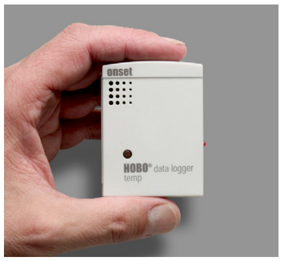
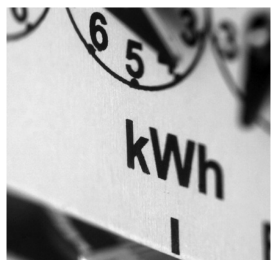
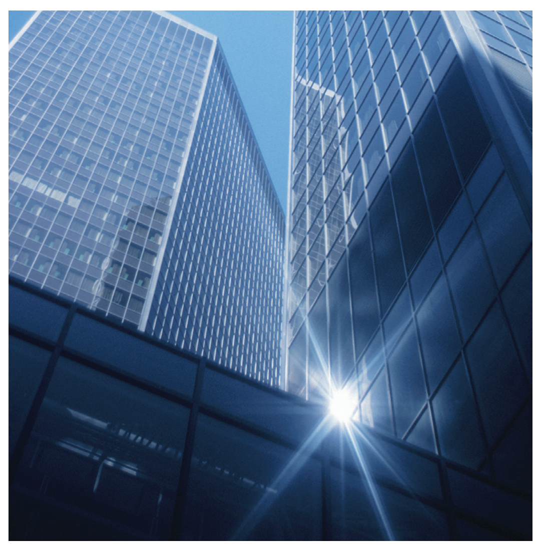




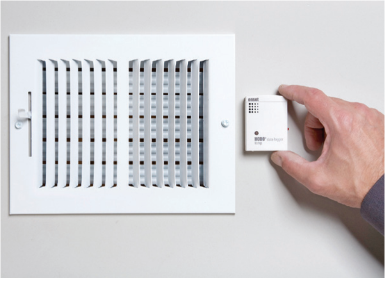


The Energy Professional's Guide to

Data Loggers & Building Performance

The Energy Professional's Guide to
Data Loggers & Building Performance

An Introduction to Data Loggers



HOBO U10 temperature data logger

“I just think the only way we are really going to get to the point we need to get to is to start collecting the real data.”

This comment, made in 2009 by New York Public Service Commission chairman Garry Brown, conveys a growing sentiment about the need for solid, objective data on building energy performance.

When it comes to determining actual building performance, it all comes down to data. Data takes the guesswork out of energy management, and drives decisions as to what energy conservation measures need to be taken in a facility.

Portable data loggers are ideal tools for collecting building performance data. These affordable, compact devices can help establish energy performance baselines, and reveal a buildings performance under real-world, rather than modeled, circumstances. They offer fine-tuned visual performance feedback, measuring changes in temperature and energy use when people enter and exit a building, turn on and off lights, or run heating and cooling systems. They can also be used to help ensure that indoor air quality and comfort are maintained in a building.

By monitoring and recording simple variables like temperature, RH, CO_2, and light or motor On/Off, data loggers can help detect and document whether “too hot or too cold” comfort complaint conditions are real, whether a facility is threatened by conditions suitable for mold growth, and whether energy savings can be realized through ensuring that lights are off when areas of the building are unoccupied.

More sophisticated measurements – such as AC Current, AC Voltage, power demand (kW), energy consumption (kWh), pressure, and differential air pressures – provide valuable information for troubleshooting HVAC/R systems, sub-metering, building commissioning, and measurement & verification of energy savings.

Typically, data loggers are battery-operated, standalone measurement tools containing a microprocessor, memory, and sensors for measuring and recording one or more variables over time. They are typically quite small, enabling them to be deployed almost anywhere throughout a building, with some designed to work in outdoor or more hostile industrial environments.

Simple items such as lighting fixtures and motors under constant load can be easily evaluated with data loggers by taking a single power measurement and then monitoring the runtimes.

HOBO U30
External sensors

HOBO U12
4 External channels

HOBO U10
Temperature/RH

Some data loggers have internal sensors, so that measurements are made only at the logger location, while others utilize sensors on external cables that allow for monitoring at some distance from the data logger itself. A data logger may offer a combination of internal and external sensors, as well as external channels accepting pulse, 4-20mA, or DC voltage inputs from other sensors for even greater flexibility.

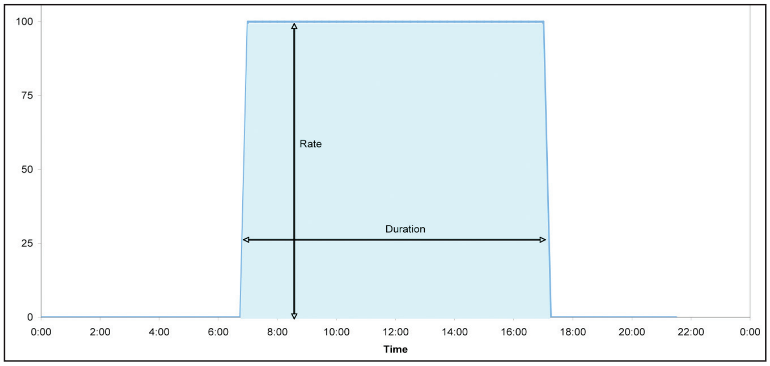
Data loggers typically operate unattended for hours, days, or months at a time. Specialized software is used to configure the logger (select sampling intervals, synchronize logger and computer clocks, etc.) and to off-load the recorded data from the logger to a PC or MAC computer for graphing and analysis.

It is important to note that, in addition to “standalone” data loggers that communicate with computers via USB, there are a number of web-based data logging options available that provide users with convenient access to data remotely over the Internet via GSM cellular, Wi-FI, and Ethernet-based communications.

Components of Energy Use

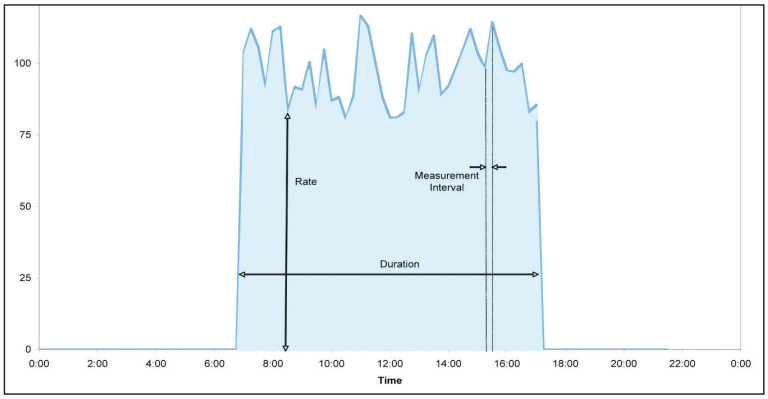
The energy use of any building or component can be divided into two parts: the *rate* of energy use and the *duration* of that energy use. The energy use rate for electricity is expressed as Watts or kilowatts; for thermal loads, the rate may be expressed as thousand British Thermal Units per hour (MBTUH). In the simplest cases, the rate of energy use remains constant while the duration varies. The energy use is then the product of the two components.

Data loggers provide valuable information on building system behavior that may not be available from building automation systems.



Simple items such as lighting fixtures and motors under constant load can be easily evaluated with data loggers by taking a single power measurement and then monitoring the runtimes.

For many systems of interest, the rate of energy use changes, often as a function of some other driving variable. Examples include cooling loads on a chiller, motor fan power on a variable air volume (VAV) system, and dimmable lighting fixtures. In these cases, both the energy use rate and the duration must be monitored. During commercial energy audits, data loggers typically monitor the rate of energy use for short periods; the total energy use is the sum of energy consumed during each monitored interval.



Information from multiple data loggers or concurrent building-automation system (BAS) data can be used to explore and establish relationships between different variables. Examples include relationships between cooling-energy use and outdoor air temperature, fan power in a VAV system as a function of return air temperature, economizer damper position, and indoor temperature as a function of time-of-day.

Understanding the nature of the load is fundamental to selecting the proper variables to measure and the appropriate measurement interval. The likely variation of the load, what drives that variation, and how quickly it varies all determine the selection of monitored points and measurement frequency.

Data Loggers in Building Performance Monitoring

Data loggers provide valuable information on building-system behavior that may not be available from the building-automation system (BAS) or where a BAS does not exist. They can also be used to confirm operation of the BAS itself as sensors or actuators may not be accurate or functional. Following are some of the most common building-performance applications where data loggers are needed (specific use cases are discussed later):

Commissioning & Retrocommissioning

Building commissioning (Cx), retrocommissioning (RCx), and monitoring-based commissioning (MBCx) are all variations of building-performance optimization. Modern buildings are complex and dynamic structures that rely on computer-based systems to control the heating, cooling, ventilation, lighting, and other critical systems. To minimize energy use and maximize comfort, these systems must work and continue to work properly.

LEED for Existing Buildings encourages initial and ongoing commissioning activities. Energy & Atmosphere credits 2.1, 2.2, and 2.3 all require investigation and diagnostics of a building's control system and HVAC equipment. Data loggers can supplement a control system or provide information on small buildings where control systems may not provide sufficient information.

HVAC System Diagnostics & Troubleshooting

Data loggers provide information to diagnose the cause of comfort complaints and HVAC system problems. Information from the building-automation system (BAS) may be unavailable or unreliable, requiring data loggers to observe system or building behavior.

Measurement & Verification

The International Performance Measurement & Verification Protocol (IPMVP), Federal Energy Management Program (FEMP) M&V Guidelines, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 14 define methods to determine savings from efficiency projects. IPMVP / FEMP Options A and B and Guideline 14 Retrofit Isolation rely heavily on data logger information to measure component and system performance.

IPMVP / FEMP Options A and B and Guideline 14 Retrofit Isolation rely heavily on data logger information to measure component and system performance.

LEED for New Construction Energy & Atmosphere credit 5: Measurement and Verification allows retrofit isolation (Option B) approaches to be used to verify energy use and performance of major building components.

Load Profiling & Load Disaggregation

Often, only the total building energy use is known but the load profile (load variation as a function of time) is not known. Data loggers can be used to observe a building load profile to determine when systems turn on and off or to compare the load to another variable such as temperature or occupancy. A building load profile is an integral part of calibrating a simulation model.

Systems that use the most energy represent the greatest efficiency opportunities. Determining energy use by function – lighting, cooling, fan, heating, plug loads – can identify cost-effective efficiency projects.

LEED for Existing Buildings Energy & Atmosphere credit 3.1: Performance Measurement —System Level Metering requires disaggregating the building load into its major components. If the existing building-automation system (BAS) is not adequate and expansion is being considered, monitoring different pieces of equipment can identify which points are the most cost-effective to connect to the BAS to achieve the required 40% or 80% monitoring rate.

Emerging Technology Research

The acceptance of new energy-efficient technologies into the marketplace is often hampered by lack of experience and supportable performance claims. People are skeptical of anything new. Data loggers can be used to monitor the performance of new and emerging technologies such as transpired solar collectors, occupancy-sensor thermostats, variable speed drives for unconventional applications, and anything with easily measured energy inputs or outputs.

Renewable Resource Assessment

Before installing expensive renewable energy systems, it may be helpful to identify the local resource. Although solar and wind resources are available from reliable sources, these values are usually regional long-term averages that have intentionally avoided local factors that may impair (or enhance) resource availability. Geographic features such as hills and valleys may alter wind resources at a specific site; local weather conditions or nearby buildings may affect the amount of solar radiation that can be effectively collected. Data-logging weather stations can be used for short-term monitoring to compare site-specific conditions relative to weather data from a nearby weather station. This provides information needed to determine local correction factors and assess the expected long-term performance potential of a system.

Applying Data Loggers

The diversity of available sensors and selection of measurement intervals make data loggers incredibly flexible. Almost any energy consuming device or comfort condition can be quantified. Following are some common examples.

HOBO U9 Light On/Off records light on and off status.

Lighting Systems

Lighting energy use is defined by two quantities: power (Watts) and operating hours. The power draw of individual lighting fixtures is easily measured, but operating hours are more difficult to establish. Estimated operating hours typically have large amounts of uncertainty either because schedules may not be known absolutely or because human behavior is somewhat random. Savings based on assumed operating hours are fine for assessing whether a project is economically feasible, but not for reporting actual savings to the end user.

For efficiency projects involving fixture upgrades only, savings are defined as:

$$kWh_{saved} = (\#\ fixtures)(1\ kW/1{,}000W)(W_{pre} - W_{post})(operating\ hours)$$

The assumption is made that the operating hours remain the same regardless of fixture type, so operating hours can be measured either before or after the upgrade.

For projects that include controls that reduce operating hours (occupancy sensors or BAS controls), savings are defined as:

$$kWh_{saved} = (\#\ fixtures)(1\ kW/1{,}000W)(W_{Pre} * OpHours_{Pre} - W_{post} * OpHours_{Post})$$

If operating hours are expected to change, it is necessary to separate the pre- and post-retrofit conditions to avoid double counting the savings. Where pre-retrofit operating hours cannot be reliably estimated, they should be measured.

In practice, lighting savings are calculated by taking a building lighting inventory and assigning each item to a space type with similar operating hours. Common space types might be open office, private office, conference room, common area, and storage. Time-of-use lighting loggers, such as Onset® HOBO® U9 Light On/Off loggers, are then deployed for two to four weeks to measure the operating hours of a sample of fixtures for each space type. The average operating hours for each space type are used in the previous equations to calculate the savings from each space type and ultimately from the entire building.

Because many HVAC components – fans, compressors, cooling towers, boilers – are variable load devices, data loggers provide valuable performance information.

Time-of-use lighting loggers record when the state changes between on and off. Translating this information into operating hours is easily accomplished with simple spreadsheet calculations. Allocating the operating hours into time-of-use or day-of week period is a little more difficult, but can also be done using spreadsheet calculations.

HVAC Performance

Because many HVAC components – fans, compressors, cooling towers, boilers – are variable load devices, data loggers provide valuable performance information.

Electrical loads are the easiest parameters to measure. Applications requiring thermal load quantification often require precision temperature sensors and flow meters to produce meaningful results.

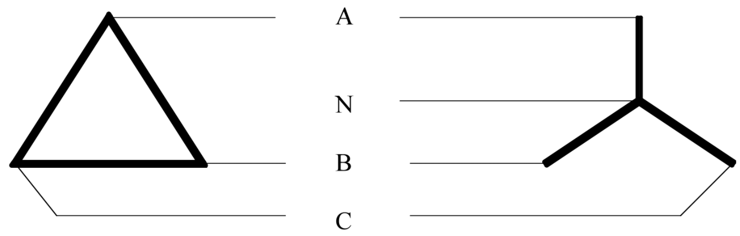
Calculating electrical power from measured values on direct current (DC) circuits is easy: power in Watts is equal to volts multiplied by current in Amperes. For alternating current (AC) circuits, the current is not always in phase with the voltage and the previous relationship is not exact. For inductive loads such as motors and magnetic ballasts, the current lags behind the voltage. This phase shift can be expressed in units called power factor, which provides the relationship between true power, voltage, and current. For single-phase AC circuits, the true power in Watts is:

$$P_{AC}\text{, Watts} = V * A * PF$$

Power factor of a motor ranges between 0.5 and 0.9 depending on the motor load. The power factor listed on the nameplate is at full-load conditions and decreases at less than full load. For this reason, motor measurements requiring accurate power values require simultaneous voltage and current measurements with an instrument that detects the phase shift between the voltage and current. If motor status or relative power will provide adequate information, current measurements are sufficient.

Another factor that complicates motor measurement is the presence of total harmonic distortion (THD). Switching power supplies such as those in variable speed drives, electronic ballasts, and computers produce a current waveform that is synchronized with the voltage but is ‘chopped’ at frequencies greater than 60 Hz. The presence of total harmonic distortion degrades the accuracy of some current transducers. Where accurate power measurements are required, use a true power transducer that can retain accuracy in the presence of THD.

Most motors greater than 5 HP use three-phase AC power. There are two configurations available: delta and wye. The delta configuration uses three conductors while the wye configuration uses four – the fourth conductor is the neutral.



In a delta configuration, voltage is measured line-to-line: V_{AB}, V_{BC}, V_{AC}. Because the instantaneous sum of all currents must be zero, only two currents (and their corresponding voltages) need to be measured using the third leg as the reference. In a wye configuration, voltage is measured line-to-neutral: V_{AN}, V_{BN}, V_{CN}.

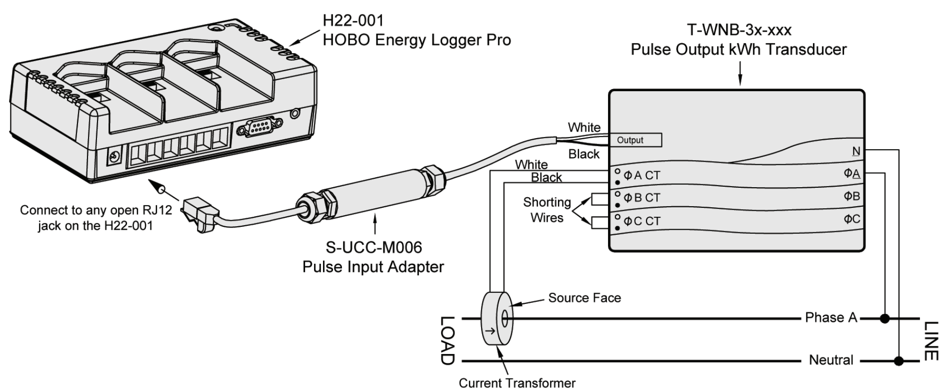
When working with individual motors, it may be acceptable to assume that the phases are balanced—all three voltages and currents are equal—but this assumption should be checked. If the phases are balanced, the measured line power in a delta circuit is:

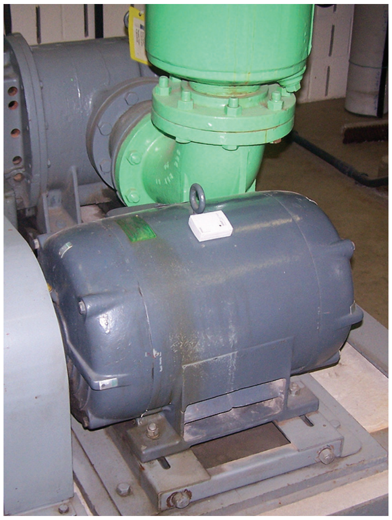
$$P_{total}, \text{Watts} = \sqrt{3} * \text{V line} * \text{A line} * \text{PF}$$

while for a wye circuit it is:

$$P_{total}, \text{Watts} = 3 * \text{V ph} * \text{A ph} * \text{PF}$$

The factors √3 and 3 are derived from the relationships between the phases. The presence of power factor means that monitoring voltage and current with separate data loggers will not provide accurate power measurements – a data logger such as the H22 HOBO Energy Logger with a kWh transducer must be used if high accuracy is required (see example below).





HOBO U9 Motor On/Off data logger records motor on/off status.

Motors

The easiest parameter to monitor is motor runtime. This can be accomplished by either using a vibration or magnetic field status data logger or by measuring the input current. A current sensor detects motor status and reports the data at defined intervals. When the current is greater than zero, the motor is considered “on.” Vibration and magnetic field loggers, such as Onset HOBO U9 State and Motor On/Off loggers, record when the state changes between on and off. Translating on/off recorded data from the logger into operating hours is accomplished with simple spreadsheet calculations. However, allocating operating hours into time-of-use or day-of-week periods requires supplemental manipulations.

While a building-automation system (BAS) reports the intended operational status of equipment, it is common to find equipment accidentally or intentionally bypassed. Data loggers provide independent assessment of actual status. They can be used to verify that air handlers are shutting off at night, determine compressor run time and staging sequence, measure boiler or furnace run time, and reveal problems with control logic such as having hot and chilled water pumps run simultaneously.

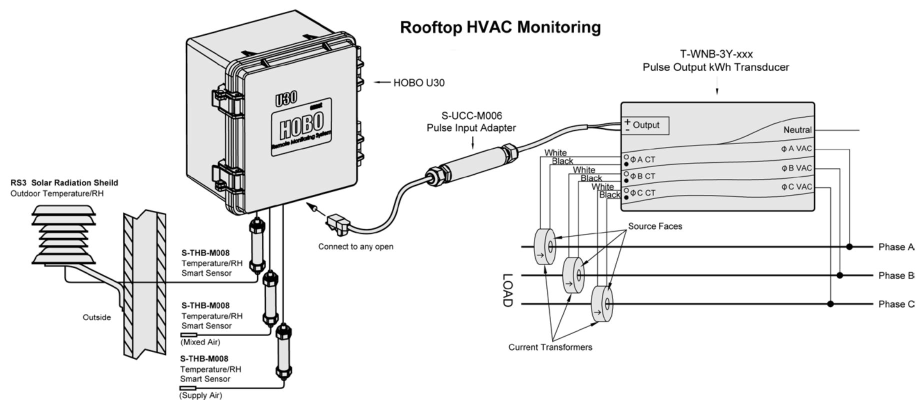
Rooftop Units

Rooftop units are often installed in buildings that lack building-automation systems. Monitoring the operating current will show the operating schedule (on/off) and differentiate between fan-only and cooling mode. The current may also indicate the number of operating compressors in a multi-compressor system.

Runtime and operating current increase at higher outdoor air temperatures. Some of this increase is due to greater cooling load and the balance is due to the condenser rejecting heat to a higher ambient temperature. Comparing the operating current to outside air temperature using statistical models can provide insight into how load changes with temperature. If statistically valid cooling load models are desired, then true power, rather than current, should be monitored using data loggers.

While it is theoretically possible to determine air-conditioning performance under real operating conditions, in practice this is very difficult. Where savings are to be estimated from rooftop unit replacement, it is common practice to use the manufacturer’s performance specifications coupled with monitored runtime or measured power.

Economizers can reduce or eliminate the need for mechanical cooling. When economizers do not work properly, they either miss opportunities to provide free cooling or they remain fully open and significantly increase cooling-energy use.

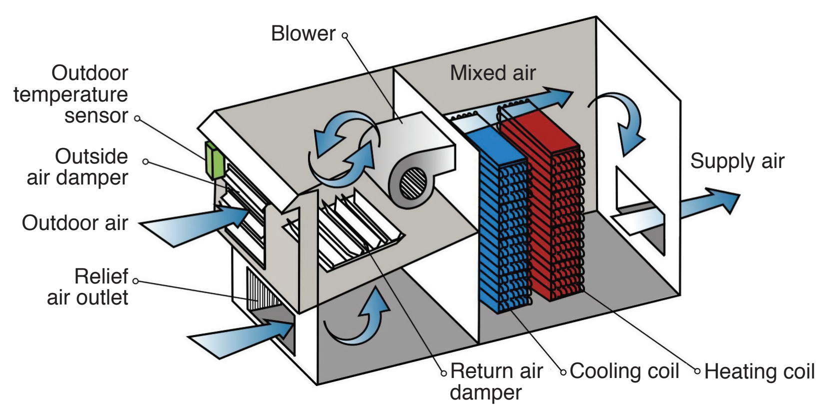


Supply Air Temperature

For energy efficiency reasons, the cooling supply air temperature may be modulated so that the coldest air is delivered when cooling load is the greatest. This strategy can improve chiller performance at part-load conditions and reduce the amount of reheat required in a variable air volume (VAV) system. If the BAS reported supply air temperatures cannot be trusted, data loggers with external temperature sensors placed in the duct work can report supply temperatures either at the air handler or the zone level.

Air Economizers

Large buildings with high internal loads often need to be cooled even when outside air temperatures are mild. Air-side economizers take advantage of cool air by replacing return air with outside air. Economizers can reduce or eliminate the need for mechanical cooling. When economizers do not work properly, they either miss opportunities to provide free cooling or they remain fully open and significantly increase cooling energy use. Improperly functioning economizers are a common source of energy waste, but fortunately are easily diagnosed and repaired.

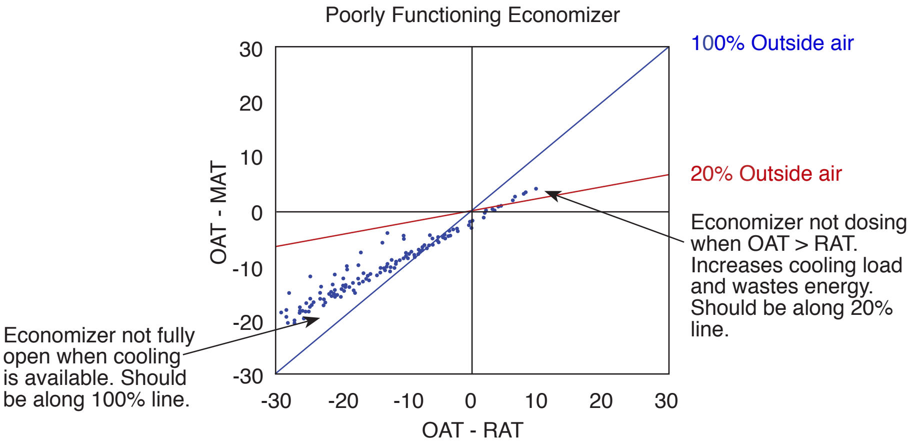


There are two types of economizer controls: temperature and enthalpy. Temperature-controlled economizers change status based on return supply and return air temperatures. Enthalpy-controlled economizers consider both outside air temperature and humidity and are preferred in humid climates.

Data loggers can be used to evaluate economizer performance requires monitoring temperatures at three points: return air (RAT), outside air (OAT), and mixed air (MAT). Instead of plotting three temperatures as a function of time, plot the difference between the outside air temperature and the mixed air temperature (OAT – MAT) as a function of the difference between outside air temperature and return air temperature (OAT - RAT). The slope of the resulting line is the outside air fraction (OAF), which is defined as:

OAF = (OAT-MAT) / (OAT – RAT).

When the economizer is functioning, it should be fully open and using 100% outside air when the outside air temperature is less than the return air temperature. This will appear as a line with a slope of 1. When the outside air temperature is greater than the return air temperature, the economizer will close to the minimum air position of approximately 20% - the actual value depends on the design minimum air quantity. Deviations from this control strategy indicate problems with temperature or humidity sensors, actuator linkages, leaky dampers, or improper control strategies. In the following example, the dampers are stuck in a single position that draws in about 50% outside air, indicating that the economizer is missing opportunities to provide free cooling when the air temperature is low enough and drawing in too much air when it is hot, unnecessarily increasing cooling load.



Inaccurate mixed air temperature measurement may indicate economizer problems where none exist. Air handlers rarely are configured to fully mix return and outside air ahead of the filter bank or cooling coil. Placement of the mixed air temperature sensor—either the BAS's or the data logger's—may bias the measurement. Where the design of the air handlers suggests that poor mixing may be a problem, it may be necessary to use data loggers with multiple sensors to measure the mixed air temperature.

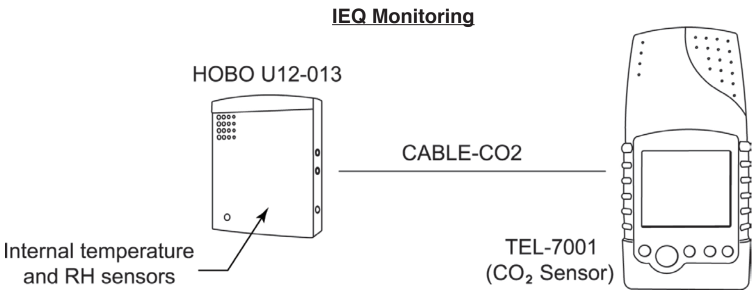
Indoor Environmental Quality

HOBO U12 data logger coupled with a Telaire 7001 sensor can monitor carbon dioxide concentrations in a building or room.

A common problem building owners and facility managers face is comfort complaints – it's too hot or too cold. Hot and cold are relative terms and no single temperature will ever satisfy everyone. Data loggers can be used to objectively assess what the temperature is and when, allowing an easy way to diagnose why space temperatures are deviating from acceptable values. A single data logger, such as an Onset HOBO U10 Temp/RH logger, recording every 15 minutes, could show problems with warm-up or cool-down in the morning, or show that solar gain is overheating a space in the later afternoon. A data logger measuring temperature at the ceiling, at chest height, and at the floor can quantify the extent of stratification caused by insufficient air movement or barriers like cubicle walls. Additional data loggers near the thermostat and inside the supply register could be used to verify that the thermostat is properly controlling the space temperature – or not – and that the correct air supply temperature is being delivered. Including humidity measurement in areas with humidity sources provides information on the ventilation or humidity control effectiveness.

ASHRAE Standard 62.1-2007 calls for specific amounts of outside air, ranging from 10 to 20 CFM per person, to be supplied to occupied spaces determined by building function. Design outside air quantities are based on expected peak occupancy, which may result in excess outside air when the building is not fully occupied.

Demand-controlled ventilation (DCV) that varies outside air based on occupancy is an improvement over fixed-rate ventilation. DCV systems measure the concentration of carbon dioxide in a building as an indicator of occupancy. DCV systems try to maintain a constant carbon dioxide level of approximately 1,000 ppm. Sensors such as the Telaire 7001 coupled with a HOBO U12 data logger can monitor carbon dioxide concentrations in a building or specific rooms and demonstrate whether a space is getting too much or too little outside air and when.



Monitoring Plans

Even though portable data loggers are typically inexpensive, it is not cost-effective to measure every piece of equipment that might be affected by an energy-efficiency or retrocommissioning project – there may be thousands of lighting fixtures or hundreds of variable air volume (VAV) control boxes. Nor is it practical to measure equipment for an entire year to determine baseline or operating characteristics. In typical commercial energy audits, it is far easier and cost-effective to measure a representative sample of equipment for several days or weeks and extrapolate the findings to the balance of the population and year. Following are some points to consider when developing your monitoring plan.

Sample size & selection

Sampling is a method of estimating a cost-effective number of items to measure in order to be assured that the results represent the entire population. The degree to which the measured samples represent the population is the *precision* (P). A precision of 20% indicates that the measured value is within ±20% of the true value. The corollary to precision is *confidence* (C), which indicates the repeatability of the measurement process. To access the reliability of a measurement, both the precision and the confidence need to be known. If a sampled measurement has a precision of 20% at 80% confidence, it means that there is an 80% probability that the measurement is within 20% of the true value. For any set of measurements, there is a trade-off between precision and confidence. Increasing the confidence decreases the precision. In the extreme, 100% confidence results in a meaningless precision.

Sampled measurements are often used to estimate lighting operating hours. Typical practice is to divide a facility into common usage groups with similar operating hours, each of which may still contain hundreds or thousands of lighting fixtures. However, most fixtures will operate on similar schedules, making sampled measurements a practical way to reliably estimate the behavior of the entire population. The number of samples required to meet any desired precision and confidence criteria is dependent on the variation within the usage group. Mathematically, this is known as the coefficient of variation (C_V) and is defined as:

$$C_V = \text{Standard deviation(hours)} / \text{average (hours)}$$

The problem with developing a sample size is that the coefficient of variation cannot be determined in advance. An educated guess about the likely C_V is necessary to determine an appropriate sample size. For lighting operating hours, a C_V of 0.5 is a good starting point, but for lights with occupancy sensor controllers, a C_V of 0.75 might be more realistic. The assumption of coefficient of variation will strongly influence sample size and ultimately measurement cost & effort.

For very large populations where 20% precision at 80% confidence is needed, the sample size (n) is calculated as:

$$n = 1.282^2 * CV^2 / 0.2^2$$

The result is rounded up to the nearest integer. (The value 1.282 corresponds to an 80% confidence level, 0.2 is 20%.) The following table shows the influence the assumed C_V has on sample size.

C_V:	0.25	0.5	0.75	1.0
Sample size (n):	3	11	24	42

When the measurements have been completed, the actual C_V can be calculated from the average and standard deviation. If the actual C_V is less than the assumed value, the desired precision and confidence levels were met. If not, the precision should be calculated based on the measured C_V and reported. The two most common errors in conducting a sampled measurement plan are:

1. Assuming an initial C_V that is not representative of the process being monitored; and,
2. Failing to calculate the actual C_V and resultant precision afterwards.

Selecting an initial C_V on which to base a sample size requires some knowledge and insight of the process being monitored. What works for lighting operating hours may be totally inappropriate for fixture power measurements. The result can be either too many samples (not cost-effective) or too much uncertainty in the results.

Failing to calculate the actual C_V and resultant precision from the monitoring results means that only half the job was completed. The assumed C_V was necessary to determine an initial sample size that meets the target precision and confidence level; it does not guarantee that those targets will be met.

There is no single monitoring duration that can be applied to all situations. In general, the monitoring duration should be long enough to capture the likely range of expected behavior, but not longer.

A more thorough discussion on sample-size determination, precision, and confidence is beyond the scope of this document. The three major measurement & verification guidelines (IPMVP, FEMP M&V Guidelines, and ASHRAE Guideline 14) all provide significantly more information on sampling plan development and evaluation.

Monitoring Duration

There is no single duration that can be applied to all situations. In general, the monitoring duration should be long enough to capture the likely range of expected behavior, but not longer. Building lighting operating hours could take as little as one week, unless that week happens to be during Christmas vacation. Select a monitoring period that is representative of typical behavior.

For systems that respond to weather-sensitive loads, it may take several weeks or several months to capture a full range of behavior. If full-load conditions are desired, then air-conditioners should be observed in the summer and furnaces in the winter. If part-load conditions are desired or acceptable, a spring or fall period might work.

Data Logger Installation

While data loggers are simple to operate and deploy, installation may require reaching in to live electrical cabinets or equipment with moving parts. Following are some safety and quality assurance guidelines to follow.

If you have any doubts about your ability to work in a live electrical cabinet, have a trained electrician install the data logger at your direction. You may also need to refer to your local building code as some states require the electrical work be performed by a licensed electrician.

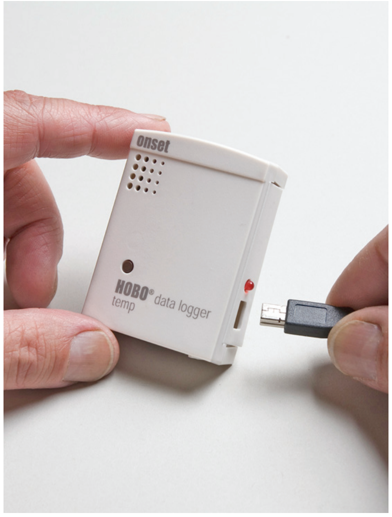
Safety

Current and true-power transducers may require installation in live electrical cabinets, offering the potential for lethal accidents. Current transducers do not require a physical connection with a conductor, but working in close proximity to unshielded connections is dangerous regardless of the voltage. True-power transducers require a physical connection to a conductor on each circuit phase. ALWAYS wear insulating gloves rated for at least 600 VAC and safety glasses when working in live electrical cabinets. *If you have any doubts about your ability to work in a live electrical cabinet, have a trained electrician install the data logger at your direction. You may also need to refer to your local building code as some states require the electrical work be performed by a licensed electrician.* NEVER work in a live electrical cabinet where more than 480 VAC may be present.

In some facilities, union shop or safety rules prohibit non-employees from working on any electrical equipment. Check with the supervisor or shop steward before proceeding with any logger installation. A complete discussion of electrical safety is beyond the scope of this document. Please refer to qualified safety instructors or licensed electricians for additional guidance.

Air handlers and rooftop units contain belt-driven rotating parts. Avoid working in any area where you could accidentally catch fingers, loose clothing, or equipment in moving parts. If the parts are stationary, do not assume that they will remain so unless the power has been removed. HVAC equipment starts and stops in response to external controls. Find another access point away from the moving parts or remove the power.

While personal safety is paramount, consider the safety of the data logger, sensors, and customer equipment as well. Secure data loggers and sensors with wire ties or electrical tape to prevent them from falling off and becoming tangled in moving equipment.



HOBO U10 temperature data logger

Quality Assurance and Secondary Measurements

Not every data logger installation will go perfectly – the wrong sensor (or setting) may be used during installation, sensors may be connected to the wrong wire or placed in the wrong location, or the actual value of the parameter may exceed the expected value.

When installing data loggers, it is useful to take live readings from the data logger to ensure that the logger is working and the sensors are connected properly. Or, if using a web-based energy logging system, it should be possible to simply log onto the Internet to remotely access system diagnostics and ensure proper system functionality. When monitoring true power, ensure that the current transducers are pointing in the correct direction and that the voltage probes are connected to the correct phase– it makes a difference!

Secondary measurements help ensure that the data logger is reading the correct value. When installing current or true-power transducers, take readings with a clamp-on ammeter or another (calibrated) true-power meter and note the exact time the reading was taken. This can then be compared to the downloaded data to ensure that the data logger reading is reliable. The same principle applies to temperature measurements.

Despite the steps taken above, problems may still arise. Download the data—at the site if possible—and observe the graph using accompanying graphing and analysis software, such as Onset HOBOware software. Does the data make sense? Do the observed values exceed the transducer capacity? Did a voltage probe fall off a terminal? Is the data all zeros? Identifying problems immediately allows corrective steps to be taken while on site.

HOBO U-Shuttle
Enables convenient, easy data offload from HOBO U-series, H21 and H22 data loggers

Data Evaluation

Specialized graphing and analysis software packages such as HOBOware® have many useful plotting and data evaluation features and can export data to other spreadsheet programs for additional manipulation and calculations. Following are some points to consider when interpreting collected data.

Most portable data loggers have accompanying graphing and analysis software that can be used to active and readout data loggers, and graph and analyze results.

Software applications such as Onset's HOBOware Pro software, provide a highly intuitive "point-and-click" interface that eliminates the need for programming. The user simply connects the data logger to a PC or Mac computer and the software automatically recognizes the device and asks a series of configuration questions. This includes setting a sampling interval and selecting an immediate or designated future logger activation time.

In terms of graphing and analyzing data, packages such as HOBOware allow you to analyze and extract key information from multiple data loggers with a few simple clicks, and combine multiple graphs to compare data between sites.

Software with alarm capabilities provide instant notification via cell phone or email if conditions exceed set thresholds. Data export capabilities are also provided for users that need to perform further data analysis using Microsoft Excel or other spreadsheet programs.

Data Manipulation in Excel

Microsoft Excel™ can combine data from multiple sources such as data loggers, and building-automation systems.

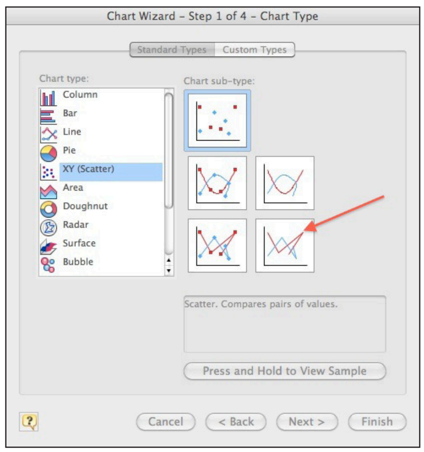
Graphing

Excel provides significant control over the display of data. The first step to creating a graph is to open the .CSV data file and select the time stamp plus the columns of interest— the observation number column is not needed. In the following example, the time, temperature, and relative humidity have been selected.

Using the first column of data as the X-axis value allows better scaling, selection of specific time periods, and the ability to add data with different date ranges and frequencies.

	A	B	C	D
1	Plot Title: 9675414			
2	#	Time, GMT-07:00	Temp, ºF()	RH, %()
3	1	12/25/09 11:15	67.413	27.848
4	2	12/25/09 11:30	67.928	27.132
5	3	12/25/09 11:45	68.142	26.232
6	4	12/25/09 12:00	68.828	26.534
7	5	12/25/09 12:15	69.213	26.377
8	6	12/25/09 12:30	69.6	27.944
9	7	12/25/09 12:45	69.3	28.703
10	8	12/25/09 13:00	68.4	28.428
11	9	12/25/09 13:15	67.5	28.556
12	10	12/25/09 13:30	67.627	29.063

Then select Insert > Chart or click on the Chart Wizard. Select type "XY (scatter)," sub-type line. This will make a graph that can be scaled and formatted much more easily than a graph made with the "line" graph option.

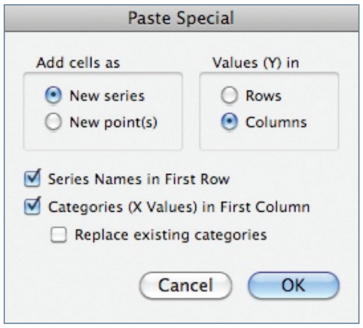


Microsoft® Excel screen shot

In Excel, a "line" graph is extremely limited in how it can represent data. It plots all observations sequentially without regard to the X value. This makes it impossible to scale the graph, select limited portions, or plot additional data with a different data collection frequency or start time. The "XY (scatter)" graph is a far better option. Using the first column of data as the X-axis value allows better scaling, selection of specific time periods, and the ability to add data with different date ranges and frequencies.

For example, to view just a portion of the data requires only changing the X-axis format and scale. Double-click on the x-axis and select "scale." The minimum and maximum will appear to be two numbers approximately 40,000 in magnitude – this is how Excel stores dates internally. (The date is the number of days since 1/1/1900). Simply enter the desired date range in MM/DD/YYYY format and Excel will make the conversion. If you want to set the major unit for 12 hours, use 0.5 (1/2 a day).

To add additional data to the graph – even data with a different observation frequency – copy the data of interest and include the time stamp in the left-most column. Then go to the graph and selected edit > paste special, and accept the default options.



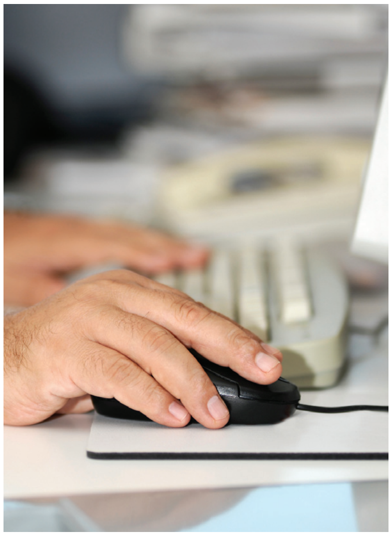
The new data will use the new time stamps on the plot so that all data points are aligned and synchronized with the X axis. Be certain that you save your work as an Excel file or you will lose your graphs!

Synchronizing Observations

A common situation is trying to work with data recorded at different intervals. For example, rooftop unit power measured in 15-minute increments is to be compared to hourly weather data. One approach is to expand the weather data to 15-minute intervals.

To expand the hourly data so that each 15-minute observation has a corresponding weather observation, the easiest approach is to use the VLOOKUP function. This is a database function that matches the time stamp in one column with the timestamp in another column and brings back the associated information. The function takes the form VLOOKUP (lookup value, lookup array, column, type). In the following example, the VLOOKUP function is used to align 15-minute temperature observations with hourly weather data.

	A	B	C	D	E	F	G
1	Recorded Data from Hobo				Data from Weather File		
2	Time, GMT-07:00	Temp, ºF()	Wet Bulb Temp, ºF()		Date/Time	Wet Bulb Temp, ºF()	
3	12/25/09 11:15	67.4	=VLOOKUP(A3,$3:$F$60,2,TRUE)		12/25/09 12:00	31.4	
4	12/25/09 11:30	67.9	#N/A		12/25/09 13:00	34.8	
5	12/25/09 11:45	68.1	#N/A		12/25/09 14:00	33.4	
6	12/25/09 12:00	68.8	31.4		12/25/09 15:00	33.9	
7	12/25/09 12:15	69.2	31.4		12/25/09 16:00	37.1	
8	12/25/09 12:30	69.6	31.4		12/25/09 17:00	36.8	
9	12/25/09 12:45	69.3	31.4		12/25/09 18:00	37.8	
10	12/25/09 13:00	68.4	34.8		12/25/09 19:00	39.6	
11	12/25/09 13:15	67.5	34.8		12/25/09 20:00	39.6	
12	12/25/09 13:30	67.6	34.8		12/25/09 21:00	40.3	
13	12/25/09 13:45	68.6	34.8		12/25/09 22:00	39.8	
14	12/25/09 14:00	69	33.4		12/25/09 23:00	35.9	



The VLOOKUP function in cell C3 takes the timestamp in A3 and finds the closest value greater than the timestamp in the array E3:F60. (The "$" signs keep the array the same when pasting the equation into other cells.) The "2" tells the function to return the value in the second column; the TRUE tells the function that the array is sorted and that it is acceptable to return the closest value rather than an exact match. The first few cells return "#N/A" because the original timestamp values are less than those in the array.

Analyzing Runtime Data

Data loggers that record runtime, such as the HOBO U9 Series (lighting, motors), do not measure variables at defined intervals. Instead, they record the time when the state changes between on and off. Because of the random nature of state changes, calculations and graphing can be a little more difficult.

Since we are usually interested in the "on" time, calculate the interval between the previous "on" state and the current "off" state. In the following example, the cells in column C test to see whether the state is "on" or "off." If the current state is off, the interval is simply the "off" time minus the "on" time. Multiplying the difference by 24 returns the result in hours, which are then totaled. The double-quotes in the last field tell the IF statement to return a blank value, which is ignored when the values are summed.

	A	B	C	D	E
1	Date/Time	State			
2	6/17/09 15:56	OFF			
3	6/19/09 17:27	ON	=IF(B3="OFF",24*(A3-A2),"")		
4	6/19/09 21:09	OFF	3.7		
5	6/19/09 21:21	ON			
6	6/19/09 22:47	OFF	1.4		
7	6/20/09 0:31	ON			
8	6/20/09 1:10	OFF	0.7		
9	6/20/09 2:56	ON			
10	6/20/09 3:26	OFF	0.5		
11		Total Hours	6.3		

Allocating "on" times into specific periods (occupied/unoccupied or weekday/weekend) is complicated by the fact that the "on" state can be any duration and may span more than one period. One way to accomplish this is to use the VLOOKUP function to synchronize observation, as discussed previously. Create a column of time stamps in hourly (or other) intervals and use the VLOOKUP function to return the on/off status.

Common Equations

Other useful manipulations include condensing data into hourly (or daily) values, segregating into weekend or unoccupied periods, and determining whether a motor is on or off. Excel provides the following functions that extract information from the timestamp fields, make comparisons to other values, and combine results using Boolean operators.

Value	Purpose
=WEEKDAY(date, type)	Returns a value from 1 through 7 depending on the day of the week. Type 1: Sunday = 1, Type 2: Monday =1
=HOUR(timestamp)	Returns the integer hour (0-23)
=VLOOKUP(value, array, column, type)	Returns value in an array corresponding to the lookup value. The column number refers to the column in which the desired data reside. Type is TRUE if the array data is sorted. The function will return the closest match. Type is FALSE if the array data are not sorted. Only exact matches will be returned.
=IF(condition, value if true, value if false)	Perform logical test using =, >, <, >=, or <= conditions. Both text and numerical values are allowed. Use double-quotes “” to represent an empty field.
=AND(logical 1, logical 2,…)	Combine logical results returning TRUE if all logical statements are TRUE
=OR(logical 1, logical 2…)	Combine logical results returning TRUE if any logical statement is TRUE

For example, to differentiate observations between occupied and unoccupied periods, add columns that determine whether the day of the week is a weekend or weekday and whether the building is occupied based on the hour. In the following example, the building is occupied Monday through Friday from 8 AM to 5 PM. The “weekday” column tests to see if the day is Monday through Friday, the “Hour” column tests to see if the hour is between 8 AM and 5 PM, and the “Occupied” column combines the logical results to determine if the corresponding observation occurs Monday through Friday between 8 AM and 5 PM.

	A	B	C	D	E	F	G
1	Time, GMT-0700	Weekday	Hour	Occupied			
2	1/1/10 12:00	=(WEEKDAY(A2,2)<6,TRUE,FALSE)					
3	1/2/10 12:00	FALSE	=AND(IF(HOUR(A3)>=8,TRUE,FALSE),IF(HOUR(A3)<=17,TRUE,FALSE))				
4	1/3/10 12:00	FALSE	TRUE	=AND(B4,C4)			
5	1/4/10 12:00	TRUE	TRUE	TRUE			
6	1/5/10 12:00	TRUE	TRUE	TRUE			
7	1/6/10 12:00	TRUE	TRUE	TRUE			
8	1/7/10 12:00	TRUE	TRUE	TRUE			
9	1/8/10 12:00	TRUE	TRUE	TRUE			
10	1/9/10 12:00	TRUE	TRUE	TRUE			
11	1/10/10 12:00	FALSE	TRUE	FALSE			
12	1/11/10 6:00	FALSE	TRUE	FALSE			
13	1/11/10 7:00	TRUE	FALSE	FALSE			
14	1/11/10 8:00	TRUE	FALSE	FALSE			
15	1/11/10 9:00	TRUE	TRUE	TRUE			
16	1/11/10 10:00	TRUE	TRUE	TRUE			
17	1/11/10 11:00	TRUE	TRUE	TRUE			
18	1/11/10 12:00	TRUE	TRUE	TRUE			
19	1/11/10 13:00	TRUE	TRUE	TRUE			
20	1/11/10 14:00	TRUE	TRUE	TRUE			
21	1/11/10 15:00	TRUE	TRUE	TRUE			
22	1/11/10 16:00	TRUE	TRUE	TRUE			
23	1/11/10 17:00	TRUE	TRUE	TRUE			
24	1/11/10 18:00	TRUE	FALSE	FALSE			
25	1/11/10 19:00	TRUE	FALSE	FALSE			

To calculate average, maximum, minimum, number of observations, or standard deviation values by occupied / unoccupied periods, learn to use pivot tables within Excel. Pivot Tables segregate a dataset by user-defined fields and perform arithmetic calculations on each group. A discussion of pivot tables is beyond the scope of this document.

Choosing Data Loggers

Data loggers, of course, are not all the same and with so many choices available today, it can be challenging to know which one is right for your application. Following are some important factors to consider when evaluating data loggers.

Accuracy specifications vary widely among different data loggers, so when shopping around be sure to look for accuracy charts that indicate accuracy over an entire measurement range – not just a single value.

Measurement Accuracy

Once you know what parameters you'll be measuring, you need to make sure to choose a data logger that provides the accuracy you need. Accuracy specifications vary widely among different data loggers, so when shopping around be sure to look for accuracy charts that indicate accuracy over an entire measurement range – not just a single value. As a general rule, it's good to look for a data logger that will provide at least twice the accuracy of what your application requires.

Another important factor is data logger resolution, which refers to the number of increments of a value a data logger is capable of reporting. This is important if you plan to deploy a logger for months at a time, or want the logger to record data in 10-second intervals. You should also ask about a logger's response time.

If you're unsure about your application's accuracy and resolution requirements, an experienced supplier should be able to help you determine which product will meet your needs.

Software and Ease of Configuration

All data loggers use software for setup and configuration, but some loggers require more customization than others. User-friendly loggers can be set up and launched by someone with no training in electrical wiring or programming.

The user just connects the logger to a PC and the accompanying logger software automatically recognizes the device and asks a series of configuration questions. The user simply chooses a sampling interval and selects an immediate or designated future launch time. There is no wiring or programming involved, even for multi-component weather stations.

Ask about the software that comes with the data logger. Applications are generally Windows-based, but some manufacturers also make Macintosh versions. The software should enable you to quickly and easily perform tasks such as setting configuration parameters, designating launch times, and off-loading data with point-and-click simplicity.

Check the software's graphing and analysis capabilities, including whether you can combine graphs to compare data between sites, or if you can view all of a site's data clearly in a single graph. Depending on the scope and type of data, the manufacturer may also have special application-specific software available.

There are a number of other capabilities to look for. For example, the software should allow you to select a range of data in a graph, and display the maximum, minimum, average and standard deviation for the measurements in that range. It should also allow you to save data analysis projects for future use.

Finally, since data often needs to be passed into other software programs such as spreadsheets or modeling programs, make sure that the logger software allows you to quickly and easily export data with the click of a mouse. Also be sure that you can print graphs and tables, which is especially important for documentation purposes.

Battery Life

Data loggers are generally extremely low-power devices. However, because they are used in a variety of environmental conditions and sample at different rates, battery life can vary widely. As a general rule of thumb, make sure the data logger you select has a battery life of at least one year.

Most logger manufacturers' software will indicate when the logger's battery power is getting low. You may also want to ask your supplier about whether or not the data logger battery is user-replaceable, as this can eliminate the time and expense of having to ship the logger back to the manufacturer for battery replacement.

Memory

The storage capacity of a data logger can vary widely between models. In general, be sure to buy a logger that provides enough on-board memory to cover the sampling rate and deployment duration you need. If you are unsure of how often you will be able to offload and relaunch your deployed data loggers, it may be best to buy a logger with more memory to prevent any gaps in data.

Cost of Ownership

Today's battery-powered data logging devices are very reasonably priced, and can be a real value if you plan to use them over and over again in multiple applications. It is, however, important to look closely at the total cost of ownership when shopping around. Will the logger need to be periodically calibrated by the manufacturer, and if so, how much will it cost over time? How much does the software cost? How much will you have to spend on cables and structural components for a weather station? Asking these questions will help you understand the true cost of owning the data logger over the long-term.

Product Support

Data loggers should be easy to use and not require a great deal of technical assistance. However, as with any high-tech product, there will always be questions.

Seek out a supplier offering a range of product support services. These often start with the initial assessment of your application requirements, and should include telephone and internet-based support resources.

Does a potential supplier have the track record and financial stability to maintain its role as a long-term solutions provider? Be assured that the company will be there to meet your future data logging requirements. Finally, ask the supplier for application notes and other references to gain a sense for how its loggers perform in applications similar to yours.

Onset welcomes comments, suggestions and questions about applications of its data loggers to specific building performance applications. Comments and questions will be used to improve future versions of this guide. Please direct inquiries to comments@onsetcomp.com or 508-759-9500.

About Onset

Onset is the world's leading supplier of data loggers. HOBO data loggers and remote monitoring systems can be rapidly deployed in a building performance monitoring applications, including energy audits, Measurement & Verification, building commissioning and indoor air quality studies.

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

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