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HOBO® Data Loggers

Using Data Loggers Beyond Equipment Scheduling

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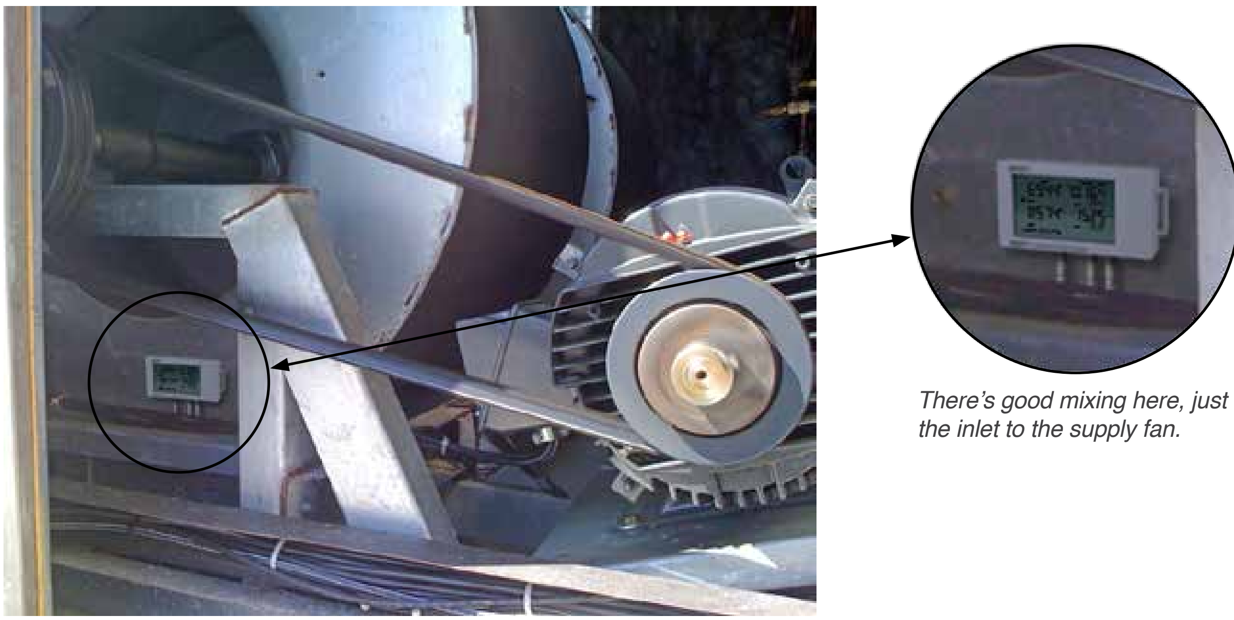
Carbon Lighthouse CEO and Co-founder

Data is a powerful tool. Data loggers are great for finding equipment-scheduling opportunities in buildings, but their use does not stop there. This article discusses three ways to use data loggers to find opportunities beyond scheduling.

I. Economizers

A study touted by Facility Dynamics and Pacific Gas and Electric found that out of 123 economizers in the field, 79 had failed. This means if you go to a building with three economizer-equipped air handlers, it is likely that two of them are not actually economizing.

How can you tell? With data loggers. In this case you'll need three: one to measure the outside air temperature, one to measure the return air temperature, and one to measure the mixed air temperature. Or, you could use a single 4-channel data logger with three temperature sensors. Getting a good reading on mixed air temperature can be difficult since air striation can make things difficult. We have found that placing the sensor just before the inlet to the supply fan, or just after the filters, can be a reliable spot to get a reading.



There's good mixing here, just before the inlet to the supply fan.

Temperature of the mixed air follows a simple equation, related to the percentage of outside air being used:

$$MAT = OAT \bullet x + RAT \bullet (1 - x)$$

where:
x = the percentage of outside air
MAT = Mixed Air Temperature
OAT = Outside Air Temperature
RAT = Return Air Temperature

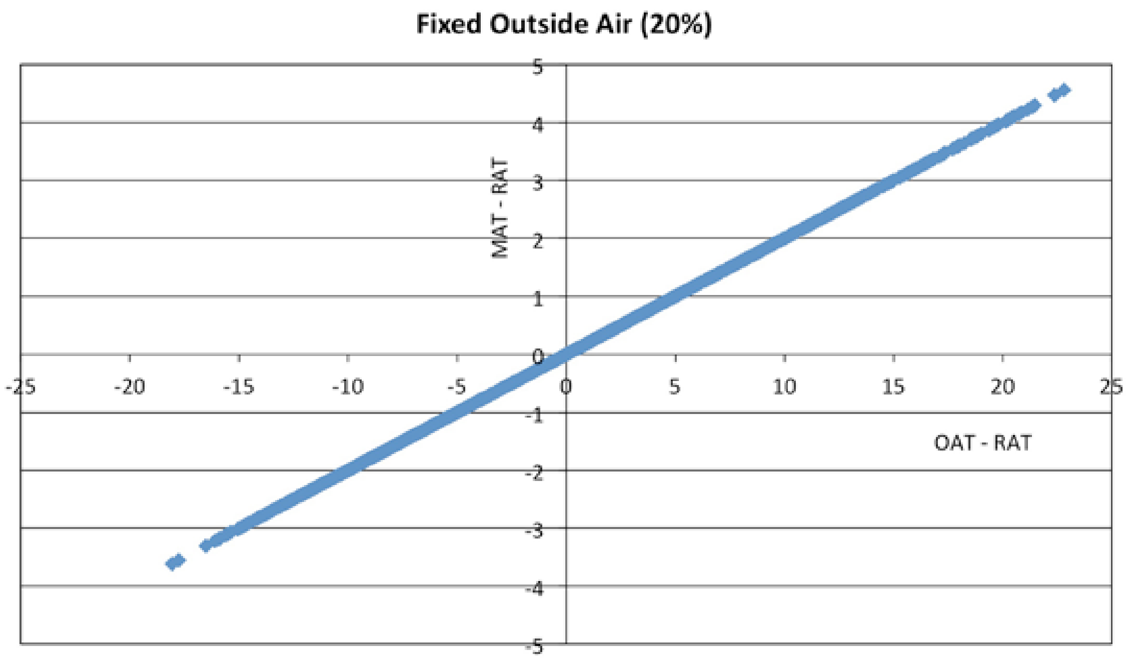
You can solve this equation for x, yielding the relationship:

$$x = \frac{MAT - RAT}{OAT - RAT}$$

Using data loggers, you can learn what the MAT, RAT, and OAT are and determine if the economizers are working.

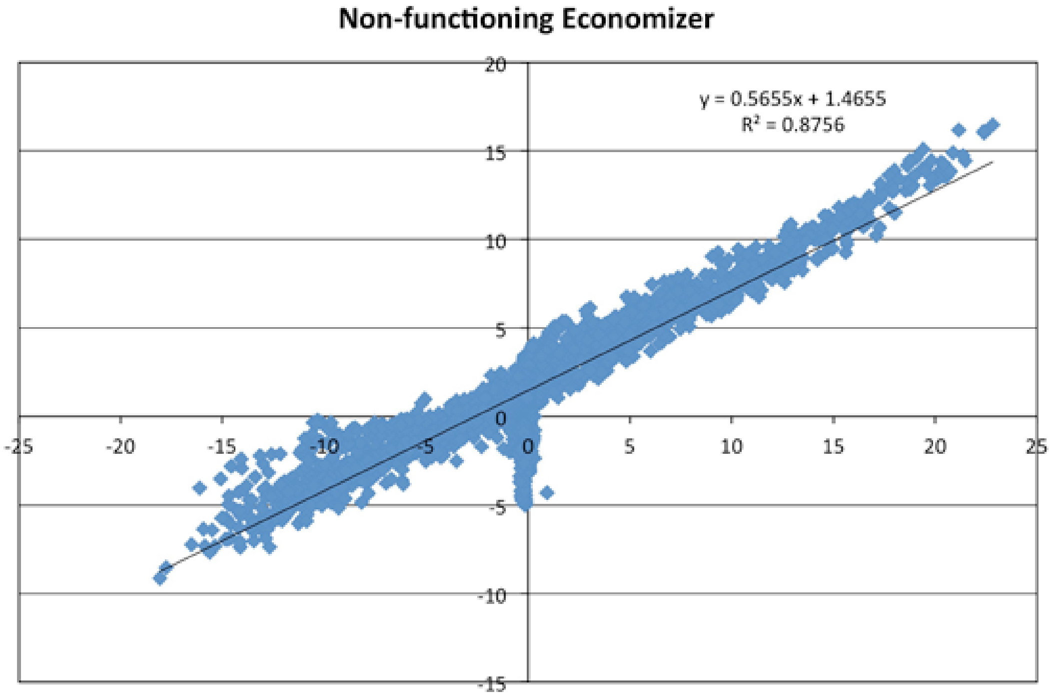
Unfortunately, the outside air temperature may be pretty close to the return air temperature, which would make the equation go to infinity since the denominator would be zero. However, some simple graphs will resolve this problem.

Make a scatter plot of your logger data so that the x-axis is OAT – RAT, and the y-axis is MAT – RAT (you need to throw away the data in which the unit was turned off), and you will see one of two things. If there is no economizer, you will see something like this:



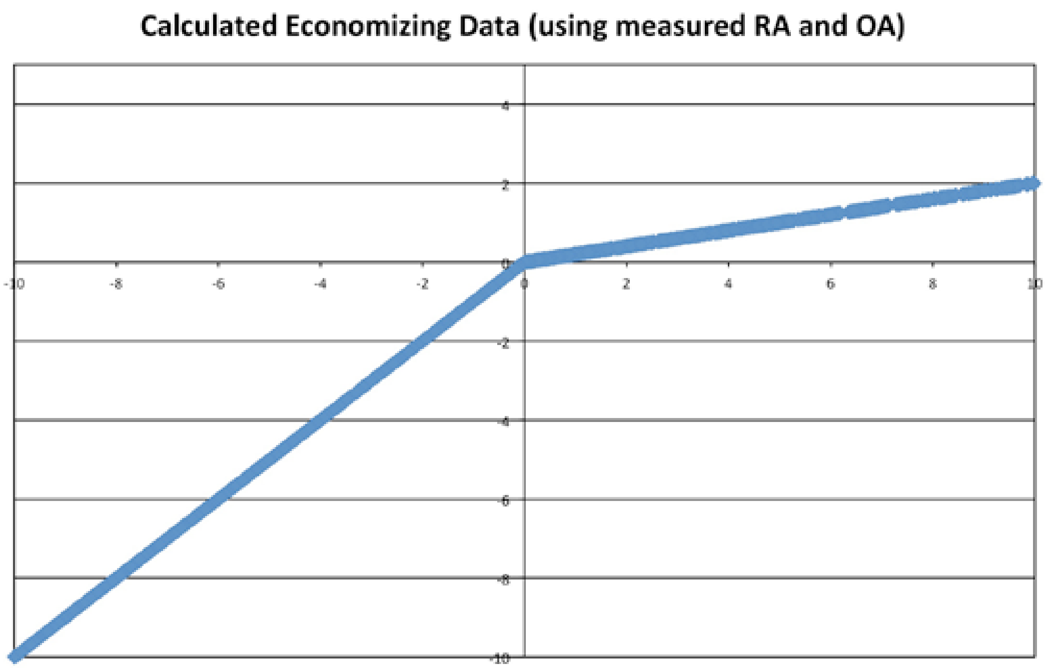
(This graph was made using measured outside air temperatures and return air temperatures in a building, but using a theoretical model to determine mixed air temperatures based on dampers stuck letting in exactly 20% outside air.)

Note that the slope of the line is 0.2. The economizer will be between these positions when the outside air is less than 55°F, which will appear on the left side of the graph. Using real-world data, we get graphs more like the following:



Note that the graph does not go exactly through 0, and that the slope is closer to .57, indicating this air handler is stuck at 57% outside air.

If the unit were equipped with an economizer, it would look more like the following:



Note the difference in slopes. On the left side of the graph the slope is 1, indicating the unit is at 100% outside air. On the right side of the graph, the slope is 0.2, indicating the economizer dampers are at a minimum.

Now that you can tell whether or not your economizer is working, you can calculate the savings.

A building's cooling (or heating) system takes the mixed air and cools it down (or heats it up) to the desired supply air temperature. The energy use is equal to:

$$1.08 \bullet CFM \bullet \Delta T = Energy\ (BTUs)$$

where:
1.08 = a units constant related to the density and specific heat of air at sea level (note, you need to use a different constant at higher altitude). This makes the equation give an energy result in BTUs.
CFM = the flow rate across the fan, which you can look up in the building design documents
ΔT = the difference in temperature from mixed air temperature to supply temperature

Knowing this, you can download Typical Meteorological Year (TMY) data to get hourly weather patterns at your site, and calculate the mixed air temperature with and without an economizer every hour for the year. Using the airflow rate of your system, you can then calculate the energy savings from installing or repairing an economizer. (You need to know the schedule of the unit as well; data loggers are great for determining a piece of machinery's schedule. Also, please note that the above calculation does not account for any latent cooling. We have found a factor of 0.25 or 0.3 is conservative as an adder to account for dehumidification in the San Francisco Bay Area.)

Armed with the knowledge of quantified savings, it is much simpler to try to convince a building owner or manager to install an economizer. Rather than saying, "Economizers generally pay for themselves in six months to four years," you can tell the owner, "Replacing this economizer in your building will save $2,200 per year and cost $1,500." Citing the exact costs and savings specific to an individual building is a powerful tool in encouraging an organization to reduce its energy use.

All of the data required to make that building-specific, and hence powerful statement, comes from inexpensive data loggers and a little bit of spreadsheet analysis. Although it may seem complicated now, after you've done the Excel analysis once, you can just copy and paste in new logger data and it will immediately tell you what the savings are for any given project. And that's just the beginning of using data loggers for purposes beyond equipment scheduling.

II. Cycling Fans

Variable Frequency Drives (VFDs) are wonderful pieces of equipment. Most contractors interested in efficiency recommend their customers install VFDs on their pumps and fans for great energy savings. VFDs, however, can be expensive.

Again, the problem with convincing a customer to reduce energy use is that while costs are known, savings are not – unless you have data loggers. With data loggers you can accurately calculate the energy savings from installing VFDs ahead of time, and then present the customer with hard numbers for both costs and savings.

Variable Frequency Drives

Here's how: VFDs take advantage of the affinity laws. You actually only need one of them in this case:

$$\frac{P_1}{P_2} = \left(\frac{RPM_1}{RPM_2}\right)^3$$

this can be rewritten as:

$$P_1 = P_2 \cdot \left(\frac{RPM_1}{RPM_2}\right)^3$$

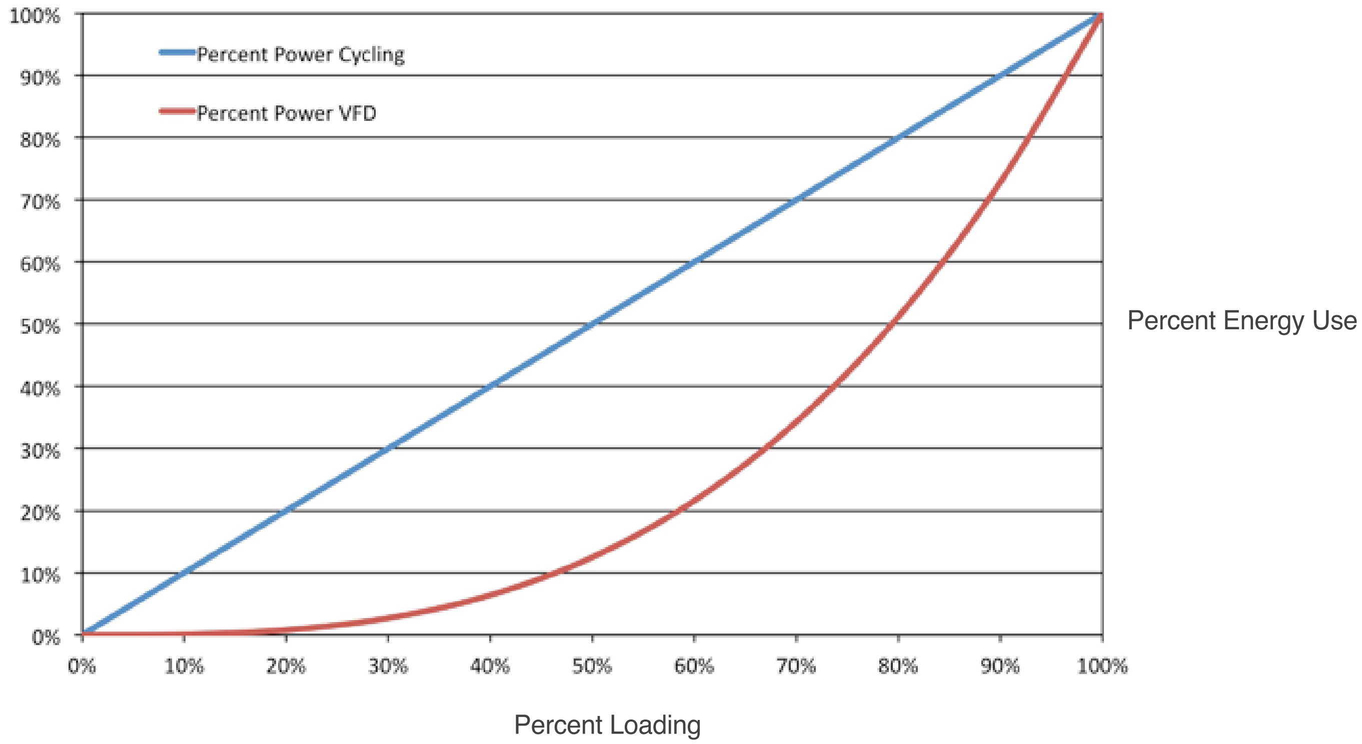
where:
P_1 = Fan or pump power at a slow (or fast) speed
P_2 = Fan or pump power at a fast (or slow) speed
RPM_1 = Speed at the slow (or fast) speed
RPM_2 = Speed at the fast (or slow) speed

(NOTE: We have found the affinity laws are a bit idealized compared to results in the field. If you are installing a VFD on a pump or a fan with high static, you're better off using an exponent of 2.2 as opposed to 3. If the fan has relatively low head, then you can use an exponent of 2.7 instead of 3.)

The important thing to note about the above equation is that as VFD speed decreases, power decreases like the cube. So if you cut the speed in half, you end up using only 12.5% of the power. To illustrate, assume P_2 is the original power of the fan when operating at 60 hertz without a VFD, then we see:

$$P_1 = 100\% \left(\frac{30}{60}\right)^3 = 12.5\%$$

Imagine a 100 kW fan were cycling half the time. Over the course of an hour, the fan would use 50 kWh, whereas if a VFD was installed and turned down to 50% speed, it would use only 12.5 kWh over the course of the hour. This represents savings of 37.5%. You can see the savings from installing a VFD in the graph below:

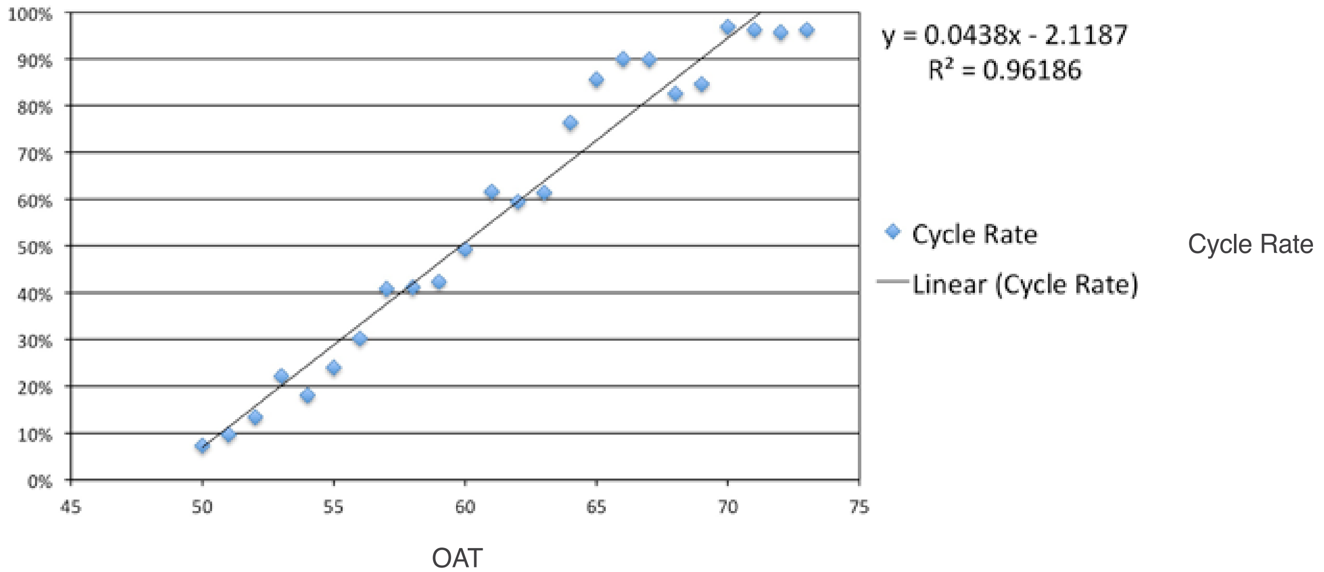


This is all good theory, but how do we predict ahead of time what the speed of the fan is going to be? Won't this change throughout the year based on outside weather conditions?

This is where data loggers are extremely helpful. To predict the fan speed, we need to measure the current cycle rate of the fan and regress this against weather.

Hook up a current transformer (CT) to your data logger, and measure the current going into your fan motor. You need to use one-or two-minute interval data so you can accurately calculate the cycle rate. Use another logger to measure the outside air conditions at the building (or, if you have access to NOAA data, you can download it there). Now, calculate your cycle rate for each hour, and compare that to your outside air temperature data. Please note, cooling towers track wet bulb temperatures, whereas an evaporator fan is more likely to track dry bulb temperatures.

You should get a graph something like this:



Note that the fan starts coming on at 49°, and by 72° is at 100%. Between these two temperatures the cycle rate follows the equation:

$$\text{Cycle Rate} = 0.0438 \bullet \text{OAT} - 2.1187$$

Now we get to the good stuff. If the fan is cycling at 50%, it means that the load your system is actually experiencing is 50% of the design capacity. Since energy use follows the equation:

$$1.08 \bullet CFM \bullet \Delta T = Energy\ (BTUs)$$

if we reduce the CFM by half, we get half the energy transfer – which is exactly what your fan is doing by cycling off half the time. So the VFD speed is equal to the fan cycle rate. (Note: there is a built-in assumption here that by reducing the speed, we are not changing the delta T across the coil. In fact, by reducing fan speed we will probably get a slightly higher delta T, which means we could reduce the speed even further. So, this assumption will in fact make your savings estimates slightly conservative.)

Now you can set up your spreadsheet and calculate your savings exactly. In one column, take your annual weather data. In the next column, calculate your cycle rate based on the weather (make sure to cap the cycle rate so it doesn't go lower than zero or higher than 100%). The next column is your baseline energy use: the cycle rate times the fan kW draw (which you would have measured with a real power meter to account for power factor and voltage at your site). Lastly, the final column uses the fan affinity laws discussed to calculate the energy use of the fan with a VFD.

Subtract those last two columns, and you have calculated your energy savings ahead of time – all just by taking data loggers to the field and doing a quick regression. (Make sure to account for scheduling.)

III. Simultaneous Heating and Cooling, Boiler Lockouts, and Supply Air Resets

Many people believe a supply air reset is a great way to reduce the energy use in Variable Air Volume (VAV) systems, and it can be. If you do not have a good Direct Digital Controls (DDC) system, however, you may need to install new controllers and sensors to enable it. Is it worth the cost? Even if there is no cost, would you like to be able to report the savings to management?

To determine the savings and find out if it is worth the cost, data loggers can help.

To calculate the savings from a supply air reset is actually not an insurmountable challenge. It can be broken up into a few steps based on collecting a few pieces of logger data:

1. Log the supply air temperature coming out of the air handler you want to enable with a supply air reset.
2. Log the outside air temperature (in this case, dry bulb is just fine).
3. Log some of the hottest zones in the building, or the zones where you've noticed the lowest discharge air temperature coming out of the registers. These are usually on the south or west sides of the building.

Counter-intuitively, a supply air reset is actually more of a gas- or oil-saving measure than an electric cooling saving measure. Here's why: If you are always supplying 55° air but your coldest VAV box is discharging 62° air, you could reset your supply air temperature to 61°. This would save cooling energy since you would no longer need to cool the air all the way to 55°, and it would also save heating energy since you wouldn't need to reheat the air to 61°. Sounds like it saves energy on both sides? It does. But if it is 75° outside or hotter, it is likely that your coldest VAV box is actually discharging 55° air or pretty close to it. So, you shouldn't reset your supply air temperature, and hence won't get either heating or cooling savings.

On the other hand, if it is 35° outside and your supply air temperature is 55°, it is likely your coldest VAV box is at least 65°. If you are economizing, you are using no cooling energy to make 55° air, and then you are using quite a bit of gas or oil to heat that supply air temperature up to 65° discharge air. Why bother heating? Why not just set your economizers to make 65° supply air and save the gas? You won't save energy cooling the air since you hadn't used energy to cool the air to begin with, but you'll save a great deal of gas or oil.

That is exactly what a supply air reset does, and why it is primarily a natural gas or fuel oil saving measure, and not a cooling measure.

Armed with your logger data and the few concepts above, you are now ready to calculate your savings.

Air Handling Unit

Unless you've been with the building since construction or you have a good controls system, the first thing you should probably do is check the supply air temperature across a range of outside temperatures to make sure you are not already doing a supply air reset. The supply air temperature is likely to jump around a little bit, but this is not necessarily indicative of a supply air reset. If the supply air temperature is always between 52° and 58°, this is probably indicative of compressor cycling, not any sort of reset schedule. Do a regression of supply air temperature based on outside air temperature to check. If your line is basically flat – e.g. always 55° or 58° – then you do not have a supply air reset. If your line slopes significantly – it is 55° whenever it is above 75°, or 65° whenever it is less than 40°– then you probably do have a supply air reset. If you don't already have a supply air reset, we are finally ready to calculate the savings from implementing one.

The simplest way to control a supply air reset is based on outside air temperatures. This is how we will calculate the savings. The equation we will rely on is:

$$1.08 \bullet CFM \bullet \Delta T = BTU$$

1.08 is a units constant and changes based on altitude. If you're in Denver, for example, you need to replace the constant.

CFM is not terribly complicated to calculate: the cut sheets for the air handler will tell you the maximum CFM, which occurs during the cooling design day. The next points you will need are the outside air temperature at which the VAV boxes close to minimum position, and what that minimum position is. Now, you're ready to set up a linear ramp based on the outside air temperature to calculate CFM. Here's an example:

Suppose you know the following about your building:

- The design day is 100°
- The maximum air flow through the air handler is 50,000 cfm
- The VAVs ramp to a minimum when the outside air is 45°
- The minimum position is 25%

Then set up the following chart:

Outside Air Temperature	CFM
100	50,000
45	50,000•0.25 = 12,500

We are now prepared to calculate CFM based on the outside air temperature. If the outside air temperature is 100° or higher, the CFM will be 50,000. If the outside air is 45° or higher, the CFM will be 12,500. Between those two, the CFM will follow a linear ramp between the two points.

The equation for a line is y = mx + b, so let's set up an equation where 'y' is CFM. The slope, 'm', is equal to the change in CFM over the change in outside air temperature:

$$m = \frac{50{,}000 - 12{,}500}{100 - 45} = 681.82$$

The y-intercept, 'b', can be found by solving for a known point, namely 100° outside air temperature, and using the slope found above:

$$50{,}000 = 681.82 \cdot 100 + b \rightarrow b = 50{,}000 - 68{,}182 = -18{,}182$$

We should check that the equation works, so let's plug in 45° outside air:

$$CFM = 681.82 \bullet 45 - 18{,}182 = 12{,}499.99 \approx 12{,}500$$

Great. We can now calculate CFM based on the outside air temperature using the equation for CFM we developed.

Once we know the ΔT, we can finish calculating the energy savings. There are actually two ΔTs, the ΔT from your mixed air to your supply air, and then the ΔT from your supply air to the discharge air. From mixed air to supply air tells you your cooling energy use, and from supply air to discharge air tells you your reheat use.

To calculate the cooling use, we need to know the mixed air temperature across a range of outside air temperatures. If you do not have an economizer and use a constant 20% outside air, this is simple:

$$MAT = OAT \bullet 0.2 + \mathrm{RAT} \bullet 0.8$$

where MAT is your mixed air temperature, OAT is your outside air temperature, and RAT is your return air temperature.

For RAT, you can usually assume this is roughly the same temperature as your space, or one or two degrees higher. If you assume a flat 72° all year round, you will be fairly accurate.

For OAT, you can download a TMY file for data on the outside air temperature every hour of the year for your building.

If you do have an economizer, it is also relatively easy to calculate your mixed air temperature. Assuming you have a supply air temperature setpoint of 55°, and the outside air is less than 55°, your MAT will be 55°. If the outside air temperature is greater than 55° but less than say 70°, your MAT will be the same temperature as the outside air temperature. Above 70°, your MAT will follow the equation above.

Using the weather file to learn the outside air temperature every hour of the year, you can thus calculate your MAT.

On to cooling energy: simply multiply 1.08, CFM, and (MAT – SAT) to find your cooling energy.

Reheat energy: this is more complicated. You will need to know your average discharge temperature across a variety of outside air temperatures. Again, data loggers are useful. Log your discharge air temperature at a few boxes, and the outside air temperatures as well. Next, graph the discharge air temperatures on the y-axis and use OAT as the x-axis. Add a quick trend line and you can see what your discharge air temperature should be across a range of outside air temperatures (don't forget to remove the data from the trend line for unoccupied times).

Now, we're finally ready to put this all together and calculate some energy use. In the base case, we have energy use with a static supply air setpoint. In the retrofit case, we have a supply air reset.

We haven't discussed boiler resets, but they are really simple: lockout your boiler (and heating water pumps) when it is more than 70° outside. The 70° will change a bit based on your region and building, but 70° is a good starting point. Calculating savings from a boiler lockout is very simple: your heating energy use above 70° goes to zero, and your energy use for your pumps goes to zero as well.

We can also combine a supply air reset with a boiler lockout. All of this looks like the following:

Outside Air	CFM		OAT	Discharge		OAT	SAT		m	b					
100.0	50000.0		30.0	100.0		75.0	55.0		-1.0	130.0	DISCHARGE				
45.0	12500.0		75.0	55.0		45.0	65.0		681.8	-18181.8	CFM				
									-0.3	80.0	SAT				
Outside Air Temperature	Mixed Air Temperature (no economizer)	Supply Air Temperature (base case)	Discharge Air Temperature	CFM	Base Cooling Energy Use (BTUs)	Base Simultaneous Heating Load (reheats)		Supply Air Temperature (w/Reset)	Cooling Energy Use	Heating Energy Use	Heating Energy Use with Boiler Lockout		**Cooling Savings**	**Heating Savings**	**Heating Savings w/Boiler Lockout**
35	65	55	95	12,500	129,600	540,000		68	-	360,000	360,000		129,600	180,000	180,000
40	66	55	90	12,500	143,100	472,500		67	-	315,000	315,000		143,100	157,500	157,500
45	67	55	85	12,500	156,600	405,000		65	21,600	270,000	270,000		135,000	135,000	135,000
50	68	55	80	15,909	216,491	429,545		63	73,309	286,364	286,364		143,182	143,182	143,182
55	69	55	75	19,318	283,745	417,273		62	144,655	278,182	278,182		139,091	139,091	139,091
60	70	55	70	22,727	358,364	368,182		60	235,636	245,455	245,455		122,727	122,727	122,727
65	71	55	65	26,136	440,345	282,273		58	346,255	188,182	188,182		94,091	94,091	94,091
70	72	55	60	29,545	529,691	159,545		57	476,509	106,364	-		53,182	53,182	159,545
75	73	55	55	32,955	626,400	-		55	626,400	-	-		-	-	-
80	74	55	55	36,364	730,473	-		55	730,473	-	-		-	-	-
85	75	55	55	39,773	841,909	-		55	841,909	-	-		-	-	-
90	76	55	55	43,182	960,709	-		55	960,709	-	-		-	-	-

The worksheet above shows the savings at a range of temperatures. To calculate the annual savings, you need to download a TMY weather file and do an 8,760 hourly analysis. That uses the exact same methods outlined here, but extends for 8,760 rows, one for each hour of the year. Please note, none of this accounts for the efficiency of your cooling or heating system. The heating energy savings should be divided by the efficiency of your boiler, and the cooling energy savings should be divided by your unit's Coefficient of Performance (COP). Lastly, don't forget to take scheduling into account, and don't forget the pump savings from your boiler lockout.

Other informational resources available from Onset:

Choosing an Occupancy and Light On/Off Data Logger – 5 Important Considerations

This paper provides guidance on features to consider when choosing an occupancy and light on/off data logger, including calibration, LCD display, logger accuracy and range, speed of deployment, and time-saving software. Learn how to select the right logger for identifying ideal locations in your building where changes in lighting could result in cost savings up to 80%.

Utility Incentive Programs: How to Get More Money Quickly and Easily

"Utility Incentive Programs: How to Get More Money Quickly and Easily," is aimed at making the process of applying for and receiving energy efficiency incentives and rebates faster, easier, and more rewarding. Authored by Carbon Lighthouse, an energy firm that makes it profitable for commercial and industrial buildings to eliminate their carbon footprint, the paper discusses the two main types of incentive and rebate programs, how utility efficiency program managers think, and how to use data to get more incentive dollars for your projects.

Using Data Loggers to Improve Chilled Water Plant Efficiency

Chilled water plant efficiency refers to the total electrical energy it takes to produce and distribute a ton (12,000 BTU) of cooling. System design, water quality, maintenance routines, cooling tower design, and cooling coil load all affect chiller water plant efficiency and the expense of operating the system.

Data Logger Basics

In today's data-driven world of satellite uplinks, wireless networks, and the Internet, it is common to hear the terms "data logging" and "data loggers" and not really have a firm grasp of what they are.

Most people have a vague idea that data logging involves electronically collecting information about the status of something in the environment, such as temperature, relative humidity, or energy use. They're right, but that's just a small view of what data logging is.

Addressing Comfort Complaints With Data Loggers

This paper offers facility managers, HVAC contractors, and others with valuable tips on how low-cost data loggers can be used to validate temperature-related comfort complaints.

Monitoring Green Roof Performance with Weather Stations

Data logging weather stations are the ideal tools for documenting green roof performance. A weather station can measure weather parameters such as rainfall, stormwater runoff, temperature, relative humidity, wind speed, solar radiation, and a host of non-weather parameters such as soil moisture on a continuous basis (say every five minutes, hourly, or an interval appropriate to the situation).

Using Data Loggers Beyond Equipment Scheduling

While data loggers are a great tool for identifying equipment-scheduling opportunities in buildings, their usefulness far exceeds just that one function. This paper discusses how the use of inexpensive data loggers and some spreadsheet analysis can provide all the evidence needed to make powerful building-specific cases for saving money by replacing failed air-handler economizers. It also describes how information from data loggers can be used to accurately calculate the energy savings that can be realized from variable frequency drives (VFDs) on pumps and fans, supply air resets, and boiler lockouts

Analyzing Air Handling Unit Efficiency with Data Loggers

Operating a heating, ventilation and air conditioning (HVAC) system at optimum efficiency in a commercial setting is complicated, to say the least. There is a very real chance that any number of setpoints, levels, and feedbacks at boilers, chillers, pumps, fans, air delivery components and more can cause costly inefficiencies.

Finding Hidden Energy Waste with Data Loggers: 8 Cost-Saving Opportunities

The first step to reducing building energy costs is identifying energy waste. Statistics on utility bills or name plates on equipment, while useful, are not enough to identify what practices and equipment are contributing to high energy use. Portable data loggers can be used to obtain critical energy use information in a wide range of commercial building types – from manufacturing plants to office buildings.

Monitoring HVAC Performance with Data Loggers

Building operators and managers have the difficult job of providing comfortable working conditions and coaxing aging mechanical equipment to operate at peak performance while minimizing energy costs.

Access our full resources library at: www.onsetcomp.com/resources

About Onset

Onset is the world's leading supplier of data loggers. Our HOBO data logger products are used around the world in a broad range of monitoring applications, from verifying the performance of green buildings and renewable energy systems to agricultural and coastal research.

Based on Cape Cod, Massachusetts, Onset has sold more than 2 million data loggers since the company's founding in 1981.

About Carbon Lighthouse

Carbon Lighthouse makes it profitable for organizations to become carbon neutral by combining efficiency, solar, retro-commissioning, and a host of other alternative energy technologies into one simple service for clients. Within its first year of operation, Carbon Lighthouse completed projects at 70+ office towers, schools, and industrial facilities in California and Oregon. If desired, clients can defer payments to Carbon Lighthouse, ensuring projects are cash-flow positive in the first year.

Contact Us

Our goal is to make your data logging project a success. Our product application specialists are available to discuss your needs and recommend the right solution for your project.

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