Yale University's Complex "Central Building Utilities Metering System" (CBUMS)

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Editor's Note: Metering is the vital first step toward improving efficiencies—thus saving money—in any type of building utility service. Author Boed has developed a sophisticated centralized metering system for two distinct utility distribution areas at Yale, as described in his article below.

"CBUMS," the metering system at Yale University, encompasses supply networks for electrical, steam/condensate, and chill water. The first of the two building areas covered by this centralized metering system is (YSM)—the Yale School of Medicine, in the Medical School Area, which manages its own operations and maintenance. Included in the YSM area is the Yale-New Haven Hospital (YNHH) which is an independent health care organization adjacent to YSM. Steam and chill water for YSM and YNHH are generated in Yale's Sterling Power Plant, and electricity is purchased from the local utility company, United Illuminating.

In the second area—the Central/Science area—electrical, steam/condensate, and chill water are provided to the various buildings from Yale's Central Cogeneration Plant.

The Yale Utilities Department manages each of the respective generation and distribution systems, and developed CBUMS—the Central Metering System—to monitor all of them.

AUTHOR'S FOREWORD

The objective of the Central Building Utilities Metering System (CBUMS) is to provide real time monitoring, alarm reporting, on line diagnostics and report generation for billing, energy management and engineering relevant to the utilities systems. CBUMS is an integral part of the Yale real time facilities network called Maxnet. The CBUMS meters installed throughout the buildings communicate with their servers via serial communication and industry standard communication drivers. The servers reside on the Campus Ethernet backbone, sharing information with other servers connected to Maxnet. Engineers and managers within the Facilities Department have direct access to all information residing on the Maxnet. Clients within or outside Yale can access the data available on the Maxnet by Netscape browser. Interested parties can look up the information via the Internet (http//med-max.med.yale.edu/FIXPics). Try it!

V.B.

YALE FACILITIES MAXNET

Networking of existing facilities is a challenge. At Yale, this is due to the fact that existing facilities were developed over time with very little consideration for data management and integration. Systems, whether Building Automation Systems (BAS), power plant automation and control systems or utilities metering systems were installed over time as new buildings were erected or as part of renovation of existing mechanical systems. Consequently, the installed automation systems became individual isles of automation not able to communicate with each other.

One of the requirements of modern facilities management is information management and sharing information with the clients. By systems integration facilities can interconnect systems within the same categories (i.e. BAS), as well as systems of different categories.

Figure 1 is a schematic of Yale integrated real time systems, including building automation systems in the Central and Science areas, power plant systems in the Central Power Plant (CPP), Sterling Power

Plant (SPP) in the medical school area, and building utilities metering in all three areas.

Thanks to Maxnet, engineers and managers have the opportunity to view system graphics on their office PCs, receive real time data, alarms, management reports, history reports and trends from areas of production, distribution and building consumption. Integration of real time systems into one Facilities Information and Data Management System has provided a unique opportunity to collect, format and distribute data to the facilities' engineers and managers.

Furthermore, Maxnet provides information to the clients and other interested parties within and outside Yale via the Internet browser, as indicated above. Providing information to the end users, thus encouraging better management of resources and energy conservation is a continuous effort of the facilities department. The integrated Facilities Information and Data Management System was designed in house, using commercially available systems, components and services.

FLOW METERING VS. ENERGY METERING

The translation of "You can't manage what you can't measure" into an energy conservation language means, *"You can't manage energy if you don't measure it."* In the past, there were several attempts by the energy and utilities industry to circumvent the requirements for positive measurement to obtain energy credits or incentives. However, the fact remains that unless we have a positive understanding of energy consumption at individual building or departmental levels we do not really know how the energy is used and where are the energy saving opportunities.

The sole requirement of energy metering sets us apart from the so-called flow metering utilized by the manufacturing industry. Industrial flow measurement is concerned with measuring flow within a certain range of the production process. Measuring of flow in utilities distribution systems is quite different. Let us look at the differences for each metered media. (Figures 3 and 4)

Most *electrical metering* applications are concerned with kilowatthour readings used for customer billing. Energy metering at Yale provides real time readings of voltages and amperes of the electrical sys-

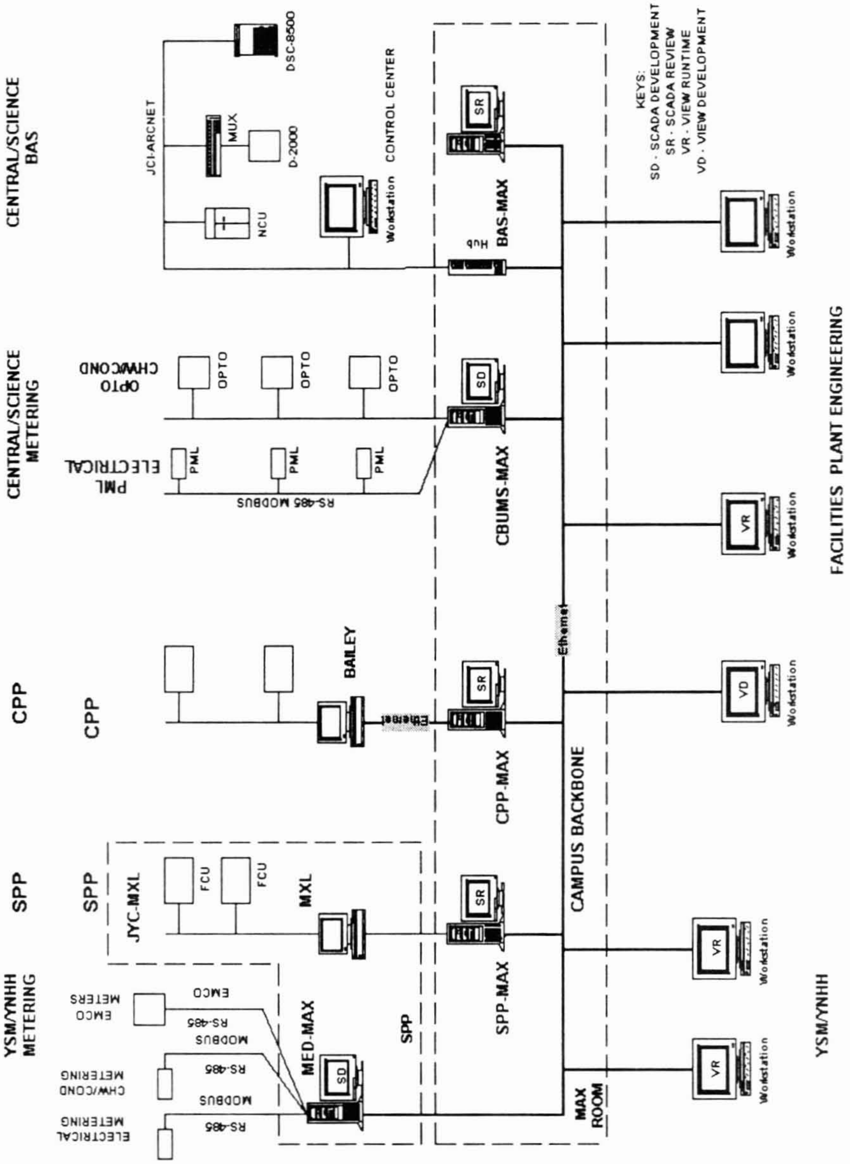

Figure 1. Yale Facilities Maxnet

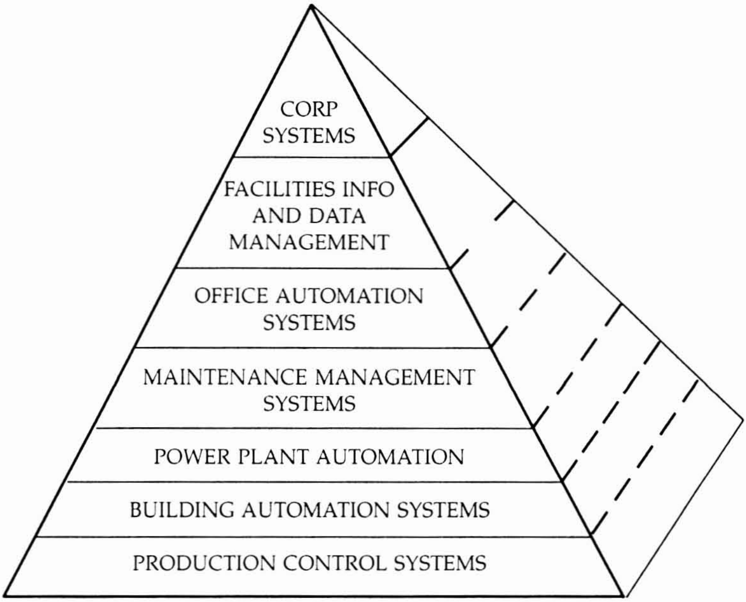

Figure 2. Facilities Information and Data Management Pyramid

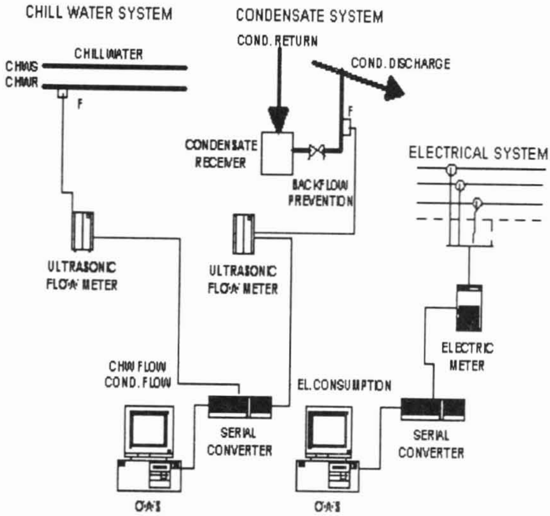

Figure 3. Flow Metering

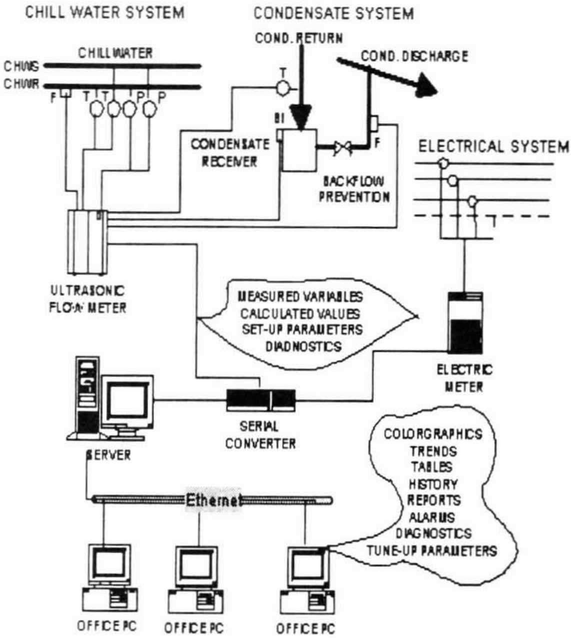

Figure 4. Energy Metering

tems, and provides measured, calculated as well as diagnostics data on line for clients on the network. The system also provides daily and monthly reports compiled for each meter and for each building, respectively.

Industrial *chill water metering* is concern with metering of flow within a certain range of the process. The major differences between industrial and utilities metering are in oversized distribution piping and large turndown ratios due to peak and off-peak consumption. Another difference is that the industry is concerned with measuring one value only—flow.

Energy metering, in addition to chill water flow metering also involves measuring of other variables essential for energy calculations, such as temperatures and pressures. Energy metering at Yale provides flow, temperature and pressure readings from which the real time data, energy consumption, and systems diagnostics data are provided to the users. The system also provides daily and monthly reports compiled for each meter and for each building, respectively.

Metering of *steam consumption* at Yale is calculated from the metered condensate discharged from the condensate receiver. Each metering point consists of flow measurement, measurement of the condensate temperature and of the discharge cycle of the condensate receiver. The system then provides calculations of desired values as well as systems diagnostics. Similar to the other media, daily and monthly reports of steam consumption is being compiled for each meter and for each building, respectively.

REAL TIME DATA ACQUISITION

Real time data acquisition of the installed system involves: (a) collection of data from the connected field points by the particular meter(s), and (b) collection of data from each meter by a server, at a real time scan rate.

The server is set up to provide:

1. Instantaneous reading of the connected field points, calculated values, and readings of meter diagnostic data provided by the meters. The diagnostics data can be utilized by other processes and/or displayed for the customers, engineers and managers in a form of color graphic displays, trends graphs, reports, etc.

2. Alarm reporting is an important function for operation and maintenance of distribution systems and buildings. Custom-defined alarm limits, or programs, provide early warning for the maintenance department, thus preventing failures before they actually occur. For example, an electrical metering system can provide an early warning related to unbalanced load of feeders, prior to causing an overload condition and failure of the overloaded phase. It alerts the maintenance department to distribute the connected loads more equally, prior to phase overload. Another example could be a high condensate return temperature (measured over time), alerting the maintenance department on defective traps.

3. Performance analysis can be divided into several groups, such as (a) analysis of the distribution system (for example, analysis of

pressure and flow relationships throughout the chill water distribution system); (b) analysis of building performance (for example, high differential pressure of the building chill water system could mean dirty chill water coils of AHUs); c) analysis of the meter self diagnostics data, (for example, signal deterioration of an ultrasonic flow meter could mean aeration in the chill water pipe); loss of signal of an ultrasonic condensate meter could mean that the vertical pipe (the sensor is installed on) is empty due to faulty back-flow prevention valve installed on the condensate receiver's output.

4. Report generation is divided into several categories, such as (a) meter reports (metering of individual feeders—daily, monthly, etc., reports); (b) building consumption reports (combination of energy consumption metered by more than one meter—daily, monthly, etc. reports); (c) special reports used to measure building performance. For example, building consumption prior to and after an energy retrofit project, comparison of building loads of the same building category (i.e. energy consumption of two chemistry labs); (d) ad hoc reports, as requested by engineers or managers. (Figure 5)

Design, engineering and programming of the system was done jointly by Yale Plant Engineering and IndTech.

ELECTRICAL METERING

Design and selection of "electrical power meters" for the job includes the following components:

1. *Current transformers* rated for the given currents of the electrical system to be measured;
2. *Potential transformers* rated for the given voltage of the electrical system to be measured;
3. Other field gear, such as *fuses and shorting blocks* provided to protect the installed meter;
4. *Electrical power meter* for the given configuration of the electrical system to be metered.

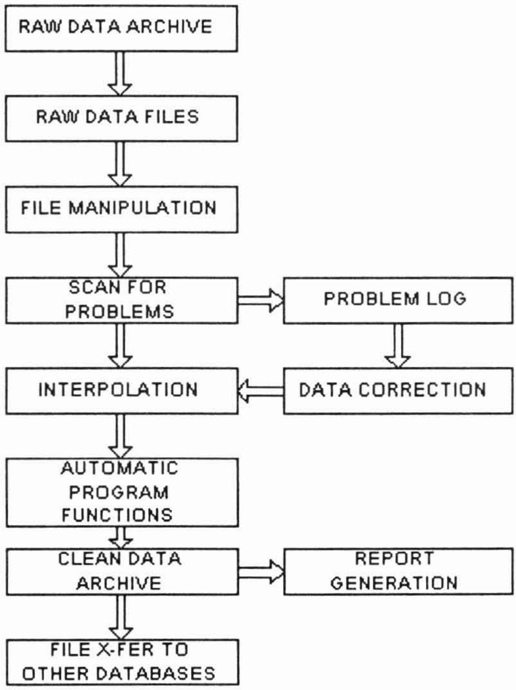

Figure 5. Data Manipulation.

(Items 3 & 4 are installed in common enclosures.)

We have installed PML 3300 series meters with Modbus communications option for the Central and Science areas several years ago. For the YSM/YNHH metering we have installed the new PML 7300 series meters. Two main features are important for electrical power meter selection:

a) *Communications*, selection of appropriate communications protocol or driver including definition of the data transmission protocol, compatible with the communication options of the site. We have selected RS-485 transmission protocol with a Modbus driver for the entire installation. Electrical meters in the Central and Science areas communicate with their server via dedicated telephone circuits, while in the YSM/YNHH areas via dedicated twisted shielded pairs of wiring. The change of communications media was due to local conditions rather then network performance or reliability.

b) *Data transfer* over the network. The PML meters have a variety of data available on their registers to be read by the server. These include real time readings of field variables, such as line, and line to neutral voltages, phase currents, frequency, and provide calculations of variables such as kilowatts, kilowatt-hours, kilowatt demand, kilovolt-amperes, kilo-vars, power factor, etc. The meters also feature on-line setup capabilities and diagnostics, including voltage and ampere unbalance, demand limiting, and other data visible and accessible via the network.

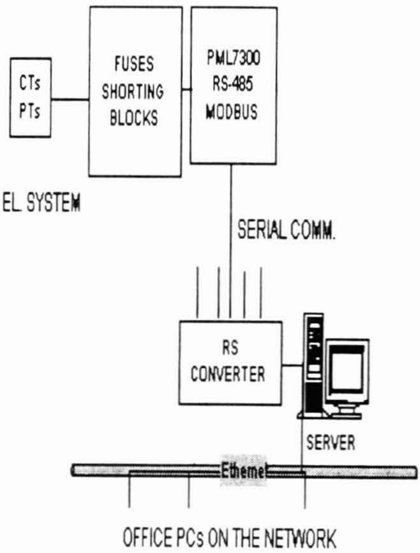

Figure 6. Electrical power metering

CHILL WATER METERING

Chill water metering at Yale is by ultrasonic meters. They were selected for their ease of installation, good turn down ratio, features and communication options. Earlier installations in the Central and Science areas are either Panametrics or Controlotron meters. At the time of installation the meters did not have any communication options compatible with industry standard drivers or protocols. However, Controlotron has developed a Modbus interface for the YSM/YNHH installation.

The chill water flow reading from the meters without serial communication are connected to OPTO or Metasys DX panels. Other analog points, such as temperature and pressure sensors, are also connected to the OPTO or DX panels.

The OPTO panels communicate with the CBUMS server via RS 485 serial communication and Modbus driver. The DX panels are on the Metasys ARCNET N 2 bus. The Metasys interface to Intellution FIX server is a DDE gateway interface. The disadvantage of the earlier installations without serial communications is that they do not provide on line diagnostic or on line meter set-up.

Field points for chill water metering include

- flow (return and/or supply);
- temperature (return and supply);
- pressure (return and supply);

Since ultrasonic meters are either one or multi-channel meters, the first channel can be used for metering of, let's say a return flow, the second channel can be used for metering of the supply flow of the same feeder. Chill water losses in the buildings with metered supply and returned flow can be determined from the differential flow.

If the engineers are not concerned with chill water leaks (i.e. alarm reporting of leaking chill water coils), the second channel can be used for metering of another flow (i.e. another chill water riser), or for metering of the condensate. Both options are used in our applications.

The ultrasonic flow computers have two temperature inputs per channel. The inputs are used for tonnage and energy calculations.

$$\text{Chill water Tonnage} = \text{Flow x DT} \times .042;$$
$$\text{Consumption Btu/HR} = \text{Tonnage} \times 12{,}000.$$

If accurate measurement is required, for example for customer billing, the engineers should be using precision-matched pairs of 1,000 Ohm RTDs for temperature measurements. If lesser accuracy is acceptable, the building chill water return temperature can be used in the calculation along with a common chill water supply temperature measured at the appropriate location of the distribution system.

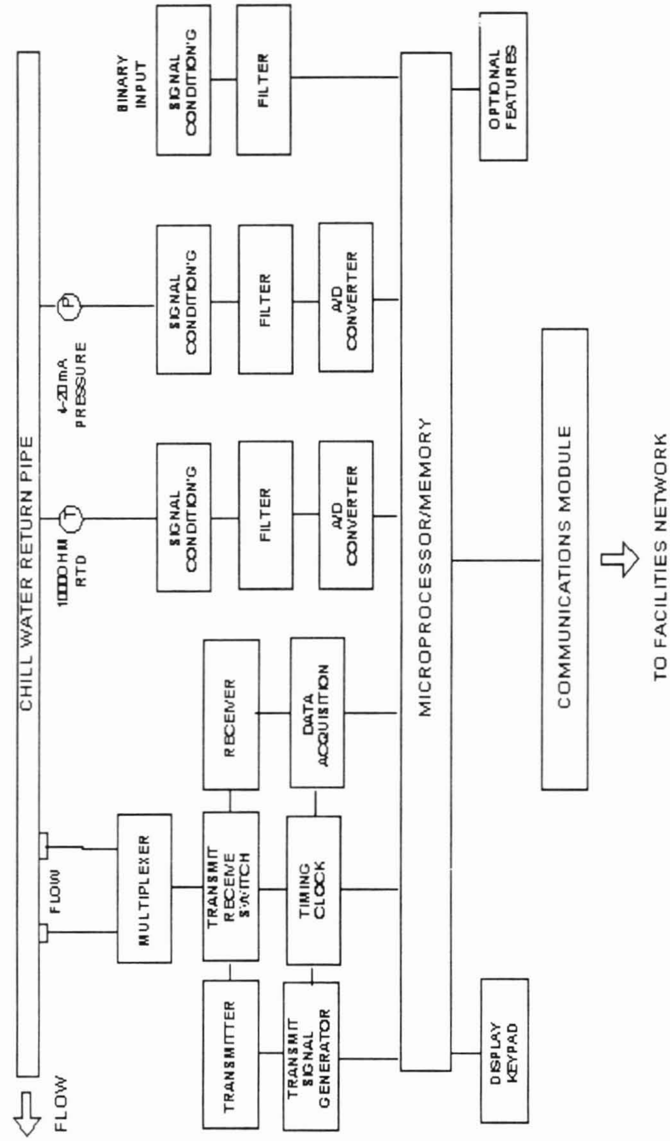

Figure 7. Block diagram of an ultrasonic energy meter.

Ultrasonic flow meters also come with two 4-20mA inputs per channel. We have used these inputs for pressure monitoring. The pressure data can be used for diagnostics of the distribution system and/or diagnostics of the building performance. We have developed a diagnostics package, which provides graphical representation of the actual and calculated pressure distribution for each building on the distribution system.

The CBUMS server reads the registers of each meter at periodical scan intervals. The data provided are in the following categories: actual values, calculated values, set-up and diagnostic data. The data are utilized in displays, trends, alarm reporting and report generation.

CONDENSATE METERING

One of the operating requirements imposed on many utilities metering projects is to limit the shutdowns to the minimum. This requirement eliminates selection of in-line meters since they have to be cut into existing piping, which require prolonged shutdowns. Based on our earlier, mostly unsuccessful experiments with insertion type vortex shedding flow meters (Nice meters), we have decided to measure condensate with ultrasonic meters, and convert the obtained measurements to pounds of steam and Btus. We have selected the same ultrasonic flow meters as for chill water metering based on their good turn-down ratio, communications option and their utilization throughout the University.

Condensate from individual loads is collected into condensate receivers or liquid movers and returned to the power plants. Since every building connected to the plant is measured, the steam production is equal to the sum of individual consumption plus losses. The losses are distributed to individual buildings relative to the measured flows.

To convert condensate flow to pounds of steam consumed, a multiplier of 8.1 can be used (for a 180 degree F condensate) in the conversion equation

$$GAL_{COND} \times 8.1 = lb_{COND} = lb_{STM}$$

The equation provides for a fairly accurate calculation and good cost distribution across the system—without a need for expensive in-line temperature sensors at each condensate return line.

However, measuring condensate temperatures can be desirable for some applications to indicate blown steam traps or other system problems and/or for more accurate calculation. The temperature sensor can be located either in the condensate line before the condensate receiver, or on the receiver itself. The values of the multiplier can be found and calculated from the steam table using the specific volume V_f [cfpp] for actual condensate temperatures as:

$$I/V_f \times (231\ in^3/gal) \times (ft^3/1728\ in^3)$$

For normal condensate temperature, the enthalpy per unit mass h_{fg}, is approximately 1000 Btu per pound. Therefore the energy consumed in Btu is:

$$1000 \times lb_{STM}$$

It should be said that the improved accuracy of the calculation using actual temperatures is minor, and does not justify the expense for the sensor and its installation (installed cost could be as high as $1200 per sensor). However, a diagnostic of a blown trap may justify the cost for a condensate temperature sensor.

Location of the ultrasonic meter transducers as well as of the condensate temperature sensor is important:

The *transducers* should be located in a section of a pipe always filled with condensate. If the pipe becomes empty, the meter will report such condition (a valuable troubleshooting feature), and will reset itself when the pipe is filled. However, since the pump-down event may have long "off" intervals (while the condensate is collected in the receiver), it may take several seconds (to a minute) for the meter to reset itself upon start of the pump-down cycle. This could contribute to a relatively high error.

Therefore, there should be a good quality check valve installed in the discharge line of the receiver to prevent back-flow and empty pipe situations. Ultrasonic transducers should be installed either on a vertical condensate pipe or on a "dip," a pocket in the piping configuration. This would assure presence of condensate in the pipe during the off cycle of the receiver. The transducers should be located as close to the receiver as practical, while observing all manufacturers' requirements for straight piping.

The *temperature sensor* can be located either on the incoming condensate return pipe, or on the condensate receiver. Since the sensor on the incoming pipe is used for alarm reporting of high condensate temperatures, indicating presence of steam in the condensate due to blown traps, it should be submerged in the condensate. The measured temperature in the incoming condensate line is close to the actual condensation temperature of the steam in the coil, therefore the calculations are more accurate.

However, the cost of installation could be higher, since we may need more than one temperature sensor for each condensate line and/or sections of a receiver (duplex, triplex). Another drawback is the temperature fluctuation reported during long periods of no load conditions, when the sensor picks up the temperature of the empty pipe.

Sensors located on the receiver will more likely remain submerged in the condensate. This solution could be less expensive, since only one sensor is used per receiver. In either case, the challenge is to find a proper location for the condensate temperature sensor. Location of condensate temperature sensors on the discharge line is not recommended, since it cannot provide alarm reporting and its present values could be far off from the actual temperature of the condensate.

Another method of condensate metering is monitoring the discharge cycle of the receiver. Condensate receivers have relays for starting the pumps. A binary input monitoring the event sends a signal indicating a discharge cycle. The event multiplied by the capacity of the receiver equals to gallons discharged per event. The value totaled over an hour will provide the consumption in gallons per hour.

Although the method is not as accurate as direct metering, for cost allocation or energy management, it could provide data with sufficient accuracy for a reasonable cost. In installations with liquid movers the binary signal of an event is taken from a pressure switch, which monitors the ejection of a medium pressure steam to evacuate the vessel.

The event is also used for diagnostics, such as for indication of failure of the medium pressure steam valve of a liquid mover or "baked" contact of the motor starter of a condensate receiver. Both methods were used for condensate measurement in Yale applications.

METERING AS PART OF YALE FACILITIES INFORMATION AND DATA MANAGEMENT NETWORK (MAXNET).

As shown in Figure 1, metering information collected by the Central Building Utilities Metering System (CBUMS), data from the power plants and building automation systems, connected to the same network are accessed from individual office PCs. The data are distributed via a secured Ethernet to facilities engineers and managers; and to the customers via the Internet. This gives the engineers and managers a unique opportunity to view and evaluate data from the individual systems presented in the same format.

We use graphic screens accessible from the menus or graphical overviews to display real time data and alarms. The screens are set up with "soft buttons" which allow the users to move from one screen to another. There are "dialog boxes" set up to access individual meter registers, thus providing detailed on-line information on all data available from the meters. Each screen contains "soft buttons" for navigating around and moving from one area of the university or system to another, or to different features of the system, such as trend graphs, reports, diagnostics, etc.

The data files are stored and presented in formats commonly used by engineers and managers. Eventually the data will be uploaded to a so-called data warehouse, where it will be archived and available for future use (such as for engineering evaluation, design, space allocation, etc.). Since the data management software tools (Microsoft Access97, Excel 97), are the same as commonly used in office systems, the data are readily available for other systems on the network. Such systems are the utilities cost accounting system, and all the PCs connected to the Facilities Automation Network (FAN).

COST ALLOCATION AND BENEFITS OF THE METERING SYSTEM

The cost and the benefits block diagram is a two track flow chart, depicting individual components of the installation, including cost allocation, as well as the benefits the networked system provides. The majority of the cost is associated with installation of the metering system.

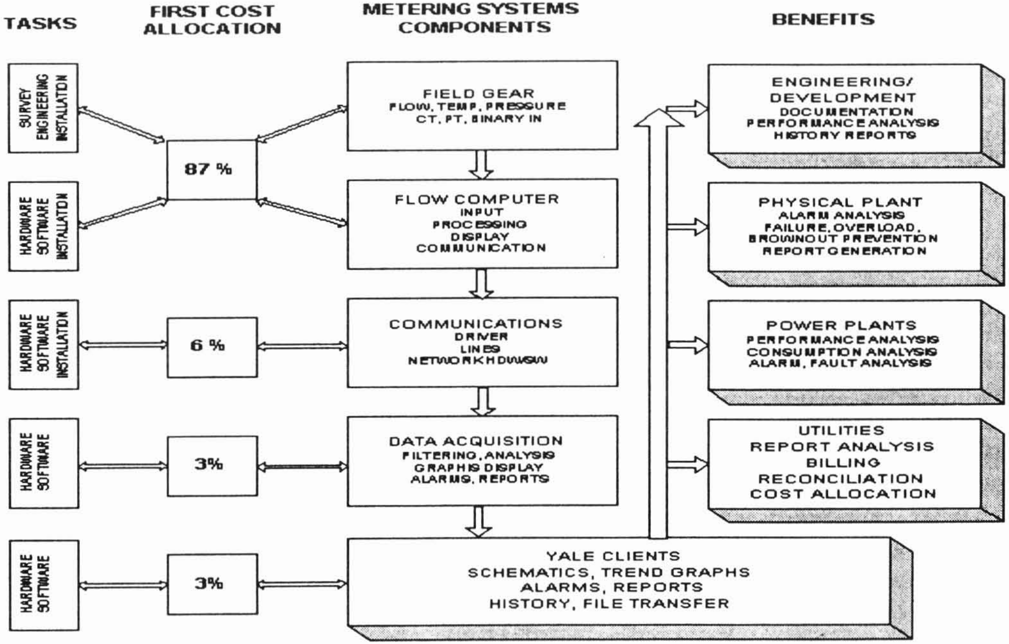

Figure 8. Cost Allocation and Benefits

A much lesser percentage of the cost is associated with communications, data acquisition, etc. The incremental cost (of about 13% of the total cost) provides Yale with the benefits of a networked metering system. Since the information is distributed over the network, individual departments can use it for their specific tasks.

The data presentation is in a form of color-graphic screens—using engineering drawings bound with real time readings, trend graphs, spreadsheets, alarm reports, consumption reports, etc., customary for SCADA systems. This provides data which are utilized in the daily tasks of the engineering operations, power plant and utilities departments.

Another benefit is the capability of the server to compile data and transfer data to other computers on the network for further use or for filing of historical data in a common file accessible by other departments. There are also customers (departmental chairmen, business managers, etc.); interested in the consumption data for encouraging energy conservation or in consumption reporting essential for their projects and government grants.

Financial benefits of the CBUMS Project to Yale can be divided into the following categories:

1. PROTECTION OF INVESTMENT (minimized replacement cost), due to the following:

- System design allowing future upgrade and expansion
- Use of commercially available hardware, software, and communication protocols
- Selection of hardware, software, designs, as per Yale standards
- Utilization of existing Yale networks and telecommunication systems
- Statistical analysis and reporting formats customary for the users
- Compatibility of the network and its components with other systems at Yale
- Trained in-house engineering and O&M personnel

2. ENERGY SAVINGS (cost avoidance), due to the following:

- Customer awareness
- Optimization of Power Plant parameters
- Modification/redesign of building systems

- Flattening of peak demand
- Continuous monitoring and adjusting of building system's performance
- Minimizing cost for make-up water and chemical

3. FAULT PREVENTION (repair vs. emergency repair cost), due to the following:

- Alarming out-of-limit phase loads, overloads, low voltage
- Alarming chill water flows, temperatures and pressures
- Alarming condensate system and receiver function
- Chill water or condensate leak prevention. Continuous analysis of building and system performance.

4. MINIMIZING DAMAGE TO EXPERIMENTS, FURNISHINGS, EQUIPMENT AND BUILDINGS, due to:

- Continuous monitoring of systems parameters
- Engineering analysis of system performance
- Early detection of problems

- MORE ACCURATE COST ACCOUNTING TO RESEARCH GRANTS, due to positive and accurate metering of energy, as opposed to estimated consumptions based on occupied space.

CONCLUSION

Implementation of an on-line energy metering system is a challenging task. Its success depends on prudent engineering, meter selections, selection of a proper computer system, systems engineering, networking, installation and commissioning. However, such a system represents an invaluable analytical tool for facilities engineers and managers. It provides data essential for operation and troubleshooting, as well as data for engineering, billing and energy conservation.

ABOUT THE AUTHOR

Viktor Boed, CEM, has a graduate degree in electrical engineering from the Brno Technical University in the Czech Republic. As a

consulting engineer he has designed building automation systems in Europe and the U.S. and taught courses in electrical engineering at the Brno Technical University as well as in Cairo, Egypt. Boed came to the U.S. in 1979 and worked as a product manager and a senior research engineer for Johnson Controls, Inc. in Milwaukee, WI. He joined Yale University in 1983 as manager of building automation and became manager of plant engineering in 1989, where he is involved today in design and implementation of automation systems for buildings, power plants, maintenance management systems, utility metering systems, and a facilities real-time communications network. The Plant Engineering Division also is involved in implementation of energy conservation projects, and review and approval of capital projects for the university.

Boed is an active member of the Association of Energy Engineers and started the Connecticut AEE chapter. He is the recipient of the Energy Manager of the Year and the regional Energy Engineer of the Year awards, and is a frequent speaker at World Energy Engineering Congresses and other professional conferences. He also is a member of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and was on the ASHRAE SPC 135 committee that developed the ANSI/ASHRAE Standard 135/1995, BACnet (a data committee protocol for building automation and controls network). Viktor has published numerous technical papers in various trade magazines. He has also written two books, *Efficient DDC Systems Implementation*, (Chilton, 1996), and *DDC Applications Engineering*, (CRC Press, 1998).