The Benefits of Monitoring Industrial Energy Systems

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ABSTRACT

For more than 30 years, instrumentation installed in all types of buildings from schools and hospitals to giant industrial plants including meat packing, foundries, heat treat, cement, injection molding, assembly and more has uncovered an amazing array of hidden problems, provided the key to the often low-cost solutions and verified the results.

This paper summarizes two projects where both problems and opportunities in compressed air and industrial refrigeration systems had been hidden for many years. By installing sensors on key points and clearly presenting the resulting data and analysis on real-time screens and in historical reports, the owners and operators were able to immediately slash their utility costs through low cost changes in operation and control as well as other management actions. Within one month of the start-up of the monitoring system, by simply changing the control sequence on the 15,000 Hp compressed air system, one plant saved 20% of the compressed air costs, or more than $250,000 a year. In the second plant, the data showed that the repair or replacement of bad valves in the ammonia refrigeration system would reduce refrigeration costs by 75%, create a 150% redundancy in the system and avoid a planned expansion of several hundred thousand dollars. In this case, however, the owner used the resulting data to determine that the refrigeration system should be shut down and the operation moved to another facility, providing even greater savings.

This paper discusses how to design permanent instrumentation to monitor key points in industrial energy systems. It uses two actual projects to present point and sensor selection and illustrates how software can be used to create "virtual monitoring points", reducing the number of actual physical points required and their cost. By showing how the data was analyzed and effectively presented in these projects, the reader will gain an understanding of how the problems that had remained hidden for so long were exposed.

It discusses the total facility energy balance concept and its benefit over simply looking at equipment or systems by themselves. It also talks about the role of "Theory" in the "Real World" and how comparing theoretical models with actual monitored data was in one of the projects, the key to unlocking the hidden opportunities. It touches on the need for communication and cooperation between those in engineering offices and the people in the field.

BACKGROUND

In 1974, in the middle of the first “Oil Embargo”, I was hired by an Engineering Consulting Firm to start an Energy Conservation Department. After seven years in the Air Force, much of the time spent working with instrumentation systems on fighter aircraft, it was immediately obvious to me that buildings had no instrumentation specifically to monitor energy usage. After five years of doing audits, studies, projections and designs, all headed toward capital projects, I wanted more. I wanted to be where the action was; where the energy was actually being used. So in 1979 I started my own business and began contracting to serve as Building Energy Manager for a number of facilities with all fees to come from actual documented savings. I had no idea what I would find or how much I could save.

For my first project, I designed, built (on my living room floor from an Apple II Computer) and installed my first Energy Monitoring System in a Mental Health Hospital. I wrote all of my own software, soldered the thermocouples, made the cables and used a 300 baud Hayes modem to connect to the system from my house. The resulting data was used to reduce the annual utility costs by 59% through changes in operation, maintenance and control alone; no capital projects were required.

Starting with schools , hospitals, office and other commercial and institutional buildings, the system evolved into the Holmes AutoPilot Energy Monitoring System and was eventually installed in industrial plants owned by G.E., RCA, Alcoa, Hoover, Rexnord, Golden Castings, Mariah Meat Packing and many more. In one project for GenCorp , a huge International Company, the AutoPilot system and approach won the annual Six Sigma Competition and was identified as ***The Number 1 Opportunity to Increase Profits Corporate-Wide***.

PROJECT #1 - G.E. APPLIANCE PARK, LOUISVILLE, KENTUCKY

The AutoPilot Monitoring System was originally installed on 5 main electrical transformers and 54 existing submeters on main feeders to allow the owner to accurately bill individual buildings and departments on the 1,100 acre site for their share of the $12 million dollar annual electric bill. As Rick Urschell, the project engineer responsible for the project began statistically analyzing the resulting data as a part of a Six Sigma project, he was surprised to see how much of the facility’s total, more than 10% of the monthly consumption and demand, was being used by the feeders serving the air compressors.

In order to zero in on the compressed air system with compressors located in a central plant and three remote compressor buildings, the Monitoring System was expanded to pick up 11 compressors totaling 15,000 Hp, seven existing airflow meters plus the system pressure at various locations on the site. Reports and graphs provided electrical demand and consumption data, airflow, efficiencies and operating costs.

Compressed Air Costs – March

Bldg. No. 31			
	Comp No. 07	$15,970	13.0%
	Subtotal	**$15,970**	**13.0%**
Bldg. No. 32			
	Comp No. 08	$0	0.0%
	Comp No. 10	$23,303	18.9%
	Subtotal	**$23,303**	**18.9%**
Bldg. No. 33			
	Comp No. 09	$28,588	23.2%
	Comp No. 11	$23,728	19.3%
	Subtotal	**$52,316**	**42.5%**
Boiler House			
	Comp No. 01	$1,351	1.1%
	Comp No. 02	$16,184	13.2%
	Comp No. 03	$7,051	5.7%
	Comp No. 04	$4,707	3.8%
	Comp No. 05	$2,180	1.8%
	Comp No. 06	$0	0.0%
	Subtotal	**$31,473**	**25.6%**
	Total	**$123,062**	**100.0%**

Within a month of completing the air compressor expansion, Rick called our office to let us know that he had already found and implemented changes in operating procedures that were reducing the operating costs by 20% which, on an annual basis would save between $200,000-$300,000. The keys were the screens and reports that showed the entire system and it's overall efficiency. In his words, "There is no way we could have done this without the AutoPilot System. Before we could monitor the entire system from one location, we were making decisions based on individual machines and buildings with no way to determine the overall effect. Unfortunately a lot of those decisions were wrong."

He said that previous operating procedures had been established with the intent of producing the most efficient operation but the AutoPilot data showed that many of the previous assumptions were wrong. In addition to operating changes, differences in operating efficiencies among the various machines uncovered some problems with the compressor maintenance program. He discovered that as loads dropped at night and on weekends, the system pressure would rise and some of the compressors that were not controlling properly would bypass or relieve excess air and just essentially waste much of their energy.

As a result of his findings and the savings opportunity available through good management alone, with no additional capital investment required, the main AutoPilot workstation was moved to the Boiler

House where the operators used the Real-Time displays to maintain the maximum Compressed Air System efficiency under all operating conditions. As the compressed air load varied with the day of the week, time of day, shift, weather, etc., the operators were able to tune the system and run compressors in combinations that kept the overall system efficiency at its peak under all conditions.

Operator's Real-Time Screen

Thursday May 14 4:17 PM

	KVA		cfm		cfm/kva
Comp No. 1	-	Comp No. 1	-	Comp No. 1	-
Comp No. 2	620	Comp No. 8	3,746	Comp No. 8	3.77
Comp No. 3	-	Comp No. 9	5,580	Comp No. 9	4.91
Comp No. 4	-	Comp No. 10	5,199	Comp No. 10	5.59
Comp No. 5	-	Comp No. 11	3,608	Comp No. 11	3.38
Comp No. 6	-	BH Meter 1	361	Boiler House	0.58
Comp No. 7	-	BH Meter 2	-	BH Meter 2	-
Comp No. 8	993				
Comp No. 9	1,137	Total	18,494	Total	3.90
Comp No. 10	930				
Comp No. 11	1,068				
Total	4,748	Pressure	102.2 psig		

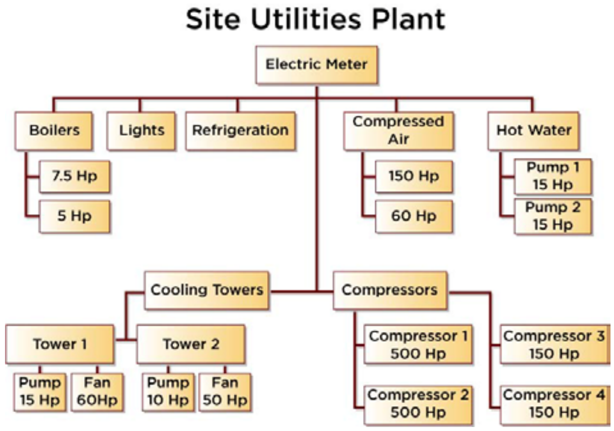
A key to success was that the analysis was all done by the software with the data presented to the operators in a format they could easily understand. They didn't have to be engineers. They didn't have pour through strip charts or volumes of data. They knew their plant and equipment and once they had the Real-Time data showing system efficiency, they could take it from there; similar to driving your car to keep the mpg readout at its peak.

PROJECT #2 - MARIAH MEAT PACKING, COLUMBUS, INDIANA

An AutoPilot Energy Monitoring System was installed in the Mariah Plant to help them understand, manage and hopefully, reduce their utility costs. As the President of Mariah, John Stadler, told me during our initial discussions, "Of course I am interested in cutting my energy costs; that is a key to our remaining competitive in this industry. Utilities are my third largest expense after raw product and personnel and I have no idea where that money goes"

MONITORING SYSTEM DESIGN

Electrical users included refrigeration compressors, cooling towers, air compressors, pumps, lights and production equipment. Most of the gas went to two large steam boilers and their burner operation was monitored along with the gas meter.



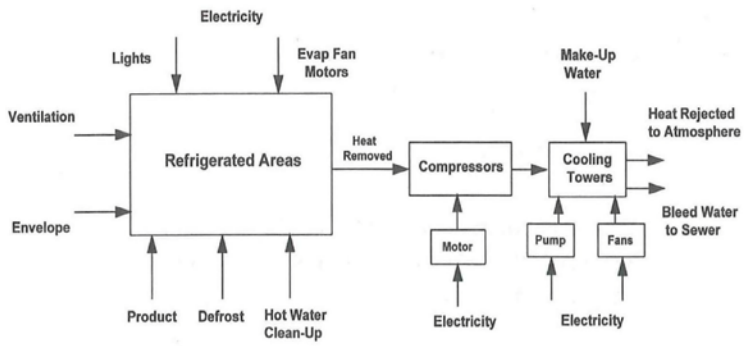
Past utility records provided the breakdown of electric, gas, water and sewer costs. Electricity accounted for two thirds of the total annual costs. The majority of the monitoring points were therefore for electricity, concentrating on the largest system, refrigeration.

[redacted]

After the monitoring system was installed, the data clearly showed that the refrigeration system accounted for two thirds of the total plant electrical consumption and costs.

ENERGY MODEL SHOWED REFRIGERATION SYSTEM CAPACITY 2 TO 3 TIMES REQUIRED

A spreadsheet model of the refrigeration system showed that it had between two and three times the amount of refrigeration capacity needed on the hottest day of the year. And yet the local utility company engineer had told me that the plant was preparing to spend $100,000 for electrical transformers with the intent of adding additional cooling capacity.



Refrigeration System Energy Balance

Heat Load	Monday 27-Apr	Thursday 20-May	Saturday 13-Jun	Year
Envelope	174	277	321	174
Ventilation	96	245	307	96
Product	1,205	1,205	-	1,205
Cleanup	126	126	-	126
Defrost	20	20	5	20
Total Tons	1,621	1,873	633	1,621
Calculated KWH	2,432	2,810	950	831,800
Actual KWH	10,701	17,695	13,947	5,215,800

Refrigeration System - Model vs. Actual

SYSTEM EXPANSION AVOIDED

I called the President of Mariah and told him that he was getting ready to spend several hundred thousand dollars for refrigeration equipment that he didn't need." He set up a meeting with the plant manager, plant engineer and the maintenance staff who had requested the new equipment. At the meeting, Mariah personnel told me that some of them had worked there for 30 years and on a hot summer day they ran out of capacity and it required a tremendous effort on their part to keep the meat cool. "This is an old, poorly insulated plant and we need more refrigeration equipment. How can you say that we have excess capacity?"

Without the math, I explained the thermodynamics of the plant. The refrigeration system was there to remove the heat from the freezers and coolers, the heat from the warm product (meat) that was brought into those areas to be cooled or frozen. It also had to remove heat and humidity from people, lights, motors, evening cleaning and sanitation using large quantities of steam and scalding water, and from defrosting the cooling coils. In the summer, the refrigeration system also had to remove the heat that came through the roof, walls and the air leaking in from the outside. Because parts of the building were 75 years old and the insulation was not very good, it was natural for the workers to assume that was the major reason it was hard to keep cool.

I showed them the breakdown of all the different factors; of course in the winter, when it was colder outdoors than in the coolers and freezers, no refrigeration was required for the roof, walls, infiltration air, etc. This was something that probably none of them had ever thought about. In fact, the heat went the other way, from the indoors to the outside, "Free Cooling". ***Seventy five percent of the refrigeration load was for cooling meat and related processes.*** They naturally thought first of the insulating factor of the old walls and roof, but that was not really the most significant factor even in the hottest part of the summer when it was less than 15% of the refrigeration load, and was no factor in the winter.

After thinking about it for a few minutes, I said, "You are looking at what you use and I am looking at what you need. The data from the monitoring system when compared to the spreadsheet model of the energy needs of the plant shows you have between two and three times the amount of refrigeration capacity you need on the hottest day of the year. In terms of an Energy Balance for the total plant, Heat In has to equal Heat Out. It has to balance. We have to find out why it doesn't. That will tell us why your refrigeration system is out of capacity. Rather than spending a lot of money on new transformers and chillers you don't need, we just need to find out why what you already have isn't doing its job."

FINDING A 400 TON MISSING LOAD

The Mariah personnel seemed to understand all of this but the natural question still was why do we run out of cooling on a hot day in the summer? What really convinced them was the data the monitoring system had collected during the previous winter. Data from a Monday morning at 2 AM when it was minus 20 outside showed the refrigeration system was providing 400 tons of cooling. This required running more than 600 horsepower, or approximately 600 Kilowatts of compressors. (At five cents a kilowatt hour this would cost $30 an hour, $720 a day.) There were no lights on and no people in the plant. No hogs had entered since the previous Friday at 5 AM and all of their heat had been removed with a few hours. Everything had been cleaned and sanitized that same day. The only thing running was the refrigeration system.

The cooling coils in the freezers and coolers had an automatic defrosting system. Periodically, hot refrigerant was blown through the cold coils so the ice buildup on the surface would melt and evaporate. There were automatic valves provided at each coil to control and regulate the process. The hot gas came from piping that ran from the refrigeration plant to each of the cooling coils throughout the building. If those old automatic valves weren't working properly and the hot gas was continuously leaking into the coils in the freezers and coolers, a tremendous amount of heat would be introduced that no one was aware of. The refrigeration system would have to run a lot more, use much of its capacity just to support itself and it might not have enough left for the rest of the plant on a hot summer day of full production.

To confirm my suspicion, I went into the plant with the assistant plant engineer on the next cold weekend. The engineer went to each of the coils and began manually closing isolation valves that were in place to allow removal of the automatic valves for repair. I sat at the computer screen and watched the electricity used by each compressor, the total refrigeration system and the main plant electric meter as they dropped. The refrigeration system started out at 600 KW, then dropped to 500, 400 and down to less than 30 kilowatts.

On a hot summer day, the plant cooling load peaked at less than 200 tons, so the confirmation of the 400 ton false load meant they had nearly three times the refrigeration capacity they required, a 200% backup. They certainly didn't need to spend $100,000 for new electrical transformers and then perhaps, a couple of hundred thousand more for new refrigeration equipment. Those are avoided costs, ones that never show up on the books but can have a huge impact on profitability. By repairing the automatic valves on the cooling coils, a 600 kilowatt false load in the refrigeration system could be eliminated. That would reduce the plant's demand by 600 KW and its electrical consumption by 600 KWH every hour of the year for an annual savings of $250,000, more than 25% of Mariah's total annual utility costs.

Assuming that the problem had existed for at least the 30 years that the plant had been running out of cooling in the summers, those bad valves had cost more than $5,000,000 in electrical costs not to mention the pain and suffering of the employees trying to keep everything safe, sanitary and working properly without enough refrigeration during hot summer days.

WHY DIDN'T SOMEONE ELSE CATCH THIS PROBLEM?

The project and resulting data uncovered the fact that the biggest energy user in the plant, the refrigeration system, was using five times the amount of electricity that it should and had been doing so for perhaps as long as 30 years. The local utility had previously done an energy audit and completely missed the problem. So had all of the Mariah employees, maintenance personnel, outside contractors, operators, and everyone else who had worked on the system in the previous 30 years. There is a good chance I would have missed it too without the real-time and historical data from the monitoring system.

JUSTIFYING THE COST OF AN ENERGY MONITORING SYSTEM

John Stadler, the President of Mariah clearly understood the need for energy information and approved the installation of a Monitoring System without asking for an estimate of savings. So did Rick Urschell, the Project engineer at G.E. who installed the System as a part of a Six Sigma project; so he could use it to find opportunities for savings. In my experience, Rick and John's understanding and attitudes were unique. More often than not I have been asked, "Why should I invest in a monitoring system? How can I justify the cost of instrumentation? What are you going to find? How much will it save? What will the payback be? What is the ROI?"

If I knew those answers at the beginning of a project, I wouldn't need to install monitoring. But how could I possibly know what would be found when in nearly every project the monitoring has uncovered problems that couldn't be seen without it; that had previously been hidden from everyone's view. In the case of Mariah, the monitoring had essentially allowed us to look inside of the refrigeration system and see information that no one else had seen. It allowed us to identify the existing problems, and determine the causes and the solutions. It allowed Mariah to avoid spending money on equipment they didn't need. At G.E. it gave operators information that they had lacked that enabled them to operate their compressed air system more efficiently and save hundreds of thousands of dollars every year. Managing energy with and without a permanent monitoring system is analogous to the difference in the way medicine was practiced before and after the x-ray machine.

For 32 years I have been installing permanent energy monitoring systems. With a background in instrumenting energy systems on fighters during my seven years in the Air Force, it was clear to me from my very first energy conservation project that in any effort to conserve energy and reduce utility costs, the installation of a monitoring system must be the first step. It's the best money you can spend with the quickest payback. As the first line on the cover of our 1990 sales brochure read, "The first step in cutting utility costs is finding out where you are spending your money." It's as true now as it was then. Thankfully, as the first generation that grew up with computers is moving into management positions, more and more people understand and are making information-based decisions like John did.

ROI CRITERIA SHOULD NOT BE APPLIED TO INFORMATION SYSTEMS

Justifying the cost of energy monitoring instrumentation based purely on savings projections and the ROI, makes no sense at all; not without a very accurate crystal ball. It's not appropriate. It may be for some capital projects but it's certainly not for instrumentation. What if John Stadler or Rick Urschell had insisted on such criteria? Mariah and G.E. would have missed the huge savings that resulted. So would have RCA, GenCorp, Golden Castings, the Commons Mall, the Jackson County Hospital, the Quinco Mental Health Hospital and many other of our projects where monitoring uncovered hidden problems and tremendous savings opportunities. Projects where the owner did not require us to **guess** what we might find before purchasing the system. Luckily after a few projects, our approach and results spoke for themselves.

I have seen people use the ROI criteria to justify a capital project with a 15 or 20 year payback and reject spending money on instrumentation that often has a payback in weeks or months, because no estimate of savings could be provided. In my experience, instrumentation will always expose a 10% or 20% savings opportunity in energy systems. In several of our projects, energy costs for the total facility were reduced 40% or more with no capital improvements required; the savings resulted entirely from changes in accountability, responsibility, operation, maintenance and control that were only possible because of the data from the monitoring system. Trying to justify spending money on instrumentation that is required to uncover potentially huge savings opportunities that may have been there and gone undetected for years, in some cases since the building was built, is a Catch 22 or chicken and the egg situation. It doesn't work.

In hind sight, after a huge opportunity has been exposed, it's easy to ask why someone didn't catch the problem much earlier. But we have found them in sophisticated systems in Fortune 100 facilities operated by top notch people. In most cases it's no one's fault; it's the status quo. It's the norm, the current state of buildings and building systems. People get used to how their buildings or systems run, assume or are told that's the way it has always been and needs to remain, and in the absence of information to the contrary, accept it.

MONITORING IS AFFORDABLE

What is the whole purpose of energy monitoring instrumentation? Is it to produce billing quality information, to know down to the penny, how much Chiller #3 cost to operate yesterday or last month? No. That's not the objective. The objective is not to measure power; it is to measure energy and reduce energy consumption and costs. Power measurement is expensive, energy measurement is not. The objective is to find waste, inefficiency and opportunities to cut costs, save money and verify the results. You're not billed separately for how much energy the chiller uses. You are only billed for what passes through your utility meters. In this case, the electric meter. By installing inexpensive current transformers (CTs) on one phase of an electrical panel or motor and measuring nominal voltage and power factor with a hand-held multimeter, the KW can be calculated by the monitoring software. By placing inexpensive temperature sensors upstream and downstream of a pump or fan and using the performance curves to determine gpm or cfm, basic thermodynamic calculations in the software can produce the heating or cooling Btuh and avoid the cost of a Btuh meter. You might not be able to tell the Chiller's cost in cents but you can tell within a few dollars.

Instrumentation doesn't have to be extensive nor expensive. By selecting the right points to monitor and combining hardware and software to present the resulting data in a clear format to those who understand a facility and its systems, a huge return can result from a small investment. And as sensors improve, wireless and other technologies advance and linking data through the Web becomes more prevalent, the cost of monitoring will continue to decrease. Energy Monitoring presents a tremendous opportunity and should be the first step in any effort to manage and reduce utility costs. Done right, the cost of the monitoring is not a net cost but the key to unlock the savings.

UTILITY COST ACCOUNTING

The real question people should be asking is not how much can we save from instrumentation, but where is every dollar going that we are currently spending every month on utilities? Just the same as they demand for every dollar spent for purchases other than utilities. How can you, your company, your boss justify spending one dollar on energy, on utilities without knowing where those dollars are going? How can you not have instrumentation? Why are you treating energy dollars differently from all other dollars? If you don't think thousands or millions of energy dollars spent each month are worth tracking, why do you track other expenditures? Why do you assume that the benefits of a cost accounting system do not apply to energy costs? Do you just assume that utility costs are a fixed overhead that you have to pay? That you have no choice? If you do, you couldn't be more wrong. Why don't you manage your energy dollars like you manage all of your other dollars?

An effective Energy Monitoring System is really a financial management tool if you think of energy in terms of dollars rather than KWH, Therms or gallons. Can you imagine a business where every department just spends what they want to keep their department functioning? Do you tell your employees to just to do the best they can to keep their expenses low? That you trust them to know what's best? No matter how good your employees are, without information their hands are tied. Think of the waste.

That is basically how utilities and utility costs are (not) managed today and why there is such tremendous potential from monitoring. Everyone runs their equipment and systems the way they have been trained or the way they have decided they need or want to; without any instrumentation, feed back or incentive to run them in the most energy-efficient way possible. And they have no way to know the impact their actions have on operations in the rest of the plant. How can you think that monitoring or tracking energy consumption, an area where it has never been done before cannot uncover huge opportunities for savings?

SUMMARY - A FACILITY ENERGY MONITORING SYSTEM

A MANAGEMENT INFORMATION AND FINANCIAL TRACKING TOOL THAT:

- Enables firms to manage energy as a controllable resource the same way they manage other resources
- Shows you where you are, where you want to go and how you can stay on course
- Includes data formats that are clear in presentation

DESCRIPTION

A continuous, real-time and historical information system that:

- Provides actual consumption, costs and peak demand data for:
  - Total facility and each utility meter
  - Each area, department, system, product and process
  - Time of day, day of week and shift, weather variation
- Produces immediate no-cost and low-cost savings

HOW TO PROCEED

- Draw one-line energy flow diagrams of the entire facility and major systems
- Inventory significant energy-consuming equipment
- Select monitoring points – from the TOP DOWN
- Start with the meters, proceed from biggest users to smallest
- Design and install monitoring hardware

TRACK AND MAINTAIN ENERGY AND COST SAVINGS

- Generate daily, monthly and annual utility cost reports for:
  - Total facility and each utility meter
  - Each area, department, product, and process
  - Each significant system
  - Time of day, day of week, and shift
- Integrate daily, monthly, and annual utility cost reports into the existing facility financial management system.
- Assign costs to specific individuals or departments.
- Include utility costs in production reports, manager evaluations, and incentives.

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BIOGRAPHY

Bill Holmes, P.E. founded Holmes Energy LLC www.holmesenergy.com and developed the AutoPilot Monitoring System in 1979. He is finishing his PhD in Industrial Engineering and Management at Oklahoma State University with his research focused on “Using Instrumentation to Allow Industrial Plants to Manage Energy Costs Like All Other Costs.” Bill is the recipient of a DOE Award for Energy Innovation and was the Indiana Energy Manager of the Year in 1990. He is a former Purdue professor and taught for several years in the Continuing Education in Energy Management Program at the University of Wisconsin.