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Extend Economizer Operations for AHUs and Improve Ventilation with Effective Mixing

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Abstract

The importance of outdoor air ventilation continues to increase for building operators, facility managers, and other stakeholders who are responsible for the health and comfort of building occupants. There have been several studies showing increased ventilation may promote better health and a safer work environment. According to the “ASHRAE Position Document on Infectious Aerosols” in April 2020, infectious diseases can be transmitted through aerosols and HVAC systems can have an impact on the transmission routes of the disease (ASHRAE, April 2020). Generally speaking, ASHRAE suggests building designs that achieve higher ventilation rates may reduce risk from infectious aerosols.

Since the COVID-19 outbreak, numerous organizations including the World Health Organization (WHO), Centers for Disease Control and Prevention (CDC), and Occupational Safety and Health Administration (OSHA) have released guidelines for businesses and employers aimed to maintain a healthy work environment. Common amongst these guidelines is the value of increasing ventilation rates and effective dilution ventilation per occupant. The CDC and ASHRAE have recommended opening the outdoor air dampers to increase ventilation rates, however this may pose operational problems for certain air handling units (AHU) especially in cold weather environments. According to the “Guidance for Building Operations during the COVID-19 Pandemic” released in the May 2020 ASHRAE Journal, further opening the minimum outdoor air dampers increases the effective dilution ventilation per person, “but clearly becomes more difficult in extreme weather” (Schoen, L. May 2020). If the outdoor airstream is not well-mixed, there is potential for significant air stratification inside an AHU which can lead to increased operating costs (e.g., unnecessary heating/cooling operation) and nuisance freeze stat trips shutting down the AHU. Maintaining required ventilation rates will be vital for building operators to minimize the risk of transmitting infectious diseases and realizing all the benefits of improved indoor air quality.

The benefits of integrating air mixing technologies into an AHU mixing box or economizer section or as a section downstream are summarized herein.

Stratification exists inside many AHUs

AHUs are used to condition air in climate-controlled interior spaces. The fans in AHUs are often used to draw in outdoor air to provide mechanical ventilation to the interior space. Maintaining proper ventilation rates provides a myriad of benefits and reduces the risk of infectious aerosols mentioned in the Abstract. Ventilation controls indoor contaminants and maintains oxygen levels improving the health and productivity of building occupants. Maintaining these ventilation rates when outdoor air temperatures fall below 32°F can be problematic as poor mixing often exists inside the mixing box or economizer section of an AHU leading to temperature stratification.

In the February 2020 ASHRAE Journal, air and temperature stratification inside an AHU is highlighted in an engineering article, “Why Don’t Mixing Boxes Mix and What Should We Do About it? (Cramm, K. February 2020). This article shed’s light into an all-too-common misconception that “mixing boxes provide effective mixing”. In this article we’ll explain in more detail why traditional mixing boxes fail to eliminate temperature stratification and provide a more in depth look at commercially available mixing technologies and field fixes to eliminate temperature stratification.

Why Mixing Boxes Fail to Mix

A common rule used by design engineers believed to promote better mixing is to introduce the OA in the top of the mixing box, and the RA in the back of the mixing box. This theory assumes the warmer less dense RA will rise through the colder denser OA and enhance mixing. In addition, AHU manufacturer’s application data recommend directing parallel blade OA and RA dampers toward each other in the mixing box to promote collisions and further enhance mixing.

In the example shown in **Figure 1** below, a CFD analysis of this arrangement fails to eliminate the temperature stratification at the face of the air filters downstream of the mixing box. In the analysis it is identified that the velocity of the airstream is too high for the buoyancy of the RA stream to have material impact on inducing effective mixing. To help explain this, consider the operating conditions used in the CFD analysis below. The velocity in the AHU plenum shown in **Figure 1** is nominally 411 fpm and the plenum length in the mixing section is 54”. The nominal residence time for the air inside the mixing box is approximately 0.68 seconds assuming a uniform flow field inside the mixing box. The impact from the buoyancy forces is significantly minimal to overcome the rate at which the air is moving.

What about directing the different airstreams toward each other and promoting collisions as the air exits the parallel blade dampers inside the mixing box? In the analysis, the air velocity in the duct and through the dampers is significantly higher than the air velocity in the plenum. As the air leaves the dampers and enters the plenum the air is significantly deaccelerating going from 1200+ fpm to 411 fpm. Under these conditions, the air stream has low density and lacks momentum to promote “collisions” which in turn reduces the potential for effective mixing and lack of heat transfer from one air stream to another. In addition, the “draw” of the supply air fans to maintain the velocity in the AHU plenum is “pulling” the air downstream resulting in air stratification and further reducing the potential for turbulence and/or mixing.

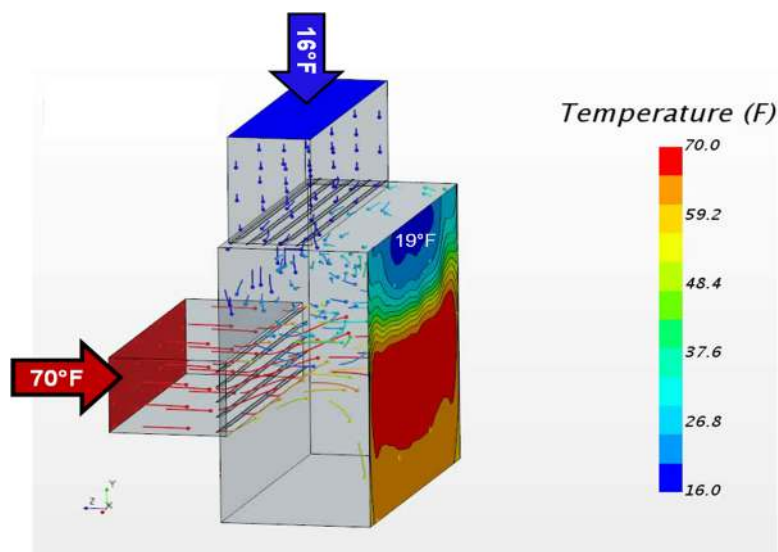


Figure 1. CFD Simulations Showing Temperature Stratification inside Mixing Box of AHU

It is not to say that mixing boxes do not mix at all. They do mix, but it is a relative term. In fact, the basic logic outlined above is correct and this arrangement mixes better than other damper arrangements in mixing boxes. In the article, “Why Don’t Mixing Boxes Mix and What Should We Do About it? (Cramm, K. February 2020) mixing boxes and stationary mixers are referenced and the author suggests, “the industry needs a standard method for testing and rating the performance of these devices.

Blender Products has spent many years researching various methods for rating performance of a mixing box and stationary mixing devices “static mixers”. The term Mixing Effectiveness (ME) was introduced (Robinson, K., Blender Products, February 2000) as a means to rate or compare any AHUs mixing box/economizer section and/or static mixer construction in its ability to reduce the temperature difference between the OA and RA entering the mixing box for given volumes of OA and RA flowing through the dampers. Reference the equation shown below:

$$ME (\%) = \left(1 - \frac{T_{max} - T_{min}}{T_{ra} - T_{oa}} \right) * 100$$

ME: Mixing Effectiveness (Indicates how much a mixing device reduces the temperature range)

T_{max}: Maximum temperature measured at outlet section of mixing device(s) (°F/°C)

T_{min}: Minimum temperature measured at outlet section of mixing device(s) (°F/°C)

T_{ra}: Temperature of return air entering RA dampers of AHU (°F/°C)

T_{oa}: Temperature of outdoor air entering OA dampers of AHU (°F/°C)

The flow dynamics of the geometry and properties of the air streams determine the temperature difference (T_{max}-T_{min}) at a downstream plane in the plenum (typically the face of the filters). While ME% will provide a relative comparison between two different geometries for given flow conditions, the method of test/evaluation (whether empirical or using CFD) to determine the temperature difference at the downstream plane must be identical for the relative comparison to be of value.

The ME% in our example shown in **Figure 1** above is calculated as 6% which yields significant temperature stratification as the air exits the mixing box. In the evaluation of hundreds of mixing box arrangements, analysis has shown that most mixing boxes range from 6-20% ME @ 50% OA without other measures taken to enhance mixing.

Lower Operating Costs by Extending Economizer Operations

AHUs using airside economizers to combine the correct balance of outside and return air have been around for years, operating in a wide range of climates and facilities. The primary benefit of airside economizer systems is the use of outside air to satisfy the building cooling requirements without the use of mechanical cooling, thereby realizing significant energy savings. Unfortunately, economizer operations are frequently abandoned in cold weather climates due to poor mixing inside the AHU and this results in temperature stratification and potential to cause damage to downstream coil sections. This can adversely affect Indoor Air Quality and lead to increased operating costs for building operators.

As utility costs rise, building operators are seeking solutions to maintain HVAC operations while monitoring indoor air quality, thermal comfort, and peak energy usage. **Figure 2** below shows the annual operating cost savings potential assuming the building operator was able to maximize the use of

airside economizing without prematurely abandoning this operation due to low temperature alarms. Operating data from the AHU used in **Figure 1** above was used to calculate the annual operating cost savings for three different locations as a function of the blended electricity rates used from various utility tariffs.

- Supply Airflow: 44,000 CFM
- Min Outdoor Airflow Requirement: 11,000 CFM (25%)

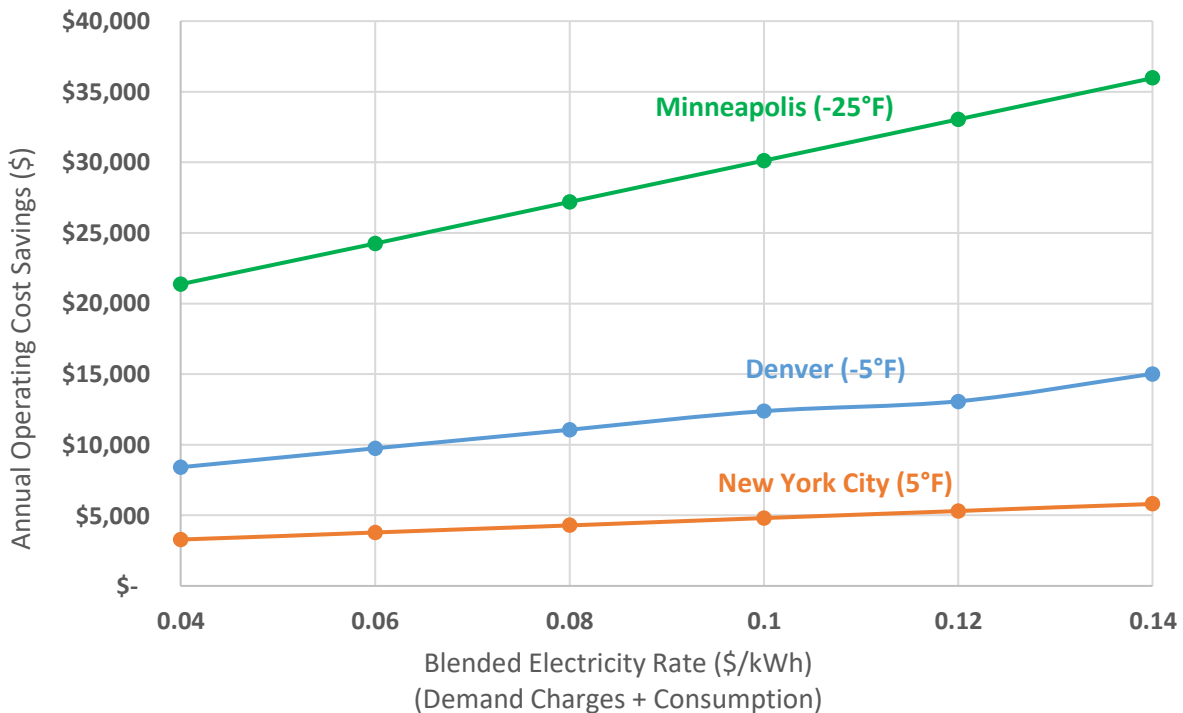


Figure 2. Annual Operating Cost Savings Potential for AHU (44,000 CFM/25% Min. OA) by Location

Air Mixing Technologies:

We have demonstrated that even the best mixing box designs with dampers in the walls of the mixing box fail to provide enough mixing to protect the AHU from freeze stat trips, unit shut-downs, and potentially frozen coils. We have also demonstrated that many field “work arounds” include taking risks with the health and safety of building occupants may result in increased operating costs. Only proper mixing of RA and OA can directly address the root cause of air and temperature stratification inside an AHU. Mixing device solutions to address stratification problems have ranged from trial-and-error field fixes to commercially available tested and proven solutions with specific application guidelines. We will look at three categories of mixing:

1. **Obstruction Mixers:** These are often referred to as baffle plates, internal walls, perforated walls/plates, etc. They are typically positioned in the mixing box to force the two airstreams into a restricted path that will force closer proximity of the two air streams and improve heat transfer from the RA to OA. These are commonly used as field fixes where there is limited distance available to apply other mixing devices. To be effective they usually create a significant amount of pressure drop and often cause air mass distribution issues which can result in uneven loading for downstream components. However, with the pressure drop high enough to be effective they generally require relatively little downstream distance compared to static mixers.

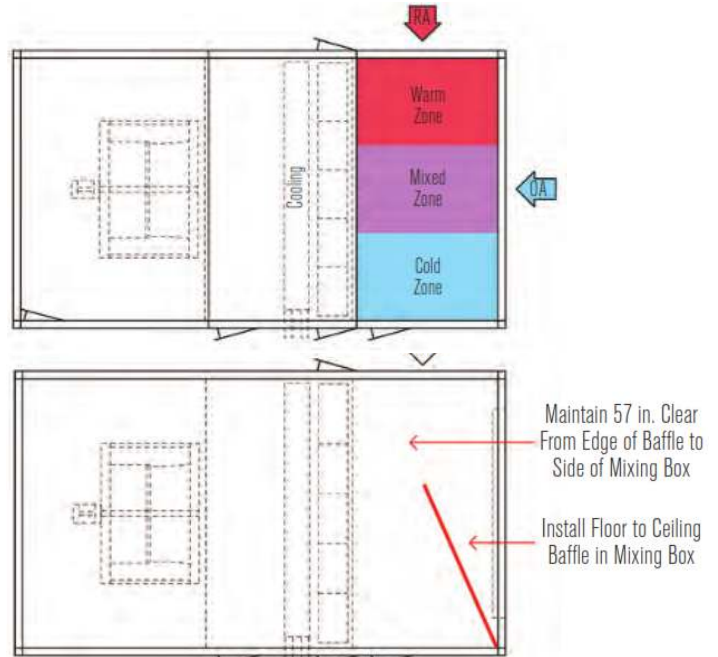


Figure 3. Example Sheet Metal Baffle in Mixing Box

Source: ASHRAE, Feb. 2020 (Cramm, K.)

2. **Static Mixers (Series IV Air Blender®):** Unlike baffle plates these devices are engineered and tested to provide predicted performance. The Air Blender® mixing products are applied at the end of or just downstream of the mixing box. They typically use turning vanes and are applied so there are proportional amounts of OA and RA entering each mixer(s). The turning vanes mix the air downstream of the device accelerating heat transfer from RA to OA. Based on air velocity, temperature difference between RA and OA, and relative volumes of the two air streams; a certain distance downstream of the mixer(s) is required for enough heat transfer to make sure freeze stat trips are eliminated.

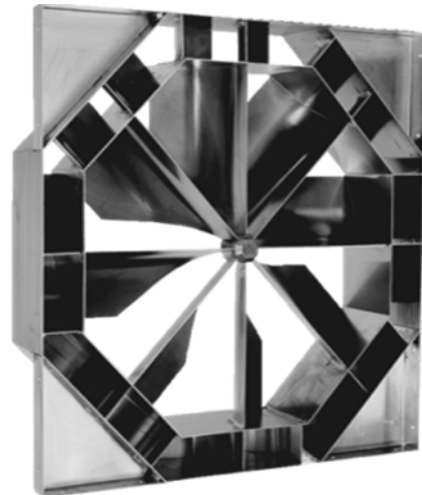
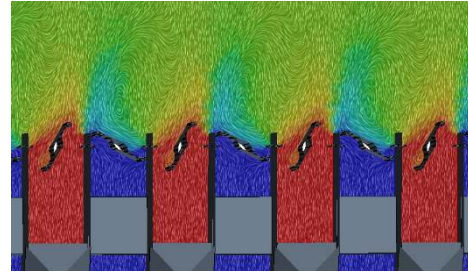
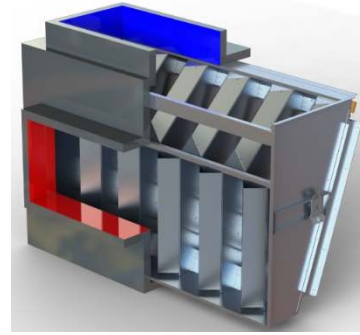


Figure 4. Series IV Air Blender

3. **Channel Blender:** In 2018, a new technology was introduced into the HVAC marketplace that is designed to provide effective mixing without the need for additional footprint. The Channel Blender provides a new means of combatting stratification and enhancing uniformity by integrating damper control into a device that produces alternating “channels” of air and promotes mixing in a short distance. These mixing devices are custom designed to be integrated inside the existing mixing box or economizer section of an AHU. Below is a summary of how integrating OA and RA dampers into a mixing device works:

- 1) Outdoor air and return air enter a standard mixing box through designated openings. The mixing device is installed to align with these openings. Each air stream flows into the corresponding compartment inside the mixing device.
- 2) Outdoor air and return air flow into adjacent channels, so there are alternating slices of outdoor air and return air flowing towards the dampers located on the discharge side of the mixing device.
- 3) The dampers are used to promote mixing zones immediately downstream of the dampers and this provides a smaller temperature gradient approximately 8" – 12" downstream.



By integrating the OA and RA control dampers into single module, the Channel Blender is engineered to

increase the coldest temperature in the plenum to eliminate freeze stat trips, protect coils, and provide a more uniform flow pattern to other sections of the AHU. Since the Channel Blender is focused on the coldest temperature and not the general mixing of all the air in the plenum, a new term for defining mixing effectiveness was developed – **Freeze Protection Effectiveness (FPE)**. The FPE is shown below:

$$FPE (\%) = \left(1 - \frac{T_{mix} - T_{min}}{T_{mix} - T_{oa}} \right) * 100$$

FPE: Freeze Protection Effectiveness

T_{mix}: Mixed air temperature (°F/°C)

T_{min}: Minimum temperature measured at outlet section of mixing device (°F/°C)

T_{oa}: Temperature of outdoor air (°F/°C)



Figure 5. Channel Blender to be installed inside a Mixing Box

Recall the air stratification present inside the mixing box as shown in **Figure 1** above. This AHU had a Supply Airflow requirement of 44,000 CFM and the CFD simulation below shows economizer operation at 25% Outdoor Air with dry bulb ambient temperature of 16°F. By integrating the Channel Blender inside the mixing box, the FPE increased from 9% (without mixer) to 77%.

Installing the Channel Blender inside the same mixing box raises the minimum temperature from 19°F to 46°F and provides a smaller temperature gradient at the exit of the mixing box. This new mixing technology does not require additional tunnel length to provide effective air mixing. It's worth noting, there is no compromise in functionality or control of the OA & RA damper sections. At a supply airflow of 44,000 CFM and 25% OA, the pressure-drop to the system increased by 0.26" wc with the Channel Blender in operation.

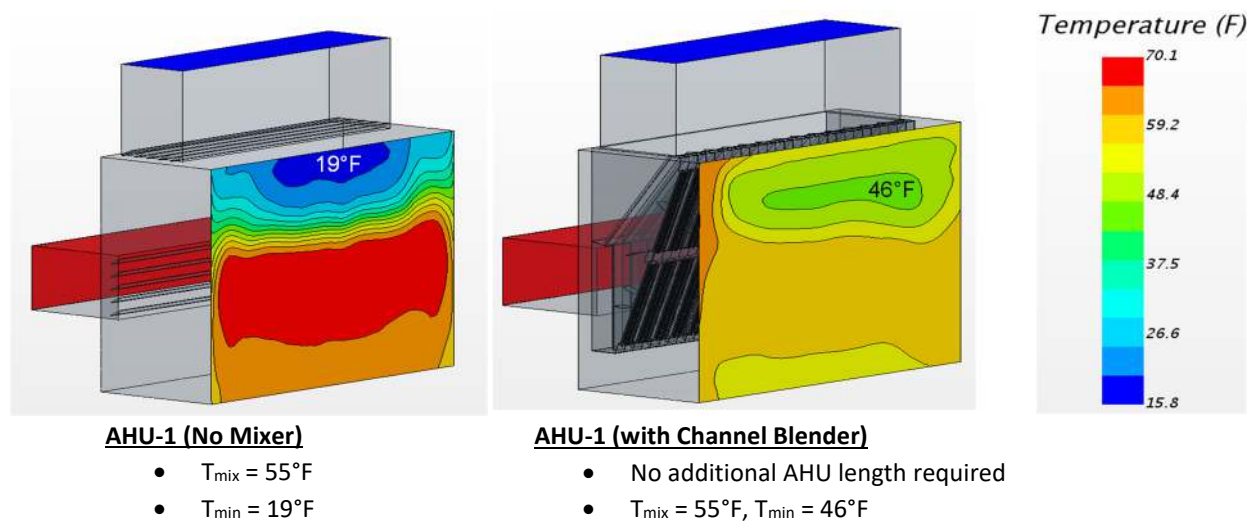


Figure 6. Comparison of Mixing Performance inside AHU (SA = 44,000 CFM, OA = 25%)

St. Peter's Health Partners – St. Peter's Hospital Case Study

Located in Albany, NY, St. Peter's Hospital had two AHUs with significant air stratification leaving the mixing box resulting in uneven coil loading and poor humidity control for areas inside the hospital. The stratification problem also resulted in numerous freeze stat alarms and challenged building operators to maintain proper ventilation requirements. The challenge was to eliminate freeze stat trips, reduce air stratification, and maintain 30% minimum OA air flow requirements during cold weather events without increasing AHU tunnel length.

Traditional mixing technologies (e.g., Air Blenders®) would have increased the tunnel length by over 80". It's worth noting, the AHUs were modified to include three industrial fans designed to promote better distribution of OA upstream of the filter section and help address uneven loading to the coil section. Even with the fans installed, the hospital continued to experience poor humidity control and freeze stat alarms.

Given the ability to improve mixing without the additional tunnel length, the project team retrofitted the existing AHUs by integrating a custom designed Channel Blender to promote effective air mixing inside the existing mixing box section for each AHU. Summary data for each AHU is provided below:

- Supply Airflow: 44,000 CFM
- Min. OA Airflow: 13,200 CFM (30% Min. OA)
- Mixing Box Dimensions: 102”H x 147”W x 18”D
- OA Design Temp: -5°F

Installation of the Channel Blender was completed in October 2019 and the facilities staff were able to operate both AHUs during the winter season without a single freeze stat trip during normal operations.

Using ASHRAE BIN data for Albany, NY, an energy analysis was performed to quantify the number of extended economizing hours the Channel Blender would provide due to the increased mixing and raising the minimum temperature above a freeze stat threshold. For the subject AHUs at St. Peters Hospital, this retrofit provides an estimated 2,124 hours of extended economizing hours annually as shown below in

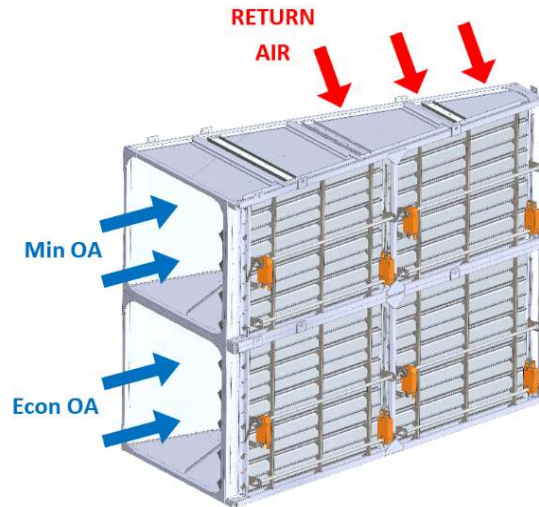


Figure 7. Custom Channel Blender Installed at St. Peter’s Hospital

Figure 8. Extending economizer operations when the OA temperatures range between 15°F to 30°F results in significant energy savings. When considering the equipment cost of the Channel Blender relative to the energy savings potential, **simple payback for the equipment installed was approximately 1.9 years.**

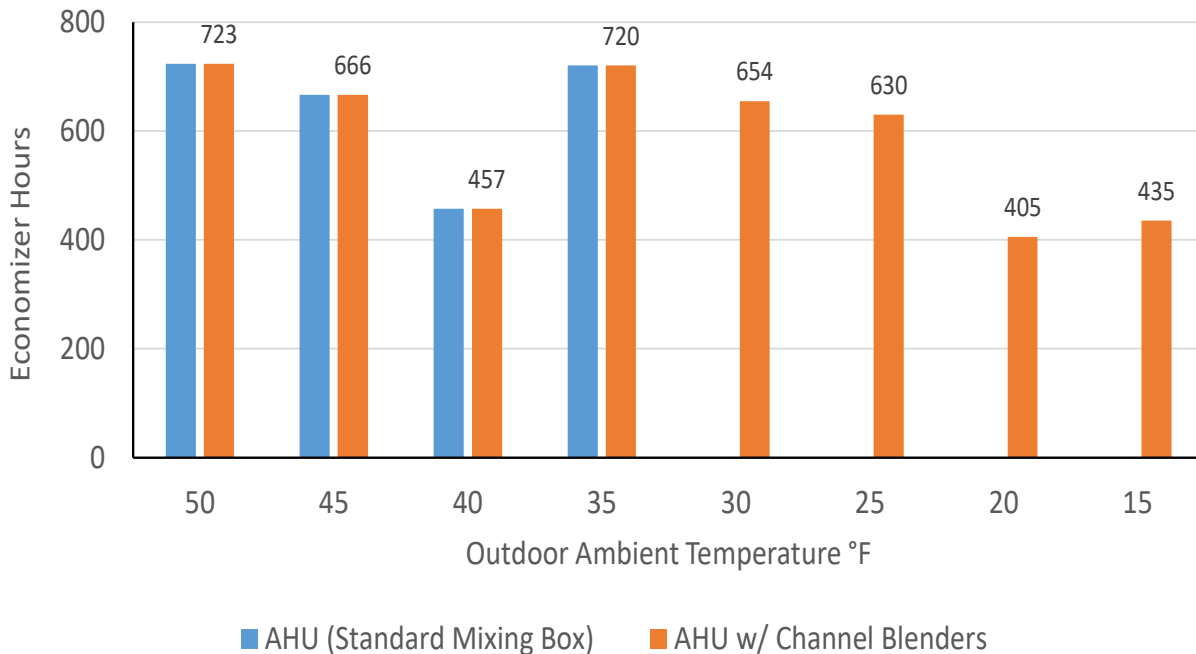


Figure 8. Extended Economizer Hours at St. Peters Hospital due to Increased Mixing Performance

Conclusions

Since the COVID-19 outbreak, the CDC and ASHRAE have recommended further opening the outdoor air dampers for AHUs for increasing ventilation rates aimed to maintain a healthy work environment. Adhering to proper ventilation rates in cold weather environments when the outdoor air temperature is below 32°F can be problematic when the OA% is high and poor mixing exists inside the mixing box or economizer section of an AHU. The cold outdoor air can lead to nuisance freeze stat trips and higher operating costs for building operators. Reducing the amount of air stratification inside the AHU can provide a myriad of operational benefits for building owners and operators.

To help combat stratification inside AHUs, there are several options to consider:

- Combine air streams inside the ductwork upstream of the AHU,
- If space restrictions exist, consider integrating the Channel Blender technology that promotes effective mixing in a short distance and promotes uniformity for downstream components inside the AHU,
- If space is available, install a static mixing device and allow for proper downstream mixing distance as recommended by technology providers,
- To help quantify air stratification inside a mixing box/economizer section, consider performing a series of CFD simulations at various operating conditions.

Increasing the economizer duration of an AHU can provide significant energy savings to building operators. **Payback periods to implement an effective mixing solution are project specific and can vary based on several factors: ventilation rates, energy costs, and design conditions.** In general, extending economizer operations in northern climates reduces the payback period to implement an effective mixing strategy and optimize performance for downstream components inside an AHU.

References

- 1) ASHRAE, HVAC Systems and Equipment, Chapter 27 – Sec. 2
- 2) Cramm, Kelley, “Why Don’t Mixing Boxes Mix and What Should We do About it?”, ASHRAE Journal, February 2020
- 3) ASHRAE Position Document on Infectious Aerosols - April 14, 2020
- 4) Schoen, Lawrence J., “Guidance for Building Operations During the COVID-19 Pandemic” ASHRAE Journal May 2020
- 5) Robinson, Keith D., “Rating Air Mixing Equipment” ASHRAE Journal February 2000
- 6) 2019 ASHRAE Handbook (HVAC Applications – Chapter 9 Health Care Facilities)