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Assessment and Optimization of Pumping Systems in Commercial Buildings

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ABSTRACT

Commercial buildings contain systems that typically include pumps – heating, cooling, water heating, pressure boosting, wastewater, and refrigeration. These systems make up at least 35 percent of commercial building energy consumption. As we improve the efficiency of our existing buildings utilizing energy audits, labeling buildings, and LEED certification, the pumping systems will need to be evaluated and optimized. This paper provides an overview of the steps to assess a building pumping system using the new ASME/ANSI EA-2-2009 - Energy Assessment for Pumping Systems standard. It also demonstrates how the new standard can be associated with industry energy audit procedures and the LEED existing building certification process. After completing energy assessment on the pumping systems, optimization must follow to assist in reducing the buildings energy consumption. Common methods to optimize pumping systems to reduce energy consumption will be introduced.

1. INTRODUCTION

Estimates show that approximately 20 percent of the world's electrical energy consumption comes from pumping systems (Europump and Hydraulic Institute, 2001). This includes industry, water and wastewater treatment, and buildings. In the U.S., the commercial building sector was 19 percent of the total energy consumption in 2008 (EIA, 2009). Within commercial buildings, pumps are found in systems for space cooling, space heating, water heating, and refrigeration. These systems make up 35 percent of the commercial building sector's energy consumption (EERE, 2009).

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE, 2009) estimates that 70 to 80 percent of the commercial buildings that will exist in 2030 are already built today. McKinsey (2009) determined that implementing energy efficiency improvements to existing commercial and government buildings gave the energy efficiency potential as 1.234 million end-use terajoules of energy (1,170 trillion end-use BTUs).

To reduce energy consumption in our commercial buildings, we must first have an understanding of where the energy is going. Energy audits on building systems or whole buildings provide the information needed to make the best decisions for energy reduction. Assessments of the pump systems can help reduce energy not only in commercial buildings, but in the buildings and processes of the industrial and municipal markets as well.

In 2007, the U.S. Department of Energy (DOE) commenced to develop standards and their affiliated guidelines for energy efficiency assessments of pumping, compressed air, and steam/process heating systems. A volunteer project team of subject matter experts from government, industry, manufacturers and energy efficiency focused organizations developed ASME/ANSI EA-2-2009 – Energy Assessment for Pumping Systems. The purpose of this Standard is to provide a standardized method of executing and communicating energy assessments of pumping systems. The Standard organizes, conducts, analyzes, and reports the pumping system assessment of commercial buildings in a manner that is compatible with ASHRAE's energy audit procedures (ASHRAE, 2004) and as required under the Leadership in Energy and Environmental Design (LEED) green building certification system (USGBC, 2009).

After conducting, analyzing and reporting the findings of the pump system assessment, the next step to improve the building's energy efficiency is to optimize those systems that were identified as the most technically and

economically reasonable. From a systems perspective, there can be many approaches to reduce energy consumption with the pump, the controls, ancillary equipment, system design, and/or operation.

2. PUMP SYSTEM ASSESSMENTS

2.1 History of Pump System Assessments

The history of pump system assessments can be viewed in three stages.

- 2.1.1 Initial efforts in pump system assessments (pre-1990): Prior to 1990, few, if any, activities were occurring to assess and optimize pumping systems in any industry. Some consultants were providing these services with their own tools and guidelines.
- 2.1.2 The true roots of pump system assessments (1990-2003): The Energy Policy Act of 1992 (EPACT) began the next step in attempts to reduce energy consumption in facilities. Under EPACT, the DOE began a number of initiatives that included the Motor Challenge Program (Scheihing, 1996). Systems-approach training became an key activity to begin the move in changing the market (Scheilhing, 1998). Most of this initial effort focus on industrial facilities and water/wastewater treatment facilities. In 2000, the DOE's Industrial Technologies Program contracted with the Oak Ridge National Laboratory to develop the Pumping System Assessment Tool (PSAT), and the related training program. PSAT and the specialist training program were established to help in identifying pump system energy efficiency improvement opportunities, primarily in industrial plants (Casada, 1999).

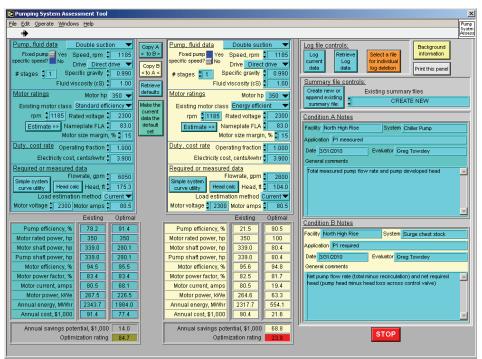


Figure 1 - Screen capture of the Pumping System Assessment Tool

Published in 2001, the collaboration of Europump and Hydraulic Institute produced an important guide, *Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems*, for a better understanding and application of Life Cycle Costs (LCC) and analysis for pump systems. The guide was developed by pump manufacturers and industry experts to become a resource for applying the LCC process to reduce energy consumption in industrial processes and buildings.

2.1.3 The next steps to transform the market (2004-present): Even with existing tools, such as PSAT and LCC analysis, and systems-focused training, the end user's focus was still primarily on the pump and other components, rather than the whole pump system. In 2004, the Hydraulic Institute Board of Directors (Asdal *et al.*, 2004) created Pump Systems MatterTM (PSM). PSM became industry's first market transformation initiative that was established and organized by a U.S. trade association. Realizing that it would take more to change the market's thinking about pump system optimization, PSM's primary objective is to change the decision-making process for improving pump

systems through life cycle costs and systems optimization concepts. In conjunction with revising the American National Standard *Management System For Energy (ANSI/MSE 2000-2008)*, ASME began work in 2007 to develop ASME/ANSI EA-2-2009 – Energy Assessment for Pumping Systems.

2.2 ASME EA-2-2009 – Energy Assessment for Pumping Systems

The ASME/ANSI EA-2-2009 - Energy Assessment for Pumping Systems (EA-2-2009) provides

- methods to organize and conduct the assessment
- recommendations to analyze the assessment data
- suggestions for the content and a format for the assessment's final report

While EA-2-2009 provides requirements to be performed during the assessment of the pump system, it does not provide direction on the various activities required to carry out the actual assessment. The supporting document, *ASME Guide for ASME EA-2-2009 – Energy Assessment for Pumping Systems*, is expected to be released in the summer of 2010. This guidance document will provide additional information on how to execute a pump system assessment.

2.2.1 Assessment organization: Prior to the actual assessment, preliminary activities must take place for a successful pump system assessment.

The assessment team should comprise of personnel that have knowledge of the pump systems to be assessed, as well as the skills to gather and analyze the collected data. The personnel on the team should also be given the authority to allocate resources for the assessment, such as other supporting personnel, tools required for the assessment, and funds for outsourcing. The team must also have the authority to schedule or coordinate internal personnel to conduct the assessment.

The facility management or owners must provide complete support of the assessment and its action plan. The importance of this assessment must be communicated to all personnel involved in the facility to insure that resources required will be made available.

The team shall be given full access to information and resources to complete the assessment. Information required may include manuals, drawings or data sheets for equipment, utility bills, or system operational data. Access will also be required to pump systems and the personnel who operate and maintain them.

The scope of the assessment needs to be determined. Some pump systems may have already been audited, or may be in process to be decommissioned. The assessment scope will keep the team focused on the pertinent pump systems. The goals of the assessment should include identifying opportunities for efficiency improvements in pump systems.

To provide for a more thorough and expeditious assessment, data can be collected prior to the actual assessment. This data may include energy data and costs, system operational data, previous audits, and interviews of key personnel involved in operating and maintaining the pump systems.

Producing an action plan will allow the team to have a clear understanding of the steps required to complete the assessment. The plan may include work scope, goals, objectives, metrics, scheduling, interviews, tools, responsibilities, and the final reporting deliverable.

2.2.2 Assessment execution: Within commercial buildings, the quantity of pumping systems is limited. However, if the scope includes a group of campus buildings, then the number of pump system assessment could increase significantly. Those pump systems with the greatest opportunity for energy savings should be given a higher priority for resources within the assessment.

For commercial buildings, the pump system may be a portion of a much larger system, such as chilled or hot water. For these systems, key personnel with knowledge of the larger systems must be included in assessment discussions to gain a clear understanding of how changes to the pump system could affect the overall building operation. For a successful pump system assessment, the overall operating system efficiency is being analyzed.

EA-2-2009 describes three different levels of pump system assessment. Table 1 provides an overview of the activities required, or to be considered, for each assessment level. As the assessment level increases, additional amounts of time, resources, data gathering and analysis, and other activities are required.

()			
	Assessment Level		
Activity	1	2	3
Prescreening opportunities	Required	N/A	N/A
Walk through	Optional	Required	Required
Identify systems with potential saving opportunities	Required	Required	Required
Evaluate systems with potential saving opportunities	Optional	Required	Required
Snapshot type measurement of flow, head and power data	Optional	Required	N/A
Measurement/data logging of systems with flow conditions that vary over time*	N/A	N/A	Required

^{*} Verify and use data from plant historical information where applicable

The primary objectives of the Level 1 assessment are to prescreen the pump systems in a facility and to determine which systems have the greatest opportunity for energy savings. Those systems with the greatest opportunity would then be assessed with the activities of a Level 2 or Level 3 assessment and analyzed further. As there are limited pump systems in commercial buildings, a Level 1 assessment can be executed on all of the pump systems. Utilizing simple worksheets, most basic information can be gathered for further analysis.

The primary objective of a Level 2 assessment is to gather operational data for existing building information systems or with portable measuring devices, such as flow meters, pressure sensors, and power sensors. That collected data is for a defined period of time and is representative of normal operation. The information from a Level 2 assessment will be used to determine an estimate of the potential energy savings of the system.

A Level 3 assessment will be performed on pump systems that have a high operating variation over an extended period of time. The assessment will measure the system conditions over a period of time that allows ample data to allow for a thorough analysis. As with a Level 2 assessment, the data can come from existing building information systems or temporary monitoring equipment that has extended data logging capabilities.

Flowcharts in EA-2-2009 provide direction as to how to determine which assessment level(s) to utilize for a facility.

2.2.3 Assessment information: The type and amount of information gathered varies with each assessment level. For a Level 1 assessment, EA-2-2009 provides recommended and optional data needed, as well as an example worksheet.

Undergoing a Level 2 or Level 3 assessment requires additional information to analyze the efficiency of the pump system. As the focus is on system efficiency, the assessment team needs to determine the boundaries and the demand of each pump system. More specific information that is required about the components within the system boundary includes

- Pump information
- Driver information (the driver is typically an electric motor in commercial buildings)
- Fluid properties information
- Physical system data layout, static head, control method

Quantitative data that requires sensors, instrumentation, or other measurement tools includes

- Electrical data motor voltage, current or power
- Flow and pressure of the fluid in the system
- Operating load profile
- 2.2.4 Assessment analysis: EA-2-2009 provides a limited discussion on the common causes and remedies for high energy use in pump systems. The remedies are limited to
 - System head reduction
 - System flow reduction
 - Maximize component efficiencies
 - Pump system run time

The standard does not make any recommendations as to software tools for the analysis of pump system performance. However, it does emphasize the need for "a thorough understanding of system requirements" before applying any type of software or other analysis tool. EA-2-2009 states that there are two methods to identify the energy savings potential

- measure or estimate the existing pump system performance and compare it to an optimal performance
- measure of estimate of the losses in the existing pump system
- 2.2.5 Assessment reporting: Standard EA-2-2009 defines the requirements of the final report that shall be completed after the assessments and analysis. The final report shall consist of:
 - Executive summary brief summary of findings and actions to be taken
 - Facility information general information about the facility that was the subject of the assessment
 - Scope and goals of the assessment includes the boundaries of the pump systems that were assessed
 - System description and identified issues include best practices found and negatively impacting issues
 - Methods and measurements of data collection to include specific pump system information, as well as a discussion on the accuracy of the information
 - Data analysis explanation of the measurements and results of the assessment
 - Pump system total annual energy baseline to allow for monitoring and adjustments to the pump systems
 - Identification and prioritization of opportunities for performance improvements the report shall include energy savings estimates and detailed descriptions of the potential activities to reach the savings estimates
 - Recommended subsequent actions to implement identified opportunities
 - Appendices supporting documentation of the pump system assessments

3. COMMERCIAL BUILDING ENERGY AUDITS AND PUMP SYSTEMS

3.1 ASHRAE Procedures for Commercial Buildings Energy Audits

One of the primary purposes of ASHRAE's *Procedures for Commercial Buildings Energy Audits* is to provide industry accepted procedures to conduct an energy assessment and analysis on commercial buildings (ASHRAE, 2004).

ASHRAE 2004 is similar to EA-2-2009 in that it is desired that the assessments identify opportunities to reduce energy consumption. However, ASHRAE 2004 looks at everything within a commercial building, which is inclusive of the pump systems that EA-2-2009 focuses. In a broader sense, ASHRAE 2004 looks at the energy consumption of the entire building and then identifies opportunities for energy reduction in any energy consuming system. ASHRAE 2004 considers various levels of effort for building energy audits in a similar manner as EA-2-2009 does for pump system assessments.

Before a building energy audit begins, ASHRAE 2004 recommends that an analysis of the building's energy use be completed. The analysis reviews the current energy consumption of the building and compares it to other similar buildings. To insure that the building energy comparison is similar, the energy use considers the cost per square foot of conditioned space per year. There is no level of comparison between this and the assessment levels in EA-2-2009, as this is a more comprehensive review of energy usage.

A Level I energy assessment includes a "walk-through" of the building to learn more about the facility, the systems, the operation, and the maintenance. Along with the walk-through, a review of the energy bills will provide initial opportunities for energy reduction with no-cost, low-cost or capital improvement projects. The findings of a Level I audit will also provide additional information to develop and prioritize a list of opportunities for further Level II or III assessments. The EA-2-2009 Level 1 pump system assessment is similar to the ASHRAE 2004 Level I building assessment in that minimal information is gathered and reviewed to provide a list of opportunities to further pursue with more analysis. Note that the activities outlined in the EA-2-2009 assessment fall well with the requirements of the ASHRAE 2004 required work.

The ASHRAE 2004 Level II procedure includes all of the efforts of a Level I assessment plus a more detailed investigation of the buildings and its systems, and a more thorough energy analysis. The energy use of each of the building systems and components is analyzed to identify and provide additional opportunities for projects to reduce energy. This Level also includes a review of the maintenance and operation procedures to determine of energy and

cost savings can be found with modifications to them. For EA-2-2009, Level 1 and 2 pump system assessments have activities that are included in the work scope of an ASHRAE 2004 Level II energy audit.

The ASHRAE 2004 Level III assessment is a more detailed analysis of building systems for more resource-intensive energy reducing activities. Data that is more comprehensive is gathered from the building systems and more extensive analysis is completed. Calculations for project costs and savings are done more thoroughly. Additional testing or monitoring of the pumps systems may be required. The requirements of ASHRAE 2004 Level III are more in line with the activities of EA-2-2009 Level 2 and Level 3 pump system assessments.

The reporting requirements of ASHRAE 2004 are much more specific, providing certain forms and information that must be reported. Again, the information assembled within the EA-2-2009 pump system assessment exceeds the quantity and quality of the requirements of ASHRAE 2004, but is fully supportive of its requirements. EA-2-2009 is also similar to ASHRAE 2004 in that no specific tools for energy analysis is recommended or required, but the best tools available for the type of assessment should be used, as agreed with the advocate of the assessment.

3.2 LEED® Green Building Rating Systems

The scoring for the Leadership in Energy and Environmental Design (LEED) green building certification system (USGBC, 2009) for Existing Buildings has prerequisites and credits in the Energy and Atmosphere section for reducing the energy consumption of buildings. Since the EA-2-2009 pump system assessment is in line with the ASHRAE 2004, the pump system assessment can assist in gaining points towards LEED certification.

- LEED Energy and Atmosphere, Prerequisite 1: This prerequisite requires that an ASHRAE Level I walkthrough analysis be conducted. Before any credit points can be given towards LEED certification, the prerequisites must be met. A Level 1 pumps system assessment would be part of this activity.
- LEED Energy and Atmosphere, Credit 1: The objective of Credit 1 is to optimize the energy performance of the building. Up to eighteen points can be gained for this credit depending upon the amount of energy performance improvement. To improve the energy performance of the buildings, the findings of the Level I audit required in Prerequisite 1 can be used to do additional building and system analysis, and to implement operation, maintenance and equipment upgrade strategies. A Level 1 and Level 2 pump system assessment can contribute to this effort.
- LEED Energy and Atmosphere, Credit 2.1: This Credit provides two points for further investigation and analysis in the energy consumption of the building. Two options are provided to fulfill this requirement. Option 1 involves the commissioning process. It is required that an ongoing commissioning plan is developed for the building's primary systems, further investigation and analysis is completed, knowledge of the various systems' energy usage, and identification of projects to reduce energy consumption. The Level 2 and Level 3 pump system assessments provide one mechanism to meet this Credit requirement. Option 2 of Credit 2.1 is simply completing an ASHRAE Level II energy audit. The Level 2 and Level 3 pump system assessment can be part of meeting this Credit requirement.
- LEED Energy and Atmosphere, Credit 2.2: Credit 2.2 involves implementing no-cost or low-cost projects and create a detailed plan for future capital projects that optimize energy consumption even further. Indirectly, the activities and outcomes from Level 2 and Level 3 pump system assessments will support this Credit and implementation of identified projects.
- LEED Energy and Atmosphere, Credit 2.3: Credit 2.3 requires continuous commissioning of building systems to continue to reduce energy consumption and to allow for system adjustments for optimized system performance. Like Credit 2.3, the activities and outcomes from Level 2 and Level 3 pump system assessments will indirectly support this Credit and implementation of identified projects.

4. OPTIMIZATION OPPORTUNITIES IN COMMERCIAL BUILDING PUMP SYSTEMS

Pump systems found in commercial buildings can vary, depending upon the type of the building, size of the building, building use, and the indoor environmental quality requirements. These systems are often overlooked as opportunities for energy reduction in a building. Depending upon the system, a pump system may have various energy reducing opportunities to consider.

4.1 Knowledge of the pump system

When new buildings are constructed, the future pump system operators are not involved in the design or installation. The system was originally designed with certain load profiles, assumptions and "engineering factors." For an existing building, a systems operation or load may have changed over time from the original design. When looking at upgrading an existing building, it is important to know what the current needs are of the system. After completing a pump system assessment, it is important to take the knowledge gained and put it to good use to reduce energy and continue to optimize the system's operation.

4.2 Right-size the pump

After gaining knowledge of your system, the right pump for the application must be chosen. Many times, the pump installed in a system was the least expensive, over-sized, and not the type with the highest efficiency. Insure the most efficient pump is chosen based on the operation profile of the system. The triple bottom line requires that the "right" pump be chosen for the service. Energy consumption is most often the largest component in the calculation of the life cycle cost for a pump system. In commercial buildings, pumps can run more than 4000 hours a year.

4.3 Pump control

Based on the pump system operating requirements, the method of controlling the pump and components in a pump system can assist in reducing energy costs. The control of a pump can be as simple as on-off or the use of variable speed drives can optimize the performance of the pump in the system. Again, a thorough knowledge of the pump system will assist in determining the best method of pump control, as well as utilizing modeling program or life cycle cost evaluation.

4.4 Maintenance/Repair

While the pumps systems in commercial buildings are typically not complex or physically demanding on the pump, following the best industry practices to maintain and repair the pumps and components can extend the life of the equipment and help to keep energy costs down. Continuous monitoring of key pump and motor operating characteristics can provide information about the condition of the pump and the system. The flow rate and differential pressure should be monitored for the pump, as well as the electric power or current of the motor. A simple key performance indicator that could be used for monitoring pump system performance it the flow energy intensity. The flow energy intensity is a ratio of pump system flow rate to the power input to the pump system, and is shown in Equation (1).

$$Flow Energy Intensity = \frac{Q}{P_{input}} \tag{1}$$

The current condition of the pump system can be determined at any time if a baseline flow energy intensity is captured for a new or optimized pump system. Any major changes from the baseline flow energy intensity can help to determine when the pump system or components should be analyzed or repaired.

Another key performance indicator for monitoring a pump system is the system efficiency (Casada, 1999).

5. CONCLUSIONS

The new ASME/ANSI EA-2-2009 – Energy Assessment for Pumping Systems provides a process to perform pump system assessments with various levels of effort. While some current and past focus has been with improving the performance of specific components, EA-2-2009 requires a complete investigation and analysis of the pump system, not just the pump.

ASHRAE has developed procedures to complete commercial building energy audits with varying levels of effort. These procedures are utilized in LEED green building certification system for Existing Buildings. The procedures and activities of EA-2-2009 provide a more detailed focus on the pump systems that can be utilized in meeting the requirements of ASHRAE energy audits and LEED building certification.

The pump system assessments will identify opportunities to make improvements to the pump systems that will reduce their energy consumption. The analysis involved in determining with pump system improvement opportunities can be very complex. The primary factors in improving the energy performance of a pump system include a thorough knowledge of the system and operational requirements, installing the right-sized pump for the system requirements, the proper control method for the service, and utilizing the best industry practices for maintaining and repairing the components of a pump system.

NOMENCLATURE

Abbreviations:			
ANSI	American National Standards Institute	LCC	Life Cycle Costs
ASHRAE	American Society of Heating, Refrigerating, and	LEED	Leadership in Energy and
	Air Conditioning Engineers		Environment Design
ASME	American Society for Mechanical Engineering	PSAT	Pumping System Assessment Tool
DOE	Department of Energy	PSM	Pump Systems Matter TM
EERE	Energy Efficiency and Renewable Energy	USGBC	U.S. Green Building Council
EIA	Energy Information Administration		•
Symbols:			
BTU	British thermal unit	m	meters
gal	gallons	min	minute
h	hour	P	power (kW)
kW	kilowatts	Q	Pump capacity (gal/min, m ³ /h)

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