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
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.

$$T_{\text{cold}} = 65^\circ\text{F}$$

$$T_{\text{cold}} = 85^\circ\text{F}$$
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

- The movement of the independent cables are synchronized using clamps

- Cable set for 2nd mixer control
- Cable set for T/C frame control

- First mixer frame – vertical flow deflection
- 2nd mixer frame – horizontal flow deflection

- Air sampler
- T/C grid frame
- Insulation having 4” thickness
Photos of the test section
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.

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<th>#</th>
<th>Mixer spacing (Dh)</th>
<th>Overall length (Dh)</th>
<th>Temp. @ upper inlet (°F)</th>
<th>Flowrate @ upper inlet (CFM)</th>
<th>Vel. @ upper inlet (FPM)</th>
<th>Temp. @ lower inlet (°F)</th>
<th>Flowrate @ lower inlet (CFM)</th>
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Experimental conditions for mixing performance investigation.
Metric for mixing effectiveness

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

\[ \varepsilon = 1 - \frac{s(\Delta T_{downstream})}{s(\Delta T_{upstream})} \]

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
- \( \varepsilon \): Percent effectiveness.
### Experimental Results

- **Heat map showing temperature distribution at a cross-section**

  - **Inlet air measurement**
    - **Hot air (150 CFM)**
    - **Cold air (150 CFM)**

  - **Mixer spacing**
    - 1st mixer
    - 2nd mixer
    - Overall length

  - **Measuring station**

  - **Scale (°F)**
    - 90.0
    - 88.0
    - 86.0
    - 84.0
    - 82.0
    - 80.0
    - 78.0
    - 76.0
    - 74.0
    - 72.0
    - 70.0

  - **Upper inlet**
    - ε = 49.9%
    - ε = 60.0%
    - ε = 65.2%
    - ε = 69.7%
    - ε = 74.7%

  - **Lower inlet**
    - ε = 49.9%
    - ε = 60.0%
    - ε = 65.2%
    - ε = 69.7%
    - ε = 74.7%

- **Inlet air measurement**
  - **Upper inlet**
    - ε = 49.9%
    - ε = 60.0%
    - ε = 65.2%
    - ε = 69.7%
    - ε = 74.7%

- **Scale (°F)**
  - 90 F
  - 72 F

- **Overall length**
  - 0.6 Dh
  - 1.0 Dh
  - 1.5 Dh
  - 2.0 Dh
  - 2.5 Dh
  - 3.3 Dh

- **ε**
  - 49.9%
  - 60.0%
  - 65.2%
  - 69.7%
  - 74.7%
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 $D_h$.
The effect of total flowrate and flowrate ratio between inlets on effectiveness

Experimental Results

- **Variation of mixing effectiveness for different total flowrate with constant flowrate ratio of 0.5**
  - Temp. at upper inlet: 88.5F
  - Temp. at lower inlet: 76.5F
  - 89.8F 76.0F

- **Effect of the ratio of inlet flowrate on mixing effectiveness for total flowrate of 300 CFM**
  - 89.2F 75.9F
  - 89.8F 76.0F
  - 86.4F 76.8F
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. $k-\omega$ turbulence model with $y+$ treatment for representative mixer geometries
  ii. $y+$ less than or equal to 1 to resolve the viscous sublayer
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.

\[ \text{Mixing Effectiveness} = \left(1 - \frac{S.D. \text{downstream}}{S.D. \text{upstream}} \right) \times 100 \]  

\[ \text{Standard Deviation of Temperature} = \sqrt{\frac{\sum_i (T_{f,i} - \bar{T})^2 A_{f,i}}{\sum_i A_{f,i}}} \]  

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

Computational domain

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

Velocity field color shows the velocity in x-direction

Mixer location

1.5Dh from mixer inlet

Numerical Results: Louver-baffle Mixer
A pair of louver mixers is used to enhance mixing effectiveness.

Numerical Results: A Pair of Louver Mixer

- Computational domain
- Static pressure probe
- 1st Mixer location 1.5Dh from 1st mixer inlet
- 2nd Mixer location

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**

- Orifice with \( D = 7.2 \text{ in} \)
- Static pressure probe

**Velocity field color shows the velocity in \( x \)-direction**

**Variation of static pressure and effectiveness downstream of the duct with a orifice-target mixer**
Perforated target plate was applied to reduce velocity non-uniformity.

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

Computational domain:
- Orifice with $D=7.2$ in
- Static pressure probe
- Perforated target plate

Numerical Results: Orifice-target Mixer

- Velocity field color shows the velocity in x-direction
- Variation of static pressure and effectiveness downstream of the duct with a orifice-target mixer

Graphs showing:
- Static pressure
- Mixing effectiveness

Key points:
- 1.5D$_h$ from orifice inlet
- 3.89, 5.00, 6.11, 7.22 X/D$_h$
- Orifice location
- Target location

1000 CFM
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 ( rulings ) 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 ( ) 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