HIGH PRESSURE STEAM SYSTEMS:
LESSONS LEARNED FROM THE WORLD TRADE CENTER (1997-2001) APPLIED TO TODAY'S WEB-BASED MONITORING

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Due to the high maintenance aspect of steam systems, many mechanical components regularly fail, costing building owners thousands of dollars in losses. Today, detailed manual walk-throughs augment real-time systems that notify operating engineers when critical components fail. It is only through a combination of both these methods that top energy efficiency can be attained. Developing a real-time steam consumption profile and successfully implementing a peak demand reduction program can easily save $38,400 (USD) for the six (6) months of the demand charge period, with savings two to three times greater for facilities larger than one million square feet. Real-time monitoring the high-pressure steam traps in a New York commercial building with at least twenty-five (25) of these traps can save an additional $30,000-$50,000 annually in most facilities. Manual surveys of the low pressure heating systems usually yield as much savings as the high-pressure traps. Savings and pay back are directly related to the age and complexity of a facility's steam system.

Before the widespread use of web-based monitoring systems, however, the World Trade Center (WTC) and the approach of its Mechanical Operations Team in the four years leading up to 9/11, showed that a plan for a comprehensive steam system maintenance program could significantly reduce steam consumption. The WTC exemplified the fact that the best results are achieved using a comprehensive, all-inclusive plan to identify leaks and limit consumption. Much of that learning is being applied today to augment the latest technology used in the new structures being built at the site. This is their story.

A World Class Steam System

New York City's District Steam System is the largest in the world, with a sendout of 30.8 billion pounds, 1,800 customers south of 96th Street in Manhattan, and 105 miles of mains. The New York steam system opened for business in 1882 and the city's current utility company, Consolidated Edison of New York (Con Edison), purchased the system from New York Steam in 1936. Capacity is 12.5 million lbs/hr (Mlbs/hr) with a peak winter load of 10.5 Mlbs/hr. Steam is used for heat, hot water, air conditioning, sterilization, cooking and humidification.

New York's steam distribution network is a "once-through" system, i.e. there is no return condensate. This also means that chemical treatment occurs at Con Edison facilities, precluding local adjustments to steam composition. Therefore, delivered steam may be more acidic from the effects of distribution. The age of the piping system also contributes to the selection of equipment. To meet these conditions, the best choices for most steam specialties are from industrial manufacturers such as Armstrong, Sarco, TLV, Leslie, Spence, etc. The core transmission pipe operates at 400 psig,, 475ºF. Distribution lines operate at 200 psig, 413ºF. The system extends from Battery Park north to 96th Street on the West Side and 89th Street on the East Side of Manhattan. Of the steam system's two primary load centers and distribution grids, one is located uptown and serves the concentration of large buildings in the midtown area, and the other is located downtown, serving the southern tip of Manhattan.

Four hundred and fifty (450) of the utility's largest customers use 70% of the load. Customer deliveries in 2005 break down as 69% large commercial buildings, 29% high-rise apartments, and 2% small residential or commercial establishments. In the summer months, steam is used to generate 625,000 tons of air conditioning. Utilizing this steam avoids of 375 MW of electric demand during critical summer periods.

Con Edison invests $70-$80 million annually in its generation and distribution systems to ensure the highest levels of reliability and safety. Within this massive system, no other large commercial facility in New York was as aggressive and forward-thinking in their approach to preventative maintenance of their steam system as the World Trade Center.

THE MANUAL APPROACH TO COMMERCIAL STEAM SYSTEM MAINTENANCE 1997-2001

The work began with an upgrade of the high-pressure steam trap rigs in the steam and mechanical equipment rooms. Then, we performed a facility-wide change-out of all safety relief valves on the steam and water systems, and moved on to upgrading all steam-driven condensate pumps at remote locations, focusing on efficiency through steam trap maintenance. Chronic trap and HP condensate system failures, difficulty in scheduling building shutdowns, and an interest in standardizing the steam system equipment all contributed to the rationale that the work was worth the effort. The result was a systematic approach to reduce steam consumption and an increase in the efficiency of all equipment.

The techniques and manual processes that were developed over these 4 years represent the practical application of engineering knowledge. Never before had it been applied so systematically and in such a comprehensive manner. Being so logical, it was never considered worth the effort when weighed against other more actionable and immediate tenant issues.

Safety concerns were identified first and then steam losses were prioritized in order of magnitude. Steam turbine system problems, while also a priority, were not part of the all-electric WTC chiller plant. New York steam turbine systems will be discussed separately because of their importance and uniqueness.

The Upgrade: Step By Step

High-pressure steam traps in the main steam room were first items to be addressed . At the time, this was the largest steam room in the city, with two (2) parallel 100-foot headers of 30-inch steam piping positioned across the room from each other and connected by many utility meter rigs. Leaks were calculated by ultrasonic testing as well as visually, where possible.

All-welded trap assemblies were supplied for the drip legs, using Armstrong stainless steel bucket traps with a universal connector. Other components of the assemblies included an integral local LED indicator showing trap status (OK, cold, blow-thru), three-way visual test valve, inlet/outlet shutoff ball valves, check valve, strainer with blow down, SCH40 316SS piping and all components meeting ANSI 300lb pressure/temperature requirements. All remaining HP drip legs were also upgraded to these rigs throughout the Center's 15 MER's and at the bottom of the A & B Tower high pressure (HP) risers. Each tower had redundant HP risers that were used one at a time under normal operation.

Upon completion of this work, the immediate annual savings were over $200,000. Usually, when all the high-pressure drip traps in a facility are tested and upgraded, about half of the total losses are identified and removed. High-pressure drip traps require manual testing at least every six (6) months because losses are so high (e.g. ~$35,000 for a 1" disc trap annually using $25/Mlb as the average steam rate). Usually the losses from the high-pressure traps can justify a continuous monitoring system that reduces steam leaks from months to hours.

Safety Relief Valves (SRVs) on the steam and secondary water systems were next. This included the cataloging and replacement of all one hundred sixty five (165) valves. SRVs were located on HP flash tanks in every mechanical equipment room, all domestic hot water generators (hot water shell side), and all secondary hot water heat exchangers (chilled water shell side, steam shell side, and secondary water tube side.) Safety was the main driver of this project but many steam leaks were eliminated as a result of the new valve installation.

Steam-driven condensate pumps in remote locations were upgraded to reduce maintenance costs of the electric motor driven pumps. Condensate was collected at the bottom of both towers and used to heat the perimeter heating system for the plaza buildings. High-pressure condensate throughout the sub-grade was collected via typical dual electric motor-driven pumps that required regular maintenance. The steam-driven type of condensate pump eliminates typical pump failures of seals, floats, switches, and motors. Through the use of steam or compressed air as its motive force, these pumps effectively move condensate with minimal maintenance.

A Facility-Wide Steam System Survey was the bonus for getting these early projects completed and the initial savings realized. Approval was given for a larger program, one that would develop a baseline steam trap database for the entire facility's 2000 traps and really dig into the system. It is only through detailed identification of all potential leak points that a system can be effectively managed. All system steam traps were identified, tagged and tested, with notes made of system inefficiencies and recommendations to improve piping practices and steam specialty component selections. For example, leaking bypass valves, relief valves, flanges, control valves and shutoff valves were noted and given to mechanical staff as action items. Large insulation gaps were also identified and given for repair. The primary methods used for testing and identifying these losses were visual and ultrasonic listening. (Infrared is effective on low-pressure, but only gives a partial picture and is inaccurate for high-pressure traps.) Through careful examination of the trap database generated from the walkthrough, trends of failure and success can be seen and changes for applications can be implemented. A significant change noted was the absolute failure of orifice traps on both drip applications and on heating equipment. A systemwide change-out to the orifice traps had been undertaken in the

1980's but had resulted in hundreds of blowing and blocked traps on high and low pressure systems. The orifice trap is effective on clean, constant load systems but New York City commercial buildings have constantly changing steam loads and the steam distribution system tends to have more particulate matter. The stainless steel inverted bucket proved to have a longer service life and handled dirt, scale and/or water hammer more effectively. Steam losses were calculated based on orifice size, pressure and hours of operation adjusted for the presence of condensate passing through the orifice along with the steam.

This comprehensive steam system upgrade took four (4) years to execute from start to finish and reduced steam consumption annually by one million dollars. Upon completion of the initial work, we surveyed the building for the second time (2000 steam traps, 165 safety relief valves, condensate piping system upgrades, HP flash tank upgrades) and were in the process of repairing the identified steam leaks when 9/11 occurred. Hundreds of newly installed stainless steel steam traps, all-welded trap assemblies and test valves worth hundreds of thousands of dollars were lost in the destruction. The knowledge, however, was not. It has been translated into modern web-based technology and management systems in order to assist facilities in achieving their energy-saving goals in a more efficient manner.

Key Elements of a Steam Strategy

- Survey steam traps and valves annually to identify steam leaks
- Continuously monitor HP, critical steam traps
- Continuously monitor steam consumption at meters & major usage points (chillers, heating systems)
- Develop steam operating strategy
  - Immediate
  - Longer term

A Note On Evaluation Of A Steam Chiller Plant

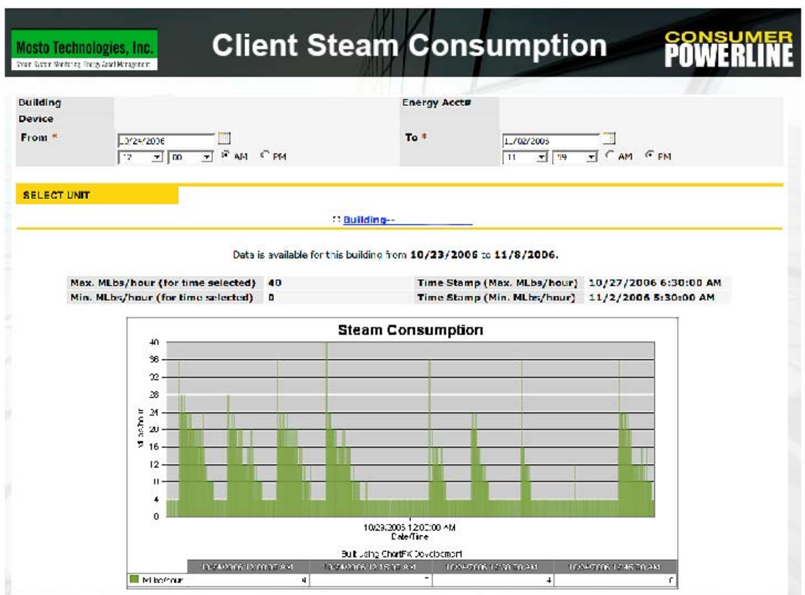
The most expensive and critical piece of steam equipment for a facility on the steam distribution network is the steam turbine or absorber. Steam must be supplied at the correct pressure and at an acceptable quality over a range of flows. The supply piping must be trapped correctly and have a properly selected steam separator installed immediately upstream of the inlet to minimize condensate carryover into the machine. Steam separators - typically specified as a centrifugal type - must be sized based on the actual flow range expected at the machine, not just the pipe size. If the velocity is too low through the separator, it will not be able to perform its task of condensate removal. In that case, excessive condensate is fed to the condensing turbine with eventual damage to all stages at a significant cost to the user. Other factors influencing the quality of steam supplied to the refrigeration machine include condensate piping sizing and configuration, size of high-pressure flash tank, size and location of drip legs, and selection of steam traps. Most separator manufacturers recommend inverted bucket type traps because of their mechanical nature, superior ability to handle water hammer, dirt or scale, and long service life. Problems that have led to damage of turbines include undersized traps, lack of drip leg/trap installation, incorrect trap selection, undersized flash tanks and incorrect separator selection.

The steam and condensate system must be correctly configured around the refrigeration machine so that it supplies and returns efficiently. Then the utility streams must be measured and compared against their design conditions. Flows of the steam and chilled water supply to the machine and chilled water should be measured. Inlet and outlet chilled water temperatures also need to be measured to calculate tonnage produced. Steam flow meter selection is critical. An industrial-rated, full-line size type of vortex-shedding meter is best because of its sensor reliability, turndown and ability to withstand the presence of condensate while delivering one percent (1%) accurate flow readings. Chilled water flow measurement offers several reliable options including ultrasonic, insertion vortex shedding and magnetic methods.

THE AUTOMATIC WEB-BASED MONITORING OF COMMERCIAL STEAM SYSTEM MAINTENANCE

Cutting Edge Technology

Chiller Plant Monitoring and Control are now online and efficiency is being calculated via the local Building Monitoring System (BMS) to the web using the recently developed BACnet and Modbus protocols. The opening up of proprietary BMS protocols through the use of universal gateways and communication has been the key in allowing BMSs to work with web-based platforms. The advantage of using a supervisory platform on the web is that it allows far more complicated, universal control schemes to be implemented at the building level, to the benefit of the facility. Current models include the use of real-time utility pricing to determine which refrigeration machines should be on-line (electric, steam or gas.) This type of flexibility has increased the design of multi-fuel chiller plants that offers daily cost savings in this age of energy deregulation. Buildings such as 1 New York Plaza and The Time-Life Building have constructed multi-fuel chiller plants specifically in this fashion and save hundreds of thousands of dollars annually in fuel costs.



A Real-Time Steam Consumption Profile is no longer a luxury. With the advent of steam demand charge rates by utilities such as Con Edison, whose program will go into effect next year, there is an absolute need for a facility to be aware of their consumption profile. Again, there is an advantage to the web-based model of monitoring steam profiles over the local

BMS that includes more complex and informative data presentation and standardized trending analysis. In New York, the Con Edison custody transfer meters are vortex shedding type, with a pressure-compensated pulse output available showing Mlb/HR consumption rates. Here the data must be collected and presented in an effective way (15-minute intervals) to mirror the method Con Edison uses to calculate the demand charge. Through observing this profile and making operation adjustments, facilities are able to manage and minimize the costs of demand charges while making the operation of their heating systems more efficient.

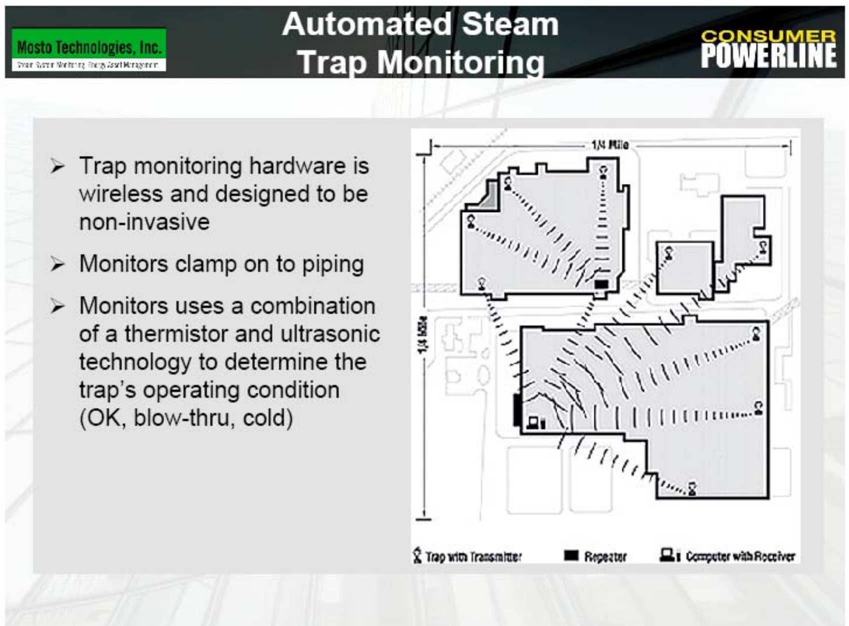
Peak Demand Management Programs are quickly becoming a requirement with the coming demand charge for steam during the heating season. Becoming aware of how a commercial facility uses steam with relation to time has not historically been necessary in New York. Most facilities have programmed control systems or set manual procedures that begin a warm-up cycle around 6 AM to prepare the interior space for occupancy by 8 AM. On the coldest days of the year this policy has made it necessary for Con Edison to produce a very large amount of steam (almost 10 MM lb/HR) for this short period of time. To reduce the shared burden of this recurring condition, beginning in 2007, there will be a premium charge placed on consumption during 6-11 AM, Monday through Friday, from November through April. Facilities that can reduce consumption during these hours by closely monitoring in real-time and preventing spikes of steam usage will be able to take advantage of lower base steam rates. By having access to 15 minute interval consumption data, facilities can choose from many energy-saving actions that will reduce their steam bills during the heating season. These include: warming-up the interior space more slowly over time; initiating it sooner; increasing the efficiency of equipment being utilized; increasing their nighttime setback set-point; reducing leak points in the system; and making use of the large mass of water in heating systems to store energy to be released during the peak demand window. An 8Mlb/HR reduction in the peak demand value will net a facility about $6,500 per month, or $39,000 in reduced steam charges. This is based on the demand charge being around $800/Mlb/HR. There are many buildings that can reduce their characteristic heating spike by 12-15 Mlb/HR with some basic operational changes, to net around $75,000 in annual steam cost reductions. Of course, not all facilities have this latitude or flexibility in modifying their operations, but there is always some peak demand charge reduction to be realized with careful monitoring of steam as it is being used. Payback analysis of this service has shown it delivers the initial cost in one to two months of operation.

Steam Strategy - Immediate

- Optimize warm-up cycle through equipment stagger start/earlier initiation
- Revise BMS algorithms to sequence valve/air handling unit operation
- Revise equipment on/off control to full modulation
- Close air handling unit outside air dampers during building warm-up cycle
- Control indoor temperature by zone/exposur
- Incorporate night setback

The natural progression of this type of meter monitoring is to install sub-meters at all major steam assets to develop individual profiles and to better understand how the facility sum is reached. With the implementation of this strategy, any deviation from the typical range of consumption is quickly noted and adjustments can be made. The ideal candidates in equipment include steam chillers, perimeter/interior hot water heat exchangers, major fan MER's that use steam preheat coils, large kitchen feed lines, health club feed lines and large domestic hot water generators.

Once a facility starts to scrutinize their consumption of steam as a whole, the natural progression brings them not only to supply-side subsystem measurement, but also to reducing losses significantly through web-based monitoring.



Real-Time High-Pressure Steam Trap Monitoring generates savings on a similar scale as peak demand management. All critical and high-cost traps have their losses reduced from months to hours. In New York City, a 180PSIG 1" drip trap can cost almost $40,000 in annual steam losses. The average trap failure rate experienced in a system-wide survey is between 15-20 percent. For a one million (1 MM) square foot facility with twenty-five (25) HP/critical traps, the typical losses found in an annual walkthrough survey are from $20,000-$80,000, depending on the age and complexity of the system. These typical losses support not only the annual walkthrough of all traps, but also the remote real-time web-based monitoring of the high-pressure traps. The initial cost to implement this type of system is about $40,000 with an annual monitoring service fee of about $2,500.

The technology for this system has recently been made available from several manufacturers, with Armstrong International supplying the best combination of sensor/transmitter and web-enabled receiver. Trap status is monitored using an ultrasonic or temperature sensor. An RF signal is then generated by the sensor/transmitter and relayed back to the receiver. The receiver communicates to a server on the web every time there is a state change (OK to blow-thru) at a particular trap. The server then sends out an e-mail to notify the appropriate personnel to schedule maintenance which can eliminate the leak within hours instead of days or months. It has taken many years to make the sensing and communication technologies affordable and reliable when in close proximity to the aggressive ambient conditions present around high-pressure steam (>300_F surface temperature.) Now, steam losses can be reduced in a day or two, as opposed to six months. The delivery of a one-year payback ensures that these systems will become part of the scope of regular preventive maintenance in many locations throughout New York and other steam loops in the United States, including Philadelphia, Boston, Baltimore, Washington DC, Pittsburgh, and Chicago.

Web-Based Supervisory Control Via the BMS utilizes the data collected to feed control algorithms and complex control strategies, generate outputs and slow pumps or fans, open and close valves, bring on-line or shutdown equipment, and initiate energy efficient operations. This is already being performed using real-time electrical consumption data and space temperature monitoring. The goal is to reduce peak load and bid the differential into lucrative electricity markets created to encourage large users to shed load voluntarily. The same approach can be taken to reduce steam peak demand charges by initiating energy-saving actions during the 6-11 AM period. Con Edison Steam is evaluating a similar type of revenue-generating program in which several premier New York buildings are taking part this winter. Several event days will be called and the total consumption during the 6-11 AM hours will be compared to a similar temperature day from the previous year. The differential, if lower this year, will create revenue based on a premium rate per mlb. Peak demand management ideas to generate revenue continue to be developed and executed as more buildings participate. Even lowering the pressure of the heating system can be implemented to reduce consumption by 20-30 percent.

Detailed control strategies can be programmed using a web supervisory platform and outputs sent to the BMS using either a BACnet gateway or Modbus type universal protocol. This standardization in communication among commercial BMS systems has allowed the implementation of such supervisory control systems, which have been available in the industrial sector for years. Sophistication of control will follow, as will scrutiny of energy consumption and waste in the commercial sector.

Another current use of this type of technology is multi-fuel chiller plants that utilize real-time pricing to drive the choice of equipment operation. One New York Plaza is in the process of bringing this system on-line. Rockefeller Center's central electric & steam chiller plant has used real-time pricing, since it's inception in 1988, to dictate its choice of equipment. Now, with the use of web-based supervisory level control algorithms, even more detailed decisions can be made based on outside air temperature profiles and overall interior space conditions. While these types of chiller plants are unique now, they will become the basis of all major upgrades in the decade to come as the ability to measure and direct control outputs become more transparent.

The way vendors sell to facilities, the way management companies position themselves to owners, the owner/operator's decision to reinvest, and the demands of primary tenants will all be affected in the coming years by the development of web-based technology and how it magnifies the overall energy picture. As voluntary energy-reduction markets continue to emerge and help pay for upgrades, all important aspects of the steam distribution system and critical equipment will be monitored in real-time.

We Will Remember

The spirit of the World Trade Center will live with us forever. The efficient operation of its mechanical systems and steam equipment will always remind us of what can be attained with a unified, focused approach. From an environmental point of view, there are larger returns than just reducing emissions when steam consumption is lowered. During the non-heating season, when boiler output is below normal, significant steam usage reduction can keep entire energy plants off-line. There is a much larger value to this effect because of the huge cost associated with bringing a plant up and running it at a partial load. As with most cost-raising trends in our fuel supply, they create opportunity in energy-saving projects not typically realized. The commitment of management enabled the WTC program to develop into one that could deliver compound savings. The belief of the engineering and operations team created something that not only lowered costs, but also spurred innovation. In fact, if real-time technology could be applied to an existing World Trade Center today, the consumption reduction would be almost twice what we experienced.

That is its lasting legacy.