OUTDOOR AND RETURN AIRFLOW MIXING WITH PARALLEL DAMPERS

C Sun, F Finaish* and HJ Sauer

Department of Mechanical, and Aerospace Engineering and Engineering Mechanics
University of Missouri-Rolla, Rolla, MI, USA

ABSTRACT
Thermal mixing of two airstreams with dissimilar temperatures and velocities entering a mixing chamber, equipped with parallel air dampers, is studied experimentally. The thermal mixing for outdoor airflow ratios in the range between 15% and 45% was examined at several stations in the mixing chamber. At each flow ratio, the return airflow damper was kept fully open while the outdoor air damper angle was changed from 30° to 90°. The results show that as the two streams flow into the mixing chamber and proceed downstream of the dampers-controlled inlets, most of the mixing occurs within a downstream distance equal to one height of the chamber. Furthermore, the results suggest that directing the two streams toward each other by altering the outdoor dampers from the fully to partially open position leads to improved mixing in the entrance region. However, this influence diminishes downstream of the dampers.

INDEX TERMS
Thermal Air mixing, flow dampers

INTRODUCTION
In typical air-handling units of heating and air-conditioning systems, cold outdoor and warm return airflows are drawn into a chamber in a manner to minimize air stratification prior to leaving the HVAC unit. However, since the two flows have different conditions of temperatures and velocities, air stratification can still develop and lead to adverse effects related both to temperature control and indoor air quality. It has been recognized that air stratification can result in a variety of problems as reported by (Alyea1958), (Haines 1980) and (Delaney et al., 1984). The most widely recognized problems are coil freeze-ups, nuisance freeze-stat trips, energy waste due to sensor error, and indoor poor air quality. It has been suggested (Heating, Piping and Air Conditioning Engineering Data File, 1961) that the distance between the mixing chamber and the first coil in the moving air stream will have an effect on mixing efficiency. The shorter the distance the greater will be the difficulty in obtaining good mixing. It was also proposed that symmetrical return and outdoor air intakes can insure adequate mixing and uniform flow. Recently (Robinson, 1998 &2000) conducted a series of temperature tests to study mixing effectiveness of a combination mixing/filter box in a constant-volume air-handling unit. The test results showed that the mixing effectiveness varied as the damper position changed and significant stratification existed throughout the range of damper positions tested. The author concluded that the mixing efficiency by use of parallel blade dampers was not sufficient to reduce the stratification present in the unit to acceptable levels and the lack of mixing may be a result of a low damper velocity. Even though many factors of mixing chamber layout have been discussed, the information presented is largely limited to suggestion and rules-of-thumb for system designers.

* Contact author email: finaish@umr.edu
To further the understanding of these issues, this study considers a wider range of damper angles and flow ratios of outdoor and return air streams to investigate the dependence of thermal mixing of the two air streams on these parameters. The angle combinations of return airflow and outdoor airflow dampers examined are ($\theta_R / \theta_O$): $90^\circ/30^\circ$, $90^\circ/45^\circ$, $90^\circ/60^\circ$, and $90^\circ/90^\circ$. For each case, temperature distributions at 36 points are collected at five downstream test stations with $x/D=0$, 0.5, 1.0, 1.5, 2.0, where D is the height of the mixing chamber. These data were collected for three outdoor airflow ratios ranges between 15% and 45%.

**TEST FACILITY AND METHOD**

The experimental work was conducted on a flow mixing facility developed at the University of Missouri-Rolla. A photograph of this facility is shown in Figure 1. Figure 2 shows the sketch of the experimental set-up. The 1.875m (75 inch) long mixing chamber with a square cross section of 0.5m (20 inch) x 0.5m (20 inch) is connected to two inlets, each with a 0.25m (10 inch) x 0.25m (10 inch) cross-section area, to provide for the return and outdoor airflows. Each inlet is equipped with a series of four conventionally manufactured flat-plate dampers. A control mechanism for each set of dampers allows for controlling the damper position of wide open ($90^\circ$), partially open (0$^\circ$ to $90^\circ$), or fully closed (0$^\circ$). To provide for a smooth flow prior to the damper stations, a plenum for 6.25 to 1 contraction ratio is installed upstream of the return and outdoor air dampers. Flow turbulence levels for the return and outdoor airflows are controlled by honeycomb panel and three anti-turbulence screens installed upstream of both contractions. The return airflow is generated by a 27 inch bisected fan driven by a 3 hp AC induction motor. This arrangement is capable of producing $0.85 \text{ m}^3/\text{s}$ (1800 cfm) at 5.7 cm (2.25 inch) of water static pressure. An AC inverter is utilized to control the flow velocities in the range between 0 m/s and 20.3 m/s (4000 fpm). The outdoor airflow is generated by a
blower/duct assembly installed in the plenum upstream of the contraction duct. The outdoor airflow speeds are controlled by AC invertors and potentiometers by which power input fed to the outdoor airflow blower can be regulated. Return airflow heating and temperature control are accomplished by 4 chrome steel sheath heaters and a microprocessor controller. This controller supplies a feedback signal to the four strip heaters located downstream of the motor-fan arrangement. A blender is installed downstream of the four strip heaters to blend the flow and reduce thermal stratification of the return airflow.

The two inlet velocities were monitored by using pitot-static tubes connected to a differential pressure transducer. The temperature data are collected by using a high-speed, multi-channel and real-time analog to digital with 22-bit resolution data acquisition unit. To obtain the temperature measurements, 60 T type duplex insulated thermocouples are connected to 2 IO Daq/56 modules. Of these 60 temperature sensors, 36 are mounted in the downstream test station in the mixing chamber, 20 are mounted in the return air inlet duct and 4 are mounted in the outdoor air inlet duct. All 60 thermocouples were calibrated using a certified thermometer of higher accuracy at 1.1°C (34°F) and 54.5°C (130°F). The accuracy of the thermocouples is on the order of ±1°F. The temperature difference between the airstreams is maintained at 4.4°C (40°F) with an outdoor airflow rate of 347 cfm (0.16 m³/s) and a return airflow rate of 0.2 m³/s (424 cfm) for 45% ratio, 0.38 m³/s (810 cfm) for 30% and 0.93 m³/s (1967 cfm) for 15% outdoor air ratio. As shown in Figure 2, the temperature data is collected at 5 downstream test stations [x/D=0, 0.5, 1, 1.5, 2]. To measure the temperature distributions at each station, 36 thermocouples were mounted on a movable grid that can be easily maneuvered downstream in the mixing chamber. The collected temperature data is utilized to quantify the thermal mixing by computing the range and statistical mixing effectiveness.
The range mixing effectiveness is defined as:

$$E_R = \left(1 - \frac{T_{\text{max}} - T_{\text{min}}}{T_1 - T_2}\right) \times 100\%$$

(1)

where $T_{\text{max}}$ and $T_{\text{min}}$ are maximum and minimum temperature readings at downstream test station. $T_1$ and $T_2$ are the temperatures of the two inlet airflows.

While the statistical mixing effectiveness is defined as:

$$E_{SD} = \left(1 - \frac{SD_{DS}}{0.5(T_2 - T_1)}\right) \times 100\%$$

(2)

where $SD_{DS}$ is the standard deviation of the temperature distribution measured at downstream test station. $SD_{DS}$ can be written as:

$$SD_{DS} = \sqrt{\frac{\sum_{i=1}^{n}(T_i - \bar{T})^2}{n-1}},$$

(3)

where $\bar{T}$ is the average of temperature readings at downstream test station with definition as:

$$\bar{T} = \frac{\sum_{i=1}^{n}T_i}{n}$$

(4)

where $T_i$ is the individual temperature reading.

RESULTS

Using the acquired temperature data, the range and statistical thermal mixing effectiveness are calculated and plotted in Figure (3). These plots show the dependence of the thermal mixing on the downstream distance for three outdoor flow ratios. As shown, in each case four dampers angle combinations are tested. As seen, the dependence of the thermal mixing effectiveness on the downstream distance for 15%, 30%, and 45% increased significantly in the range of $x/D=0$ and 1.0. Slight increases in the thermal mixing levels are achieved at further distances downstream from $x/D=1$ to $x/D=2$. Furthermore, the best mixing case ($\theta_R / \theta_O = 90/30$) for each outdoor air ratio shows a significant higher value of thermal mixing effectiveness than the least mixing case ($\theta_R / \theta_O = 90/90$) at the first station where $\theta_R$ and $\theta_O$ are the return and outside air damper angles respectively. However, as the mixing flow develops further downstream, effectiveness values seem to converge at $x/D > 2$. This suggests that the influence of the outdoor damper angle on mixing far downstream of the inlet is minimal.

CONCLUSIONS

With the return air damper fully open, as the outdoor air damper changes from fully open ($90^\circ$) to partially open ($30^\circ$), the least mixing is observed at $90^\circ$ outdoor air damper angle.
Figure 3. Dependence of Range and Statistical Mixing Effectiveness on Downstream Distance for Damper Angle Combinations Producing the Best and the Least Mixing
while the best mixing is obtained at 30° outdoor air damper angle for 15% and 45% outdoor air flow. For 30% outdoor air, 60° outdoor air dampers angle produced the best performance. The thermal mixing experiences a significant increase within the downstream distance of one chamber height. At further distances downstream, only slight increases in the thermal mixing were observed. Moreover, the influence of the outdoor damper angle on the thermal mixing is negligible at downstream distances at x/D>2.

The information presented in this article provide a useful source of data on the mixing of cold outdoor and return flows in Air Handling Units. The data presented provide insight on the influence of the dampers angles on thermal mixing and the mixing levels at downstream locations in a given Air Handling Unit. The results may serve as guide in determining requirements for designing and specifying air handling equipment.

ACKNOWLEDGMENTS
This work was supported by the Center for Indoor Air Research with Dr. Lynn Kosak-Channing as Project Monitor. The authors would like to acknowledge the assistance provided by Robert Van Beccelaere of Ruskin.

REFERENCES