

Building Re-Tuning Training Guide: Air-Side Economizer Operation

Summary

The purpose of the air-side economizer control guide is to show, through use of examples of good and bad operation, how air-side economizers should be utilized and efficiently controlled.

An air-side economizer is a duct/damper arrangement in an air-handling unit (AHU) along with automatic controls that allow an AHU to use outdoor-air to reduce or eliminate the need for mechanical cooling. When there is a need for cooling and if the outdoor-air conditions are favorable for economizing (outdoor-air temperature is less than return-air temperature), unconditioned outdoor-air can be used to meet all of the cooling energy needs or supplement mechanical cooling. In a properly configured economizer control sequence, the outdoor-, return- and exhaust-air dampers sequence together to mix and balance the air-flow streams to meet the AHU discharge-air temperature set point.

In humid climates, the use of dry-bulb temperature based economizers is not recommended. However, if used, the outdoor-air temperature should be 5 to 10°F lower than the return-air temperature. There are times when economizing should not be used. This includes during building warm-up periods and cool-down periods, when the outdoor conditions are not favorable for economizing, or during unoccupied periods, when the supply fan is operating (unless introduction of outdoor-air is advantageous to the unoccupied or cool-down period).

When an economizer is not controlled correctly, it may go unnoticed because mechanical cooling will compensate to maintain the discharge-air at the desired discharge-air set point. This may include periods of time where too much outdoor-air is being introduced to the AHU (when the economizer control is attempting to maintain a minimum outdoor-air set point) or when there is not enough outdoor-air being introduced to the AHU (when the economizer control is attempting to bring in the maximum amount of outdoor-air). Failure to correct/mitigate this situation, in all likelihood, will lead to increased fan, cooling and heating energy consumption.

Data need to verify the air-side economizer control

To analyze and detect deficiencies in economizer operation and control, for single-duct variable-air-volume (SDVAV) AHU(s), the following parameters must be monitored using the trending capabilities of the building automation system (BAS):

- Outdoor-air temperature (OAT)

- Mixed-air temperature (MAT)
- Discharge-air temperature and set point (DAT and DATSP)
- Return-air temperature (RAT)
- Outdoor-air damper position signal (OAD)
- Cooling-coil-valve signal (CCV)
- Outdoor-air fraction (OAF).

In most BASs, the outdoor-air fraction is probably not computed and trended. If OAF is not recorded in the BAS, it can be computed externally using the outdoor-, return- and mixed-air temperatures:

$$\text{OAF} = \frac{(\text{MAT} - \text{RAT})}{(\text{OAT} - \text{RAT})}$$

The recommended frequency of data collection is between 5- and 30-minutes. When analyzing the air-side economizer operation, the trends to look for include:

- How close is the outdoor-air fraction compared to the outdoor-air damper position signal?
- Is the minimum outdoor-air damper position reasonable (between 10% and 20%)?
- Is the outdoor-air damper open when outdoor conditions are not favorable (outdoor-air temperature > return-air temperature)?
- Is the outdoor-air damper closed or at minimum position when outdoor conditions are favorable for economizing and the AHU is in cooling mode?
- Does the cooling coil operate during economizer mode?
- Does the cooling coil operate when the outdoor-air temperature is lower than the discharge-air temperature set point?
- When the cooling coil is open, is the outdoor-air damper fully open, if the conditions are favorable for economizing?
- Do outdoor-air dampers close to minimum position for freeze protection?
- Is the mixed-air temperature between the outdoor-air and return-air temperatures?

- When conditions are not favorable for economizing, is the mixed-air temperature closer to return-air or outdoor-air?
- When conditions are favorable for economizing, is the mixed-air temperature closer to outdoor-air or return-air?

In addition, the last section of this guide will discuss various economizer sequencing options and their limitations.

How close is the outdoor-air fraction compared to the outdoor-air damper position signal?

In most cases, there will be significant differences between the OAF and OAD, especially at low OAD values. Therefore, using OAD values can be misleading because it does not reflect the true outdoor-air intake.

The calculated OAF should only be used to investigate the true percent of outdoor-air entering the AHU when the outdoor-air temperature is significantly ($\pm 5^{\circ}\text{F}$) different than the return-air temperature. As these two temperatures get close to each other, the OAF calculation may not be accurate. Review the plot of outdoor-, return-, and mixed-air temperatures, outdoor-air damper position signal, and outdoor-air fraction vs. time to determine the right time to compare the calculated OAF to the outdoor-air damper position signal. Figure 1 below shows this plot for 1 day.

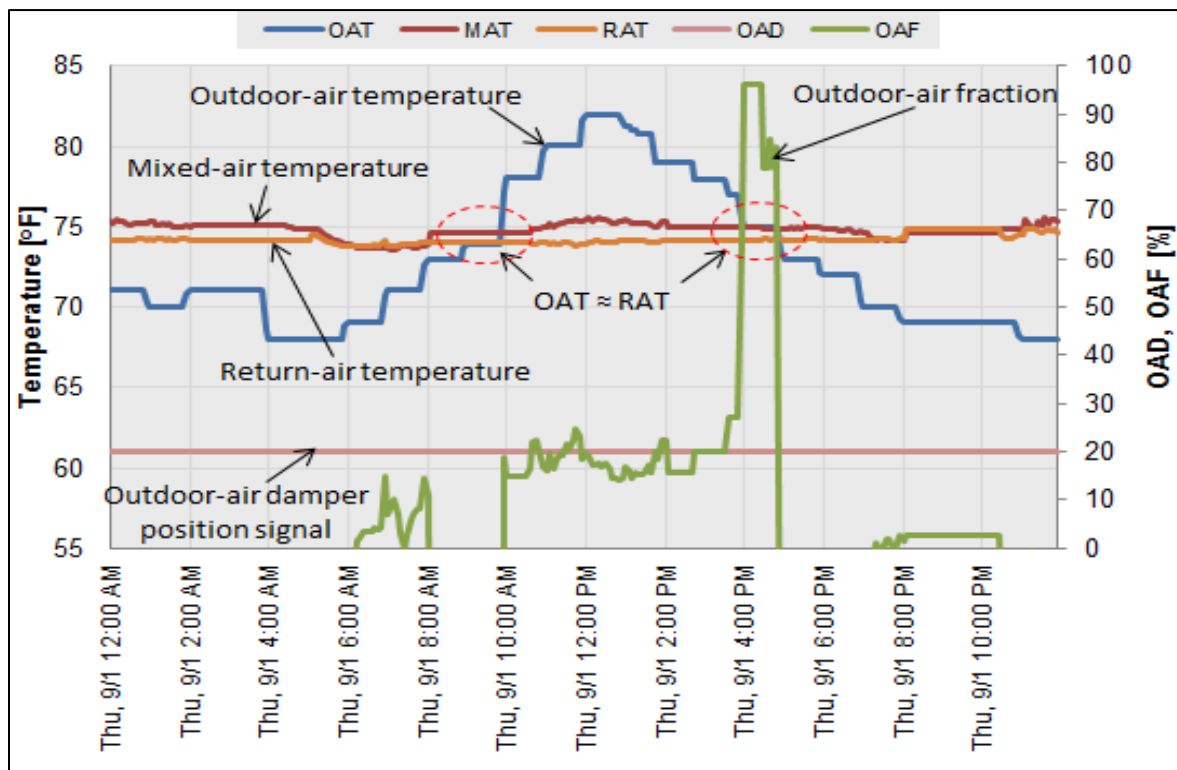


Figure 1: Determining the accuracy of outdoor-air damper position signal by comparing it to the outdoor-air fraction during times when the outdoor-air temperature is significantly different than the return-air temperature. In this case, the OAF calculation becomes unrealistic around 10:00 AM and 4:00 PM.

From Figure 1, the best time to compare the OAF to the OAD is between 10:00 AM and 4:00 PM. You can see that the OAF covers the OAD quite accurately at about 20% outdoor-air. This is good operation for this case because the AHU is bringing in the minimum amount of outdoor-air when the OAT is greater than the RAT. However, if the calculated OAF deviates from the actual outdoor-air damper position by more than 50%, it may be an opportunity to alert someone to investigate the economizer system.

Suggested Actions

If the calculated OAF isn't automatically calculated in the BAS, it should be added and tracked for all AHU(s).

Is the minimum outdoor-air damper position signal reasonable (between 10% and 20%)?

To meet the ventilation requirements, the AHU must provide a certain amount of fresh air when the building is occupied. The ventilation requirements are determined at the design stage based on the zone occupancy and other parameters. The ventilation requirements are then translated into the outdoor-air damper opening, which is generally referred to as the minimum damper position to meet ventilation requirements. Typically, the minimum damper position is between 10% and 20%. Check the minimum damper position by reviewing the plot of outdoor-air temperature and outdoor-air damper position signal vs. time. Figure 2 below shows these trends for a 2-day period in which the outdoor-air temperature varies between 65°F and 80°F. Once the OAF has been added to the BAS, it should be added to the graph to provide additional insights. You can see that the OAF matches the OAD for a period of time at 30%, indicating that 30% outdoor-air is being introduced into the AHU. During this period, the OAT is greater than 70°F, so the AHU should not be in economizing mode. Additionally, the OAD is always 30% open, indicating the possibility of 30% outdoor-air entering the AHU at all times. If the building is not occupied 24/7, then the outdoor-air dampers should be closed during unoccupied times and building warm-up or cool-down periods.

The building operator should verify the schedule of this AHU and adjust accordingly. The building operator should revisit the ventilation requirements for the space served by the AHU(s) and ensure that the space is not being over-ventilated with outdoor-air (reduce the minimum outdoor-air damper position signal set point, if possible).

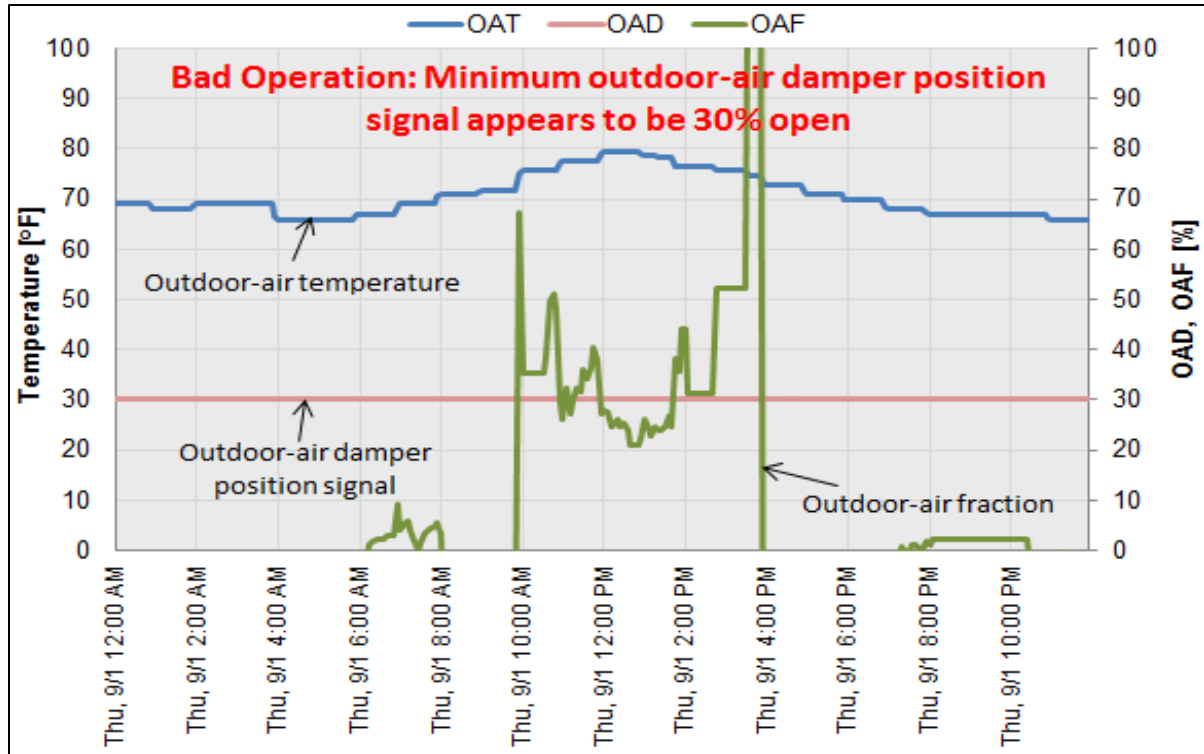


Figure 2: Minimum outdoor-air damper position signal too high (30%).

Suggested Actions

The economizer should always operate during favorable conditions (outdoor-air temperatures between 40°F and 60°F in humid zones and whenever the outdoor-air temperature is lower than the return-air temperature in dry climates) to supplement or eliminate the use of mechanical cooling. Outside of this temperature range, the economizer control should set the outdoor-air damper to the minimum position required to satisfy ventilation requirements. The outdoor-air damper should be locked out to the minimum position for freeze prevention when the outdoor-air temperature is below 40°F, and the outdoor-air dampers should be completely closed if the mixed-air temperature becomes lower than 40°F.

If the minimum damper position is greater than 20%, more outdoor-air may be entering the building than required, and significant additional heating or cooling may be occurring at the AHU to maintain the discharge-air temperature set point. Check ventilation requirements for the spaces served to ensure that the required minimum damper position is properly configured. Also, check to make sure the damper is fully closed during unoccupied hours and during the building warm-up/cool-down periods (unless the outdoor-air temperature is conducive to economizer operations during the cool-down period). The damper should open 30-minutes prior to occupancy to flush the building.

Is the outdoor-air damper open when outdoor-air conditions are not favorable (outdoor-air temperature > return-air temperature)?

If the outdoor-air damper is open above the minimum outdoor-air damper set point to satisfy the ventilation requirements, at temperatures considered unfavorable for economizing, this can be an indicator of poor economizer control, a failed/failing economizer damper actuator, loose linkages, broken damper seals/sections or excess discharge-air static pressure/reduced return-air static pressure. Figure 3 below shows the graph of the outdoor-air damper position signal, outdoor-air temperature and return-air temperature versus time for a 2-day period. The outdoor-air temperature varies between 60°F and 85°F. From the graph, the outdoor-air damper opens up to 100% at 6:00 AM both days, and stays open at 100% until 11:00 PM. During this time, the outdoor-air temperature increases to over 80°F (which is greater than the return-air) for the majority of the afternoon. This could be an indicator that the economizer controls have failed, or that the damper is overridden to be fully open during the occupied period. To understand the impacts of a damper open 100% during high outdoor-air temperature conditions, review the plot of outdoor-air damper position signal and cooling coil valve signal versus time. Figure 4 shows the same 2-day period, and you can see a strong correlation between the outdoor-air damper position signal and the cooling coil valve signal. As the outdoor-air damper goes to 100% open, the cooling-coil-valve opens between 40% and 60% to maintain the discharge-air temperature set point.

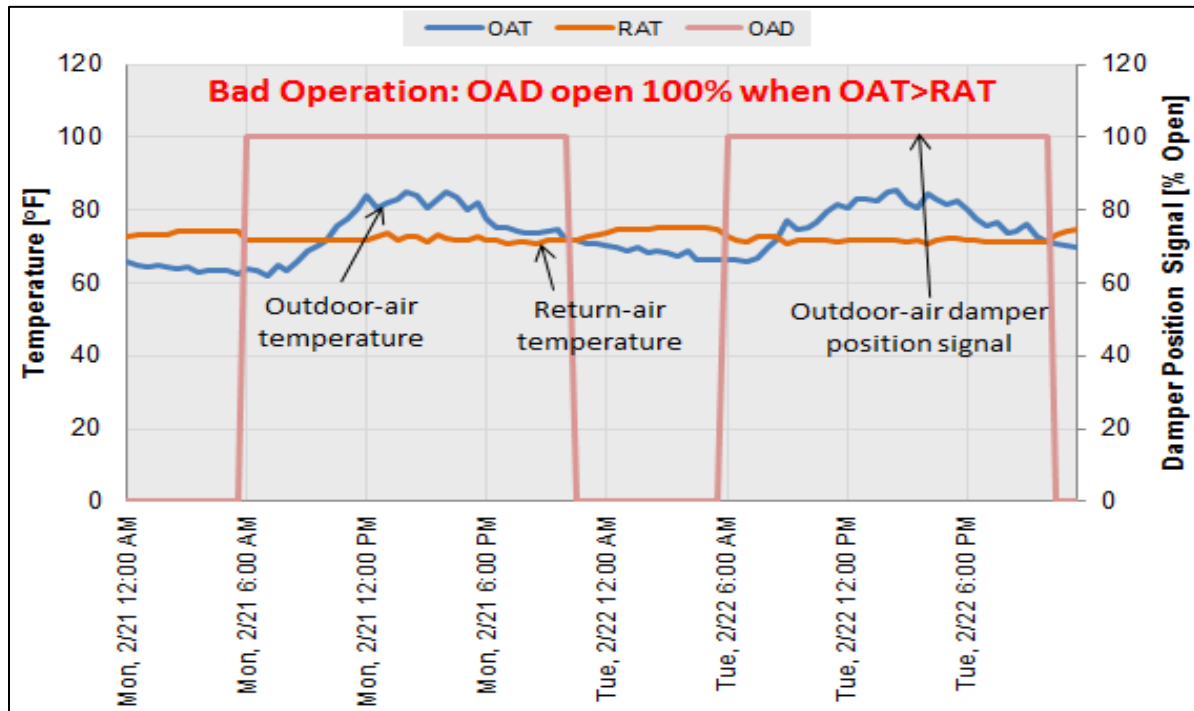


Figure 3: Outdoor-air damper letting in too much outdoor-air when conditions are not favorable for economizing.

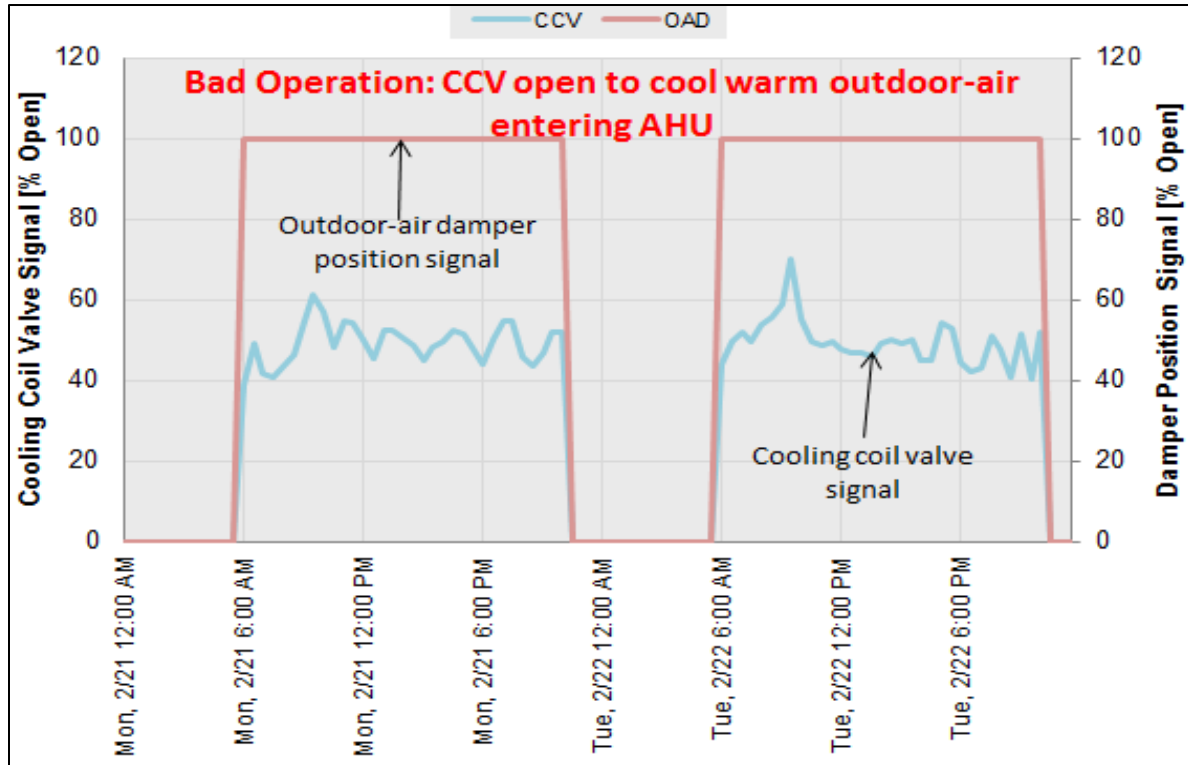


Figure 4: Comparison of cooling coil valve and outdoor-air damper position signals.

Suggested Actions

If the outdoor-air damper position signal is greater than the minimum outdoor-air damper position signal specified in the control logic during periods when the outdoor conditions are not favorable for economizing, check to make sure that the outdoor-air damper is commanded to the minimum position. If the outdoor-air damper position is set to the minimum, but the OAF is 100%, check to see if something is obstructing the outdoor-air damper from closing or if the damper actuator has failed. Remove anything obstructing the outdoor-air damper, or have any broken parts replaced as soon as possible. When finished, command the outdoor-air damper fully closed, fully open, and to the minimum position, and make sure the outdoor-air damper is responding correctly at each position specified in the control sequences.

Is the outdoor-air damper closed or at minimum position when outdoor conditions are favorable for economizing and the AHU is in cooling mode?

For most climates, when the outdoor-air temperature is less than the return-air temperature and the AHU is in cooling mode, it is favorable to economize. When the outdoor conditions are favorable to economize, the outdoor-air damper should always open first for cooling before mechanical cooling is activated. If the mixed-air temperature is higher than the discharge-air temperature set point with the outdoor-air damper fully open, mechanical cooling can be used

to supplement free cooling. Figure 5 below shows the plot of the outdoor-air damper position signal and outdoor-air temperature vs. time. This plot is for a Friday where the outdoor-air temperature varies between 38°F and 50°F. The outdoor conditions are favorable for economizing, and it appears that the outdoor-air damper position signal is only open to the minimum of 15%. This cannot be classified as bad operation, however, until further investigation is done. It is possible that the cooling load is being fully satisfied by the outdoor-air with the damper at 15% open.

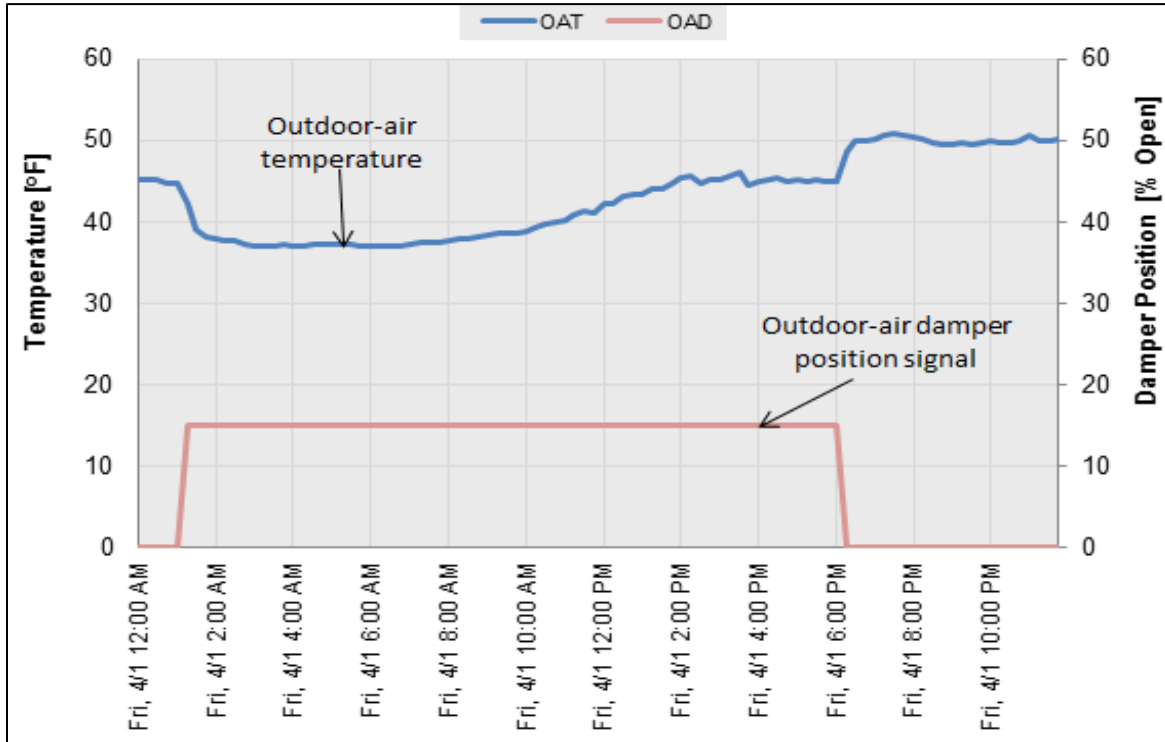


Figure 5: Outdoor-air damper position signal at minimum position during favorable economizing conditions.

To determine if the economizer is working properly in this situation review the chart of outdoor-, return-, mixed-, and discharge-air temperatures vs. time (Figure 6). For the Friday highlighted in Figure 5, the mixed-air temperature should nearly equal the discharge-air temperature. If the mixed-air temperature is higher than the discharge-air temperature, then additional (mechanical) cooling is occurring at the AHU to meet the discharge-air temperature set point.

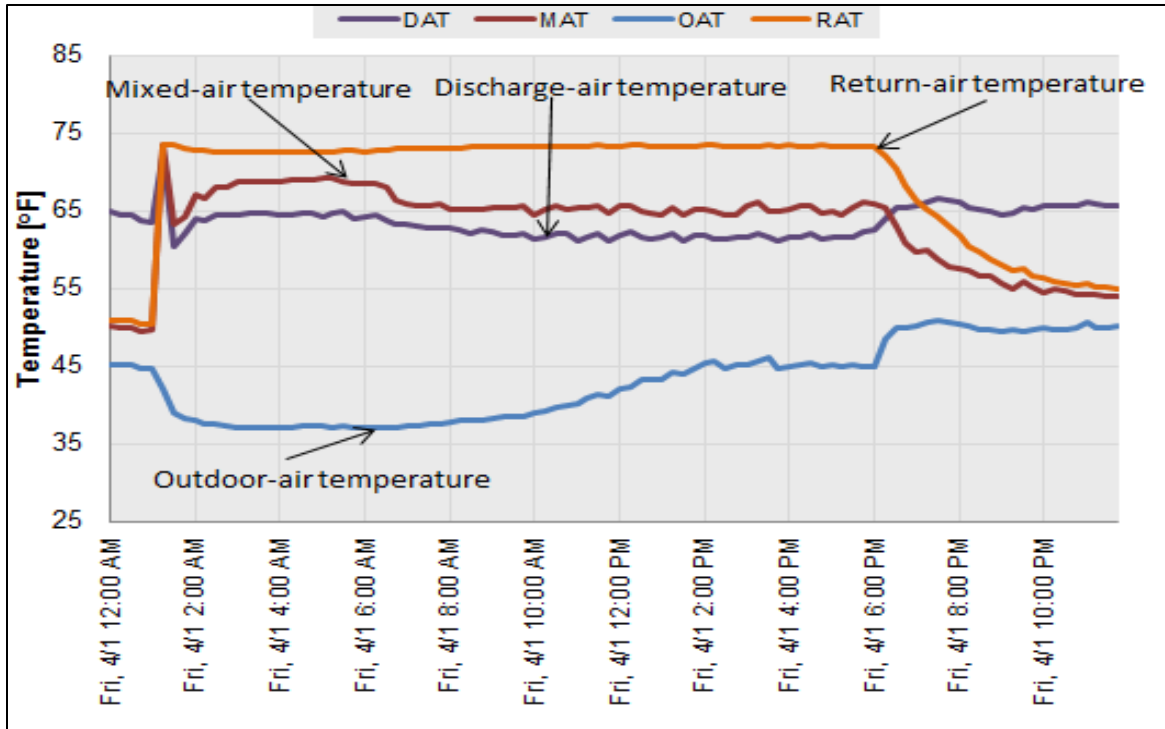


Figure 6: Mixed-air temperature is not cool enough to meet discharge set point from economizing only.

The chart in Figure 6 reveals that the mixed-air temperature is always 3 to 5°F warmer than the discharge-air temperature, indicating that mechanical cooling is occurring to meet the discharge-air temperature set point for this AHU. Because the outdoor-air damper is at the minimum position, energy is being wasted. It is possible that the outdoor-air damper is overridden to the minimum position in the BAS, or that there is poor economizer control operation. If this economizer were working properly, the outdoor-air damper would modulate accordingly to ensure that the mixed-air and discharge-air temperatures were nearly equal. Then, if full economizing were required (outdoor-air damper 100% open), and the mixed-air temperature was still warmer than the discharge-air temperature set point, mechanically cooling would be enabled.

Suggested Actions

If the outdoor-air damper is closed or set to the minimum position when the outdoor conditions are favorable for economizing, check to see if the mixed-air temperature is greater than or equal to the discharge-air temperature in the BAS or review the plot of mixed-, discharge-, return-, and outdoor-air temperatures vs. time. If the mixed-air temperature is warmer, then check to see if the outdoor-air damper is overridden to the minimum position or if the actuator is broken. If the outdoor-air damper is overridden, release the override to allow the outdoor-air damper to operate properly. If broken, fix or replace any necessary parts for the outdoor-air damper system and test the modulating ability by commanding the outdoor-air

damper fully open, fully closed, and to the minimum position. Make sure the outdoor-air damper is responding correctly at each position specified in the control sequences. If the outdoor-air damper was already working fine, then check the controls to make sure that economizing is allowed, and that it is properly implemented.

Does the cooling coil operate during economizer mode?

A cooling coil operating during economizer mode can mean two things: the first is that the economizer is not capable of satisfying the load, so mechanical cooling is required to supplement the free cooling; the second is that the economizer is not functioning correctly. If the outdoor-air damper was stuck open during weather unsuitable for economizing ($OAT > RAT$), the cooling coil must work harder to maintain the discharge-air temperature set point. If the outdoor-air damper is only partially open when outdoor conditions are favorable for economizing, yet the mixed-air temperature is still warmer than the discharge-air temperature, then mechanical cooling will be required to meet the discharge-air temperature set point. See the following section regarding cooling coil operation when the outdoor-air temperature is lower than the discharge-air temperature set point.

Suggested Actions

For outdoor-conditions favorable for economizing, require full economizing (outdoor-air damper open 100%) before mechanical cooling can occur. Make sure the outdoor-air damper is being properly controlled, and responds correctly to commands given in the control.

Does the cooling coil operate when the outdoor-air temperature is lower than the discharge-air temperature set point?

During times when the outdoor-air temperature is less than the discharge-air temperature set point, the economizer should be able to meet the set point without any additional mechanical cooling. The cooling coil should never open under these conditions, and can be a major waste of cooling energy if it does. Figure 7 below is a plot of the cooling coil valve signal, outdoor-air damper position signal, discharge-air temperature set point, and outdoor-air temperature vs. time for a 2-day period. The outdoor-air temperature ranges from 40 to 50°F, while the discharge-air set point is always 55°F. The cooling coil operates at times up to 20% open while the outdoor-air damper position is only open 30%, which is indicative of poor operation. Figure 8 shows a similar 2-day period in which the cooling coil valve is closed and the economizer satisfies the discharge-air temperature set point.

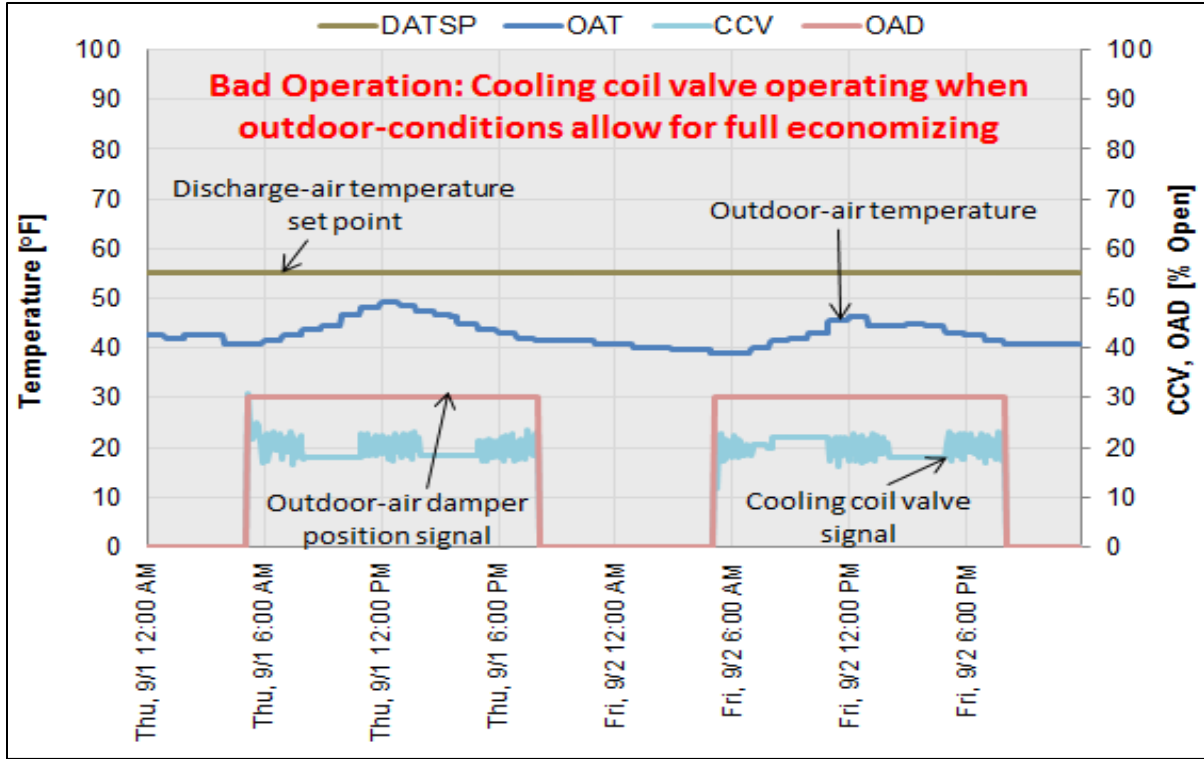


Figure 7: Cooling coil valve opening when outdoor conditions allow for full economizing, wasting cooling energy.

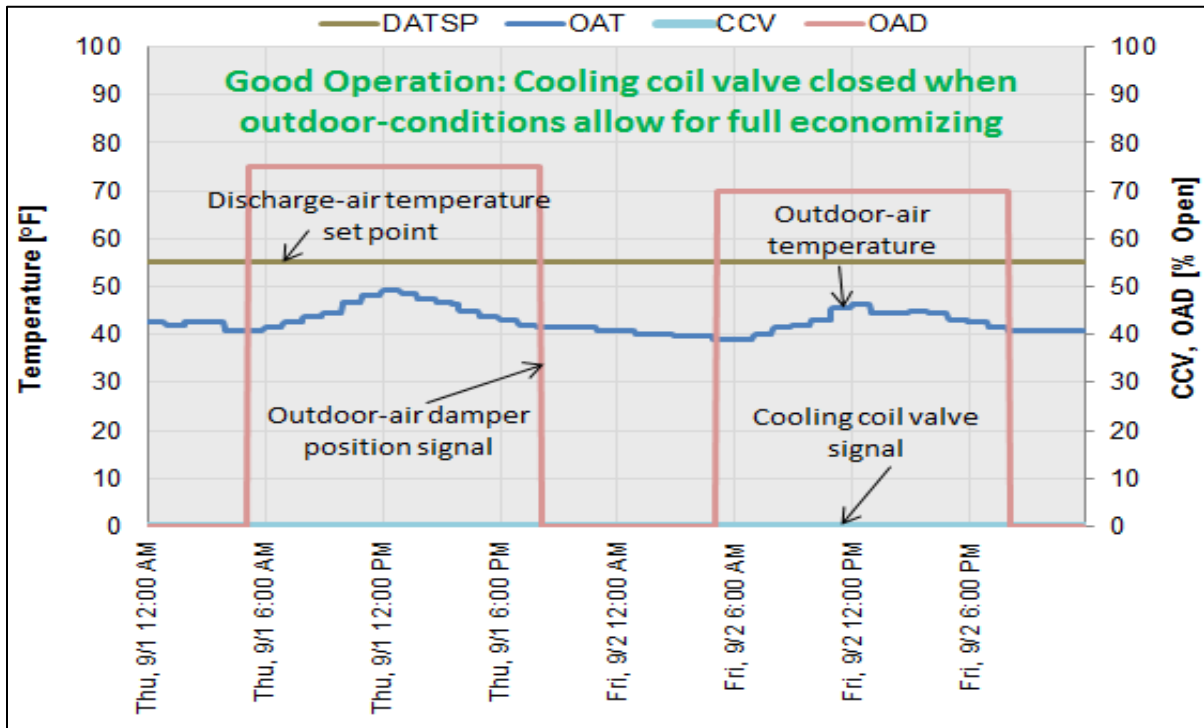


Figure 8: Cooling coil valve closed when outdoor conditions allow for full economizing.

Suggested Actions

For outdoor-conditions favorable for economizing, require full economizing (outdoor-air damper open 100%) before mechanical cooling can occur. Make sure the outdoor-air damper is being properly controlled, and responds correctly to commands given in the control. When the outdoor-air temperature is lower than the discharge-air temperature set point, the cooling coil should remain closed. Economizing can satisfy the load under these conditions.

When the cooling coil is open, is the outdoor-air damper fully open, if the conditions are favorable for economizing?

When conditions are favorable for economizing the outdoor-air damper should always be 100% open before mechanical cooling is enabled. This ensures that free cooling is fully utilized before mechanical cooling is utilized. Figure 9 below is a graph of the cooling coil valve signal, outdoor-air damper position signal, and outdoor-air temperature vs. time for another 2-day period in which the outdoor-air temperature is between 40 and 50°F. The outdoor conditions are great for economizing, yet the outdoor-air damper is only 50% open while the cooling coil operates at 30%. Figure 10 shows an example of good operation, where the cooling coil is open roughly 10% when the outdoor-air damper is open 100%. This indicates that economizing cannot satisfy the load fully, so some mechanical cooling is required.

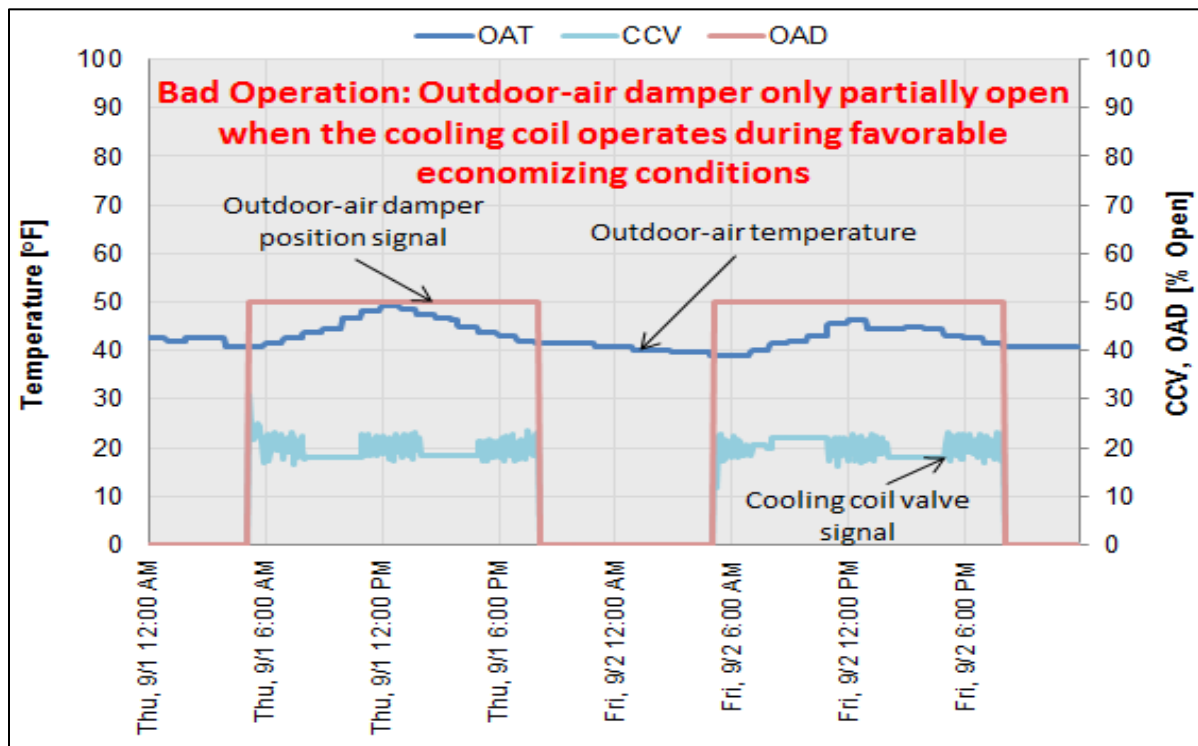


Figure 9: Outdoor conditions favorable for full economizing, yet the cooling coil operates because the outdoor-air damper is not fully open.

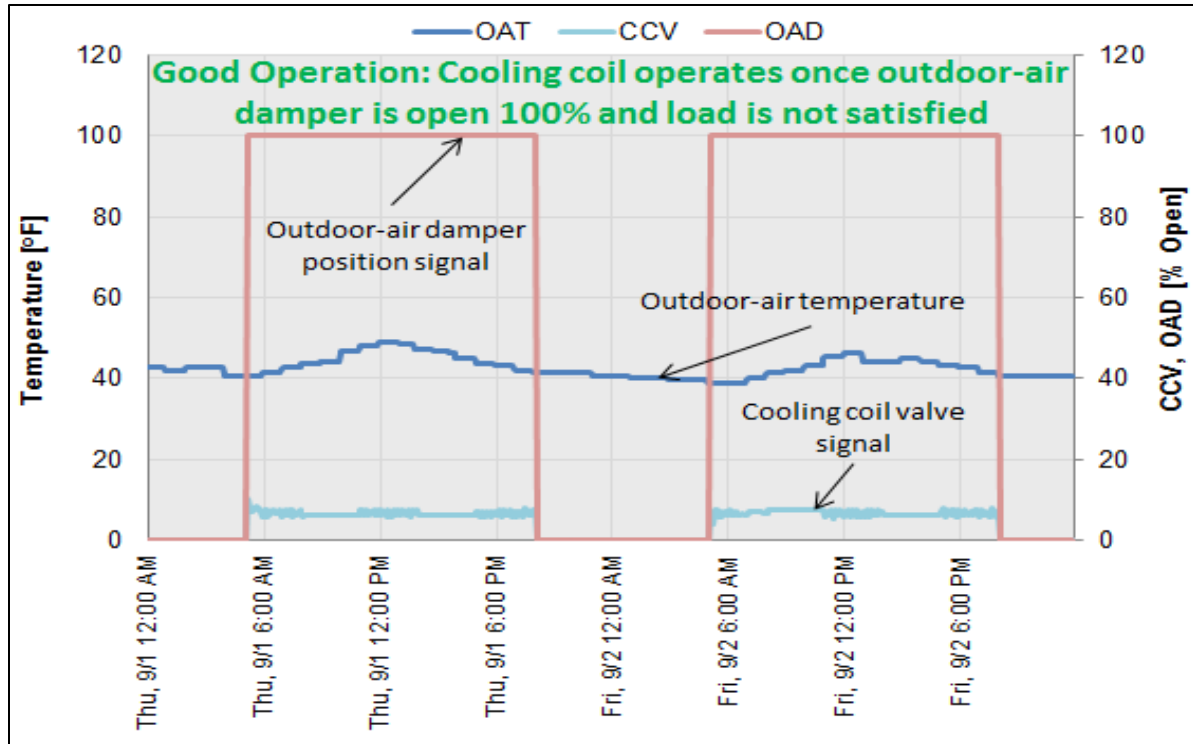


Figure 10: Full economizing enabled before mechanical cooling is enabled.

Suggested Actions

For outdoor-conditions favorable for economizing, require full economizing (outdoor-air damper open 100%) before mechanical cooling can occur. Make sure the outdoor-air damper is being properly controlled, and responds correctly to commands given in the control.

Do outdoor-air dampers close to minimum position for freeze protection?

The control logic in the BAS should have the outdoor-air damper locked out to the minimum position when outdoor-air temperatures fall below 40°F. Additionally, the outdoor-air damper should be fully closed if the mixed-air temperature drops below 40°F. If this control logic is not implemented, the coils can freeze, causing the air-handler to fail. At outdoor-air temperatures below 40°F, make sure that the damper is responding to the minimum position requirement in the control logic, and make sure the outdoor-air damper closes completely if mixed-air temperatures drop below 40°F.

Is the mixed-air temperature between the outdoor-air and return-air temperatures?

The relationship between the mixed-, outdoor-, and return-air temperatures gives the outdoor-air fraction, which is discussed and shown in equation form at the beginning of this section. By

reviewing the graph of discharge-, mixed-, return-, and outdoor-air temperatures vs. time, the building operator can get an idea of outdoor-air operations.

The mixed-air temperature must always be between the return-air and outdoor-air temperatures when the AHU is properly working. If the outdoor-air damper is closed, the mixed-air temperature should be equal to the return-air temperature, and if the outdoor-air damper is fully open the mixed-air temperature should be equal to the outdoor-air temperature. For modulating damper position, the mixed-air temperature will be somewhere between the outdoor-air and return-air temperatures. This relationship indicates the outdoor-air fraction.

Suggested Actions

If the mixed-air temperature is not between the outdoor- and return-air temperatures, then there may be a sensor error. Replace any sensors that aren't working properly.

When conditions are not favorable for economizing, is the mixed-air temperature closer to return-air or outdoor-air?

When outdoor conditions are not favorable for economizing, the mixed-air temperature should always be closer to the return-air than the outdoor-air temperature. The outdoor-air damper should always be at the minimum position for this scenario. Figure 11 below shows an example of bad operation, when the mixed-air temperature is closer to the outdoor-air temperature when it is between 25 and 35°F. When the outdoor-air gets this cold, the outdoor-air damper should be at the minimum position required to satisfy ventilation. In this example, too much outdoor-air is being brought in, and the AHU must heat the mixed-air to satisfy the discharge-air temperature set point. Figure 12 shows correct operation for this example, where the mixed-air temperature is nearly equal to the discharge-air temperature just by bringing in the minimum amount of outdoor-air required to satisfy ventilation requirements. It is closer to the return-air temperature than the outdoor-air temperature in this case.

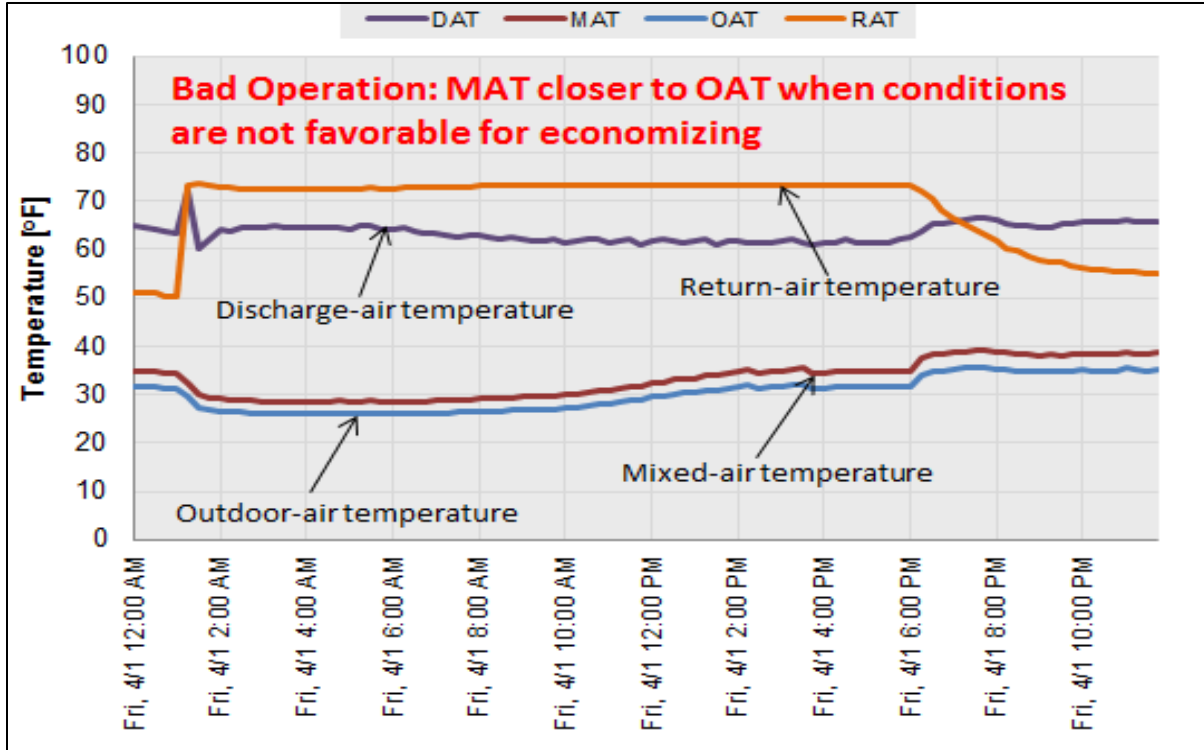


Figure 11: Mixed-air temperature closer to outdoor-air temperature when outdoor conditions are not favorable for economizing.

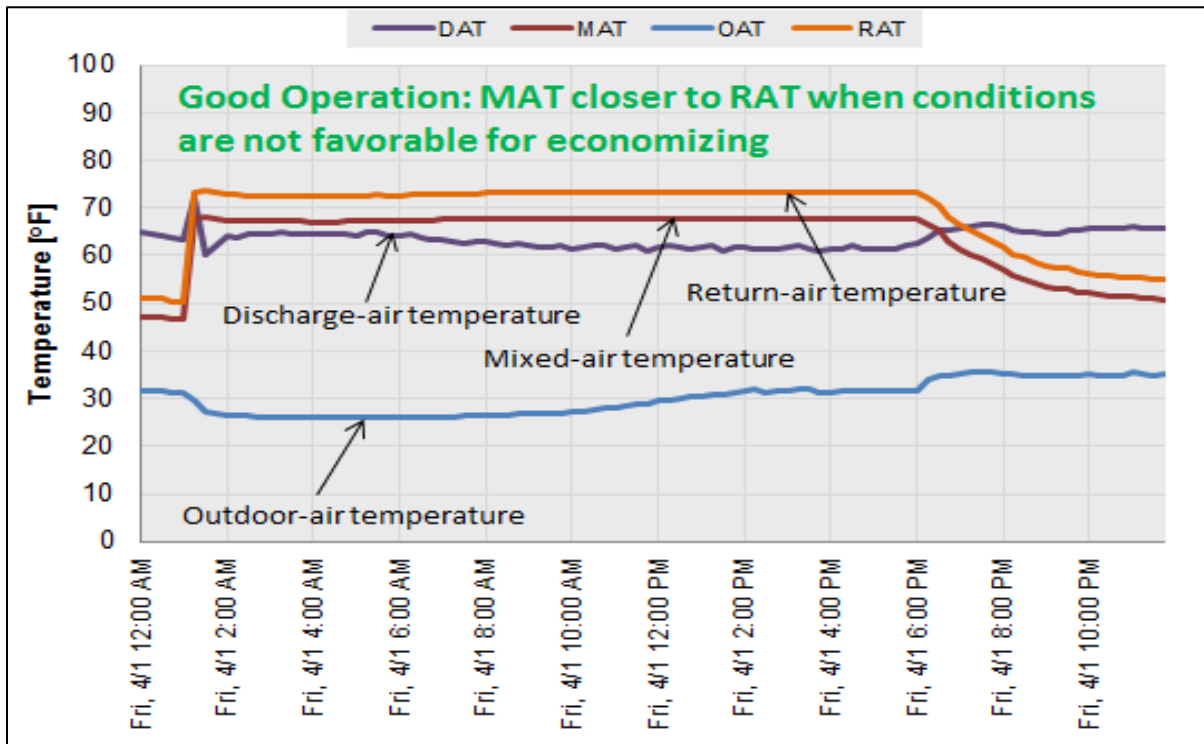


Figure 12: Mixed-air temperature closer to return-air temperature when outdoor conditions are not favorable for economizing.

Suggested Actions

When conditions are not favorable for economizing, the outdoor-air damper should be at the minimum position to satisfy ventilation requirements. If it is open more than this, check to see if the damper is working properly, and check the minimum position set point in the BAS to make sure it is less than 20% open at its minimum position.

When conditions are favorable for economizing, is the mixed-air temperature closer to outdoor-air or return-air?

When outdoor conditions are favorable for economizing, the mixed-air temperature should be closer to the outdoor-air temperature than the return-air temperature to utilize as much free cooling as necessary to meet the discharge-air temperature set point. Figure 13 is an example of bad operation, when the outdoor-air temperature is between 40 and 50°F and the mixed-air temperature is closer to the return-air than the outdoor-air temperature. Cooling energy will be wasted satisfying the discharge-air temperature set point when the load could be satisfied by the economizer.

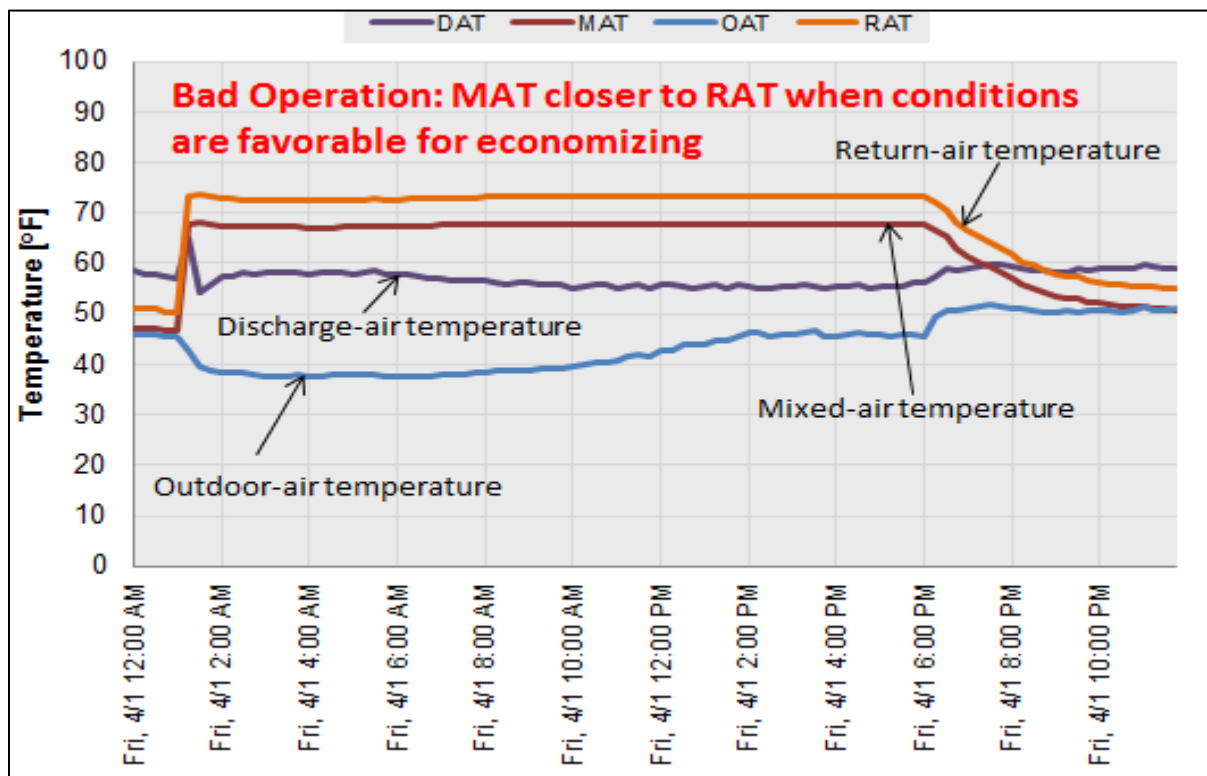


Figure 13: Mixed-air temperature closer to return-air temperature when conditions are favorable for economizing.

Figure 14 shows an example of good operation, with the outdoor temperatures favorable for economizing and the mixed-air temperature equaling the discharge-air temperature. This indicates that the economizer is satisfying the load completely, and the cooling coil is closed.

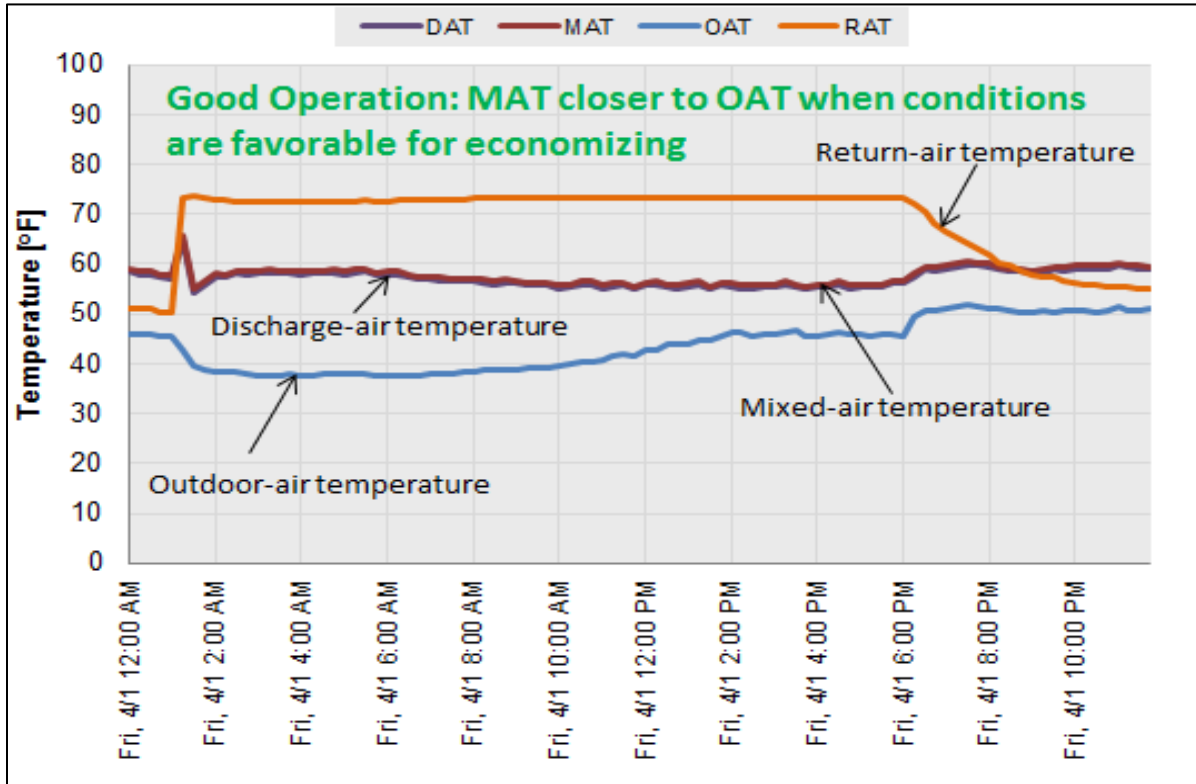


Figure 14: Mixed-air temperature closer to outdoor-air temperature when conditions are favorable for economizing.

Suggested Actions

When conditions are favorable for economizing, the outdoor-air damper should be modulating between the minimum position to satisfy ventilation requirements and fully open to satisfy the discharge-air temperature set point. If the damper is not modulating, check to see if it is working properly by commanding it fully open, fully closed, and to the minimum position and make sure it responds to the command. Make sure that the cooling coil is opening only when the economizer cannot satisfy the load.

Economizer Controls

There are several economizer control sequences that may be implemented in your BAS. These can include outdoor-air dry bulb, outdoor-air enthalpy, differential dry bulb, and differential enthalpy. Outdoor-air dry bulb is set up to economize when the outdoor-air drops below a fixed outdoor-air temperature set point; outdoor-air enthalpy is set up to economize when the

calculated outdoor-air enthalpy drops below a fixed outdoor-air enthalpy set point; differential dry bulb is set up to economize when the outdoor-air temperature drops below the return-air temperature by some temperature differential, usually 1 to 2°F; and differential enthalpy is set up to economize when the calculated outdoor-air enthalpy drops below the calculated return-air enthalpy by some differential, usually 2 Btu/lb. Enthalpy controls are typically utilized in humid climate zones (Houston, Miami, etc.). There are several economizer sequencing options, three commonly used ones listed below in detail.

Economizer Sequence Option A

When the economizer is enabled, the economizer dampers will modulate open from the minimum position to that required to maintain the mixed-air temperature set point. The default mixed-air temperature set point is 55°F, but can be user-adjustable. When the fan is off, the outdoor-air damper will be closed. When the fan is running, the outdoor-air damper will be maintained at the minimum position unless there is a call for more outdoor-air. If the mixed-air temperature drops below the mixed-air temperature low limit set point, the outdoor-air dampers will close. The default mixed-air low limit set point is 45°F.

This option has no relation or linkage to mechanical cooling and can still be found on large AHU. This means that there is a separate discharge-air set point for mechanical cooling, and the mixed-air set point can be set too high to optimize free cooling, or too low to cause heating to always occur.

Economizer Sequence Option B

When the economizer is enabled, the economizer dampers will modulate open from the minimum position to that required to maintain the discharge-air temperature set point. The default discharge-air temperature set point is 55°F, but can be user-adjustable. When the outdoor-air damper is greater than 75-100% open (usually set in the control code) for more than a user-specified time delay (usually 5-15 minutes, but can be as great as 30 minutes), mechanical cooling will be activated (as long as the outdoor-air temperature is above the outdoor-air temperature cooling lockout set point; usually 50 to 60°F). If the mixed-air temperature drops below the mixed-air low limit set point, the outdoor-air damper will close. The default mixed-air low limit set point is 45°F. When the fan is off, the damper will be closed. When the fan is running, the damper will be maintained at the minimum position unless there is a call for more outdoor-air.

This option is more intelligent than sequence Option A because it links the economizer to the mechanical cooling system. However, it is highly possible that the description above for option B is not fully implemented, i.e., outdoor lockouts may or may not exist, mixed-air low limits may

or may not exist, etc. To fully optimize this sequence option, all lockouts and limits should be properly set in the BAS control logic.

Economizer Sequence Option C

When the economizer is enabled, the economizer damper will modulate open from the minimum position to that required to maintain the zone temperature at the zone temperature set point. The default zone temperature set point is 72°F, but can be user-adjustable. When the outdoor-air damper is greater than 75-100% open (usually a setting in the control code) for more than a user-specified time delay (usually 5-15 minutes, but can be as great as 30 minutes), mechanical cooling will be activated (as long as the outdoor-air temperature is above the outdoor-air temperature cooling lockout set point; usually 50 to 60°F). If the mixed-air temperature drops below the mixed-air temperature low limit set point, the outdoor-air damper will close. When the fan is off, the damper will be closed. When the fan is running, the damper will be maintained at the minimum position.

This option is typical for rooftop units (RTUs) or smaller AHU(s), and is also more intelligent than sequence option A, because mechanical cooling and economizing are linked to operate at maximum efficiency.