An Improved Method of Collection, Visualization, and Analysis of End-Use Data for Designers

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Introduction

Current site data collection systems make hourly measurements of weather, system performance, and energy usage, which are then used to calibrate DOE-2 or other computer models of the facility to determine retrofit energy savings over a basecase condition. This hourly method of model calibration is not detailed enough for design professionals to characterize system performance. Companies that guarantee retrofit energy savings require much more accurate and detailed data, particularly for aggressive redesigns with energy savings of 40 to 80 percent.

The new data collection and visualization system presented here gives designers information needed to understand and improve system configurations and features to facilitate superior designs in future projects. At present, designers cannot reliably and accurately evaluate the performance of many critical areas of their completed designs. Mistakes may be repeated unknowingly for many years; if the electronics and computer industry has advanced light years, the HVAC design industry has moved forward by feet.

Figure 1 shows a layout of the monitoring systems discussed in this article.

Three areas have been addressed in the "DESIGNER" monitoring system for effective real-world use by designers: accuracy, data collection and storage, and data visualization and analysis.

Accuracy

HVAC equipment or system performance varies and degrades over time; thus very accurate, long-term stability sensors must be used. This is particularly important when numerous measurements are compounded to produce a result.

As an example, a designer wants to measure the performance of a chiller in kW/ton, with an accuracy of ±3% over 5 years. This is a minimum acceptable level of accuracy that will give us enough confidence to study the degradation of chiller performance over time.

At chilled water ΔT of 10°F, 2% accuracy on chiller tons is:

$$Tons = Flow \times \Delta T \pm 2\% = \pm 1\% \ \pm 1\%$$

A magnetic flow meter can give ±1% if properly located.[1,2] To get 1% of 10°F, ΔT requires 0.1°F on two sensors, or ±0.05°F per sensor.[3]

To measure kW/ton:

$$kW/Ton = \frac{CT \ x \ PT \ x \ Transducer}{Flow \ x \ \Delta T}$$

Given transducer accuracy at ±0.25%, CT accuracy at ±0.5%, and PT accuracy at ±0.5% for very high quality sensors, kW accuracy is ±1%, and total error is: ±3% = ±1% ±1% ±1%.

To track these sensors over time, very stable instrumentation is needed. For instance, 7½ digit voltmeters, precision probes mounted in direct contact with water, and high-resistance sensors are needed to minimize the effect of cable resistance on readings. Also, very accurate and stable multiplexers, analog-to-digital converters, and hand-calibrated probes are desirable.

Figure 2 shows a matched pair probe in a triple point cell, running over 10 hours; matching is much better than ±0.1°F.

Data Collection and Storage

After the hardware has been selected, a data-acquisition system capable of collecting and storing large amounts of data is needed. Designers require information on system performance and operating characteristics that is based on many system operating conditions, going back in time as far as possible.

For example, a designer wants to verify the performance of a chiller based on cooling load and condensing

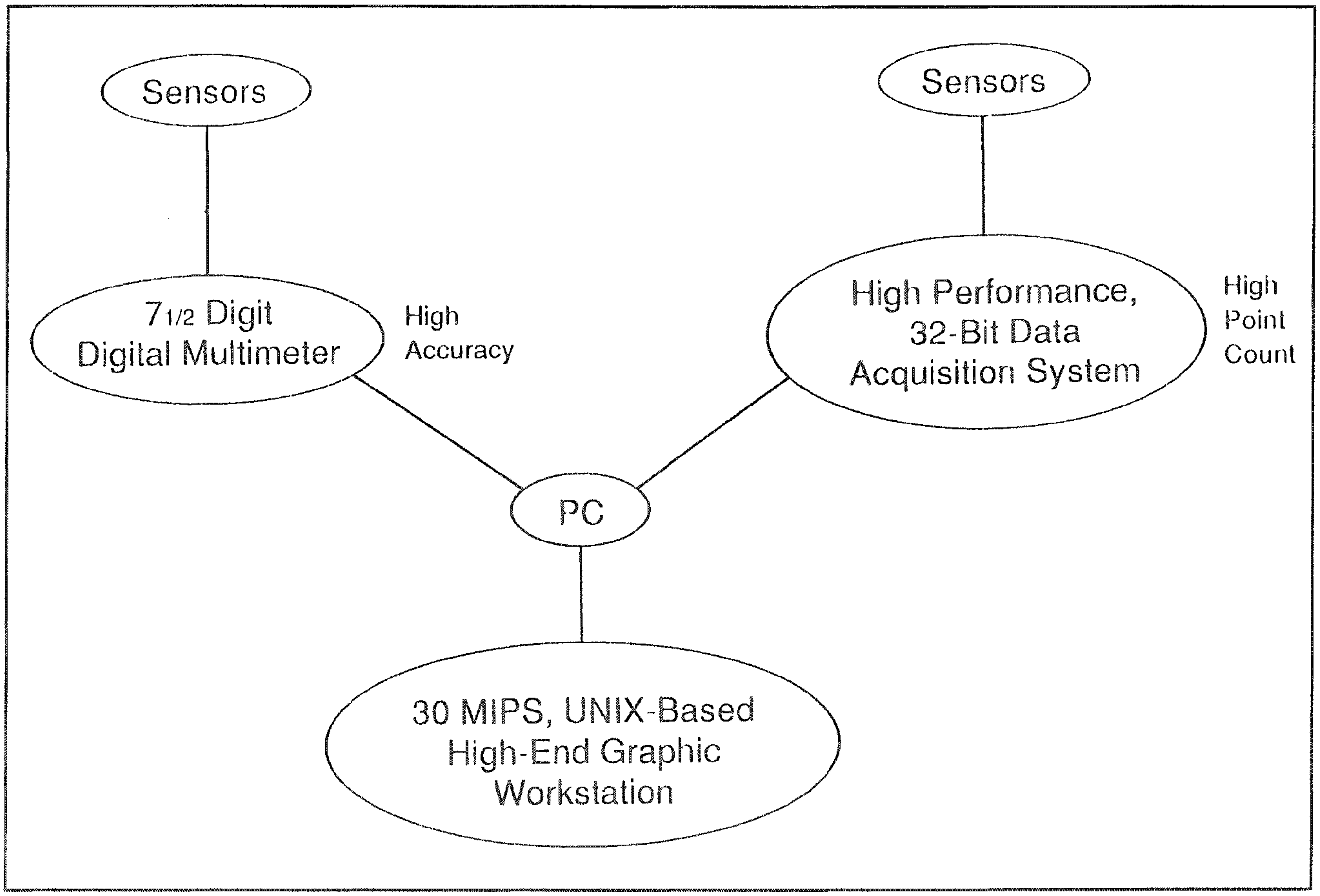

Figure 1. Monitoring System Architecture

temperature to determine the point of peak operating efficiency. (The actual measured efficiency may vary widely from the manufacturer's published data.) The designer would need to see a curve showing chiller efficiency as a function of cooling load and condensing temperature. This curve is best constructed with short time-base measurements (perhaps 1-minute intervals) to get the instantaneous performance data required.[4] This amounts to 60 minutes x 24 hours x 365 days, or 525,600 readings per annum for one variable alone.

Effective collection and storage of 1-minute time base data for each point in a monitoring system also requires special system architecture and high-volume storage. This is not a problem, however, as data storage media are inexpensive and declining in price; systems can readily be obtained with storage capacity in excess of 20 gigabytes.[5]

Data Visualization and Analysis

To adequately visualize and analyze the data collected, a high-speed workstation with high resolution graphics is needed. Only in this way can realistic volumes of data be displayed at one time. For example, to see a three-dimensional surface of 365 days x 15-minute sampling requires 35,040 points, while comparing four parameters at one time requires 140,169 points. A 19-inch workstation screen contains 1,280 x 1,024, or 1.3 million pixels. Of this total, about 75% is usable, as 25% is consumed by menus on the screen, leaving 983,000 pixels. If the points were contiguous per pixel, 14% of the remaining pixels would be used for the 140,169 data points. In actuality, however, each data point is spaced out on average in a 9-pixel area, so the number of pixels required to display the data points is 140,169 x 9 or 1.26 million. Obviously, some resolution may be lost even with a 19-inch high resolution monitor.

By using high-resolution high-speed graphics systems, it is possible to have interactive manipulation and visualization of data. Access to large data sets at high speed is important to allow the designer to see the multiplicity of interactions that occur with systems.

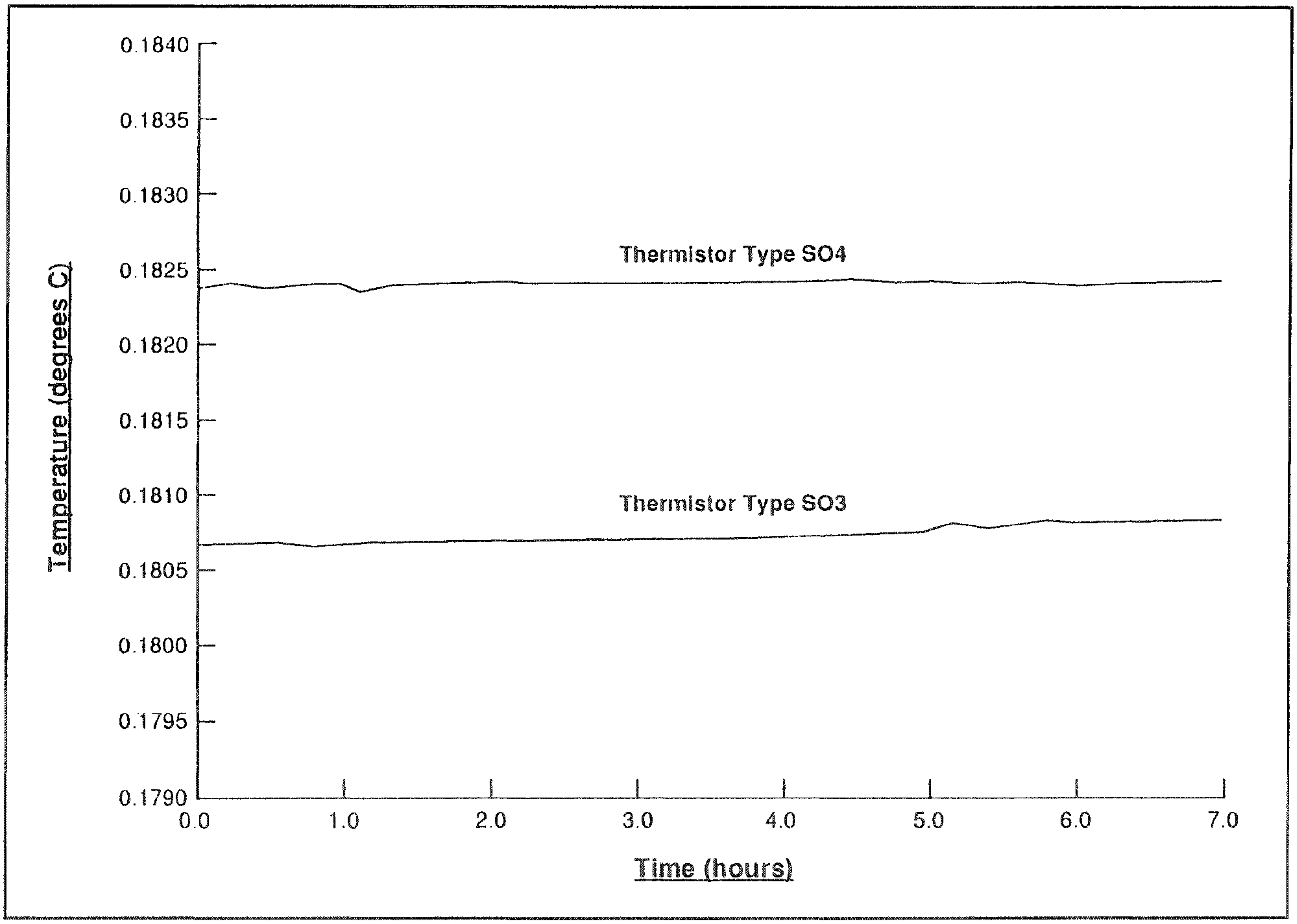

Figure 2. Performance of Thermistors in Triple Point Cell

The visualization system is simple enough that any HVAC designer can view and analyze data without having to learn a new operating system or script programming language. Giving designers access to the data will finally close the feedback loop that prevents the industry from evolving. Our experience to date with a California utility project shows that even with the best of intentions, the lack of adequate tools to provide feedback for the designer is a severe limitation.

Conclusion

A number of data collection projects have been conducted. These projects were designed to provide information on facility energy usage to the design and energy engineering community, not to provide feedback on the performance of installed systems. In almost every instance, the data collected using conventional methods have either never found their way to the outside world, or if they have, the data have been of little or no use to the design community. This is because conventional, dedicated monitoring systems are not configured to collect and store data that are useful to designers. In many cases, these systems can only be operated by statisticians and computer specialists. In the case of energy monitoring and control systems, the authors have never heard of any currently available systems that provide sufficient accuracy, reliability, and data storage capabilities to be of any use to designers.

Making the design community aware of the technology available for assisting them in refining their designs could raise expectations to the point that manufacturers of conventional monitoring and control equipment would be prompted to react with new products capable of performing the tasks required.

If we are to advance the industry of mechanical systems design we must give the designers easy access to the information they need to improve their designs. Only in this way will we achieve our society's goal of an energy-efficient economy.

Endnotes

1. While magnetic flow meters are expensive, it is the authors' experience that other less expensive methods of flow measurement are too inaccurate and unreliable for long-term monitoring applications.

2. The authors have tested the accuracy of magnetic flow meters by installing three meters in series in a single pipe. Different brands were tested on various pipe diameters; the results showed an accuracy of ±0.6%.

3. ±0.05°F is difficult to achieve, but it is possible if thermistors are calibrated with highly accurate measuring equipment.

4. The authors have tried 5-,10-,15-, and higher minute intervals, but information is lost, especially during transients like rapid weather change. When using 1-minute interval data, system problems such as hunting of chilled water setpoint, hunting of dampers, VAV static pressure fluctuations, and unstable inverter control can be seen. These transients escape 15-minute and hourly data. There has been some speculation that 1-minute data is too short due to the time delays in sensor dynamics. Looking closer at this example, we can see that CT & PT are in milliseconds, and kW transducer gain is below 1 second. Magflows may be several seconds, because they use low-frequency pulsed magnetic fields, but they can be adjusted for faster response. Thermistors of 1/8" diameter in direct contact with flowing water (no thermowells) will be in seconds (given a 4" diameter pipe or bigger). Electronics is subsecond to do analog to digital conversion. Clearly there will be no problem using 1-minute data collection.

5. Tape drives of 10 gigabytes are available from a number of manufacturers. Two-gigabyte 3 1/2" drives and 2.7-gigabyte 5 1/4" drives are also available.