PG&E

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LAWRENCE BERKELEY NATIONAL LABORTATORY
HIGH TECH BUILDINGS PROGRAM

CLEANROOM BENCHMARKING PLAN

SPONSORED BY:

PACIFIC GAS AND ELECTRIC COMPANY
MARKET TRANSFORMATION PROGRAM

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Cleanroom Benchmarking General Plan

Executive Summary

Pacific Gas and Electric Company, through its market transformation program, is sponsoring an ambitious project to collect energy use benchmark data for energy intensive cleanroom facilities. The first goal of this project is to provide useful energy metrics and measured data to building operators to enable them to assess their building systems performance. As a second goal, it is expected that best practice information will emerge which will provide awareness of the opportunities for continual improvement. The project is intended to look for commonalities across industries and cleanliness classes by obtaining benchmark data. It will not result in a statistically valid sample set, but will provide a framework for energy benchmarking and up to eighteen cleanroom data points.

This plan is the first step in developing this project. The intent is to define the benchmarking protocol, and then use this generalized plan to guide development of site-specific plans for each facility. The plans will qualitatively address uncertainties in the collected data. PG&E customers will have the opportunity to provide input to either the general, or their specific plans. This feedback is meant to ensure that the data collected is useful and relevant.

The project will collect energy data on a variety of cleanrooms for two cleanliness classes in two industries. The primary focus will be on the cleanroom environmental systems; principally the HVAC and related systems, but will include other data as available or easily obtainable. A hierarchical approach will begin with cleanroom energy use and then "peel the onion" to as detailed a level as practical. Systems and components will be prioritized to collect energy use data to allow comparison of facility systems for the same cleanliness classes regardless of the industry. The objective will be to focus on the systems supporting operation of the cleanroom by decoupling process energy effects as much as possible.

Once data is collected, it will be entered into a database to facilitate evaluation. Individual companies participating will not be identified by name. Within the database, original design values will be recorded if known, as will standard industry practice values. Thus a building operator (or designer) will be able to see how the cleanroom systems are operating relative to design, industry standard, as well as comparison to others. Eventually as the database is expanded, best practice information will emerge.

We recognize that the accuracy and completeness of data in the database will vary from cleanroom to cleanroom, depending upon measurement methods, access, and ease of measurement. Nonetheless, the ability to categorize relative performance of a particular cleanroom will be a useful tool for identifying improvement opportunities for both retrofit of existing facilities, and future new construction. Abnormal or extreme results will be evaluated to assess whether the measurements taken were inaccurate or require further case study.

The participants will receive a brief report on their facility as well as a copy of the publicly available final report. The participants report will include the site-specific plan, measured data for their site, and observations from the site investigations and measurements. The energy cost per square foot for the cleanroom environmental systems will be estimated and included in the report. Participating companies will not be identified in the final report, as data will be presented anonymously. The short-term goals of the project include focusing on systems and components with significant opportunities for energy efficiency improvement. The program's long-term goal is to develop a robust database with energy benchmark data and make it publicly accessible. Another long- term goal (not part of this project) is to have the benchmarking database available on the web for self-evaluation.

Introduction

The cleanroom benchmarking project is focused on two key industries within the PG&E service territory. "High tech" or electronics based industries, and Biotechnology Companies were selected for this project. These were selected as a result of a PG&E study, which considered energy use, growth, location, and other factors. Lawrence Berkeley National Laboratory (LBNL) has developed this plan to define the scope of the project and identify appropriate metrics, systems, and measurement protocols to collect relevant data. This study seeks to profile specific systems that have the potential to impact cleanroom energy efficiency. Because cleanroom processes are often not cost-effectively retrofitted for energy savings, the most significant areas of potential are in the environmental systems. This study will focus on HVAC related systems including recirculation air systems, make up air systems, and exhaust air systems as a first priority. Energy use in other energy intensive systems will be collected such as in chiller and boiler systems in the central plant, and other process utilities will be collected as a lower priority. Measured energy use data will be collected by energy engineering contractors. Then the data will be categorized, evaluated, and entered into a database. Finally, an analysis of the results will be made and presented in a report to the participant and summarized for anonymous reporting to the industry.

A variety of cleanrooms of two cleanliness classes in each industry will be included. Up to eighteen cleanrooms in 9 facilities are targeted (assuming on average 2 separate cleanrooms per facility). The actual classification of cleanrooms and level of detail for measured data is expected to vary based upon availability and ease of measurement. This generalized plan will outline requirements for site-specific plans, which will detail the extent of the data collection. An energy-engineering firm will utilize the site-specific plan, arrange for the measurement equipment, and work with the facility operator to obtain needed measurements. It is expected that the facility operator will provide in-house staff or preferred contractors to install electrical metering due to safety and operations concerns.

The program has several short term and long-term goals. The short-term goals of the program are as follows:

1. Create an energy use study useful to Biotech and High Tech Industries
2. Create a self-contained study that reaches meaningful conclusions at its completion. This may also set the stage for future work.
3. Define metrics useful for clean room energy efficiency.
4. Begin Identifying best practices for use in new construction or retrofit.
5. Create a database format accessible to building owners.
6. Present and receive feedback through Industry roundtable meetings.

Goals for later phases of the program include:

7. Provide methodologies for self evaluation
8. Prepare Cleanroom Design Guide
9. Realize the energy efficiency opportunities

A major challenge of the benchmarking program will be in consistently defining the cleanroom envelope and the boundary of the benchmarking study. Since the goal of the program is primarily to compare only facility environmental systems' energy use for cleanrooms of like cleanliness class, it will be important to accurately account for the process and/or plug load effects so that the energy use from the facility systems of interest are determinate. Systems and components that account for small (judged to be less than 5%) facility energy use will be ignored, with the possible exception of lighting systems which are expected to have some immediate efficiency opportunities even if the relative percentage of savings is lower.

Procedure

This generalized plan will guide the development of site-specific plans, and will help to ensure that comparable data is collected for the selected cleanrooms. Before any work can commence at a PG&E customer site, the customer and PG&E must sign a PG&E monitoring agreement. Non-disclosure agreements, if required by the customer, will also be executed. Once these agreements are in place, site work can begin.

Following an initial site visit to assess the facilities to be monitored, a site-specific plan will be established based on the general plan for the project. The PG&E customer will have opportunity to provide input to the benchmarking plans, which should help to ensure that the measured data is useful. The site plan will be submitted to customer contacts as well as PG&E staff and other involved parties for review, comment and revision during a one week period before moving ahead with site monitoring.

The customer facility staff or preferred contractors will install electrical metering equipment based upon direction from the energy engineer. The energy engineer responsible for collecting the data will work with the facility staff to collect existing data, and to coordinate the site work to obtain any additional data. It is expected that the existing facility security and safety programs will be followed and particular care will be taken to avoid disruption of production activities. For obtaining measurements in nonintrusive areas, the energy engineer will directly place necessary instrumentation and collect the data. The specific systems and components, and the measurement methods are described in this plan. They will be customized for each site.

Once the measured data is obtained, it will be entered into a Microsoft Access database. The database will allow for comparisons to design (if available), standard industry practice, best practice, and other cleanroom values. As the data in the database becomes more robust, it will become a useful tool for building operators to self-evaluate their building performance, and observe performance associated with best practice. They can also see if the cleanroom is performing as intended. The benchmark data will provide a mechanism to discover areas of exceptional performance and highlight areas for potential improvement. In cases where performance is less than optimal, there will be a natural tendency to investigate the cause and possible improvements. This will invariably lead to establishing best practices.

As the energy use measurements are obtained on site, the energy-engineer will record any observations for areas of potential improvement or further study. Any specific observations and recommendations will be summarized and presented to the building representative in the site report, along with the measured data.

LBNL will review the data to provide an assessment of current practice and possible energy efficiency improvement opportunities. Comparisons of the relative efficiency of various system designs will be made to the extent possible. As the database is populated with more data, best practices are expected to be evident. Unusual extremes in reported efficiency data will be highlighted for possible future case study.

For each cleanroom facility benchmarked, a brief site report will be provided. The report will include the site-specific plan, collected and measured data, and observations concerning the cleanroom facility systems operation. This report will be reviewed with the site staff. In addition, an industry roundtable discussion hosted by PG&E will be used to present benchmarking results and conclusions. It will also be an opportunity to receive industry input and validate the usefulness of the data.

Final reports of the cleanroom energy benchmarking for each industry will be prepared by LBNL. These reports will include the benchmark data and an analysis of findings. The reports will be publicly available and will be distributed by PG&E to the PG&E customers who participate.

Site Selection and Characteristics

The following factors will be considered when selecting cleanrooms for this project:

1. *Within PG&E territory* - First preference will be to benchmark existing PG&E customers' cleanrooms. Should additional sites be needed, they may be added from other service territories.

2. *Biotech or "high tech"* - Two industry segments will be targeted.
3. Management commitment for energy efficiency – The customer will likely have an energy advocate and will have a strong management commitment for improving energy efficiency.
4. *Willing to share data anonymously* – The program participants will agree to confidentiality agreements (if required by the customer) and report data anonymously.
5. *Several cleanrooms in one facility* – It is assumed that two or more cleanrooms may be included from a given facility. Although this is not a limiting consideration, facilities with multiple cleanrooms will be more desirable for this project.
6. *Have existing energy use data and metering* – Ideally, the customer will have some or all of the performance (operating) data and will make it available for the database. Existing metering will facilitate taking new benchmark data.
7. *Facility is accessible without disturbing process* – Particular care will be taken to obtain measurements without disturbing on-going production.
8. *Ability to meter areas of interest* – Most, if not all, of the areas of interest must be accessible for measurement.
9. *Industry innovator/leader* – Generally, industry leaders and innovators will be participating in this study.
10. *Size of firm* – The study will include a mixture of large and small firms.

Once a site has been selected according to the criteria above, specific cleanroom facilities will be based, when possible, on the following areas of interest:

1. *Function* – The process being carried out inside the cleanroom space should pertain to the Biotech or "high tech" industry.
2. *Class Rating* – For the "high tech" (electronics industry), Class 10 and class 100 cleanrooms are preferred. For the Biotech industry, Class 100 and class 100,000 cleanrooms are preferred.
3. *Cleanroom Size* – Collecting data on both small and large cleanrooms may yield insights into related energy intensity and economies of scale for cleanroom facilities. The project has a preference for a mix of cleanroom sizes.
4. *Recirculation System* – The type of air recirculation system serving the cleanroom has a significant impact on the energy intensity of the environmental systems. The project has a preference for a mix of recirculation systems including fan filter units, pressurized plenum, and ducted HEPA/ULPA filters.
5. *Vintage* – Few cleanrooms last longer than 5 years in operation without retrofit or redesign. Therefore, the project has a preference for newer cleanrooms, including those that may be old but more recently retrofitted as well as recently constructed cleanrooms.
6. *Central Plant Type* – The project has a preference for a mix of central plant types including air cooled chillers, water cooled chillers, and those central plants both with and without free cooling.

The selection criteria for cleanroom sites reflect only preferences, not requirements, for characteristics represented in the group of cleanrooms to be studied. In pursuing diversity in cleanroom size, design, age, and central plant design, the project does seek to establish a statistically valid data set representing each type of cleanroom configuration. Instead, the selection preferences reflect an interest in investigating the major factors that affect energy consumption at the cleanroom level.

Applicable weather data used in the design of the facility will be determined and recorded in the database. Actual weather conditions will be recorded during the metering of weather dependent systems. Although cleanroom energy use is expected to be relatively weather independent, this assumption will be tested at a small sampling of the sites. Site historical energy use will be examined (if available) to observe trends, and weather related impact. Existing metering at the site level or building level will be noted.

Facility Characteristics and data provided by participant

To enable the energy use data to be analyzed and effectively used for comparison, a number of facility characteristics will be recorded. Existing design information, and operations data will also be necessary. This information will be useful to establish the site-specific plans, to categorize the data, to explain differences in cleanroom performance, and to help identify best practices. The information will include:

- Type of construction – UBC designation
- Local building code requirements
- Cleanliness classification(s) of cleanrooms
- Floor plans
    - Square footage of cleanroom
    - Square footage of other adjacent spaces
    - For multi-use buildings, the percentage of the cleanroom in question to the total
- Volume of cleanroom (ceiling height)
- Existing metering/EMCS capabilities
- Annual hours of use
- Processes within cleanroom/process utilities serving the cleanroom
- Ability to identify and separate process loads
- Environmental conditions design basis
- Design descriptions (architectural features, HVAC design, etc.)
- Year facility was built/known modifications and their installation dates
- Commissioning records
- Certification reports including particle counts and air flow measurements
- Occupancy
- Existing energy use data (benchmark data)/ EMCS data/ utility bills
- Sequence of operations/control sequences
- Single line drawings
- Schematic drawings (primarily HVAC)

- Selected major equipment vendor information including O&M manuals

Site-Specific Plan

The procedure that will be followed for each customer site will be governed by the site-specific plan. The PG&E customer will have opportunity to provide input to the benchmarking plans, which should help to ensure that the measured data is useful. The site plans will identify the specific energy use data that will be collected. First, any relevant existing energy benchmark data will be collected and an assessment made as to additional data points or additional accuracy that may be required. It is possible that the facility currently has monitored data available. An assessment of the accuracy of the data will be made and if determined to be adequate, it will be entered into the database. Engineering judgment will be exercised in comparing the relative accuracy of existing data or data taken through building management systems. Most likely, however, additional more accurate physical measurements will be taken.

Elements of the site-specific plan will include:

- Review of site characteristics affecting data collection including level of access to equipment, total area served by single central plant site serving the cleanroom sites, and a brief plant description.
- Discussion of existing data acquisition system if present on site including depth of monitoring capability, accuracy, sampling rate, and data output format.
- List of supporting documents actually available from the site for data collection from the list of requested documents submitted to the customer. (See “Facility Characteristics and Data Provided by Customer” below.)
- Measurement plan: The measurements will be based on the table of data points prioritized in Appendix A. For each site, data points will be sorted into one of four categories: direct measurements to be made by the energy engineering firm, direct measurements requiring customer contractor assistance, data to be collected from an existing data acquisition system, and data to be collected from supporting documents. The measurement plan will outline the site-specific approach to data collection in each of these categories.
- Personal resource allocation including customer appointed contractors, facility staff, and project team members.
- List of customer and project team member contacts.
- Elements from the General Plan including, but not limited to, project overview, procedure, and data reporting.

Energy Measurement

A hierarchical approach will be used to prioritize and evaluate energy use measurements. This will begin with site, whole building, and “cleanroom” energy use (if available), and progress to system level measurements, and then to key component measurements. In similar fashion, the systems are prioritized to primarily collect data on environmental systems for the cleanroom, but allow for data to be included for process utilities if readily achievable. Process loads, including chilled water loads, in total will need to be obtained to enable the comparison of cleanroom environmental systems. By accounting for widely varying process loads, the actual "cleanroom" environmental energy performance will be possible. The current benchmarking project does not seek to capture detailed process loads nor benchmark individual process equipment/tools.

The primary focus of this benchmarking is on environmental systems serving the cleanroom. An important element of each site-specific plan will be in definition of the "cleanroom" and accounting for shared systems serving other spaces. Either through measurement, by calculation, or engineering judgment non-cleanroom energy use will be accounted for. Similarly, process energy - both direct and indirect effects - will be accounted for.

This plan and its execution will be tailored to each individual site with the objective of collecting data to as great a detail as practical within a short period of time. In some respects, data will be collected where it is opportunistically feasible and ignored where it is not. The overall goal will be to populate a database with as much pertinent energy use data as practical to collect in a two to three week period.

Systems and components to benchmark

Data collection will focus primarily on environmental systems for cleanroom operation. Where available, the design basis will be recorded and used to compare to measured values. Systems will be prioritized so as to collect the most useful data for comparison of cleanroom operation and will not focus on production energy metrics. Note that the project specifically will not be measuring production efficiency such as KW/unit of production. Any measurements of process energy use will be on an aggregate basis to assist in determining the cleanroom environmental systems performance. The objective will be to measure energy use in cleanroom facility systems while accounting for, or decoupling, process systems and other mixed energy uses. This will provide a direct comparison of the performance of the "cleanroom" systems.

This project will evaluate energy use in energy intensive systems unique to cleanrooms and having a high potential for energy reduction strategies, and efficiency improvements with no impact on production. Other central plant systems, also have potential for energy efficiency improvement. Cleanrooms often require process cooling with chilled water loops separate from those required by the air cooling systems, so the design and performance of the central plant can offer significant opportunities for savings. Recirculation air systems in cleanroom environments handle extremely high volumes of air, and the relative size of the large electrical load associated with recirculation air handling allows even small percentage improvements in efficiency to yield high value savings. Make-up air handling and exhaust fan systems present similar opportunities to make energy efficiency improvements without impacting cleanroom processes or production, so these too will be prioritized for monitoring.

Energy data collection will include the overall plant level and increasing levels of detail within the plant. The detail level to be obtained for a particular facility will be determined by the physical conditions, ease of data collection (i.e.: the ability to collect the desired data within the budgeted time), and the relative contribution to energy use in the facility. For example, data will be collected on process utility systems if it is readily available or needed to isolate the environmental systems of concern. The intent of this project is to defer process related benchmarks to later phases of the program recognizing that release of process information is typically sensitive.

Energy use benchmarking will target data based upon several priorities. The highest priority will be the primary objective. Other data will be highly desirable but will be collected only if readily available and time permits. The last priority will be collected in later phases of the program. The first priority will be to obtain measured data on "cleanroom" environmental systems. To accomplish a method of comparison, normalization will be required to account for varying process loads and other factors.

As a result, the following systems will be targeted as the **first priority**:

"Cleanroom" environmental systems

- HVAC
  make-up air
  exhaust (general, solvent, scrubbed, acid, ammonia)
  air recirculation
- Heating/humidification steam
- Lighting

The **second priority** will include:

Central plant systems:

- Chilled water
- Cooling towers
- Condensers
- Boilers
- Pumps

To account for process loads:

- Total process load

As a **third priority**, measured energy data on process utility systems will be obtained provided it is readily obtainable within the data collection period. Typical process utility systems include:

- Compressed air
- Vacuum systems
- Nitrogen
- Ultra pure water
- Plant steam
- Clean steam

For the **fourth priority**, detailed measurements of process systems and equipment would be included. It is expected that for this study, only aggregate process loads will be determined to enable the cleanroom environmental systems to be isolated. Individual process equipment loads are not targeted at this time, however should they be readily available they will be entered into the database.

Metering strategies

Measurement Strategy

The general measurement philosophy will be to collect enough onsite data to yield meaningful insight into the energy usage of the facility and the energy efficiency of the systems and components of interest. This strategy will be based on the following assumptions:

- Process loads are constant over the testing period (assumption will be tested)
- Loads representing less than approximately 5% of the total energy use will be ignored
- Envelope loads represent less than 5% of the total energy load
- Accuracy of measured data will vary. A qualitative evaluation of the accuracy will be provided.
- Production metrics will not be collected, however total process loads will be accounted for by measurement, design basis, or engineering judgment.
- Existing energy use data from prior measurements, or available through Building Management Systems will be entered into the database with little or no verification. Engineering evaluation of this data, including its accuracy, will be included during reporting.
- For all high priority data points where direct measurements cannot be obtained, a value will be provided based upon design numbers, other engineering calculations, or engineering judgement.

The data collected will be used to calculate metrics, which will lead to a better understanding of the energy use in cleanroom facilities, and they will provide information on the efficiency of various systems and components.

Central Plant

While not the main focus of this study, the central plant is likely to be a dominant energy user and may well represent over 50% of the potential cost effective energy savings. Efficiency targets for many major central plant systems and components already exist (E-Source, www.esource.com). Experience has shown that central plant system design represents a significant opportunity for improvement. The equipment is quite accessible during operation so central plant data will be included as a second priority to the extent possible. A maximum of two chillers per site is budgeted for measurement.

The central plant measurements will provide both the input (kWh) and output (tons-hrs) for the plant. The main challenge will be in mixed use spaces where the systems serving the cleanroom are served from a common plant serving other spaces, process equipment, etc. Each site will be evaluated to determine the approximate loads serving the cleanroom of interest, either through direct measurement, design basis, or other engineering evaluation.

Cleanroom

To evaluate the "cleanroom", the amount of heating/cooling actually used by the "cleanroom" will need to be determined. While plant cooling loads are typically simple to measure, the chilled water flows and temperature at the clean room are often difficult to measure due to measurement constraints, primarily in determining flows. Using air-side measurements provides a far easier measurement, but adds uncertainty.

Air volume rates are difficult to determine without impacting the process in the room. They are also costly and time consuming to measure. Fortunately most, if not all, cleanrooms will have recent air balance and certification reports with the measured air volume rates. Balance and certification reports will therefore be used as the source of airflow data. An assessment of the accuracy of the data will be included in the site specific plan. This assessment will consider the method of obtaining the air flow and test measurement uncertainties. Knowing the on-coil and off-coil conditions will yield the cooling load for the cleanroom. Further refinement in evaluating the humidity control method, and outside air conditions will provide values of total efficiency and humidification energy input.

A second determination will be in the efficiency of the fans and air handlers serving the cleanroom. This will provide a direct evaluation of the fan efficiency (W/CFM). This will permit comparison to other clean rooms of the same classification. Since most cleanrooms have multiple air handlers, the measurement plan will be to obtain sample readings. For example, up to three recirculation units and at least one make-up air handler will be monitored. Assumptions that other similar units are operating in a similar manner will be made.

Certification and balance reports will likely contain particle count data that will be analyzed along with air volume (velocity) rates. The main goal here is to establish whether designers are specifying higher than needed air volume rates. The particle count rates are often highly variable due to small differences such as occupants, sensor location, cleanroom protocol, and product produced. Therefore the correlation between particle counts and air-flow taken during certification and actual cleanroom operation may not be obvious. While the accuracy of this data is unknown, it will be sufficient to provide general indication of relative energy use. It will also indicate whether a system, regardless of its energy efficiency, is moving more air and thus, using more energy than is required.

Process Utilities

Energy input to process utility systems is relatively straightforward to monitor, while the output of these systems is difficult and costly to measure. To avoid the cost of monitoring the output of these systems, often a proxy value such as design flow can be used. The site-specific plans will determine a way to account for the total process utility energy use for each facility.

Process Equipment/Tools

Total process equipment and tools energy usage is thought to be relatively straightforward to measure. Difficulties are in gaining access to the required electric panels, and isolating the load in the event that other services are being served from the same electrical feeder. In some applications, however, it may be difficult or impossible to separate these loads.

Weather

An aspirated psychrometer will be provided to obtain the dry bulb and wet bulb temperature for the site. The box location will be in a position where sunlight does not add too much heat and alter the readings during the test period. Weather data will be used to evaluate sensitivity of environmental systems (primarily make-up air) to weather, and to extrapolate results to an annual data set.

Calibration and Accuracy

Calibration and the relative accuracy of various measurement methods will be discussed in the final reports. The accuracy of the measurement will vary based upon the accuracy of the measurement equipment, physical constraints, calibration, reporting accuracy and other factors. A qualitative assessment of the accuracy of the results will be provided.

As per the ASHRAE Guideline 14P, Measurement of Energy and Demand Savings, the accuracy of the values in the database will be determined based on factors including the source of the data, sensor selection, length of data collection and the method used for normalizing the data. The accuracy of all major values will be included in the database.

Source of the data is the key factor in determining the accuracy of the value. Data measured directly by project staff will, in most cases, have a greater degree of accuracy in reflecting actual system performance than any of the other data collection methods including taking data from existing data acquisition systems of design documents. Data from the original design or system balance will have a much lower accuracy confidence level. The accuracy from these sources will be derived on a qualitative basis. Thus, the accuracy of a value will be determined based on the age of the value, the original intent of the value and the current operating condition of the equipment. It is unlikely that an original design value accuracy would ever exceed the accuracy of a measured value, thus measured data will always be preferred to design data.

Spot measurements will be conducted in accordance with ASHRAE Guideline 14P, Section 7. The period used may vary based on the requirement of the customer. Spot data is typically used on equipment that does not vary significantly with usage, such as DI Water pumps, lighting, etc. Accuracy will be slightly reduced due to the short length of monitoring, but will still be sufficient for the intended evaluation purposes.

Field calibration can increase accuracy of measured values, but due to likely time and budget constraints, it is anticipated that field calibration will be held to a minimum. In the event that any field calibration is done, the accuracy values will reflect the high accuracy attained. Instruments that have been previously installed and calibrated by the customer as part of a control system will reflect the accuracy of the calibration report.

As per ASHRAE Guideline 14P, Section 7, validation of data will reflect a series of checks to ensure that the data is reasonable for the application. Checks will include a simple graphical validation and range gate validation. In the event that a significant amount of data is judged not valid, other data collected with the same equipment or method will be review to ensure that a systematic problem does not exist.

Data Collection and reporting

Using the site-specific measurement plan, the energy engineer will first collect existing data for the metrics of concern. Additional measurements will be taken as described in the metering strategies section. The data relationships in the Access database are defined in figure 1.

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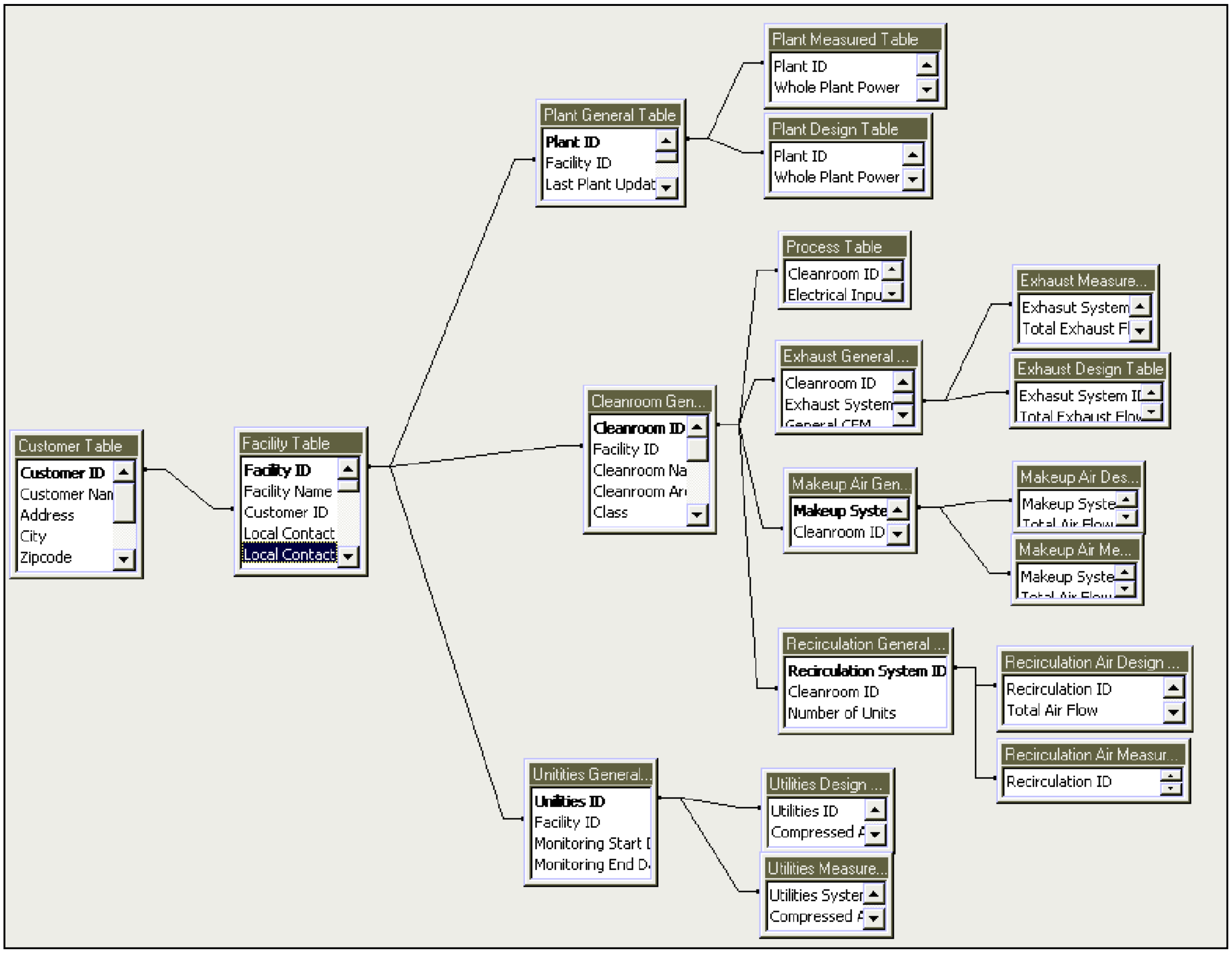

Figure 1 Database relationships.

<u>Annualizing Data Points and Adjusting for Weather</u>

Applicable weather data used in the design of the facility will be determined and recorded in the database. Actual weather conditions will be recorded during the metering of weather dependent systems. This lack of dependence on weather is because the energy use is strongly driven by process tool internal gains and the constant recirculation of air through the cleanroom. Although cleanroom energy use is expected to be relatively weather independent, this assumption will be tested at a small sampling of the sites. Site historical energy use will be examined (if available) to observe trends, and weather related impact. In addition, because we are collecting data over several days, we will have some indication of the variability of the loads and electricity use with outside conditions from day to night.

If the measurements are not strongly correlated with weather (evaluated with a simple regression curve), we plan to extrapolate from the short-term measurements to annual estimates using a straight proration. If, however, they are found to vary significantly with outdoor conditions, a simplified method to account for weather will be developed. This will likely be a simplified bin model for which all assumptions and techniques for annualization of short-term data will be documented. For example, the average cooling load for various outside weather bins that represent a typical year would be estimated. The load is then multiplied by the average kW/ton for a particular weather bin. Using such a method, the annual tons-hours and annual energy use for cooling systems can be estimated.

The method of annualization of any of the collected data will be documented in the site reports. Data determined to be weather dependent will be annualized with simplified engineering methods using bin weather data.

Data Reporting

Data collected in the database will be presented in a final report. Graphical presentation of results is preferred. Individual customer data will be presented in a brief site report. The site-specific report will include the site specific measurement plan, the measured data, and observations for efficiency opportunities. The final reports will include an analysis of the data and conclusions on best practices from the observed data. The analysis will consider factors such as building and cleanroom configuration, weather effects, age, system design, hours of use, annualized results, and other considerations.

APPENDICES

Appendix A

Cleanroom Benchmarking Project

Measurement and Prioritization Schedule

The following data tables will guide the data collection process. Proxy data from design documents or testing results will be used for data points for which direct measurement is not possible.

The priority levels below correspond as indicated:

1 – Collect this data unless site constraints exists.
2 – Collect in most cases except when there are site constraints or time constraints.
3 – Collect in some cases time permitting.
4 – Collect if data is easily available and time permitting.

All time series data for each site will be compiled into a single spreadsheet workbook. Trended data will be reported in the database with in-service average, minimum, and maximum values.

I. Cleanroom Metrics

All metrics will be calculated using data collected below.

Description	Units	Priority
Recirc AHU Efficiency	cfm/kW	1
MUAH Efficiency	cfm/kW	1
Annual Energy Cost per Cleanroom Square Foot	$/sf	1
Annual Fuel Usage	MBtu/sf/yr	1
Annual Electricity Usage	kWh/sf/yr	1
Annual Energy Usage	MBtu/sf/yr	1
Make-Up Air	cfm/sf	1
Recirculation Air	cfm/sf	1
Recirculation Air	ACH/hr	1
Cooling Load Density	sf/ton	2
Process equipment Power Density	W/sf	2
Lighting Power Density	W/sf	2
Exhaust System Efficiency	cfm/kW	3
Primary to Total Area		1

Cleanroom Energy Usage Breakdown

Typically two cleanrooms per site

Target	Units	Data Source	Duration	Priority
Total Recirculation Fan Usage	kW	Calculated based on Recirculation data	Calculated	1
Total Make-Up Air Handler Usage	kW	Calculated based on MUAH data	Calculated	1
Total Process Power Usage	kW	From electrical panels	Spot	1
Chilled Water Plant (if chilled water plant is on same meter or in same building as cleanroom that is being measured)	kW	From electrical panel or from chilled water plant measurements	Misc	1
Other Power Usage	kW	From electrical panels	Spot	1
Cleanroom cleanliness (class rating using new ISO standards)	N/A	Certification and/or design documents	N/A	1
Cleanroom Recirculation Flow (CFM)	cfm	Balance report or design drawings	N/A	1
Cleanroom Temperature	Deg F	Temperature Sensor	1 week	1
Humidity Conditions	R.H.	Humidity Sensor	1 week	1
Annual Electricity Use	kWh/yr	Utility bills	N/A	1
Annual Fuel Use	Therm/yr	Utility bills	N/A	1
Peak Power	kW	Utility bills	N/A	1
Average Power Factor	%	Utility bills	N/A	1
Facility Area	sf	Drawings	N/A	1
Primary Area	sf	Drawings	N/A	1
Secondary Area	sf	Drawings	N/A	1

Make-Up Air

Measure a minimum of one make-up air handler per cleanroom

Target	Units	Data Source	Duration	Priority
Air Flow	cfm	(Designed, TAB report)	N/A	1
Fan Power	kW	3Φ True Power	Spot	1
Variable Frequency Drive Speed	Hz	VFD	Spot	2

Discharge Setpoint Temperature	Deg F	Design	N/A	2
Supply Air Temperature	Deg F	10k Thermistor	1 week	4
Supply Air Humidity	RH	RH sensor	1 week	4
Fan Pressure Rise	Inches of static	Differential Pressure Sensor	Spot	1
Duct Pressure Drop	Inches of static	Differential Pressure Sensor	Spot	2
Filter Pressure Drop	Inches of static	Differential Pressure Sensor	Spot	2
Coil Face Velocity	fpm	Design	Spot	1

Recirculation Air Handlers

Measure a minimum of 3 recirculation air handlers per cleanroom

Target	Units	Data Source	Duration	Priority
Air Flow	cfm	(Design, TAB report)	N/A	1
Fan Power	kW	3Φ True Power	Spot	1
VFD Speed	Hz	VFD	Spot	2
Discharge Setpoint Temperature	Deg F	Control System	1 week trend from control system	2
Return Air Temperature	Deg F	10k Thermistor	1 week	3
Supply Air Temperature	Deg F	10k Thermistor	1 week	3
Supply RH Setpoint	RH	Control System	1 week trend from control system	3
Supply RH	RH	RH Sensor	1 week	3
Fan Pressure Rise	Inches of static	Differential pressure sensor if possible otherwise designed or TAB report	Spot	1
Recirculation Filter Type	N/A	(Design, TAB report)	N/A	1
Duct Pressure Drop	Inches of static	(Design, TAB report)	N/A	3
Filter Pressure Drop	Inches of static	(Design, TAB report)	N/A	3
Air Velocity across filters and coil in air handler	fpm	(Design, TAB report)	N/A	1
Pressurization	Inches of static	(Design, TAB report)	N/A	2
Sensible Cooling Load per cooling coil	Btu	Design	N/A	4
Cooling Load	Tons	Calculated	N/A	4

Exhaust

General, Scrubbed, Solvent, Acid, Ammonia

Measure a minimum of one exhaust per cleanroom

Target	Units	Data Source	Duration	Priority
Total Air Flow	cfm	TAB or Design Data	N/A	3
Fan Power	kW	3Φ True Power	Spot	3
Fan Pressure Rise	Inches of static	Differential Pressure Sensor	Spot	3

II. Central Plant

All metrics will be calculated using data collected below.

Chilled Water Plant Metrics

Description	*Units*	*Priority*
Chiller Efficiency	kW/ton	2
Tower Efficiency	kW/ton	2
Condenser Water Pumps Efficiency	kW/ton	2
Chilled Water Pumps Efficiency	kW/ton	2
Total Chilled Water Plant Efficiency	kW/ton	2
Plant Efficiency While Free Cooling	kW/ton	2

Chilled Water Plant

Maximum of 2 chillers per chilled water plant measured

Target	Units	Data Source	Duration	Priority
Chiller Power	kW	3Φ True Power	1 week	1
Primary Chilled Water Pump Power	kW	3Φ True Power	Spot	1
Secondary Chilled Water Pump Power	kW	3Φ True Power	1 week	1
Chilled Water Supply Temperature	Deg F	10k Thermistor	1 week	2
Chilled Water Return Temperature	Deg F	10k Thermistor	1 week	2
Chilled Water Head (ΔP)	Feet of head	Pressure Transducer	Spot	3

Chilled Water Flow	gpm	Ultrasonic Flow	1 week	2
Cooling Tower Power	kW	3Φ True Power	1 week	2
Condenser Water Head	Feet of head	Pressure Transducer	Spot	3
Condenser Water Pump Power	kW	3Φ True Power	Spot	2
Condenser Water Supply Temperature	Deg F	10k Thermistor	1 week	2
Process Cooling Pressure Drop across Pumps (ΔP)	Feet of head	Differential Pressure Sensor	Spot	4
Process Cooling Water Pumps Power	kW	3Φ True Power	Spot	3
Process Cooling Flow	gpm	Ultrasonic Flow	Spot	3
Process Cooling Supply Temperature	Deg F	10k Thermistor	1 week	3
Process Cooling Return Temperature	Deg F	10k Thermistor	1 week	3
Chiller Cooling Load	Tons	Calculated	N/A	2

Boiler Plant Metrics

All metrics will be calculated using data collected below.

Description	Units	Priority
Hot Water Pumping Efficiency	kW/MBtu	4

Boiler Plant

Target	Units	Data Source	Duration	Priority
Hot Water Supply Temperature	Deg F	10k Thermistor	1 week	3
Hot Water Return Temperature	Deg F	10k Thermistor	1 week	3
Hot Water Pumping Power	kW	3Φ True Power	Spot	4
Hot Water Flow	gpm	Ultrasonic Flow	1 week	4
Boiler Gas Input	CFH	From Gas Meter (if available)	1 week	4
Boiler Efficiency	%	Design	N/A	3
Total Cleanroom Gas Use	Therms	Calculated	N/A	4

III. Other Metrics

Description	Units	Priority
DI Plant Efficiency	kW/gpm	3
Nitrogen Plant Efficiency	cfm/kW	4
House Vacuum Efficiency	cfm/kW	4
Hot Water Pumping Efficiency	kW/MBtu	3
Compressed Air	BHP/100acfm	3
Boilers Efficiency	%	3
Lighting	W/sf	2

Process Utilities

Target	Units	Data Source	Duration	Priority
Compressed Air Input	kW	3Φ True Power	2 Days	3
Compressor Air Discharge Pressure	acfm	Design Data	N/A	3
Nitrogen Plant Input	kW	Electrical panels	Spot	4
Nitrogen Plant Output	cfm	Design Data	N/A	4
DI Water Plant Power	kW	Electrical Panels	Spot	3
DI Water Output usage	gpm	Design Data	N/A	3
DI Water Recirculation Rate	gpm	Design Data or site flow metering	N/A	3
Vacuum Input	kW	3Φ True Power	2 Days	4
Vacuum Output	cfm	Design Data	N/A	4
Vacuum Output Pressure	psi	Design Data	N/A	4

Other Loads

Target	Units	Data Source	Duration	Priority
Lighting Power	kW	3Φ True Power	2 Days	2

Weather

Target	Units	Data Source	Duration	Priority
Drybulb Temperature	Deg F	Temp/RH Sensor	1 week	1
Wetbulb Temperature	Deg F	Temp/RH Sensor	1 week	1

Appendix B.

Equipment

Power Monitoring Equipment

Where power consumption does not change over time (typical applications include pumps, lighting, some fans), only a spot wattage measurement is needed. This type of measurement is typically done with a hand held power meter with clamp on current sensors as shown on the right. Manufacturers include Fluke, Amprobe and Hioki.

Figure 1- Single Phase Power Meter

Often a power calculation is made with a combination Amp and voltage meter, and an assumed power factor. The error in an assumed power factor can affect the accuracy of the value by up to 10% and rarely can be trusted to with in 5% for a specific measurement. Thus unless the power factor is well known (resistance heating) or the measurement does not warrant high accuracy, the monitoring plan should include the use of a true power meter.

When measuring three phase loads with a single phase meter, it is important to remember few loads are truly balanced as each phase has slightly different characteristics, thus for maximum the power of each phase will need to be measured. When using a single phase meter, each individual phase will need to be measured. Most three phase loads use a three wire 'wye' system (motors, air conditioners), and the following calculation is needed when using ground as a low-side voltage reference:

$$kW = V_a I_a PF_a + V_b I_b PF_b + V_c I_c PF_c$$

Where

- kW is the real power
- V is the phase to ground voltage reference
- I is the measured current
- PF is the measured power factor

When using a phase to phase voltage reference the following formula is used:

$$kW = \frac{V_a I_a PF_a + V_b I_b PF_b + V_c I_c PF_c}{\sqrt{3}}$$

Where

- V is the phase to ground voltage reference

For balanced loads it is acceptable to average the current, phase to phase voltage and power factor measured values and use the following formula:

$$kW = V_{ave} I_{ave} PF_{ave} \times \sqrt{3}$$

Increased accuracy can be obtained by using a meter that can measure all three phases simultaneously. See Figure on right. Typically a three phase power meter will also provide amps, volts, power factor and total harmonic distortion. Several models also have a limited data logging capacity. For three phase power meters with changeable current probes, it is best to select the current probe rated slightly above the maximum current expected. Increasing the current rating of the probe increases the error on smaller loads. The long insulated voltage taps shown in the figure are helpful in avoiding contact with high voltage wires and are preferred. Special consideration will need to be taken in the event that the load uses voltages above 600V. In such cases of high voltage, refer to the manufacturer on the maximum voltage of the unit and if a step down transformer can be used to adjust the voltage to within the scale of the meter. Manufactures include Summit Technologies, Pacific Science and Technology, Dranitz and BMI. Costs vary widely, bases on the features included. Cost is not always related to accuracy, and a less expensive meter may yield the same accuracy as a more expensive meter, but typically will have less features.

Figure 2- Three Phase Power Meter

Where the load voltage and power factor are stable, a lower cost option to three phase monitoring is a three phase current logger. In order to avoid large errors due to an assumed power factor, a initial reading of voltage and power factor are made, and an assessment of the stability of the power factor will need to be made. If the power factor changes as the equipment loads and unloads, these types of meters are suitable only as a first cut. Several are sold as packages with specific current transformer design for the data logger.

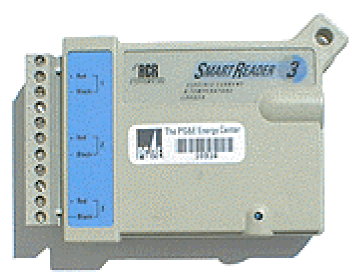

Figure 3- Current Logger

For long term monitoring of large three phase equipment a power transducer is required. The power transducer measures the true power being drawn and outputs a calibrated signal (0-10V or 4-20 mA) that is recorded on a data logger. Current transformers are used to provide a standard 0-5 Amp current signal (see below for information on CT's). Two CT's are needed for a three wire delta system and three CT's are needed for a four wire wye system. Three voltage taps are needed for all three phase applications. Some models require a separate power source, with self -powered units costing a bit more, but have reduced labor for installation. Proper installation of the power transducer should include fuse protection for the three voltage taps with a switch

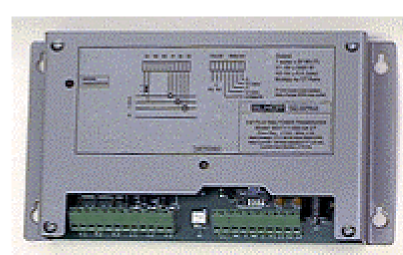

Figure 4- Power Transducer

to isolate the voltage taps for easy connection and disconnect in the event that service on the power transducer is needed.

Manufacturers of power transducers include Ohio Semitronics, Elkor Technologies, Flexcore, and Triateck.

Current transformers are needed by power metering equipment to determine the current flow without tapping into the wiring. There are two main types of CT for long term monitoring application, solid core and split core. Clamp-on current transformers are typically only used for hand held meters for spot or short term applications.

Solid core provide a more accurate reading and cost much less than split core CT, but are more difficult to install and require that the equipment being monitored be shut down during installation. Solid core CT's can only be installed with the power shut off.

Figure 5- Solid Core Current Transformer

CT's typically have a stamp that indicates the transformer ratio where the "500:5" as seen in on the top of the CT in Figure 5, indicates that the transformer can handle 500 Amps with a secondary output of 5 Amps. Before purchasing any CT's for a specific power transducer, ensure that the power transducer uses a 5 Amp maximum input. If the transducer requires a different input amperage, contact the manufacturer to see if a specific CT is recommended.

Split core CT's can be installed without disconnecting the power cables. Split Core CT's are typically installed by removing a section at the top of the CT where the leads are connected, then placing the 'U-shaped' portion of CT around the cable to be monitored and then replacing the section to form a current loop. Great care must be taken when installing split core CT's in panels or disconnect boxes that have live power.

When CT are installed before the power transducer are available, it is important to shunt the leads to the CT otherwise high voltages will build up either damaging the CT or damaging the technician who tries to install it. It is recommended that the CT's and power transducers be installed

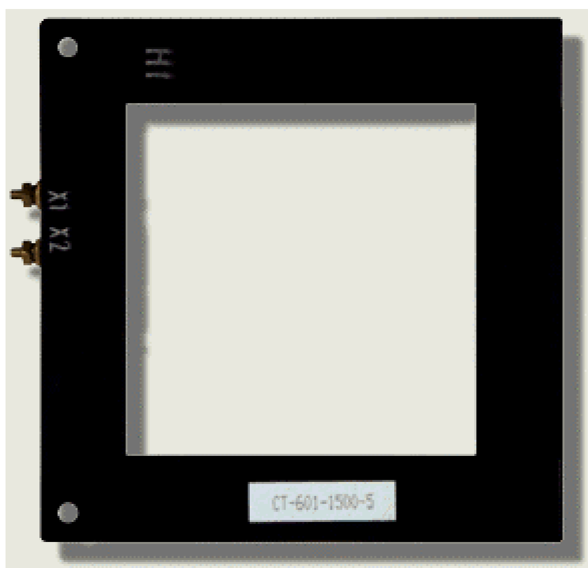

Figure 6- Split Core Current Transformer

together, while the equipment is shut down. This greatly reduces the chance of damaging the equipment and speeds installation.

Current transformer manufacturers include Ohio Semitronics, Triateck, Flexcore, Inotek, and SNC Manufacturing.

Temperature

There are three basic types of temperature sensors.

- Thermocouples
- RTD's
- Thermistors

Thermocouples typically have a much higher error (often as high as 0.2 °C) and are not recommended for applications where a thermistor or RTD can be used. Thermistors provide the best accuracy and long term stability. Thermistors can often be calibrated to 0.01 °C with very little drift over the life of the sensor. Unfortunately, thermistors are a reverse resistance sensor (meaning that resistance increases and temperature decreases), and are incompatible with several data loggers. In cases where a specific logger is needed and it is incompatible with thermistors, an RTD should be used.

Temperature sensors typically are available in several different probe styles. A hermetic style probe is typical for all water based applications. Typically the probe is inserted into a "Pete's Plug" where it is in contact with the fluid. For long term monitoring applications a thermawell can be used to protect the probe from any debris that may be floating in the fluid. When determining the cost of a thermistor sensor, ensure that any cost for tapping into the water line is taken into account, often it can double the per point cost of the sensor.

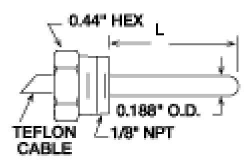

Figure 7- Thermistor Probe

For air applications an air cage thermistor should be used. The probe should be placed either facing into or perpendicular to the air flow. Air temperatures typically fluctuate by 0.5 to 1°C, thus a lower cost thermistor or RTD can be used without loss of accuracy. Air cage thermistors are simple to install in ducts, a hole is drilled into the duct and the flange is inserted and secured by a couple of machine screws.

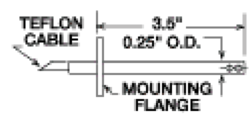

Figure 8- Air Cage Thermistor

Manufacturers of thermistors include YSI, U.S. Sensor Corp., Quality Thermistor Inc., Beta Therm Corp. and Thermometrics.

Differential Pressure

Differential pressure manometers are useful in measuring the load on fans or pumps. The pressure can be measured with a hand held meter or with a sensor and data logging unit. Where a pump has a steady load, and a well understood use profile, the hand held meter will provide a quick answer with minimal setup time. Separate meters will typically be needed for pump and fan applications. The pressure range on a differential pressure meter used for a fan applications is approximately 7 kPa. When purchasing a differential pressure meter, look for a meter with multiple pressure ranges as the accuracy at the low end of a scale can often exceed 5%.

Pump applications require a pressure range of 1,200 kPa or greater. Again, it is desirable to have multiple pressure ranges to ensure accuracy.

Manufacturers include Air-Neotronics Ltd..

Pressure sensors are useful in long term load monitoring on fans or pumps. Most fan and pump applications require measurement of differential pressure and conversion of the pressure difference to a proportional electrical output. It is important to have the pressure tap for the high and low side well into the flow in order to obtain an accurate reading. Note that manufacturers have different models for wet (pumps) or dry (fan) applications. Include the cost of pressure taps and the labor needed to install the pressure taps for wet applications.

Figure 10- Differential Pressure Sensor

For industrial high pressure applications such as large air compressors or pressure vessels a gage pressure sensor will be needed. These sensors use atmospheric pressure as the reference pressure.

Pressure sensor manufacturers include Setra, Validyne Engineering, Whitman Controls Corp., Sensortechnics Inc., Daytronic Corp. and PSI-Tronix.

Fluid Flow

Determining fluid flow is a rather complex measurement, where an average velocity needs to be measured, and the flow is then determined by multiplying the velocity by the pipe area.

Currently only ultrasonic flow meter are available for measuring fluid flow without tapping into the pipe. The sensor transmits an ultrasound pulse which is reflected from the surface of the flow stream. The elapsed time between sending a pulse and receiving it's echo determines the level of liquid in the channel. Ultrasonic flow meters are reasonably precise (approx. ±2%), given a good knowledge of the pipe carrying the fluid. Typical setup time is about 30 to 40 minutes per unit.

Figure 11- Ultrasonic Flow Meter

Manufacturers include Controlotron.

Data Loggers

Some monitoring equipment include data logging with the sensors as a single package, while other monitoring equipment require a data logging devise to store the information. Data loggers come in a wide variety of features and costs. The main criteria for selecting a data logger consists of:

- How Many and What Type of Input Signals Will be Monitored
- How Long Will it be Monitored
- What Method Will be Used to Download the Data
- How Will the Data Logger be Powered
- Where Will the Data Logger be Put

Most short term monitoring applications usually only require small 3 or 4 channel loggers. If more monitoring points are needed, multiple dataloggers can be used. Some loggers can not convert CT inputs to true power. If true power is needed, a choice must be made either to use a second power logger in addition or to install a power transducer to supply a output signal for the logger. If a second power logger is used, additional analysis time will be needed to find the power reading that matches the other monitored data. Often the meter will not be synchronized and matching the data will become more difficult.

Figure 12- Data Logger

Manufacturers include Pace Scientific, Pacific Science and Technologies, Rustrac, Logic Beach, Onset Instruments and Data Electronics.

Building Automation Systems (BAS) can be used as a data acquisition and archiving system. Care must be taken in the selection of the sensors as most BAS vendors are only familiar with basic control of space temperature which does not require high precision instrumentation. If left to a BAS vendor the precision of the instrumentation may not be sufficient to accurately measure the energy savings. Older BAS equipment may not be able to serve as a monitoring system and a dedicated data logger will need to be installed.

Some sensors can be used to serve both the BAS and the dedicated data logger. Refer to the sensor manufacturer on how to have a sensor serve two systems.