Data Logger Essentials

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Synopsis

The presentation that accompanies this paper will include a practical hands-on approach to the use of stand-alone data loggers including selection, use and data analysis. The presentation will review the various types of logging equipment and what to look for when purchasing. Typical sensors and sensor application will be reviewed. Techniques for proper deployment and recovery will be included. The effective use of data loggers in conjunction with building automation trend logging systems will be discussed. Data analysis tools such as Microsoft Excel will be demonstrated including a discussion on various file formats. By providing the audience with specific procedures and techniques they will come away with skills to aid them in the efficient and effective use of data loggers to analyze building performance.

The presentation will be based on the presenter's 20 years of practical experience using data acquisition and analysis equipment to analyze a wide variety of systems for industrial, aerospace and commercial applications.

Data loggers are powerful analysis tools that can be used to evaluate complex building relationships and solve control problems. Data loggers and the subsequent analysis of thousands of points of data can also be a huge waste of time if improperly applied. There are standard procedures and techniques that can help assure that the data logging tools are used for maximum effectiveness.

About the Author

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He has over 20 years experience in facilities management, project management and utility management. For the first six years of his professional career, Bryan worked as a Mechanical Engineer for Chevron Oil Company then Boeing Aerospace. In these roles he acquired extensive experience with sophisticated maintenance management programs, computerized data acquisition & controls and test procedure development. He then served 10 years as Project Engineer and Director of Maintenance and Operations for the South Kitsap and Auburn School Districts.

Bryan has extensive experience in the fields of computerized building management systems, utility/energy management systems, maintenance management systems, test procedure development, and facilities operations. He has been involved with building commissioning since 1989 and a full time commissioning provider since 1999.

Bryan has presented on commissioning to a variety of audiences including ASHRAE, CSI, CEFPI, the 2000 National Workshop on State Building Energy Codes and the 2001, 2002, 2003 and 2004 National Conference on Building Commissioning. He is the chairperson for the BCA Certification Committee and now leads the Building Commissioning Certification Board responsible for review and approval of BCA Certified Commissioning Professionals.

Introduction to Loggers

A Brief (and Unofficial) History of Data Loggers

Who knows when the first data logging began? Perhaps it was a cave dweller marking the days of winter on the cave wall with a burned stick to know how many days were left before they could leave the cave. Certainly the most likely first method of data logging was hand logging the information in some written media, stone, bark, skins, papyrus then eventually paper. The Roman's logged celestial activity and tried to predict future events. The concept has remained the same from the beginning, record information regarding a physical property, analyze that information then make predictions or draw conclusions from the patterns observed.

Hand logging data is still a valid and much used method. It has the advantage of being easy to set up and can be spontaneous should the need for recording data arise unexpectedly. It has many disadvantages including being labor intensive, prone to reading errors, limited number of parameters, limited rate of sampling (how fast can you write?) and cumbersome to translate into graphical representations.

In the early era of industrial development, a common form of logging device was the strip recorder. These devices use rolls or wheels of paper traveling at a fixed speed and a pen arm that moves proportionally in response to a measured parameter to draw a graph on the paper. More advanced units included multiple channels with multi-color pens for recording more than one measured parameter. A typical oil refinery control room for example would have dozens of strip recorders to record the critical temperatures, pressures and flow rates for the refining process in the plant.

Strip chart recorders are still in use for some applications. It has the advantage of being a true analog graphing device which is capable of responding nearly instantaneously to the input which is important for some types of rapidly changing data. The strip recorder provides real-time output and creates the graph all in one operation so there is no downloading, data manipulation or graphing required. Disadvantages include having limited number of channels, bulky logging devices, required paper changes, pens running dry, pens leaking, bulky storage of recordings and cumbersome transfer of data to other media.

With the evolution of the computer came the ability to record and store data in digital form. As with so many things, the constant progress in miniaturization, the micro computer and inexpensive memory has resulted in continuous new developments in the data logging industry. Some of the early computerized logging systems were not particularly portable and were very expensive. They typically were not a unitary device, but built up out of several devices. The devices were typically rack mounted in a centralized location, requiring long wires to be routed from the logging equipment to the sensed environment. A channel bank would multiplex the various sensors into a signal processor to convert the analog signal to a digital value. A mainframe computer managed the data for display on a CRT, mass storage and printing. Early print devices were fairly limited and pen plotters where needed for graphics. Figure A is a schematic of the basic layout of an early computerized data logging system. Costs for these systems ran in the tens of thousands of dollars, which equates to a per-channel cost in the thousands of dollars.

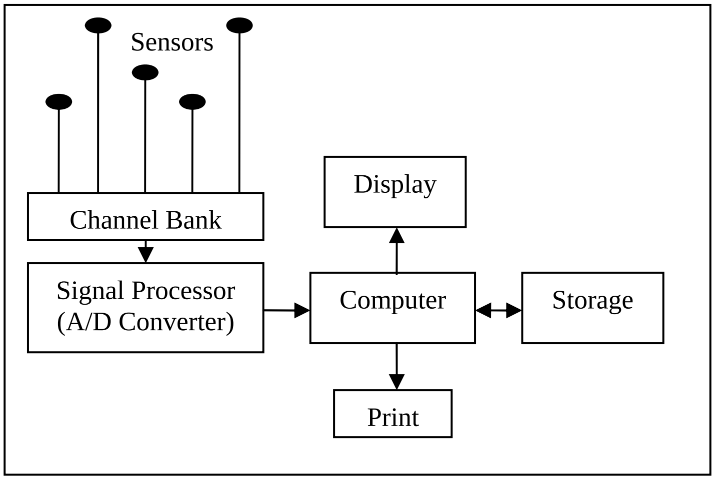


Figure A: Early Computerized Data Logging System

As computer systems evolved, the logging devices became more consolidated in function and form. The channel bank, signal processor, storage and display could be contained in one relatively compact portable device. The unit still had to be located relatively close to the environments to be monitored and the sensor wires run back to a central location. In the mid 80's, bench top logging devices were available. Some units came with the capability to connect directly to a printer. When the data logging was complete, the data was typically transferred through a serial cable to a PC for storage, analysis and reporting. The applications for downloading the data generally had fairly limited data manipulation and graphing tools so use of other applications such as MS Excel were frequently used to provide reports and graphs. A good quality 20-channel bench top logger cost about $5K, which equates to a cost of about $250 per channel (mid 80's dollars). Figure B is a schematic of the basic layout of a bench top data logging system.

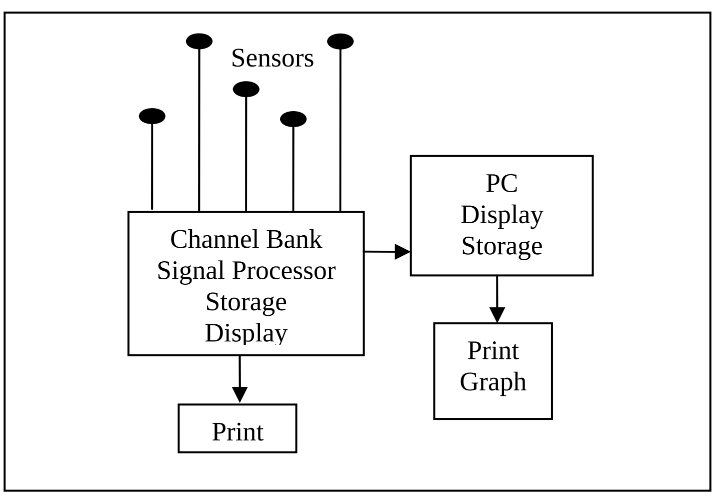


Figure B: Bench Top Data Logger

The continued evolution of miniaturization, micro-processors and the sharp drop in the cost for memory chips made possible the stand-alone data loggers available today. In these devices, the sensors, signal processor and storage are all combined in very compact cases. A channel bank is no longer needed. Figure C is a schematic of the basic layout of a stand-alone data logging system. Some units contain only internal sensors while others have the option to have external sensors attached. Some units have built in LCD displays and others connect to PDAs for quick in-field download and reading. There are versions that can be linked together in a network to form a distributed data acquisition system. The devices can be located virtually anywhere so as to be located in, or right next to, the environment that is to be monitored. Data can be downloaded via USB, radio or optical systems to a PC. The data analysis software available from the logger provider can be extremely powerful and flexible. A single logger can have 3 or 4 sensors and cost less than $100 for a cost of about $25 per channel. This makes it economical to have many stand-alone data loggers distributed in the environment running few or no wires.

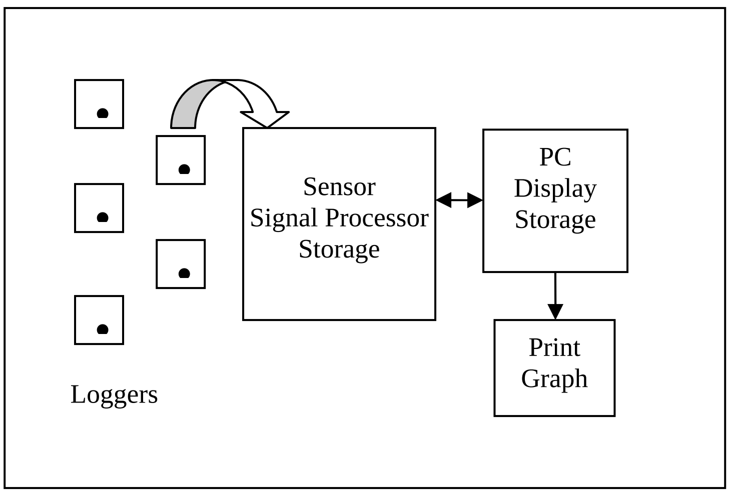


Figure C: Stand Alone Data Loggers

Interestingly, logging systems are available in all the basic forms previously discussed; from a pencil and paper to incredibly small and powerful stand-alone data loggers and anything in between. With the exception of the pencil, the modern versions are orders-of-magnitude more powerful, more compact, more feature-filled and less expensive then just a few decades ago.

Building Automation Systems (BAS) have also benefited from advancements in electronics. The first computerized BAS had very limited or no trend logging capabilities. When trend logging features were added, slow networking and limited memory in the terminal controllers significantly limited the amount and quality of the data. Modern BAS equipment and supporting software generally lack the refinements of a good data logging system, but do provide a very powerful troubleshooting and analysis tool for the commissioning provider.

The best data logging system for any given application is dependent on many factors. This discussion focuses on stand-alone data loggers in conjunction with the logging capabilities of the BAS in the context of use by a commissioning provider.

Data Logging Applications

Two of the most common reasons for using data logging in building commissioning is to demonstrate performance or for system troubleshooting. The following are some common performance demonstration and trouble shooting scenarios.

Performance

- Log occupied space environmental parameters (temperature, RH, CO2, lighting, noise) to demonstrate that the facility meets the contract requirements for the purposes of acceptance. This is generally straightforward, the system either meets the requirements or it does not.
- Log occupied space environmental parameters to demonstrate to an occupant that their environment meets standards. This can be more complicated, as even faced with hard data, some people will feel that the space is not adequate.
- Log overall building or specific system energy use to prove energy savings in support of a Utility funded project, therefore receiving grants or funding. In this case it is critical to have a highly accurate approach as considerable money can be involved.
- Energy use logging to support a Monitoring & Verification Plan to qualify for a USGBC LEED point.

Troubleshooting

- Logging occupied spaces and system parameters to evaluate why a space is having (confirmed) environmental control problems.
- Log space temperature at various distances from the ceiling to evaluate stratification and short-circuiting problems.
- Log duct static pressure, hydronic loop differential pressure or HVAC unit discharge temperature to evaluate and adjust system loop tuning and response.
- Log building static pressure and various HVAC equipment parameters to evaluate why the building static pressure fluctuates all the time to the point of slamming doors or blowing them open.
- Log economizer damper positions and various HVAC temperatures and parameters to evaluate causes for high energy use, occupant comfort problems or other problems.
- Log economizers to verify warm-up period and optimum start/stop functions.
- Log system and component start/stop times to verify scheduling.
- Log lighting controls for conformance to schedule, light levels and occupancy.
- Log heating and chilled water plant parameters to evaluate causes of high energy use and poor performance.

Data loggers are designed to measure and record a variety of characteristics of the physical environment. The following are typical physical characteristics related to building commissioning that may need to be trended to troubleshoot or evaluate the performance of a building system. This list though fairly extensive, is not intended to list all characteristics that may need to be logged. There exists such a broad range of sensors and loggers that the practitioner is free to use their creativity to meet the needs of any particular situation.

Temperature – (deg C or F)
- Heating water
- Steam
- Chilled water
- Condenser water
- Domestic water
- Conditioned space air
- Conditioned air
- Outside air

Relative Humidity (%RH)
- Conditioned space air
- Conditioned air
- Outside air

CO2 (ppm)
- Occupied space air
- Outside air

Pressure (psi, inches WC)
- Hydronic loop differential
- Steam
- Conditioned space differential air
- Duct static air
- Building static air
- Water tank depth

Light Level (foot candle)
- Occupied space
- Ambient sun
- Work surface

Current (amps)
- Building feed
- Equipment feed
- Power quality
- Mili-Amp signal for sensors

Potential (volts)
- Building feed
- Equipment feed
- Power quality
- Mili-Volt signal for sensors

Resistance (ohms)
- Resistance temperature devices
- Resistance signal for sensors

Sound (db)
- Occupied spaces
- Ambient noise pollution

Light Level (foot candle)
- Occupied space
- Ambient sun
- Work surface

Pulse (on/off)
- Power meters
- Gas meters
- Water meters

Binary Function (on/off)
- Occupancy sensor
- Photo cell
- Motor Start/Stop
- Flow switch

Miscellaneous Sensors
- Rain gage
- Liquid flow
- Air flow

Selection

There are more choices for data logging systems then ever before. This provides great opportunities for the user, but at the same time it can be a daunting task to choose from the myriad of systems available. Some characteristics have direct trade-offs such as precision and cost, generally the greater the precision the higher the cost. There is also generally a tradeoff between systems that are more universally applicable compared to those designed for a specific application. For example, a power quality data logger with three current sensors and three voltage inputs are excellent for power quality and energy use evaluation but are not particularly flexible for other applications.

Thankfully though, most characteristics of loggers are not mutually exclusive so it is a matter of finding the system that best meets your needs. In this section is a list of selection criteria with associated considerations that can be used as a decision making tool in the selection process. Take the characteristics that are important and enter them in the first column of a table. Enter the various logger systems in the column headings to create an evaluation matrix. Rate each system by category and select the one that most closely matches the requirements.

Selection Criteria

What parameters will be measured? What environment will the logger be subjected to? Will this application be for a specific highly specialized purpose, or should the system be capable of multiple applications? These are some questions that should be answered first to narrow the very broad range of available systems down to a more manageable group.

<u>Sensor and Input Configuration:</u> Will the device be dedicated to a specific sensor or input type or will it be more universal. There are some very inexpensive loggers that simply measure air temperature and relative humidity via internal sensors and have no capability to log any other parameter. Because they are so inexpensive, a logging project can use many of these sensors in a distributed fashion.

Some loggers have no internal sensors and are equipped with various input jacks or terminals for external sensors. These inputs can be dedicated to one type of device, such as a thermocouple, or be more universal and accept resistance temperature devices, 4-20mA, 0-10VDC, etc. for use with a wide variety of different sensors. Some loggers have both internal sensors and inputs for external sensors. Each type has various advantages and the best one will depend on the specific application. Generally the most universally useful units for building commissioning are the type with both internal and external sensors. If the logger is to have inputs for external sensors, how many and what type will they be? Will it use jacks or screw terminals?

There are a wide variety of sensors that can be used in conjunction with data logging systems. The following is a list of common sensors that are useful for building commissioning:

Sensor	**Parameter**	**Signal**
Resistance Temperature Device (RTD)	Temperature	Resistance (ohms0
Thermocouple	Temperature (precision)	Mili-Volts
-0.5” to 0.5” W.C. Pressure Transducer	Building Static Pressure in inches water column	4-20 Mili-Amp or 0-10 VDC
Humidistat	Relative humidity (%RH)	4-20 Mili-Amp or 0-10 VDC
CO2 Meter	CO2 concentration in PPM	4-20 Mili-Amp or 0-10 VDC
Light Meter	Lighting level (Lumens)	4-20 Mili-Amp or 0-10 VDC
Current Transformer	Electric current (amps)	Mili-Amps

Engineering Units: For loggers that accept an analog signal from a generic device such as 4-20mA or 0-10VDC the ability to program and record data in actual engineering units is an extremely valuable feature. Some loggers will only log the raw parameter (Mili-Amps) and the user must either just use that data as-is for interpretation purposes or the data will require manipulation to convert it to the actual engineering units (ppm CO2).

Cost: One of the most obvious considerations is that everyone has a budget. The cost can be a function of the application, accuracy and number of sensors. Generally it will be an exercise in finding the best bang for the buck, the unit with the most capabilities at the least cost.

Size: Most units are so small that this is likely not an issue, particularly for building commissioning applications. Some applications like food processing require the units get processed right along with the food inside the containers. These require highly miniaturized units to fit in the containers.

Mounting: This can be important depending on your application. You may need a watertight enclosure. Many units simply come with a hole in the case for hanging via a screw or a wire. Some units come with a magnetic back, which is generally very handy for HVAC work as there is almost always some steel around. The application will generally dictate the mounting needs.

Accuracy: There are three basic areas of accuracy; the sensor, the logging device receiver (A/D converter) and the number of bits the logger uses. Each type of sensor has a built-in level of error so that the signal they produce is off by that amount regardless of the measuring device. Any receiving device whether a logging device or just a readout has a built-in level of error in its ability to take an analog signal and convert it to a digital signal. These first two errors combine to form the overall input error. The last level of accuracy has to do with the number of bits the logger uses to store the data. The digital representation of analog data is discrete numerical values that jump instantaneously by an increment proportional to the number of bits used to represent the data. What looks like a smooth analog graph will appear “stair-stepped” when it is zoomed in on. If the level of precision requires a very fine resolution, then a higher bit logger will be needed. For the application, determine what level of accuracy and precision are required and only consider sensor and logger applications that meet these needs.

Calibration and Traceability: Will there be a requirement to have the ability to field calibrate the instruments or will they require factory calibration or have no calibration capability? Most systems today are fairly accurate and calibration and traceability can be costly. Many of the applications for building commissioning do not require extremely high accuracy, so depending on the specific needs, having no calibration capability may be a good trade-off to low cost. Even without the ability to calibrate a device, its calibration can (and should be) verified in the field by subjecting it to a known physical standard. For some applications, traceability to a recognized calibration source is required. In these cases, only equipment providers with the required traceability certifications should be considered.

Real Time Readout: Frequently, for building commissioning applications, having a real time reading is not a critical requirement. For some applications it is desirable to monitor the data in real time. Some units come with an LCD screen that can accomplish this. Some units can be connected via the downloading cable and the data stream monitored via the provided software on a portable computer.

Recording Indicator: This is a very important feature. Regardless of how carefully the logging plan has been executed, there is nothing worse than finding out there is no data in the unit upon download. The unit should be equipped with an indicating device to signal the user that logging is occurring.

Recording Interval: The recording interval is the time between each recording of data. Small recording intervals are needed to capture events that change rapidly. The shorter the interval, the more data points are taken and the faster the memory is used up. Most modern loggers have minimum intervals of 5 seconds or less which is typically more than adequate for most building commissioning logging activities. This is because most parameters in a building don't change that fast. Each application should be evaluated to be sure the minimum available recording rate will meet the requirements.

Storage Capacity: This is typically measured by the total number of samples the device can record. Most systems can now log into the tens of thousands of samples so this is usually not an issue, but should always be considered in the selection process.

Memory Type: Most systems (and the least expensive) use an internal memory chip and the logging device is plugged directly into the computer for data down load. Some loggers use flash memory cards so the data can be stored on the portable media and no connecting cables are needed.

Software: Often data loggers are mistakenly selected based on the merits of the device only, without looking very closely at the software that is needed for download and analysis. This software is generally proprietary in nature and the data logger is useless without it. The software is used to configure, launch and recover data from the logger. The software also can be used to view, analyze and report on the data. Most of the software is good at configuring, launching and recovering data from the loggers but often fall short in the analyses and reporting areas. For this reason, it is important for the logger software to have good exporting capabilities so that other software can be used for the data analysis. Evaluation of software is an entire discussion in and of itself and will not be fully explored here. A good approach is to get a demo of the software or use someone else's setup to get a hands-on feel for what it can do.

Connectivity: What method of connection will be used to collect the data from the logging device? The most common is the USB cable and it is typically sufficient for most applications. Some units use infrared or other wireless protocols. Units that use flash memory don't require a cable. Some units plug directly into a computer or PDA eliminating the wires.

Networking: Some data loggers have the ability to be networked. This allows the devices to be configured, launched, monitored and uploaded from one point. Complex data acquisition networks can be built around this strategy that have many of the advantages of both a distributed system and a centralized system while at the same time having few of the disadvantages of each.

Starting Options: There are typically several options for starting the beginning of the logging period; instantly after download, at a pre-determined time, event driven and via a manual input (push button). Systems that have all these capabilities are generally preferred to be the most flexible, but push button and launching at a scheduled time are the most important. These two features allow the operator to most easily coordinate the logging activities with the trend logging system or other logging events.

Data Overflow Options: When the data logger memory is full there are two options, overwrite the oldest data, or stop logging. Logging systems should have both options.

Batteries: Some units come with replaceable batteries, others with "10-year" non-user replaceable batteries. Battery life is dependent on many factors, but in particular how much the system gets used. Select a battery configuration that fits the application and specific use.

Battery Status Indicator: Battery life is variable and can be a problem on some units. Some data loggers include a battery status indicator either on the unit, via software or both. This feature is valuable to help ensure that the battery will not fail during the logging session.

Alarms: This is a capability that is not typically needed for building commissioning applications. Some units come with alarms or external outputs that will be activated when the recorded data value exceeds a pre-set limit.

Data Logger Operation

There are a wide variety of data logging devices available and the exact operation of each cannot be covered here. There are certain steps that will be required regardless of the particular unit and they are as follows:

- Planning
- Configuration
- Deployment
- Recovery
- Analysis and Reporting

Planning:

As with any endeavor, careful planning will be the difference between a successful logging project and one that requires excessive data manipulation at the end or in some cases that has to be done over.

If data logging is being undertaken then there is some goal to be achieved. A data logging plan (DLP) should be developed outlining the goals and approach. As with most projects, it is important to start with the end in mind. The DLP should outline the specific goals to be achieved or a problem statement outlining the circumstances requiring troubleshooting and hence data logging and reporting. The following is an outline for the DLP.

- Goals and/or problem statement including reporting requirements (charts, graphs, etc.)
- List of the BAS trend logging capabilities
- List of environmental parameters that are to be measured including what BAS trend logging points are to be used and what stand-alone data loggers are to be used
- Accuracy/calibration requirements for all logged points
- Sample interval for all logged points
- Sensor location for all logged points including any special fixtures required
- Logging period (start/stop date/time) – Identify if there will be some event during that period that is critical to capture
- Communication plan – Intent, impact and duration of study with building owner, facility staff or occupants

Configuration:

The Data Logging Plan will outline the various parameters for the logging project. All stand-alone data loggers and all BAS trend log systems must be configured prior to deployment or starting of trending. The configuration phase typically will include the following steps.

- Define Points
- Sensor Calibration
- Set Sample Interval
- Set Sample Size
- Set Sample Overrun Option
- Set Start Method
- Synchronize Clocks
- Assign File Name
- Trial Run

Define Points: The BAS and the stand-alone data logger may or may not have the needed points defined. In both cases, the individual points need to be activated or turned on. The input type, sensor range, and other parameters must be set specific to each sensor type. This is a critical operation and care should be taken to use the correct point definition for the associated sensor. Many of the sensor definitions appear very similar and selecting the wrong one will result in significant data errors. During this step, it is important to use consistent naming conventions so that the data makes sense later. Often, the names used in the point definitions are the column headings in the data fields and eventually will be used in graphical representations. Careful planning at this stage will reduce the amount of manipulation later when graphs are developed for the report.

Sensor Calibration: If the project is a critical application the sensors should be calibrated. The calibration should include the sensor and recording device as configured. Changes in wire lengths and other variations may invalidate the calibration. Even if calibration is not required, the calibration should be checked to ensure relative accuracy. Calibration or calibration checks are done by subjecting the sensor to a known standard environment such as an ice bath or calibrated immersion bath.

Set Sample Interval: The appropriate sampling interval is dependent upon the specific application. It used to be that this was a key trade-off because sample storage was more limited. It was critical to set the interval just long enough to capture events in the physical data so as to minimize the number of samples and conserve memory. This philosophy also drove users to use different intervals for different parameters in the same logging session. For example, the outside air temperature changes very slowly so a 15 minute interval might be appropriate for logging it. But 15 minutes is too long to evaluate the dynamics of a mixed air control via economizer dampers, which may take an interval of 2 minutes or less to evaluate properly. This practice results in a data table of values that don’t line up and contains voids, making analysis and graphing very difficult. Table 1 demonstrates what a data table would look like if three measured parameters were set at logging intervals of 15, 5 and 2 minutes and the logger started at 12:00, the "X" represents data.

Table 1: Data Misalignment Due to Staggered Sample Intervals

Interval	15 Minutes	5 Minutes	2 Minutes
12:00	X	X	X
12:02			X
12:04			X
12:05		X	
12:06			X
12:08			X
12:10		X	X
12:12			X
12:15	X	X	

Some stand-alone loggers and most BAS trend loggers have a feature that uses change-of-state or limits to determine when a data point is logged rather than at a set interval. The change-of-state feature is used on binary points such as motor start/stop. The limits feature logs analog points only when a certain limit is reached. Both are designed to reduce the amount of samples taken, conserve memory and to capture specific events. Both will result in data being recorded at arbitrary times that does not line up with the data logged on intervals. The change-of-state feature has also been known to cause some BAS logging systems to malfunction and cause data corruption throughout the entire logging system. These features should only be used in special cases when an exact event needs to be logged.

Because systems now have such large sampling capacities, it is practical to set all logging intervals to the same value equal to the least common denominator. This way, all data lines up and requires minimal manipulation and smoother data. One downside to this approach is large data files, which can be unwieldy if they are later manipulated in third party software such as MS Excel. But the efficiencies gained typically outweigh this problem, and after all, memory is cheap. The following table contains some suggested intervals for various typical commissioning logging activities. Remember, the logging intervals for both the BAS and the stand-alone loggers should be set the same if the data from these two systems are to be combined later in the analysis. Table 2 contains suggested intervals for various parameters based on a balance of memory usage and need for detail. These are only suggestions and the intervals used should always be determined by the specific needs of the logging project. It is usually better to error on the shorter durations so that short-term events can be captured.

Table 2: Suggested Intervals for Various Parameters

Parameter	1 Min	2 Min	5 Min	15 Min	30 Min
Occupied space zone temperature				X	X
Occupied space CO2 level					X
Occupied space lighting level					X
Outside air temperature					X
Duct static pressure of VAV system	X	X			
Building static pressure	X	X			
AHU supply air temperature	X	X	X		
AHU dampers and mixed air temperature	X	X	X		

If different sampling intervals are to be used, they should be common multiples so the data has voids, but lines up. For example: 2 minutes and 10 minutes, 5 minutes and 30 minutes to achieve short and long intervals.

Set Sample Size: In most BAS trend logging systems sample size is an option. This is important because system memory is used for operation of the control system as well as trend logging so memory conservation is an issue. In stand-alone data loggers, the maximum size is typically automatically calculated based on the internal memory size, the number of activated channels and the logging interval. Setting the sample size will determine how long the data logging period will be. For example if the logging interval is 1 hour for a single channel, then a sample size of 48 will get two full days of logging.

Set Sample Overrun Options: When the data logger memory is full there are two options, overwrite the oldest data, or stop logging. The first choice is generally used when a particular event that is to be logged is not predictable. The most recent data is always in memory so the user can stop the process after some event significant to the logging plan has occurred. The second choice of stopping the logging when the memory is full is useful when the exact logging period is known before hand.

Set Starting Method: There are typically several options for starting the beginning of the logging period; instantly after configuration, at a pre-determined time, event logging and via a manual input (push button). Set the appropriate method for the application. The best option to maintain uniform data integration is starting at a pre-defined time. In this way, the data from all stand-alone loggers will be in synch with each other and the BAS trend logger if properly set up. In some loggers a stop time may also be an option to set.

Synchronize Clocks: There are three areas of clock synchronization; the stand-alone logger clock(s), the BAS trend logger clock and the user's timepiece. The user's timepiece should agree with the other system clocks so the time will agree with the deployment records. Most stand-alone data loggers will use the system clock of the computer that launches them so this clock should be set prior to downloading the setup to the logger. BAS systems can have more than one clock to consider. The BAS graphical user interface computer has a clock and so does the main BAS controller. Some BAS systems use the PC while others use the controller clock. Be sure to be clear on what clock is being used to record the trend data.

Assign File Name: Depending on the system, a file name may be entered to describe the logging activity. Like defining the sensor channel names, using a compact yet descriptive file name can simplify organization activities later.

Download Configuration: Once all configuration parameters are set, the configuration is downloaded to the data logger. Typically a BAS trend logger does not require this step, though there may be some that require a similar step.

Trial Run: It is always advisable to perform a trial run to ensure that the data is being recorded as intended and can be recovered in a usable format.

Deployment:

Once the data loggers are configured, the stand-alone data loggers need to be deployed into the environment to be evaluated. The following outlines the deployment process.

- Position Loggers and Sensors
- Record Logger Deployment Information
- Verify BAS Trending
- Activate Logger

Position Loggers and Sensors: Position the stand-alone data loggers and sensors per the Data Logging Plan. Consideration should be given to who might be in the area that may interfere with the devices. It is advisable to notify the occupants if logging activities are to occur in occupied spaces. It is also a good idea to leave a business card with the devices. Protect loggers from any environmental conditions it was not designed for. Sensor wires and logging devices should be secured using screws, clamps, magnets, tie strips, tape, etc. Care should be taken to ensure that the sensor wires do not become disconnected from the sensors or data logger, make a final check before leaving installation.

Record Logger Deployment Information: It is important to record the location and channel definitions of the stand-alone loggers along with other pertinent information about the logging project. Use a standard form such as Table 3.

Table 3: Data Logger Deployment Information Sheet

No.	File Name	Channel Configuration Sensor Location				Logger Location	Launch Date/Time	Activation Date/Time	Retrieval Date/Time	Comments
		1	2	3	4					

Verify BAS Trending: Check the BAS system and verify that the trends are active. Observing the trends in real time will typically not affect the BAS trend files.

Activate Logger: If the logger was activated at download or the pre-determined start time option is set then this step is not required. For push-button types activate the logger manually. In all cases, verify that the data record indicator indicates that the unit is recording. Record the start time and any other pertinent information on the Data Logger Deployment Information Sheet.

Recovery:

At the end of the data logging period, the stand-alone loggers are retrieved and the data is recovered from the BAS trend logs and the stand-alone loggers. The following are the steps for the recovery process:

- Data Logger Upload
- Data Logger Retrieval
- BAS Trend Upload
- Backup Data

Data Logger Upload: Prior to removing the sensors, the data should be uploaded from the logger in the unfortunate event that there was a logger malfunction and the logging session needs to be repeated.

Data Logger Retrieval: Once the data integrity is verified, the loggers and sensors can be picked up and stored.

BAS Trend Upload: If BAS trend logging is part of the Data Logging Plan, the trend logs are recovered from the BAS system. Some BAS systems have the capability to be used for data analysis and reporting but in most cases, the data will be recovered and combined with the stand-alone logger data during the Analysis Phase. Most BAS systems are capable of exporting data files that can be imported by the stand-alone logger software or a third party tool such as MS Excel. Occasionally some creative tricks must be used to extract the data out of some BAS trend systems.

For example, some BAS logger systems do not have an export function, but the text data can be selected in the text-based report in the trend logging system, then copied and pasted using MS

Windows to a text editor. In this case, the column headings are typically not in the data that is copied and pasted. Therefore, the user must record what the columns of data represent for use during the data import phase. Column headings can also be typed directly into the text editor on site, being sure to use the exact same delimiters (discussed later in Data Analysis).

Backup Data: The logging effort to this point represents a significant investment. Prior to erasing the data off the loggers or before leaving the site, it is recommended that the data be backed up. There are inexpensive portable storage devices that plug into USB ports that work well for the backup and for transferring the data files from the BAS trend logging system.

Analysis and Reporting:

Once all the pertinent data has been recovered and stored the final step is to analyze the data then produce reports that support the goals of the DLP. There are three basic options for working with the data:

- BAS trending system
- The stand-alone data logging OEM (Original Equipment Manufacturer) software
- A third party software such as MS Excel

BAS trend log system: As has been previously mentioned, some BAS trend log systems have decent graphing and reporting capabilities and others do not. If all that is required is a simple plot of similar logged parameters to demonstrate compliance with standards, then BAS trend log systems with graphing capability can usually get the job done.

If more advanced analysis or reporting is required then these systems usually fall short. Typically none have the ability to merge data from other applications or logging systems. So if stand-alone data loggers are part of the DLP, then they likely data cannot be merged with the BAS data.

A critical issue is that when parameters have large value differences but need to be compared to each other on a graph, the BAS trend log system usually cannot be configured to display correctly. For example, displaying building static pressure (a value around 0.03) along with the relief fan VFD signal (a value as high as 100) results in a plot of the VFD signal and a straight line at zero representing the building static pressure. No analysis can be performed on such a plot.

The BAS reporting and graphing outputs typically cannot be annotated to point out important events in the data.

The BAS graphs cannot be easily transferred to an electronic report as the function of displaying the graphs resides in the BAS software and cannot be duplicated away from the BAS operator station. One way to get around this is to take screen captures of the graphs, then paste them into an electronic media such as MS Paint where they can be annotated and saved as an image file.

This gets the job done but is cumbersome and the graphs cannot be revised to emphasis different issues later.

OEM Software: Some OEM software is fairly limited while others contain extensive features for data analysis. This paper cannot delve into all the capabilities available (or disadvantages) of using the software from various providers, but in general if the software can perform most of the functions outlined under MS Excel below then it would be the application of choice.

MS Excel: MS Excel is a spreadsheet application with extensive reporting and graphing capabilities. With the spreadsheet functions, there is no limit to the operations that can be performed on the logged data including merging data, scaling data to engineering units and cleaning up bad data. The main disadvantage of using MS Excel is that it takes a few extra steps to bring data into the system then manipulate it. So if the project does not require the power and flexibility that MS Excel can provide, then it is most likely better to use the BAS trend logger system or the OEM software. For a further discussion of using MS Excel as a data analysis tool, see the next section.

MS Excel is a good choice if the project needs any of the following:

- Merging data from different sources
- Scaling raw data into engineering units
- Comparing data with large differences in absolute value
- Cleaning up partially corrupted data files
- Producing high quality custom graphs to fit any requirement

There are many ways to go about using the data to perform the analysis, so rather than going into a lengthy discussion on these, some representative examples are presented. The following are some examples of various real life data logging activities to demonstrate how the data can be used to report findings and solve problems.

Example 1: Office Overheating

A two-story office building had recently undergone a complete HVAC retrofit. The system was a 4-pipe fan coil with economizers. Two office spaces were reported as overheating in the afternoon on mild days (60-65 deg. F) while the remainder of the offices in the area controlled fine. The obvious things where checked for first, like leaking heating valves, extra load in the rooms, etc., but these revealed nothing. Stand-alone loggers were set up in the spaces because there was some level of distrust by the occupants that the BAS computer was reporting correctly.

Preliminary analysis included setting up stand-alone loggers to monitor the supply air temperature, space temperature at the thermostat and space temperature near where the occupant sits to evaluate zone control and microclimates. This preliminary analysis did not reveal the problem, but demonstrated that the system was capable of good control and the BAS trend log data could be trusted for further analysis. Figure D is a graph from MS Excel using data collected from both the BAS trend logging system and the stand-alone data loggers. In this case it demonstrated good room temperature control. It also shows how sensor calibrations can be different for the different systems. In this type of analysis, the goal is to find the root cause of the problem and minor disagreements of a couple of degrees are not significant to the analysis. As can be seen, both the BAS and stand-alone data show very stable space control and the absolute value of the space temperature is less of a concern because it is reflective of the user adjustable space set point.

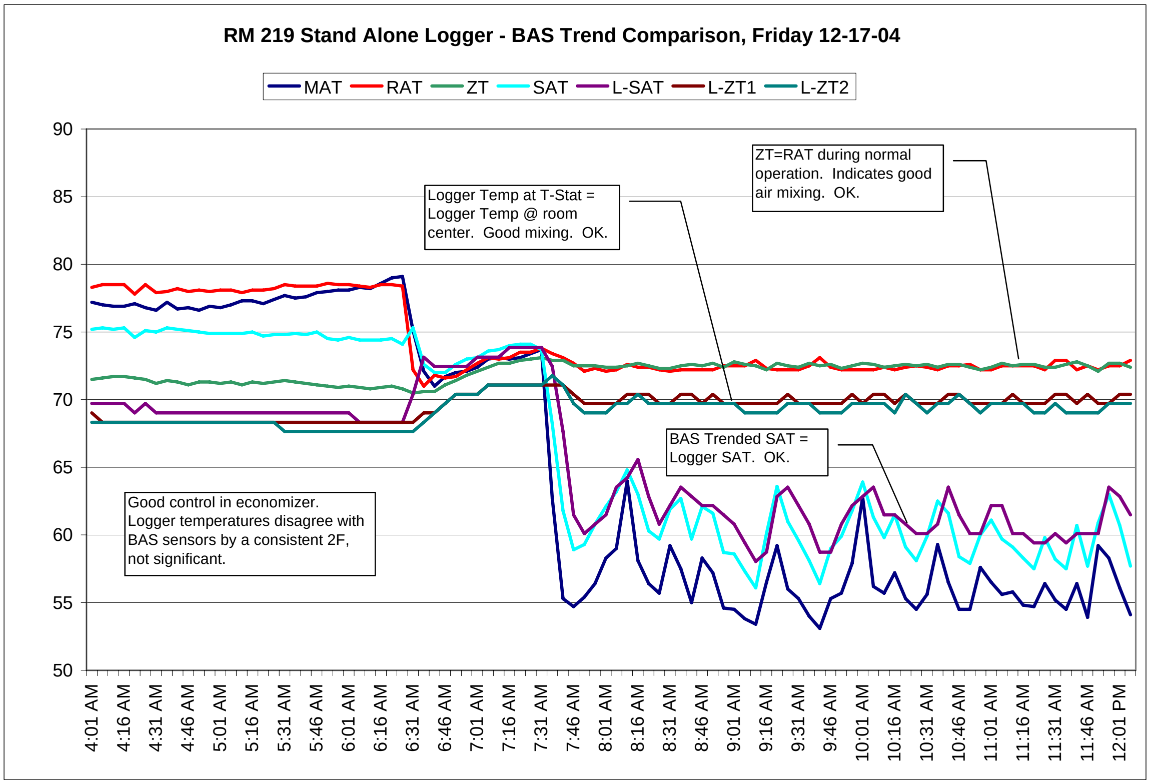


Figure D: BAS and Stand-Alone Data Comparison – Zone Temperature Control

In this case, the problem was being caused by two overlapping issues that combined to make the situation worse. The economizer dampers leaked, allowing warmer air to re-circulate back resulting in a less effective economizer function. As a side note, the installation did not include damper access doors. If they had, then this would have been checked early in the process.

The more complex issue had to do with the fact that the chiller was manually shut off by the maintenance staff during this season but the sequence of operations still activated the system on cooling demand. So as the room would start to overheat due to the ineffective free cooling in economizer, the chilled water valve would open, creating a demand for chilled water. Because the chiller was not enabled, the chilled water loop heated up due to pumping energy and the pipes passing through ambient spaces. The chilled water coil then became a heating coil, adding heat to the system and really driving the space temperature up. Figure E is a graph of the BAS trend data using MS Excel. The BAS trend logging system did not have the capability to create this level of graphics.

So in conclusion, the occupant had a legitimate complaint and the stand-alone data was not really needed to prove anything to them. The dampers where re-indexed and the sequence of operations was modified to prevent the chilled water system from running unless there is a status proof after several minutes of being commanded on.

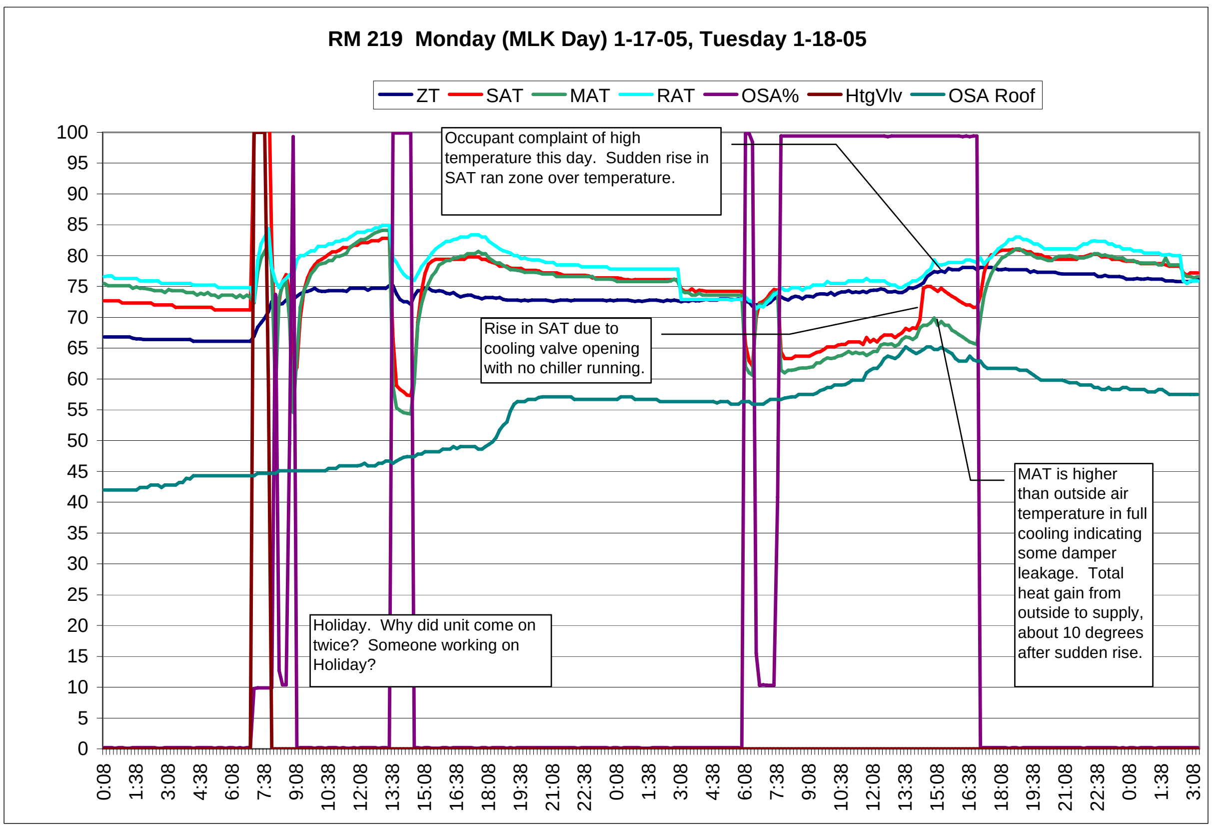


Figure E: BAS Trend Data – Occupied Space Overheating

Example 2: Insufficient Heating Capacity

An old historic ranch house that serves as a museum for the National Park Service underwent an HVAC retro-fit. The HVAC system consists of a 2-pipe changeover type fan coil system. Heating and chilled water are provided by two water source heat pumps coupled to the local spring water supply. During the winter there were complaints that the system did not have enough heating capacity.

The BAS trend logging system was used to perform the analysis. Initial observations seemed to indicate that the heat pump units were actually oversized so the reason for lack of heat was not immediately apparent. The heating water supply and return where trended along with the heat pump status and the graph in Figure F was generated using MS Excel.

Note that there are two aspects of this graph that would not be possible in the native BAS trend logging software. First is that the heat pump status is trended in the BAS system as a “0” for OFF and a “1” for ON. When graphed in the BAS system these values show up as a flat line on the bottom of the graph when graphed on a scale that will show the supply temperature. (Note that in this particular BAS system the trend line could not actually even be seen because the line formed at the bottom of the display box for the graph covers it up, making all zero values non-readable). In addition, even if the HP status could be distinguished, the actual operation of the heat pumps was at the same time so you would not be able to see them separately as only one color would show. MS Excel was used to create a different multiple for each HP status, for example “90”=OFF and “100”=ON for HP2.

The other aspect is the superimposing of the average supply temperature on the graph. This was a calculated field and is used to show that on average, the heating loop is only providing about 114 deg F water.

This analysis revealed that the heat pump sequencing needed tuning. On a call to heat the loop, the first heat pump would come on followed very shortly by the second heat pump. The sequence did not give the first heat pump the opportunity to satisfy the loop prior to bringing the second one on. The two units together would very quickly satisfy the loop temperature set point. The cycle would repeat with the net result of only an average of 114 deg F, which is not enough capacity to heat the building.

The recommendation was made to modify the sequence to bring the second HP on more slowly and to drop it out quickly. The system heating water set point was also raised to allow more run time for the system, which will also raise the average temperature. Because the heat pumps are so severely oversized for the system, there will always be some level of short cycling, but the modifications will make the system operate acceptably. This example demonstrates the use of loggers to overcome a somewhat counter intuitive problem; an over-sized heating system resulting in insufficient heating capacity.

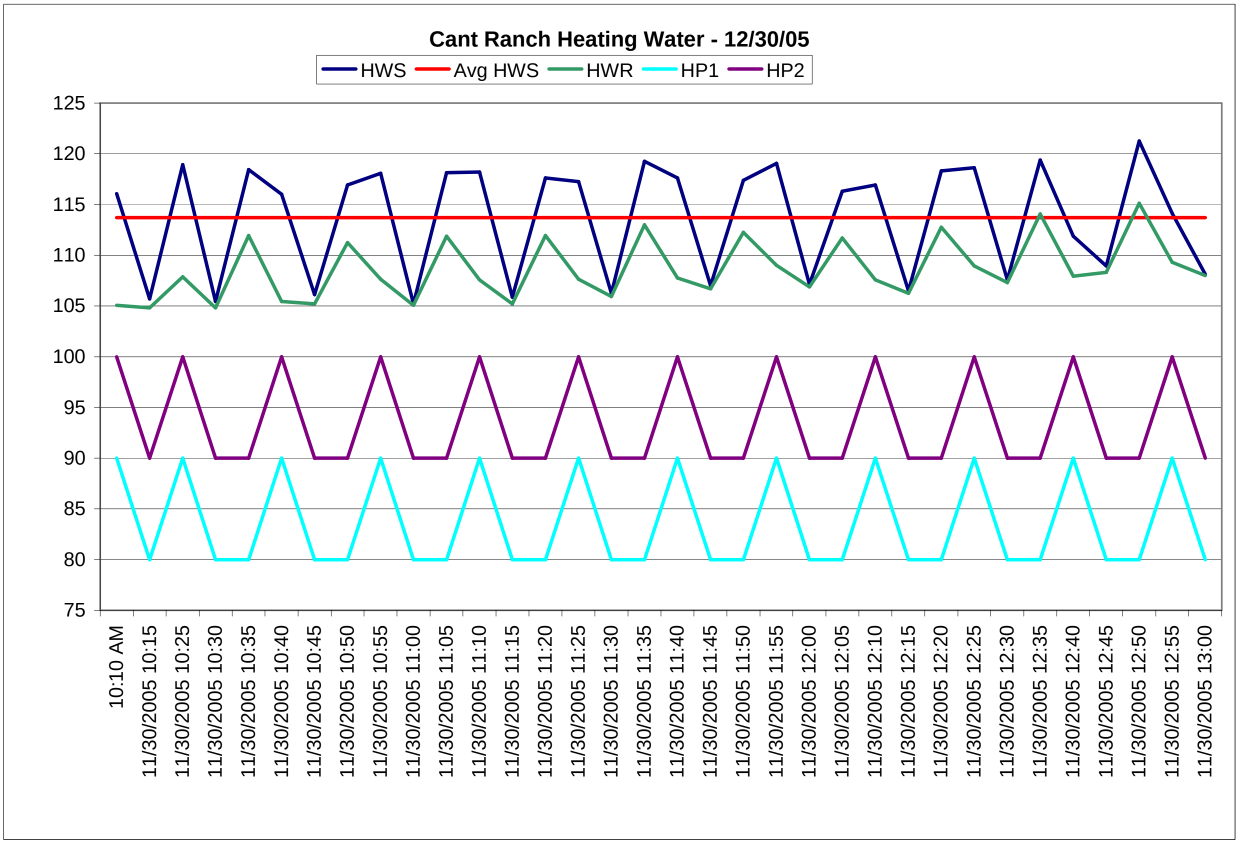


Figure F: BAS Trend Data – Heat Pumps Short Cycling

Example 3: Building Static Pressure Control Problems

The building is a large 5-story structure with a core area that is open vertically to all 5 floors. There is a single large 4-pipe air-handling unit in the basement that serves approximately 230 terminal units throughout the building. The AHU has four parallel vane-axial supply fans and two parallel vane-axial return fans. The supply and return fans are each equipped with back draft dampers for when they are not operating and the other fans are. The supply and return fans are equipped with VFDs and shift on and off based on a demand from duct static pressure and building static pressure respectively.

The air handler runs 24/7, but most of the terminal units shut down at night. During the day, both return fans need to run to control building static pressure and at night only one is needed.

The building was experiencing pressure control problems as well as other control problems that will not be discussed in this example. Recent security modifications had added walls and security doors between the office spaces and the center core. During the day, the security doors would at times be blown open to the extent that they would not latch and at other times would slam shut dangerously fast.

Preliminary investigations included using stand-alone data loggers to record the pressure differences between the spaces and the core and the core and the outside. This analysis showed that the relationship between the office pressure and the core pressure followed each other and the BAS trend logs of the building static pressure could be used in the analysis directly.

The BAS trends showed that the building static pressures would reverse about every 15 to 20 minutes. This problem was being caused by the relief fan shifting dead-band being too small. One fan would run and the VFD would ramp up in response to rising building static pressure till it hit the fan shift-on speed of 80%. With two return fans running, the building static pressure would quickly be drawn negative because the relief fan VFD sequence was set with a very slow response. With a low pressure, the VFDs would start to slow down till they reached the fan sift-off speed of 60%. With a single return fan running, the building static pressure would quickly jump to a high pressure and the cycle would continue. The problem was exasperated by the security walls and doors. They had been added without consideration for airflow paths so that most of the return air was being drawn from the office spaces and not the core. So when the pressure reversed, it was reversing more in the office areas than the core, causing the door problems.

A simple dead-band adjustment was all that was needed to fix the short cycling. Addition of transfer grills between the offices and the cores spaces was also needed to bring the overall building pressures in line. Figure G is a graph of BAS trend data demonstrating the pressure control before and after the dead-band adjustment. Note the use of MS Excel graphic tools to draw in a line for the building static pressure set point. This could have also been plotted directly by including it in the raw data.

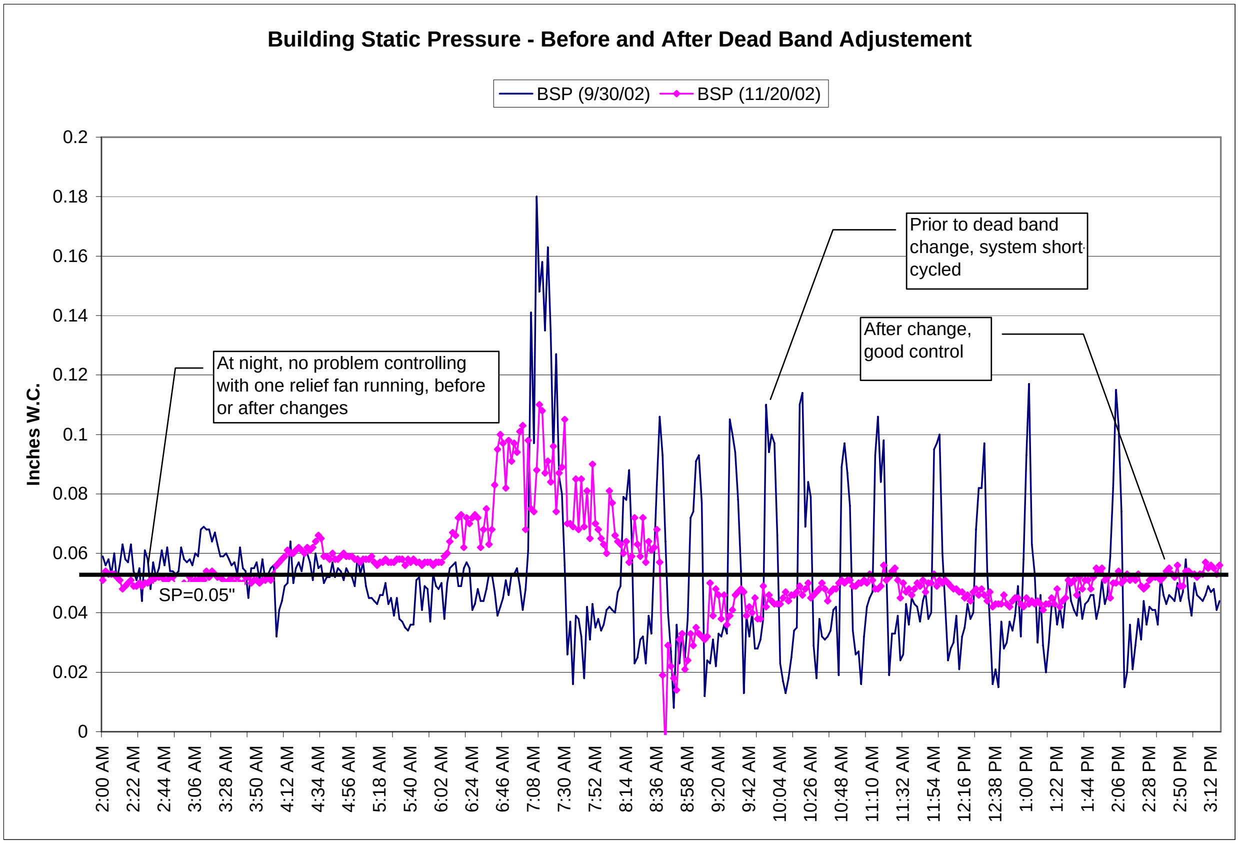


Figure G: BAS Trend Data – BSP Control Comparison

In Figure G above, the control after the adjustments is considerably better than before, however there are still some significant problems with the static pressure at start-up (and shutdown though not shown here).

Figure H and I are graphs of the static pressure problems at start-up and shutdown (occupied and unoccupied modes) of the VAV terminal units. Control technicians frequently make building static pressure control loops fairly slow. This is understandable, as too fast of a response can result in overshooting. In this case the response is too slow, taking nearly an hour to recover. The system is slow to respond to the VAV terminals opening/closing and slow to responding to the second relief fan shifting in and out. These problems were corrected by speeding up the relief fan control loop response.

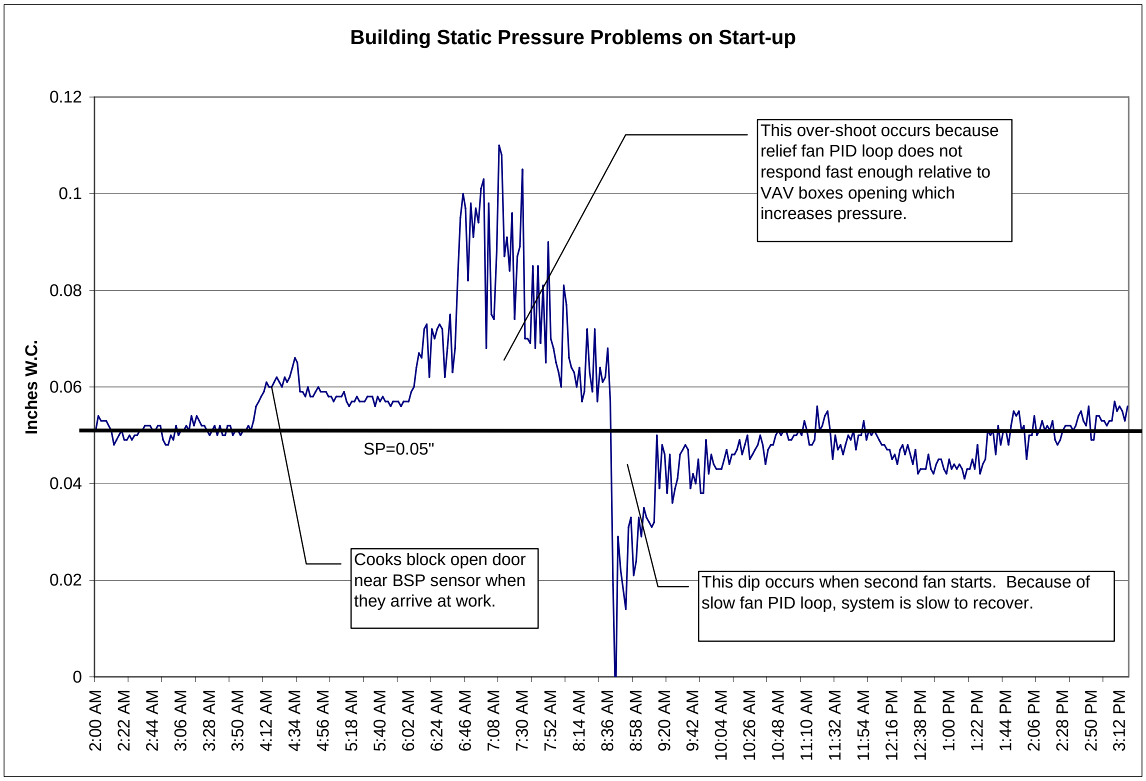


Figure H: BAS Trend Data – BSP Problems on Start-up

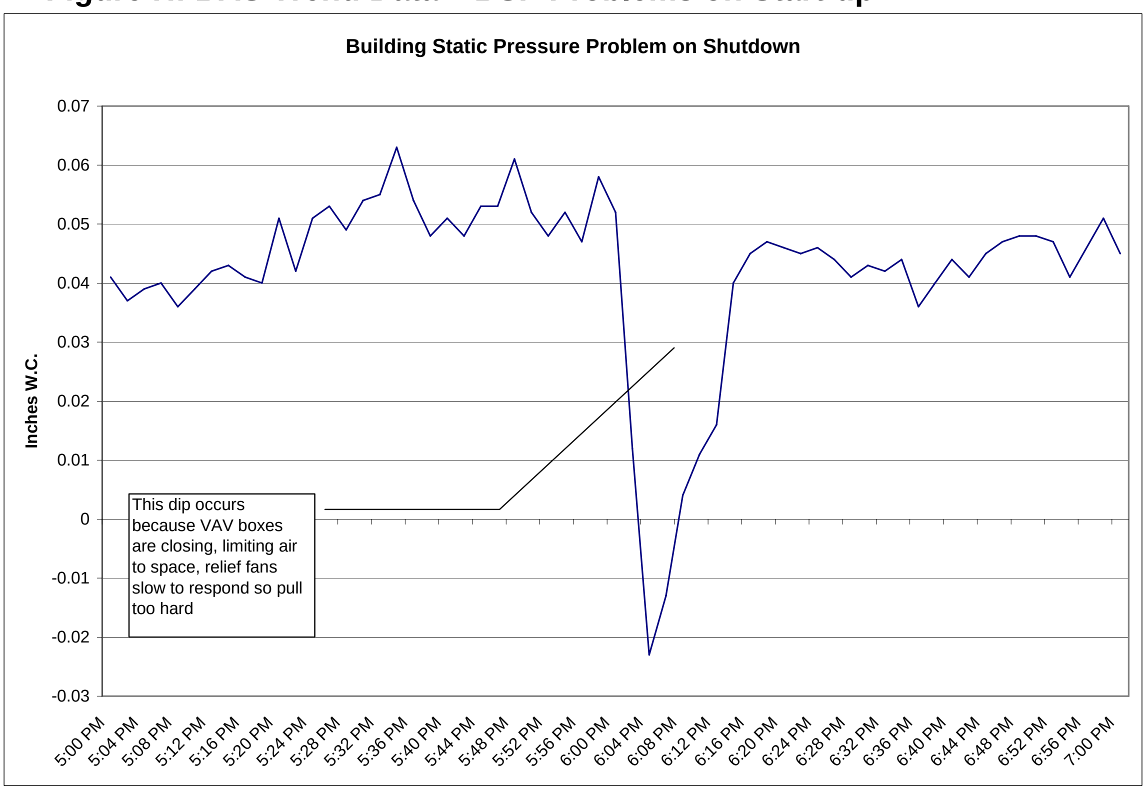


Figure I: BAS Trend Data – BSP Problem on Shutdown

Example 4: Indoor Environment Quality

In this project, the indoor environment quality (IEQ) was being questioned including temperature control, airborne contaminants and proper ventilation. The goal in this project was to check IEQ parameters and identify and investigate any problems noted.

The standard for CO2 concentration to indicate proper ventilation is 700 ppm over outside conditions. As part of the investigation a stand-alone data logger and external CO2 sensor was used to log the CO2 level in various spaces. The graph in Figure J shows how CO2 changes over time and occupants. In this case, the graph shows that the ventilation in this space is adequate.

Note that in this case additional information regarding the number of occupants was noted during the logging process then annotated on the graph. Also, the raw data from the logger was 0-2 volts corresponding to 0-2000 ppm of CO2. MS Excel was used to scale the values to engineering units. In this case, graphing 0-2 volts would not have been too bad since the scale is a multiple of 1000. But in most cases it will not be that clean and scaling to engineering units will be more critical.

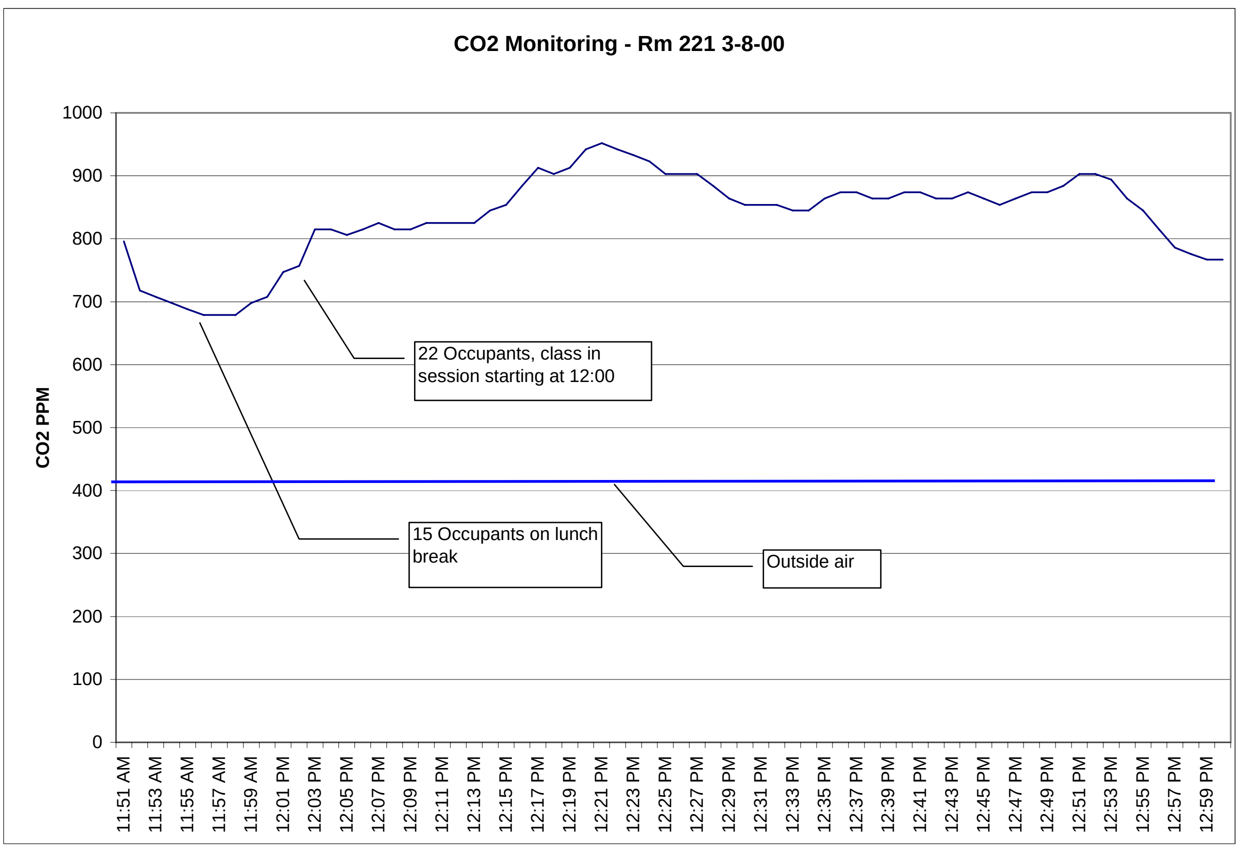


Figure J: Stand-Alone Data Logger – Ventilation Verification

Example 5: Zone Temperature Control – BAS Screen Capture

The system in this project was a heat pump with multiple-zone dampers. This type of system is particularly difficult to control because of the non-modulating on/off heating/cooling characteristics of a heat pump system. If a zone is in need of heat and the HP is in heating, then the zone damper modulates open. If the HP is in cooling and the space needs heat then the zone damper modulates closed. The system operates in reverse when the space needs cooling. The number of zones in heating or cooling determines the mode the heat pump is in.

Figure K is two screen captures from a BAS trend logging system. The screens are captured by pressing the “Print Screen” key, which pastes a duplicate of the entire screen in the clipboard. The image is then pasted into MS Paint. The image includes everything on the screen so it was cropped to make it more presentable. The two logs were captured separately, cropped and merged in MS Paint and saved as one image file, which was then used in a report.

One might consider this plot of the room temperatures to indicate very poor control. Actually, in consideration of the type of system it is, the control is actually about as good as it can get. During the morning the spaces needed heat so the heat pump cycled on and off in heating. Later the temperatures flattened out as the spaces no longer needed heat and the HP shut down allowing the rooms to “float.” Looking at each room temperature plot shows that they do fluctuate 2-4 degrees, which can be a significant problem. For this reason, HVAC systems of this type should be avoided.

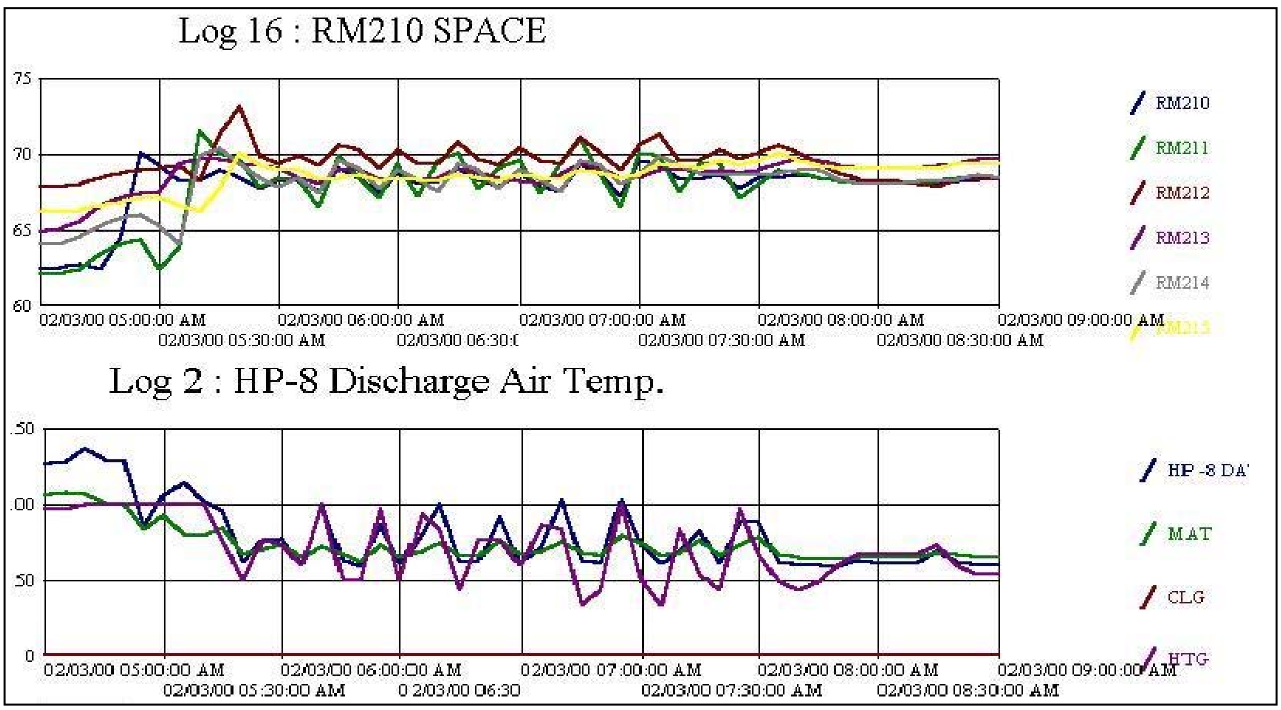


Figure K: BAS Logger Screen Capture – Multi-Zone Temperature Control

Data Analysis with MS Excel

As has been previously discussed, if the native application provided with the BAS trend logging system or stand-alone data logger has the functionality needed to meet the needs of the data logging project, then they would be the best choice for analysis. Often, the commissioning provider is faced with data from multiple systems or from systems that are archaic or not highly capable. When a more robust approach is needed, MS Excel is an excellent tool.

MS Excel is an extremely powerful and versatile application for working with various kinds of data. It is extremely prevalent software so most people are familiar with it and typically no additional software costs are involved. Because MS Excel has such extensive capabilities it is not practical to present all of them in this paper, not even those of specific interest to data logger analysis. The intent here is to present the most common tasks and give the reader an idea of capabilities to be explored as the need may arise. The basic steps in analyzing data in MS Excel are as follows:

- Import Data
- Merge Data
- Cleanup Data
- Create Report

Import Data:

Data is stored in a variety of ways. In old fashion flat-file structures data is stored in rows with the columnar data separated by some character, see Figure L for the contents of an actual data file. In data base terms, the separating character is called a delimiter and might be a comma, tab, space, semicolon or other character. The flat file structure can also be a fixed-width type. In the case of relational databases such as MS Access or SQL databases the delimiting is internal to the system and not generally transparent to the user. Some stand-alone data logging software will store its native data in a proprietary data structure while others will store it in a simple flat file that can be read by virtually anything. Nearly all logging systems, whether BAS or stand-alone, will export data in some delimited format that MS Excel can recognize.

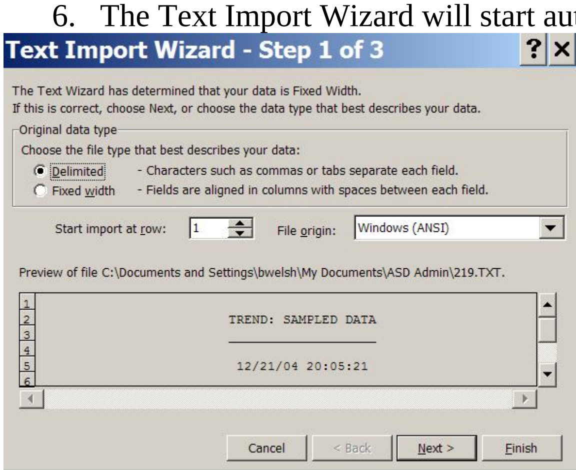
One of the most universally used file types for both BAS trend loggers and stand-alone data loggers is the comma-delimited file. These can be text files with the .txt file extension or the comma separated value file with the .csv file extension. There can be other comma-delimited files with different file extensions. In any case, they are all actually just a text file and can be opened and viewed with any word processor. To verify if it is a text file, simply highlight the file in Windows File Explorer, right click it, select the “Open With” then choose one of the text readers to open it. If the file opens and is readable, then it is a text file, otherwise if it contains a bunch of random characters, it is not.

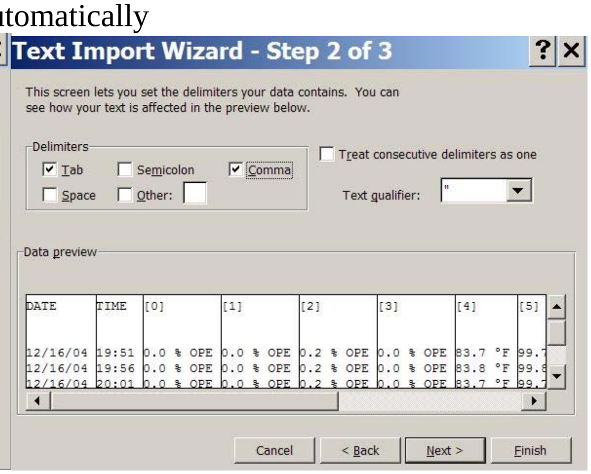
```
TREND: SAMPLED DATA
____________________

12/21/04 20:10:52

Display Range: 12/16/04 19:51 - 12/21/04 19:51
[0]= 001:001:001:219 Mixed Temp.    - TR001640.STF
[1]= 001:001:001:219 Return Temp    - TR028531.STF
[2]= 001:001:001:219 Room Temp.     - TR009928.STF
[3]= 001:001:001:219 Supply Temp.   - TR009682.STF

DATE,TIME,[0],[1],[2],[3]

12/16/04,19:51,83.7 °F,83.2 °F,73.6 °F,78.3 °F
12/16/04,19:56,83.8 °F,83.6 °F,73.7 °F,78.4 °F
12/16/04,20:01,83.7 °F,83.6 °F,73.6 °F,78.4 °F
12/16/04,20:06,83.3 °F,83.7 °F,73.6 °F,78.7 °F
```

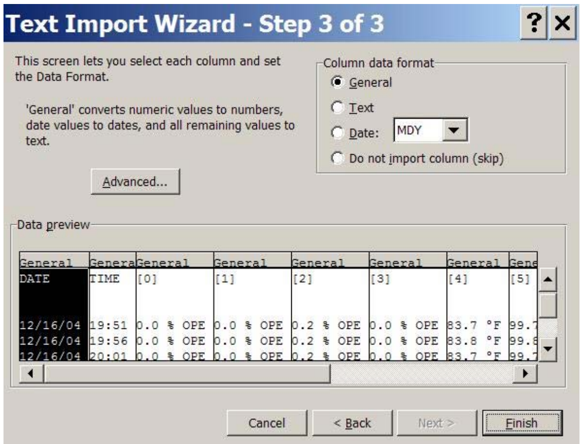
Figure L: Raw Trend Log Data as Exported from BAS (.txt)

If it has not already been done, the data from the logging system should first be exported from the stand-alone OEM software or the BAS logger system in a delimited file. The steps to import the file into MS Excel are as follows:

1. Start MS Excel
2. Choose File>>Open, the Open dialog box will appear
3. At the bottom of the Open dialog box use the "Files of type:" pull-down and select "All Files (*.*)"
4. Use the "Look in" pull down to navigate to the folder containing the data file to be imported
5. Select the file to be imported and click "Open"
6. The Text Import Wizard will start automatically







7. Select Delimited or Fixed Width, typically it will be delimited.
8. Click Next>
9. Select delimiter(s), sometimes there is more than one. Notice that the data preview shows how it will be delimited.
10. Click Next>
11. If desired, the data type can be set here saving formatting time later. Click on the column, then select a radio button. You can also exclude data here.
12. Click "Finish" and the data will show up in columnar format inside MS Excel.
13. Select File>>Save As
14. Choose to save it as a native MS Excel file (.xls), name it, click "Save"

Figure M below is the actual results of importing the text file in Figure xx. Note that MS Excel could not interpret the degree symbol and substituted "~." It will be quite common to have a variety of data issues that will need to be cleaned up as discussed later.

TREND: SAMPLED DATA

12/21/04 20:10:52

Display Range: 12/16/04 19:51 - 12/21/04 19:51
[0]= 001:001:001:219 Mixed Temp. - TR001640.STF
[1]= 001:001:001:219 Return Temp - TR028531.STF
[2]= 001:001:001:219 Room Temp. - TR009928.STF
[3]= 001:001:001:219 Supply Temp. - TR009682.STF

DATE	TIME	[0]	[1]	[2]	[3]
12/16/2004	19:51	83.7 ~F	83.2 ~F	73.6 ~F	78.3 ~F
12/16/2004	19:56	83.8 ~F	83.6 ~F	73.7 ~F	78.4 ~F
12/16/2004	20:01	83.7 ~F	83.6 ~F	73.6 ~F	78.4 ~F
12/16/2004	20:06	83.3 ~F	83.7 ~F	73.6 ~F	78.7 ~F

Figure M: Trend Data Imported to MS Excel (.xls) - Unformatted

Merge Data:

If multiple files are to combined, use the following steps to combine the files:

1. If not already open, open the MS Excel file previously created containing the first data file imported.

2. Import the next file into MS Excel as previously discussed by opening the data file and using the import wizard, but it is not necessary to save the file.
3. In the MS Excel window of the file just imported in Step 2, right click the tab at the bottom of the work sheet that contains the data and select “Move or Copy.”
4. The Move or Copy dialog box will appear.
5. Click on the “To book:” pull down and select the work book file name from the first data import.
6. Click “OK” and the system will jump to the workbook selected in Step 5 and paste the entire worksheet there.
7. Repeat Steps 2 to 6 for as many files as needed.
8. The spreadsheets that were open that contained the data files prior to moving will be empty and can be closed without saving and without affecting the text data files from the loggers.

Cleanup Data:

As noted in the results of Figure M, the imported data contains an unwanted “~F” along with the numerical data. In addition, the column headings have numbers in square brackets corresponding to the actual data titles located in a key at the top rather than the data tile itself. This is a problem because MS Excel will label the graph lines with the numerical labels, not the English language labels. Both of these problems are very easy to fix as will be discussed later.

Other times, there are more difficult problems to clean up. Because there are so many different data logging systems that have their own individual quirks it is not possible to cover them all here. Most stand-alone OEM software provides very clean exported data, while many BAS trend logging systems frequently produce files that require cleanup. Tools to solve the most common problems are presented here starting with the issues discussed in the example data, followed by the remainder in no particular order of importance or frequency used.

- Unwanted characters
- Column labels that are non-descriptive of parameters
- Columns of data with no labels at all
- Date/Time formatting problems
- Column labels that are shifted out of sequence with the columns
- Unwanted columns of data
- Data that does not scale well with other parameters
- Data that is not in engineering units
- Merging and aligning data from different files
- Data that does not line up from field to field or contains voids

<u>Unwanted characters:</u> Unwanted characters are easily removed with the Replace function in MS Excel. The steps for use are as follows:

1. Select the cells that contain the unwanted characters so that cells that may contain the same character but are desired will not be deleted. If it is known that the characters in question are not desired anywhere, select the entire sheet by clicking the box above the row label “1” and to the left of the column label “A.”
2. Choose Edit >> Replace (or ctrl H) to open the Find and Replace dialog box.
3. Type the unwanted characters in the “Find what” (in this example “~F”)
4. Leave the “Replace with:” field blank
5. Click the “Find Next” button
6. Verify that the expected characters are found, sometimes unexpected results occur
7. Click the “Replace All” button
8. Review the data to be sure it is what is expected, the replace operation can be undone if the results are not as expected.

Figure N shows the results of this and the next two cleanup steps. Note that the temperature data no longer has the “~F.”

TREND: SAMPLED DATA

12/21/04 20:10:52

Display Range: 12/16/04 19:51 - 12/21/04 19:51
[0]= 001:001:001:219 Mixed Temp. - TR001640.STF
[1]= 001:001:001:219 Return Temp - TR028531.STF
[2]= 001:001:001:219 Room Temp. - TR009928.STF
[3]= 001:001:001:219 Supply Temp. - TR009682.STF

DATE	TIME	[0]	[1]	[2]	[3]
Date	Time	MAT	RAT	ZT	SAT
12/16/2004	7:51 PM	83.7	83.2	73.6	78.3
12/16/2004	7:56 PM	83.8	83.6	73.7	78.4
12/16/2004	8:01 PM	83.7	83.6	73.6	78.4
12/16/2004	8:06 PM	83.3	83.7	73.6	78.7
12/16/2004	8:11 PM	82.6	83.8	73.9	78.8

Figure N: Trend Data Edited for Graphing

<u>Column labels that are non-descriptive of parameters:</u> This problem is simply resolved by editing the column cells with the desired heading, see Figure N above. Note that abbreviations where used such as MAT for Mixed Air Temperature in the column headings. Full English text could have been used instead, but keep in mind that if a legend is to be used when the data is graphed, the legend can become bulky. This is a personal preference and is easily changed later as MS Excel has a dynamic relationship between the data table and the graph, so if you change the headings in the table later, the graph legend is automatically updated.

Note that the original column headings and data key was left in the file. This could be removed but does not need to be. When the data is graphed, only the column headings and associated data will be selected for graphing as will be demonstrated later.

Columns of data with no labels at all: As was discussed previously, some BAS trend logging systems may produce data files without column headings. The column definitions should have been recorded during the data retrieval from the BAS system. Simply add the titles to the columns with the same considerations discussed earlier regarding headings that don't reflect actual parameters.

Date/Time formatting problems: There are several issues that can come up here. Often date/time data comes in two separate columns, but sometimes it comes in as one combined. When the date/time is combined and the data is graphed, the date labels can make the x-axis very crowded and difficult or impossible to read. To get around this problem, the date/time combination can simply be formatted as time. If the trend data spans several days then that should be noted in the annotations. The reader can easily distinguish between days based on the hour labels.

In the case of this example, the only problem is that the raw data from the logger system was in military time and a 12-hour display with AM/PM was preferred so the time was formatted accordingly, see Figure N above. To change the data format:

1. Select the cells of data to be formatted.
2. Choose Format >> Cells (ctrl 1) to display the Format Cells dialog box
3. Select the "Number" tab.
4. Choose a Category of data in the left box and a group of selections will appear in the "Type:" box to the right (Time for the example).
5. Choose a data type (1:30 PM the example)
6. Click OK.

Column labels that are shifted out of sequence with the columns: This happens fairly often and is easy to fix. Simply cut and past the headings into the proper location.

Unwanted columns of data: This can be prevented during the data import process using step 3 of 3 in the import wizard. If there are still unwanted columns of data, simply select the entire column and delete it.

Data that does not scale well with other parameters: There are two ways to approach this. The first is to use the "Lines on two Axes" feature of the MS Excel Chart Wizard (to be discussed in more detail later). With this feature, the left Y-axis can be one scale, while the right Y-axis can be another. This feature works well but sometimes takes a long time to get the results you want.

The second is to re-scale the values using the math functions of MS Excel. The column heading can be labeled with the scaling factor (BSP*1000 for example) so the reader can properly interpret the graph. To use this method:

1. Move the un-scaled data to a column further to the right in the spreadsheet.

2. Create a column for the scaled data next to the other data for logging and give it an appropriate label.
3. Create an equation in the first cell below the heading for the scaled data, MS Excel uses the "=" to start an equation. If the first cell was in row 2 and the un-scaled data was in column H, then the formula to scale times a thousand would be "=H2*1000."
4. To copy the formula and maintain the associated cell references, click on the cell to copy, hover over the lower right corner of the selected cell and a "+" will appear.
5. Right mouse click down and drag the plus as far down as you want to copy then let up.

<u>Data that is not in engineering units:</u> This problem is similar to the previous and the solution is the same as the second option given, though the formula is more complex for some variables. For a zero to any-value signal that corresponds to a zero to any-value engineering unit (0-10VDC = 0-2000ppm for example) then a straight scaling factor in the equation is all that is need as discussed in the previous solution. In the case of a 4-20mA that corresponds to the engineering units then the equation for a straight line needs to be used as follows:

> Example: A CO2 sensor that outputs 4-20mA for 0-2000 ppm
>
> The equation for a line:
> Y = mX+b, (where m = slope = rise/run and b=Y intercept)
>
> Step 1: Calculate slope
> Rise = 2000 ppm, run = 16 mA (20-4=16)
> m = 2000/16 = 125 ppm per mA
>
> Step 2: Calculate Y intercept
> Plug in slope to equation and two known points such as 2000ppm at 20 mA
> Y=125X+b
> b=Y-125X
> b=2000-125(20)
> b=-500
>
> Step 3: Create an equation in the spreadsheet with the above parameters that take the mA as input: Y=125X-500. In MS Excel "=125*[cell ref]-500"

<u>Merging and aligning data from different files:</u> If the previous steps on merging data were followed, then the workbook should contain all the files on separate worksheets (tabs). It is good practice to leave the data in these tabs unedited (except for initial cleanup to remove unwanted characters and bad data) and create new worksheets (tabs) to assemble the data in the way it is to be charted. That way, if unexpected results occur, the original data is easily available to try again.

1. Choose Insert >> Worksheet.
2. Rename the tab appropriately; keep in mind that this tab can be used to automatically label charts later. For example if you label it "Exhibit 5" this will appear on the chart if properly formatted.

3. Copy and paste the various columns of data into the new worksheet being careful to keep the date/time relationships aligned.
4. If proper steps were followed during data acquisition, then the date/times should line up and there should be no holes in the data. If this is not the case, see the discussions later on these issues.
5. When assembled, the first column(s) should be the date/time column(s). The remaining columns should be the corresponding data in the order of how the column headings should appear in the legend. Each column heading should be labeled how they should appear on the graph.

Data that does not line up from field to field or contains voids: Typically this is the result of different recording rates. This situation can typically be avoided by proper planning at the beginning of the project. Sometimes it cannot be avoided due to the flakey characteristics of some data logging systems or user errors. Considerable time may have already been invested in collecting the data to make it worth fixing.

If there are holes in the data due to different logging intervals, then these holes need to be filled or the corresponding data aligned with the voids can be deleted. The "simplest" way is to insert or delete rows to get data alignment. Deleting may reduce the quality of the data so inserting spaces is typically preferred. See Figure O, Coordinating Data with Different Recording Rates. This is simple in concept but if there are thousands of rows, this can take a long time. Excel has the ability to record macros that can be useful in repeating the same operation, see discussion on macros later.

If the data is aligned, but there are voids, the data can be proper charted by choosing an option for data voids as follows:

1. Click the chart.
2. On the **Tools** menu, click **Options**, and then click the **Chart** tab.
3. Under **Plot empty cells as**, click the Interpolated radio button.

Time	**Var_1**
1:00	77.1
1:05	77.3
1:10	77.7
1:15	78.0
1:20	78.2

Logger Data 1

Time	**Var_2**
1:00	23.2%
1:10	23.7%
1:20	24.5%

Logger Data 2 >>

Time	**Var_2**
1:00	23.2%
1:10	23.7%
1:20	24.5%

Insert Spaces Data 2

Time	**Var_1**	**Var_2**
1:00	77.1	23.2%
1:05	77.3	
1:10	77.7	23.7%
1:15	78.0	
1:20	78.2	24.5%

Data Combined for Plot

Figure O: Coordinating Data with Different Recording Rates

Macros: Any time the same operation needs to be performed more than a few times in MS Excel, then Macros should be considered. Macros record the users keystrokes and will repeat (replay) them with a single keystroke. Macros are recorded in Visual Basic for Applications (VBA), though the typical user should not need to know this. For the truly brave and advanced user, VBA can be used to perform virtually any operation desired. To use Macros in MS Excel:

Record the Macro:

1. Practice the commands that are to repeated until the proper result is achieved
2. Choose: Tools >> Macros >> Record New Macro to display the record macro dialog box
3. Enter a name for the macro (optional)
4. Enter a shortcut key (optional, but recommended)
5. Click "OK" to start the recorder
6. Execute the commands you want repeated, no more, no less
7. Notice that on the recorder dialog box, there are two buttons, one to stop the recording (dark square box) and the other to the right, which is the Relative Reference button. See the discussion below on relative reference for the proper use of this important feature.
8. Click the Stop Recording button when complete

To use the macro:

1. Save your file as undo <u>will not work</u> when running macros
2. Choose: Tools >> Macro >> Macros (Alt F8) to display the macro dialog box
3. Select the Macro to run and click "Run"
4. Alternately and usually preferably, press ctrl and the programmed hot key

When macros are recorded, the default is to use absolute references. Take for example the case where the value in a cell needs to be copied and pasted in the next two blank cells down. The user wants to be able to perform this operation hundreds of times down the table. They select the first cell containing the data to be copied, say cell A1 containing 55.5. They start the macro recorder, hit copy, use the arrow key to move down one cell to A2, hit paste, move down one more cell, hit paste again then stop recording. During the process of recording, cells A2 and A3 were filled with 55.5. They now move to cell A4, which contains data, say 66.6 and run the macro expecting to see cells A5 and A6 populated with 66.6. Instead the screen flashes and nothing appears to happen. The reason is that the macro recorded the absolute references so just recopied the contents of A1 and pasted it into A2 and A2. If the contents of A2 and A3 where deleted and the macro run again, they would be repopulated with 55.5 regardless of what cell was selected prior to running the macro.

To properly record this macro the Relative Reference button should have been pushed after starting the recording. In this way, the macro is not recording the cell references, but the relative distance to travel. Another improvement on the above macro is to add one more step at the end, to move down one more cell so that after the macro is finished the selected cell is the next cell to be copied. In this way, the user can simply hold down the ctrl key and press the programmed hot key as many times as they need to copy. The worksheet automatically advances down as the new values are pasted until the bottom of the data is reached.

If the process were to be repeated hundreds or thousands of times, even the previous macro would be tedious. This is where a good programmer who knows VBA could write a program to loop until it was completely done. But there is still a way for the macro user to make it work.

Instead of recording the macro to copy one cell, paste in two cells, then move to the next copied cell, record the operation through copying 10 pairs of cells. Each time the macro is executed 20 voids will be filled speeding the process up considerably.

Macros can be used to solve just about any data corruption problem, but remember, be sure to save a copy first before executing any macros.

<u>Combining Columns of Data:</u> Occasionally there is a need to combine two columns of data. MS Excel has a concatenation operator that can be used to accomplish this, it is simply the "&" symbol in an equation. For example if cell A1 contains "Stand" and cell B1 contains "Alone," putting "=A1&B1" into cell C1 will result in "StandAlone" in that cell. Note that they are literally concatenated. If a space was desired between all entries then use the form "=A1&" "&B1" resulting in "Stand Alone."

<u>Splitting a Column of Data:</u> Occasionally there is a need to select only a portion of a column of data. For example, if some of the data was not parsed correctly and the cells contain two pieces of data. MS Excel has two functions *Left* and *Right* that will solve this problem if the data that needs to be split is of a fixed character count. For example, if the first six characters in each cell of column "A" are the data values of interest, the *Left* function can be used to extract only those six characters, "=Left(6,A1)." The Right function works the same way, except counting from the right side. Note that in MS Excel, if you start typing in a function, Excel will pop up with the required parameters after the first parenthesis, for example "=Left(**text**,[num_chars])" will pop up after "=Left(" is entered in, then "=Left([text],**num_chars**)" pops up after "6," is added to what is already typed in.

Create Report:

The final step in the project is typically to produce a report. Sometimes the analysis to this point is adequate and the goals have been met without providing printed material. For projects that need reporting, data can be reported in tabular format or in a variety of charts and graphs using MS Excel.

The MS Excel Chart Wizard is typically all that is needed to perform this function, however to achieve the best results some customization is usually needed. The following are the steps to create a chart:

1. Verify that the first column contains the date/time and is formatted as such.
2. Verify that column headings are titled as desired for the graph legend.
3. Verify that the data columns are arranged in the order they are to appear in the legend, from left to right (after the date/time column).
4. Select the upper left cell in the data range to be graphed; this would typically be the cell containing the column heading "Time" or similar title.
5. Using the scroll bars, scroll down so the lower right cell in the data range can be viewed.
6. Hold the shift key and select the lower right cell in the data range.

7. Choose Insert >> Chart or select the icon from the tool bar to launch the 4-step wizard.
8. In step 1 there are two tabs, Standard Type and Custom Type. Choose the chart type that fits the project needs. Experimentation and the previews are the best way to see the expected results and the wizard has a "back" button to go back and change selections. The two-axis choice for plotting dissimilar values is under Custom Types. Under Custom Types the user can create user-defined types for use later. This is can be a time saver if multiple charts are to be produced.
9. In step 2 if the first column was properly formatted as a date/time and the proper data range was selected then there should be nothing to do here and the preview should look as desired. If the date/time formatting is wrong it will be necessary to cancel and correct the issue in the worksheet and start the wizard over. If the data range is wrong it can be adjusted here. If the chart type is wrong use the "back" button.
10. In step 3 there are six tabs containing chart options. Click each tab and enter the various desired parameters. These can all be changed later if they are not as desired. Typically the following would be edited each time: Chart Title, X-axis label, Y-axis label and legend location.
11. In step 4 choose where the chart will be located, in the current work sheet or as a new sheet. For printing purposes, it is typically best to put it in as a new sheet. The location can be changed later if desired.
12. Once the wizard is finished the chart can be further customized then printed. The following are some common adjustments and considerations:
    - The X-axis scale may not be appropriate. Left click on the X-axis, then right click and select "Format Axis" to display a dialog box. Select the "Scale" tab and edit the various parameters including minimum and maximum values to achieve the desired result. There are other tabs here that may be useful, experiment.
    - The Y-axis may be crowded with too many labels indicating date/time. Left click the Y-axis, then right click and select "Format Axis" to display a dialog box similar, but not the same, as in the previous operation for the X-axis. Select the "Scale" tab and change the "Number of categories between tick-mark labels" and "Number of categories between tick-mark" parameters until the desired result is achieved.
    - The default line graph has a grey background. This can be desirable, but depending on what the graph will be printed on it may not. The grey area can burn up a lot of ink in an inkjet printer. To make the plot area clear, left click the plot area, then right click "Format Plot Area" to display the dialog box. Under "Area" select the "None" radio button (or another shade or effect if desired).
    - To go back and change any of the parameters set in step 3 of the wizard, left click the outside edge of the chart area to select the entire chart, then right click and select "Chart Options" to display the dialog box. Make desired changes.
    - To create a custom and automatic header: File >> Page Setup. Select the "Header/Footer" tab. Click the "Header" button. Enter a header including special characters. "&[tab]" will result in the worksheet tab label to be displayed. "&[page]" for page number, "&[date]" for date.

As previously mentioned, MS Excel has the ability to store user defined chart types for use in the wizard. Once a particular graph style has been developed, use the following steps to create a user-defined chart.

1. First go to the chart that represents the desired characteristics.
2. Make a copy of the chart
3. In the copy, delete the title and any labels that would not be applicable to other graphs. Keep in mind that charts built off this type will inherit <u>every</u> property it has.
4. Choose: Chart >> Chart Type to display a dialog box
5. Select the "Custom Types" tab and the "User-Defined" radio button
6. Click the "Add" button and enter a name and description for the new chart type

This new chart type will now show up in the Chart Wizard under "Custom Types" when the "User-Defined" button is selected. These user-defined chart types will also be available in other workbooks.