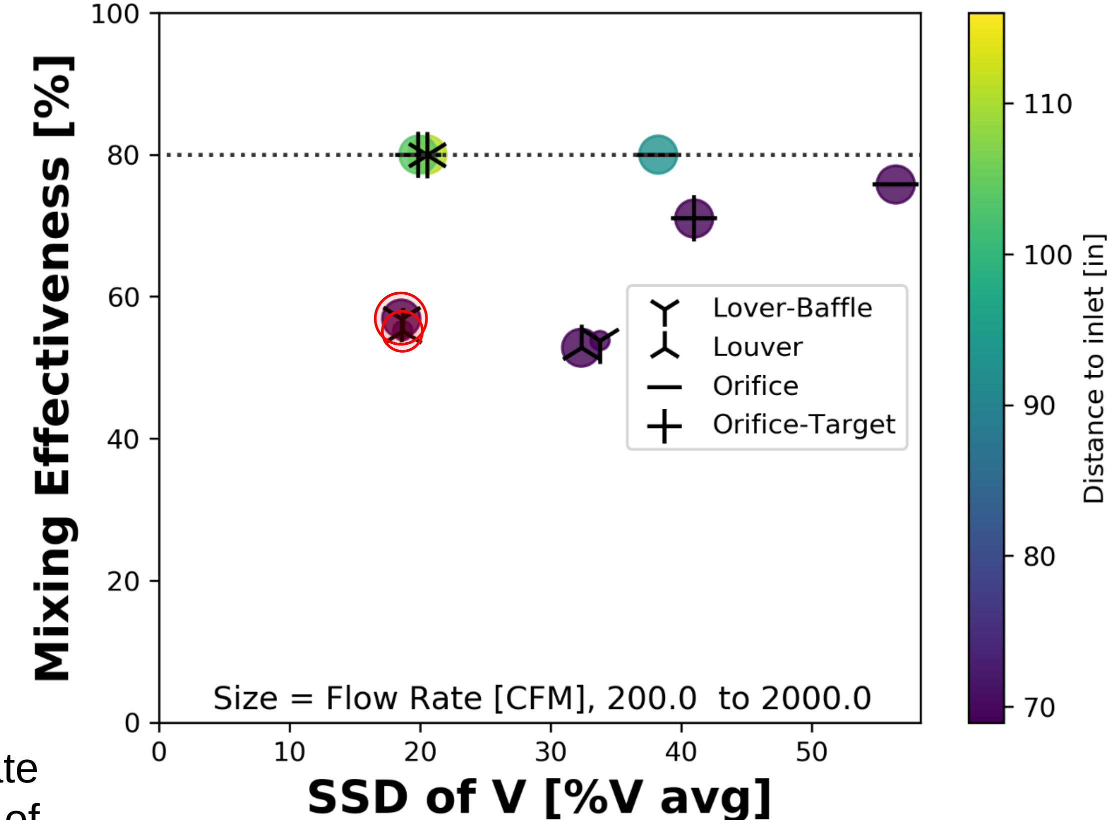
Numerical Results

❑ Conditions of variables

- Total length between 1st mixer inlet and measuring plane: 1.5 – 4.4 D_h
- Total flowrate range: 200 – 2,000 CFM (1:10)
- Ratio of hot air to total flowrate at inlet: 0.5

❑ Highlight

- Louver mixer can be a good choice for a short mixing length and low flowrate with acceptable SSD of velocity.
- Louver-baffle mixer for high flowrate is in the acceptable range of SSD of velocity, but not be able to be chosen due to high pressure drop.



Conclusion for Experimental Work

- The performance of a pair of the baseline louvered air mixer was experimentally investigated in terms of how possible variables influence mixing performance.
  - In general, longer mixer spacing and overall mixing length enhanced mixing effectiveness.
  - The effect of total flowrate on the effectiveness was insignificant.
  - Mixing effectiveness ranged from 50% to 82% for all tested conditions.
- A review paper was submitted to STBE (22-Mar-2019)
  - "A Literature Review of Air Mixing Devices for Psychrometric Performance Measurement Application (ASHRAE RP1733)"

Conclusion for CFD Work

- The louver-baffle mixer is not efficient for the 1:10 ratio of total flowrate range since it increases about 4 times of pressure drop while causing only 3% increase of the effectiveness in the range, comparing to the case of a pair of louver mixers .

- For a short duct length (e.g. 1.5 D_h) orifice and orifice-target mixer are not recommended because of high pressure drop, non-uniform velocity, and lower mixing effectiveness than for louver type mixers.

- Only louver mixer worked well with an exception of the velocity variation for all constrains (duct length equal to 1.5 D_h, 2 inWC) put by the committee.

Future work

- Perform experimental test to determine the effect of flowrate ratio on the mixing performance
- Automate the experimental setup to facilitate a number of tests with various types of mixers and test variables
- Improve the setup-fan connection to reduce pressure head in the setup
- Insulate the setup for more precise experiment
- Test candidate mixers experimentally to qualitatively compare to CFD results
- Evaluate the performance of baseline sampler
- Observe flow pattern to better understand temperature distribution

Thanks for your attention

Q&A