AC 2011-729: ENERGY CONSERVATION IN THE CLASSROOM

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Energy Conservation in the Classroom

Abstract

One of the most important areas in mechanical engineering is energy production. This broad field can be further subdivided into two primary areas: power generation and energy conservation. In recent years, there has been increasingly focused interest in generating power from clean and renewable resources, particularly those that fall into the so-called *green* category. While academic efforts in the field of power generation have tended to evolve with these changing interests, teaching and research dedicated to the conservation of energy has remained comparatively static.

From an analytical standpoint, many companies do not possess the in-house knowledge needed to fully assess the impact that simple energy conservation measures can have on their facilities or manufacturing operations. This knowledge gap can often be bridged when plans for the more efficient use of energy is correlated directly to monetary savings. Toward this end, the responsible energy engineer must be fully adept in the appropriate engineering fundamentals *and* the associated economics as well.

Spurring renewed interest in the development and adoption of both new and existing energy conservation strategies must begin in the classroom. A distinct challenge faced by today's instructors teaching engineering courses concerned with the principles and practices of energy conservation is to not only create meaningful lectures, but also to provide students with practical and engaging real-world experience. This paper presents an educational model designed to do just that: to give students a strong theoretical foundation in energy conservation fundamentals bolstered with realistic applications. Tailored towards upper-level undergraduates or beginning

graduate students, the prerequisites include undergraduate courses in heat transfer, fluid mechanics, thermodynamics, and engineering economics.

For the proposed course, in-class time spent on recitation will be supplemented with field trips crafted to improve the students' practical understanding of the subject matter. The field trips, which will be undertaken monthly, will consist of the students and instructor visiting a nearby manufacturing plant or production facility to conduct a comprehensive energy usage study. Prior to the beginning of the semester, the instructor will have made arrangements with the local participating affiliates and disclosed the mutual benefits of the program to each facility's management. As an instructional tool for the students, the study will come at no cost to the affiliates. As for the study itself, the students will be tasked with collecting energy consumption data for key processes or operations throughout the facility to establish a set of baseline energy usage profiles. These data will then be analyzed by the class to compile a list of recommendations that could improve the efficiency with which the facility uses energy. In addition, the annualized cost savings associated with implementing the suggested changes to the facility's energy management strategies or more specific items such as equipment modifications, repairs, or upgrades will be provided in a detailed report that will be compiled by the students. This report, which will be compiled by the students as part of their course grade, will be issued to the affiliate within a few weeks of the site visit.

Introduction

The field of energy engineering represents one of the broadest, most diverse, and far-reaching application areas within all of engineering science. As it pertains to each major engineering discipline, energy engineering can effectively be partitioned into two core areas: power generation and energy conservation. Within the discipline of mechanical engineering, the area of power generation has a long and well-documented history, having traditionally focused on the component and systems-level design of various thermo-mechanical devices tasked with extracting or converting useful heat energy and work from various fuel sources. As our understanding of the physical phenomena involved in the underlying energy conversion processes improves, so too does our ability to design increasingly productive and efficient energy systems. In this sense, the field of power naturally pushes the envelope for optimization and efficiency, benefiting each successive generation of energy systems that emerge. But what about existing systems that, despite being far from the end of their serviceable lifespan, have been in operation too long to benefit from the latest knowledge and technology geared towards efficiency improvements? Are there any established practices that can systematically apply these developments to older systems in such a way to boost energy efficiency while maintaining the designed performance? These questions form the basis of the second aforementioned core area of energy engineering and the main topic of this paper: energy conservation.

Owing to their large energy densities and relative ease of use compared with other combustible fuels, petroleum-derived fossil fuels such as crude oil and natural gas have risen to prominence as the fuel of choice throughout most of the industrialized world.[1] However, with various markers indicating that we may be in the midst of peak global crude oil production, the world's industrialized countries are now faced with the reality that the oil-based economies, which dominated the last century, are on an unsustainable track.[2] In the United States, there has long existed a passionate, if not somewhat capricious, public interest in generating the majority of consumed power from clean and renewable resources. These interests have manifested over the last decade in what can be aptly described as *the green movement*, giving rise to a modern-day vernacular that includes such terms as "eco-friendly" and "carbon footprint." Not surprisingly, these interests have been increasingly echoed at the federal level as well, with the United States government pumping billions of dollars annually into a wide spectrum of alternative energy and green research and educational initiatives during the last 10 years. By contrast, both federal and public support for teaching and research aimed at improving efficiency and conservation strategies for existing energy technologies and resources has either dwindled or remained relatively unchanged during the same time span.

Fortunately, there are numerous examples of how research focused on improving the various efficiencies associated with existing energy options can have a substantial impact on sustainability.[3] In addition, on the educational front, the US Department of Energy (DOE) has managed to promote the concept of energy conservation to some degree. The DOE sponsors programs at numerous universities known as the Industrial Assessment Centers (IAC)[4]. This program, based out of Rutgers University, supports teams of undergraduate and graduate-level engineering students to visit small- to medium-sized manufacturing facilities within a 150-mile radius of their campus. The purpose of these visits is to conduct a detailed technical review of each plant's operations and existing equipment with the intent of identifying key energy-saving measures that can be readily implemented to lower operating costs and/or increase productivity for the manufacturer. The federal sponsorship made available to each active IAC makes it possible for these services to be provided at no cost to the manufacturing facility. From an educational perspective, this program provides a great benefit to the students involved because it offers a unique opportunity for IAC participants to apply knowledge gained in their engineering courses in a real world environment.

Recognizing that most engineering curriculums already possess a cache of excellent courses dedicated to various topics affiliated with power generation and energy conversion, we come to the motivation for carrying out the present work: very few programs include one or more courses dedicated to the general engineering principles *and* specific application areas associated with the subject of energy conservation. The purpose of this paper is to provide a general framework and description of one potential full-term engineering course that gives students a strong foundation in basic energy conservation principles supplemented with practical, real-world applications and experience. The overall format for the proposed course is loosely based on the IAC paradigm previously discussed. This course should be suitable for upper-level undergraduates or beginning graduate students. Suitable prerequisites include standard undergraduate courses in heat transfer, fluid mechanics, thermodynamics, and engineering economics. This paper is also meant as a guide and learning tool for other schools to use.

Overview of Course Curriculum

The proposed course is divided into three primary segments, each culminating with an actual plant visit. The length of each segment can vary according to the needs of the class and availability of the manufacturing facility to host the required visits, but in general, the first segment will be the longest. The first segment should include the majority of instruction on engineering fundamentals, including reviews of the pertinent component subject areas (thermodynamics, engineering economics, etc.). It is also in this first segment that the students should also be introduced to the majority of the energy-saving techniques that will be employed during the plant visits later in the course (an array of such techniques are discussed in the sections that follow). Based on the instructor's assessment of the students' aptitudes for the subject matter, evenly-matched teams comprised of two to four students each should also be formed during the first segment as well.

Prior to the first class day, the instructor should have contacted and arranged with the three manufacturing facilities that will play host to the class during each primary course segment. If possible, the instructor should visit each site before the first class day to determine the suitability of each facility for safe, detailed auditing by teams of students. The first site visit will likely be the most critical learning experience for students because this is the point at which many new techniques and procedures are taken out of the classroom context and actually put into practice. With this in mind, the instructor should take care to select the first venue to be one that is conducive to hands-on instruction. A couple of characteristics of the ideal first venue might include:

- a relatively quiet facility in which group instruction can be conducted on the factory floor without the need for hearing protection
- a facility that features a fairly simple equipment layout or process (e.g. operations that are easy to access, visualize, and navigate) so that students can initially place an emphasis on honing the skills required to obtain accurate field measurements

Upon arriving at a given facility, the students and instructor should become acquainted with the plant personnel responsible for supervising their visit and then proceed to satisfy any site-specific safety requirements (orientations, trainings, issuance of personal protective equipment, etc.). This should be followed by a comprehensive tour of the facility with care being taken to identify energy-intensive processes or equipment used in normal plant operation.

After the tour, the instructor should meet with the class and assign specific tasks to each student team. The remainder of the site visit should be spent with the student teams collecting the data necessary for a comprehensive energy audit of the facility. These data include various physical measurements made at key points throughout the plant (to be discussed in later sections) as well as copies of the facility's electrical and natural gas utility bills for a minimum of one year prior to the date of the visit. During the first site visit, the instructor and facility personnel should 1) take care to advise the students about which data are relevant for an accurate facility assessment and 2) be prepared to spend a considerable amount of time assisting student teams in completing their various tasks. As they gain experience and familiarity with the procedures established during the initial site visit, students should be capable of assuming an increasingly autonomous role during the subsequent site visits.

During the week following the completion of the first site visit, each student team should begin the process of analyzing and interpreting the data they collected in accordance with the techniques and procedures established during the first course segment. Each team should then prepare a detailed summary of their findings along with any recommendations for facility improvement. These team summaries should be compiled into a report-like format which will facilitate seamless inclusion into a master report that will eventually be delivered to the audited facility. The master report should serve to summarize specific energy-saving measures that could be implemented to improve the efficiency with which the facility consumes energy. In addition, the report should offer consideration of the capital costs associated with these improvements as well as their projected cost savings.

Prior to inclusion into the master report, each team's summary report should be peer reviewed by at least one other team and evaluated by the instructor. After the master report is assembled, the collective work should be presented to the students for review. The instructor is ultimately responsible for the final technical review of the material prior to its delivery to the manufacturing facility.

After the first master report is completed and submitted, the instructor may proceed with the second and third site visits. The instructor should structure the later visits to build off the experiences gained in the initial energy audit while generally adhering to the overall trip format previously described. The primary difference between the first and subsequent site visits should be that for the latter, the instructor strives to have the student teams assume an increasingly independent role in managing the auditing process. Ideally, by the second site visit, the students will have gained enough experience to determine which operational data are pertinent to the audit and will feel more confident in making recommendations in their master report to the facility. For the final site visit, the auditing process should be largely student driven, with the instructor providing a more passive, observational role. The third round of summary reports and final master report should also be largely student generated, with the instructor providing the final screen for quality.

Course Content and Suggested Grading

Review of Fundamentals

It is recommended that at the beginning of the course, the instructor conduct a cursory review of the relevant aspects of the core subjects of heat transfer, fluid mechanics, thermodynamics, and engineering economics. Depending on the class, such reviews could last anywhere from two to six weeks. In addition to benefitting the students directly, the instructor is encouraged to utilize these reviews to 1) assess the strengths and weaknesses of each student in the class for the purposes of forming the well-balanced teams and 2) establish a thread of foundational grades for each student via homework, quizzes, and/or examinations.

Interpreting Utility Bills

Following a suitable review of the fundamentals, the instructor should introduce basic energy conservation techniques and strategies that will later be employed by the students during their site visits. A number of such techniques are discussed in more detail in the sections that follow. However, an important component of the energy auditing process is the ability to interpret the structure of a given facility's utility bills. For industrial plants, the supplying electric utility generally charges for the kilowatts used but also a *demand charge*. This demand charge is a measure of "how fast" a facility uses electricity during peak times [REF?] and can be better envisioned as follows. The ultimate size of any electrical power generating plant is based on the peak demand expected to occur within a given time span. During off-peak times, the electrical plants are running at a much lower capacity, which represents an inefficient use of their power generating equipment. Thus, if a manufacturing facility happens to use a significant amount of electricity during times of peak demand (perhaps mid-afternoon in hot climates, for example), the electrical utility will charge more (i.e. a demand charge) for electricity sold during that time. Unfortunately, different electrical utilities use different demand and rate charge structures, so correctly interpreting a given facility's electric bills can be a somewhat tedious task. It is therefore important for the instructor to place an emphasis on teaching the students how to accurately harvest energy audit data from electric utility bills because demand charges can have a large impact on any forecasted cost saving measures recommended. In general, billing structures for natural gas utilities are not as complicated as those for electricity. It is usually straightforward to extract an avoided cost per cubic foot of natural gas consumed. On rare occasions, other fuels such as propane, fuel oil, or even coal, may be encountered. Estimating avoided costs on a per unit mass or volume basis for these fuels in generally straightforward as well.

The following is a list of Assessment Recommendations (AR's) with a brief description of the information needed to calculate the savings. The actual calculation software can be found at:

http://texasiof.ces.utexas.edu/tiof/smeNRG.asp

Two additional software programs are used in these calculations; DOE's Best Practices MotorMaster v 4.0 software[5] and 3EPlus Insulation software[6]. Both of these are available on DOE's Best Practices websites:

http://www1.eere.energy.gov/industry/bestpractices/software.html

and,

http://www1.eere.energy.gov/industry/bestpractices/steam_systems_elearning.html

Recommended Field Equipment

Table 1 shows a list of equipment that is recommended for the energy assessment plant visits. Although this is the minimum equipment required, a shared toolbox equipped with conventional hand tools (e.g. standard- and metric-sized wrench and socket sets, ratchets, pliers, screwdrivers, etc.) should also be brought to the plant.

Table 1: List of minimum equipment required for facility assessment.

Equipment Type	Purpose
Thermocouples / IR Temperature Gun	Temperature measurements of surfaces and various process streams (liquids and gases)
Light Meter	Measurement of lighting levels in various locations
Flexible Tape Measure	General length, area, and volume measurements for lighting, heat load, and occupancy calculations, etc.
Chronometer / Stop Watch	Time measurements for quantifying items such as compressed air system pressure drop
Digital Pressure Gage	Static pressure measurement of process streams when equipment pressure is not available
Ultrasonic Detector	Compressed air system leak detection

Energy Conservation Strategies and Techniques

Repair of Compressed Air Leaks

Compressed air is very expensive from an energy standpoint. Many facilities assessed during previous audits conducted by IACs were reported to have leaking compressed air lines. Leaks can waste 20-30% of the electrical energy consumed by a compressor.[7] Fortunately, most leaks of practical significance tend to generate high-frequency sound as the air exits the pipe through the leak and can be detected easily with an ultrasonic detector (a relatively inexpensive device).

Determining the avoided cost of electricity for leaking air lines is rather straightforward. Figure 1 shows a flow chart of the steps necessary to quantify the energy loss associated with a compressed air leak. First, the volume of the air system (smaller lines < 2" can be ignored) should be calculated. Next, steps should be taken to ensure that no air-consuming equipment is operating (this could necessitate that the measurements be made during a process shutdown or during off-hours). With the compressed air system isolated and fully pressurized, the value of the system pressure near the main receiver tank should be recorded. Then the main valve between the tank and compressor should be fully closed. Using a stopwatch, the amount of time required for the pressure to drop by 10 psig should be recorded. Inserting these data into the spreadsheet previously mentioned will provide a calculation of the avoided electrical costs associated with the air leakage. Other data that will be required for the calculation program include the type of compressor (rotary screw, reciprocating, centrifugal, etc.), compressor motor data (efficiency, horsepower, etc.) and the facility's power factor (if known).

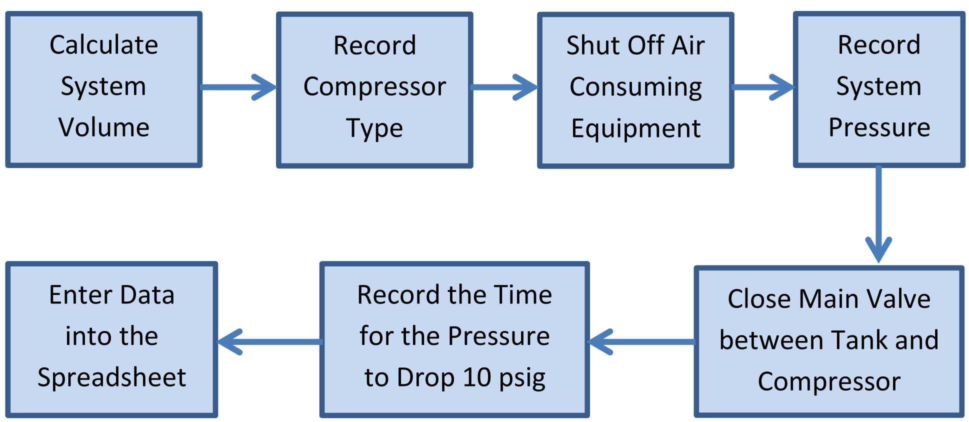

Figure 1: Flow chart showing steps to calculate losses due to compressed air leaks.

Reduction of Compressed Air System Pressure

Another simple energy saving strategy associated with compressed air involves determining whether the pressure required by the tools or processes being used matches the air pressure set point for the compressor. For example, if the supplied air pressure is notably higher than what is required at all points of use throughout the facility, there may be considerable energy being wasted at the air compressor. Figure **2** shows the steps involved in calculating the energy savings associated with matching the compressed air pressure with the equipment requirements. The information required to make an accurate assessment of the potential cost savings in such cases include the motor data (horsepower and efficiency), facility power factor (if known), current operating pressure and the lowest acceptable air pressure.

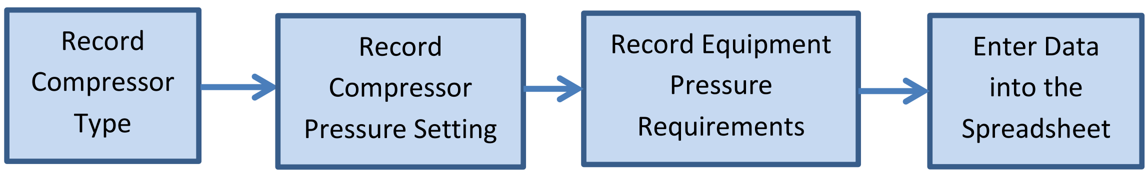

Figure 2: Steps in calculating the energy loss in too high compressor settings.

Installation of Premium Efficient Electric Motors

The efficiency of newer premium efficient electric motors is typically on the order of a few percent higher than that of standard efficiency motors. However, if the motors in question are of moderate to high power and operate for many hours per day, a significant reduction in operating cost can be realized by upgrading from standard to premium efficiency. Figure 3 shows the flow chart for assessing this project. The data needed to assess the economic advantage offered by such an upgrade consists of the rated motor horsepower, hours of operation per day, load factor, and whether the demand calculation is relevant (i.e. does the given motor run when all other motors in the factory are running or does it run when the others are shut down?). The spreadsheet program used to carry out these calculations is based off of DOE Best Practices software called MotorMaster v 4.0.

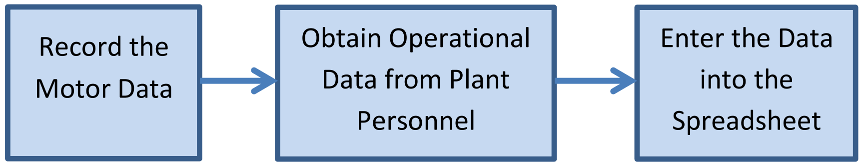

Figure 3: Steps to evaluate replacing existing electric motors with premium efficient motors.

Changeover to Synthetic Lubricants

The basis for this energy conservation strategy stems from the fact that even though synthetic lubricants are generally more expensive than natural lubricants, they tend to have a longer service life, which can minimize process downtime for maintenance and minimize equipment wear. The resulting cost savings afforded by using synthetic lubricants can, in many cases, offset the higher cost of the product. The data needed to assess potential benefits of implementing this energy conservation measure is similar to that of premium efficient motor data: namely, motor horsepower, operating hours, and load factor. The impact of demand charges are also considered in the calculation.

Adaptation of Energy Efficient Belts

Although standard drive belts are reasonably efficient, there do exist a class of energy efficient belts that have been shown to improve power transfer efficiency in belt-drive equipment. The increase in efficiency tends to increase with the rated power of the equipment in use, so larger belt-driven systems can be expected to see more of a cost savings than smaller systems. The base data required to assess this conservation measure are the motor horsepower, operating hours, and load factor. The effects of demand charges can also be considered in this evaluation.

Insulating Bare Equipment

It is generally surprising to find that many in facilities which rely on steam or hot water for various processes, the associated boiler, piping, or end-point equipment are often under-insulated (and in some cases, not insulated at all!). Such instances can be the source of huge losses in energy efficiency. The benefit of improving piping and equipment insulation can be assessed with calculations based on the DOE's Best Practices 3EPlus Insulation software. These calculations give the option of determining either the avoided cost of electricity or the avoided cost of natural gas, depending on which power source is used to ultimately generate the hot utility. Figure 4 shows the steps necessary to make this calculation. The data required to perform this assessment include basic equipment geometry, material types, and process and ambient temperatures. The software calculation will estimate the heat loss associated with varying thicknesses of insulation. The program can then convert the calculated heat loss directly into avoided costs of either electricity or natural gas.

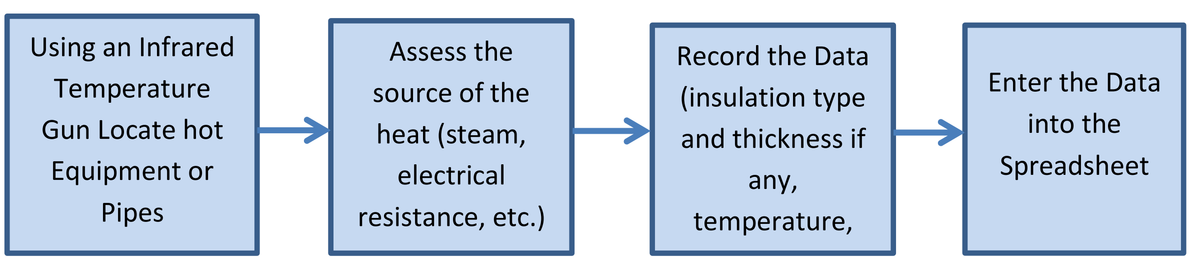

Figure 4: Steps to evaluate adding insulation to bare (or under insulated) equipment.

Tune-Up of Fired Heaters[8]

This particular energy saving measure involves tuning-up gas-fired heaters to improve the overall efficiency of their operation. To perform the assessment, two types of measurements are required: 1) the inlet and exit temperatures of the gases and 2) and the oxygen concentration in the exhaust products. Figure 5 shows a flow chart specifying the data collection procedure. Simple K-type thermocouples and a gas analyzer should be sufficient for collecting these measurements. Those data can be combined with the pertinent boiler specifications (often acquired from the name plate) to project the natural gas savings that will result from the tune-up.

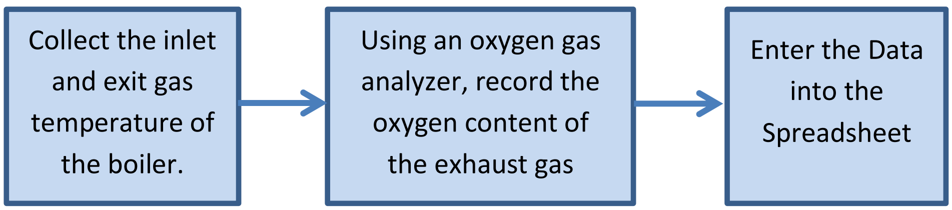

Figure 5: Steps to collect data necessary to assess boiler efficiency.

Recovery of Waste Heat

Certain facilities may have a process in which waste heat from other processes or equipment could be suitable for providing heat instead of raw fuel or electricity. To assess the efficiency gains and cost savings offered by changing over to such a setup, the following data from the primary and secondary fluid streams will be needed: the inlet and outlet temperatures of each stream, the specific heats for each stream, the mass or volume flow rates for each stream, and the type of heat source currently being used (electricity or natural gas).

Repair of Steam Leaks

Repairing steam leaks and leaking steam traps can result in huge energy savings in any system. Quantifying the magnitude of a steam leak can be very difficult, but with the aid of an ultrasonic detector, reasonably accurate estimates can often be made. Figure 6 shows the steps to quantify savings associated with repairing steam leaks. To determine the avoided cost of energy (natural gas or electricity) for a steam leak repair, the latent heat vaporization of the steam at the operating steam pressure will need to be known.[9] This quantity should be based off of the system operating pressure, which can usually be measured readily. In addition, the size of a detected leak (or steam trap orifice) needs to be estimated. Manufacturer's data for steam trap orifice sizes are readily available. The ultrasonic detector can be used to provide a reasonable estimate of the size of the leak based on the detected sound. Again, one needs to check the manufacturer's recommendations for the ultrasonic detector.

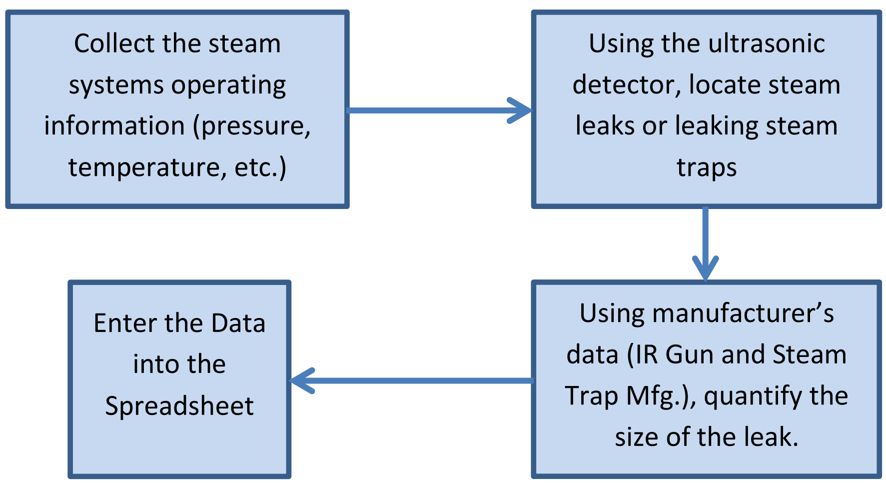

Figure 6: Steam leak analysis procedure.

Shutting Down Unnecessary or Underutilized Equipment

Although shutting down unused equipment may seem like a rather obvious energy conservation measure, many auditors are surprised to find many pieces of equipment are left in operation when they are not being used. This tends to occur most often in batch processes when individual pieces of machinery are required to run between batches. As long as the shut down and startup procedures associated with these pieces of equipment do not upset other factory processes, the cost savings that can be gleaned from implementing a shutdown strategy can be significant.

Installation of Set-Back Timers

A closely-related alternative to the previous strategy is the installation of set-back timers on underutilized equipment. Such timers can be programmed to turn on and shut down equipment automatically, eliminating the reliance on personnel to perform those tasks. With this conservation measure, the energy usage of the affected equipment can be optimized, maximizing energy savings.

Changeover to Higher-Efficiency Lighting

With a number of lighting manufacturers offering modern lighting solutions that are considerably more energy efficient than those of even a decade ago, a popular energy-saving retrofit in office buildings and factories pertains to indoor illumination,.[10] Switching from T12 fluorescent lamps to T8 lamps can provide substantial cost savings because the latter provide comparable illumination to the former while using less electrical energy. Another example involves replacing standard 400-watt metal halide bulbs with 360-watt bulbs. In large installations where many such luminaries may be present, the small decrease in luminous flux associated with lower-wattage bulbs can often be tolerated because of the much larger aggregated decrease in consumed electricity. Such changeovers can often be done gradually as bulbs degrade and require intermittent replacement.

Turning Off Unnecessary Lighting

Motion detectors placed in seldom-occupied spaces (conference rooms, restrooms, hallways, etc.) can reap significant energy savings for any facility, turning a very quick payback owning to the generally low cost associated with implementing this measure. Added benefits of motion detector installations include enhancements in occupant safety as well as security.

Power Factor Optimization

Ideally, the power factor for any facility should be as close to unity as possible. It is common for the power factor in plants operating with large numbers of electric induction motors to be well below this optimum value. Owing to an increase in the reactive component of the electrical power consumed, facilities operating with suboptimum power factors actually utilize less useful electrical energy than that for which the utility company charges. For linear loads, passive capacitor networks can be readily implemented to correct the power factor and invoke energy savings.

Limiting or Shifting Demand

As previously discussed, many facilities incur electrical demand charges from the utility companies. By shifting certain operations from peak to off peak hours, the overall demand for the facility can be lowered substantially. While this measure does not directly improve energy efficiency within the facility, it can lower the utility charges significantly, further reducing operating costs.

Industrial Chiller Upgrades or Replacement

Many large facilities use industrial chillers for climate control or to generate chilled liquids for use in various process applications. With continual advancements in refrigeration technology, chiller efficiencies have continued to increase. It therefore stands to reason that replacing existing chillers, particularly in very old installations, with newer and more energy efficient models can be economically viable. The software developed by the students in the proposed course should be capable of analyzing the economic aspects of a potential chiller replacement to help make an informed decision as to when to replace a given chiller.

Conclusions

The course outlined in this paper has the potential to provide students with a real world, application-oriented experience that will stand apart from most other engineering courses they take during their studies. A distinct advantage offered to the students by the proposed course is that it will provide them with a valuable working knowledge based coupled with a set of adaptable software tools they can take with them to their first employment stop. In addition, the spirit of the course would likely help to foster strong ties between the students, the college or university, and key industry players in the local community. Such relationships could eventually lead to sponsored internships for current students in the department as well as an eventual inroad to recruitment for new hires after graduation. This could also lead to corporate sponsorship for upper-level engineering design projects as well as teaching lab equipment donations.

Although this is a proposed course, it is important to note that the principle components of it have been previously taught at the university level. For example, the energy generation section was recently taught in the mechanical engineering department at University of Pittsburgh at Johnstown in the fall semester of 2010. Moreover, the conservation aspect has been previously taught to numerous students who have worked with the IACs at various universities. And even though the IAC engagement is not an official course in and of itself, it does represent a distinct opportunity for students to learn about energy conservation in a real-world setting. Merging these two learning opportunities together in one course should provide students with a truly unique educational experience.

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