Chapter 6

Energy Efficiency in Manufacturing Facilities: Assessment, Analysis and Implementation

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Additional information is available at the end of the chapter

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Abstract

Manufacturing facilities are one among the largest consumers of energy. Efforts to improve energy efficiency are an increasing concern for many manufacturing facility engineering managers. This can be achieved by evaluating energy end uses (e.g., lighting, processing equipment, and heating, air conditioning, and ventilation (HVAC) systems), and by implementing measures to reduce the total amount of energy consumed for one or more of the end uses. Throughout the 40 years of its existence, the US Department of Energy's Industrial Assessment Center program has developed an array of techniques to improve energy efficiency in industrial facilities. This chapter discusses recommended assessment procedures and observed energy-saving opportunities for some of the most common industrial energy systems. These systems include lighting, compressed air, boilers and steam systems, manufacturing process heating, HVAC, pumps, and fans. Implementation of these assessment recommendations has been demonstrated to increase efficiency and to thus reduce energy consumption and associated costs. While every manufacturing facility is different, and their component industrial energy systems equally unique, this chapter presents a set of analytical guidelines that can be used as a template by engineering practitioners to evaluate their facility energy use and implement subsequent energy conservation measures.

Keywords: energy management, energy conservation, manufacturing, industrial facility, efficiency

1. Introduction

As noted by Vanek and Albright [1], manufacturing facilities are one of the largest consumers of energy in the United States, comprising approximately 32% of the energy end use in the country. Efforts to improve energy efficiency are an increasing concern for many facility engineering managers. Improved use of energy in a building provides lower operating costs. This can be achieved by evaluating energy end uses (e.g., lighting, processing equipment, and heating, air conditioning, and ventilation (HVAC) systems), and by implementing measures to decrease the total amount of energy consumed for one or more of these end-use systems.

The United States Federal Department of Energy (DOE) has developed a number of programs to address energy conservation and energy management in the US industrial sector. The Industrial Technologies Program (ITP), of the Energy Efficiency and Renewable Energy (EERE) division of the DOE, has a series of initiatives to assist manufacturers in identifying areas where energy use may be decreased, as well as indicating those areas where excess energy could be redirected for other purposes [2].

One such program regards the establishment of Industrial Assessment Centers (IACs). The goal of these centers is to increase energy efficiency for small-to-medium-sized manufacturing companies throughout the United States. The focus of their recommendations is for building energy retrofits that help lower the amount of energy used in the manufacturing plant. IAC teams consist of students and faculty, from the universities participating in this effort, who conduct these energy audits and develop the subsequent energy-saving recommendations [2].

The IAC's energy audit of a manufacturing facility is conducted in three phases, consistent with the procedure detailed by Thurman and Younger [3]. The first phase involves analyzing the data from the facility energy bills to determine what energy is used and how this energy use varies over time. The second phase consists of a factory walk-through inspection and audit, looking carefully at each end-use system within the facility and recording information for later use [3]. The last phase is where specific energy savings are identified for later implementation by the facility. The IAC team performs a detailed analysis supporting specific recommendations with related estimates of costs, performance, and energy savings.

2. Lighting systems

In 2010, lighting consumed 700 TWh (terawatt hour) of site energy, which is 18% of the total electricity consumption of the United States. Of the 700 TWh of electricity, industrial lighting consumed 26% [4]. There are different lamps and lamp fixture. High-intensity discharge lights include metal halide, high-pressure sodium, low-pressure sodium, and mercury vapor, while fluorescent lights include T12, T8, and T5 linear bulbs and compact fluorescent lamps [5, 6]. High-intensity discharge (HID) and fluorescent lights are the most common lights in industrial facilities. Other lamps include light-emitting diode, induction, and incandescent lighting [7]. The most common types of fluorescent lamps are T12, T8, T5, and compact fluorescent (CFL). The number after the "T" corresponds to the diameter of the lamp in eighths of an inch (Tx equals x/8 inches in diameter). The T12 lamp is a linear tube that in twelve-eighths inches in diameter, or 1.5 inches in diameter. The T8 lamp is 1 inch in diameter, while the T5 is five-eighths inches in diameter. CFLs were created to replace incandescent and HID lamps, and consist of an endless arc pathway formed by multiple tubes joined together [6]. Fluorescent lamps are also required to operate in series with a current-regulating device or ballast.

A number of controls are used to operate lighting systems; these controls include occupancy sensors, photosensors, switches, and automatic control systems that can control lighting systems along with other systems in a facility. Depending on the manufacturing process or task that is being performed, the light level requirements can range from five to 500 foot-candles [8]. The Illuminating Engineer Society [8] provides guidance on these industrial-lighting level requirements.

High-intensity discharge and fluorescent lights require a ballast to start and operate the lights [6]. These ballasts operate with a ballast factor or ballast efficiency that is normally greater than one. Ballasts limit the current to the correct amount that a lamp is designed for, and ballasts deliver the essential starting and operating voltages to lamps. High-intensity discharge lights use constant-wattage autotransformers, constant-wattage ballast, lag (reactor) ballasts, magnetic regulator (constant-wattage) ballasts, and lead circuit ballasts for operation. For fluorescent lights, magnetic and electronic are the two types of ballasts that are used for operation [5].

2.1. Recommended assessment procedures

After the assessment team arrives at the facility, a kick-off meeting with the team members and facility personnel will take place to explain the purpose of the assessment, the process of the assessment, and the timeline for completion [3]. After the kick-off meeting, a tour of the lighting systems will take place. Once the tour is finished, data collection may begin. Each different lighting system needs to be identified, and the each lamp in the lighting system needs to be counted and recorded on a data sheet [3]. Once the type of lamp is observed, the wattage of each lamp and the ballast factor of each fixture need to be recorded. The plant personnel should be able to assist if questions arise. Alternatively, replacement lamps and ballasts may be found in the maintenance parts storage, and may provide this information. Further, a ballast detector can be used to determine the type of ballast in each light, that is, whether it is electronic or magnetic.

The operating hours of each lighting system need to be recorded and this information should come from the facility personnel. If different areas in the plant have different lighting systems, then the lighting system and type of lights that are in those areas should be recorded while counting the lights. In each different area the amount of personnel traffic should be recorded and along with the amount of vacant time. The controls and schedule of each lighting system should be recorded and this information should be given by the plant personnel. Before the lighting levels are taken using the light level meter, the daylighting panels or windows should be noted [4]. Finally, the light levels in each area need to be measured and recorded. Several measurements should be taken per area, especially in areas with critical lighting requirements. The activities and processes in each area need to be recorded, to be able to make sure the correct amount of light for the activity is reached at the work plane.

The number of each type of light should be gathered together along with the wattage, ballast factor, and operating hours. After that, these four numbers can be multiplied together to get the annual energy usage of the lighting systems [5].

2.2. Recommended assessment opportunities

One of the most common lighting system assessment recommendations (ARs) is replacing HID lighting with more efficient lighting. Either linear fluorescent tube T8 or T5 lighting or CFLs are good replacements. These lights normally have a better lumen maintenance for better light as the lamps age, and normally have a higher color rendition index (CRI) for a better differentiation in color of light (particularly needed for many quality inspection tasks) [5].

Another lighting system AR is replacing T12 fluorescent lamps with T8 fluorescent lamps. Replacing T12 lamps with T8 lamps produces an opportunity for energy and cost savings. T8 lamps have less wattage, but produce more lumens than T12 lamps [9]. The T8's life hours and ballast factor can be the same, higher, or lower than the T12's.

Incandescent lamps may also be replaced with CFLs. Replacing the incandescent lamps with CFL lamps produces an opportunity for energy and cost savings by reducing the wattage for the same amount of lumens as an incandescent. For example, 200-watt CFL lamps have less wattage, but produce more lumens than 500-watt incandescent lamps [9]. Further, the CFL has a longer expected life than the incandescent lamp.

Installing occupancy sensors (motion sensors) is a possible lighting system AR for consideration. Occupancy sensors will turn off the lights when an area is vacant. The lights should stay on a minimum of 30 min after they turn on, so as long as there are gaps in the area's traffic longer than 30 min energy savings will be seen. The only drawback to an occupancy sensor AR is that the lights have to be rapid start lighting systems or they will not work correctly [5]. Installing occupancy sensors in certain areas of the plant can result in a large energy and cost savings by reducing the operating hours of a lighting system.

A related AR is incorporating photosensors with lights in areas where adequate daylighting is available during daytime hours or in areas where daylighting panels can be installed. Photosensors will turn off the lights when the daylighting is adequate to provide light to certain areas of the plant. An indication of this possible AR is if areas around the perimeter of the plant have adequate daylighting available to help with illuminating the plant floor or warehouse [3]. By discovering daylighting panels in the plant, and measuring the light levels in the areas that have these panels, the photosensors AR can be decided upon. The light levels need to be compared to the light level requirements for the specific processes in the area. By installing photosensors in areas around the perimeter of the plant where daylighting is adequate for the lights to be shut off, then this AR will result in energy and cost savings.

De-lamping (reducing the quantity of lights) in the facility is a possible energy-saving AR. Evidence for the need for this AR is observation of areas of the plant where light levels exceed the requirements of that area and/or have high bay lights that can be lowered to increase light levels without hindering the processes [3]. Conducting light level measurements and looking at the heights of lights will help determine if there are too many lumens in a certain area or if the lights can be lowered [10]. De-lamping areas of the facility will reduce the energy for the lighting system by using the actual required amount of light for each area [9]. Lowering the lights down from the ceiling can also make de-lamping available by having more lumens at the work plane.

Turning off the lights when areas of the facility or the entire facility are vacant will save energy for the lighting systems by reducing the operating hours of the lights. This AR will also allow the lights to last longer and reduce replacement costs. The energy savings can be calculated by reducing the operating hours of the lighting system [10].

3. Compressed air systems

Nearly all industrial facilities have compressed air systems, and most could not operate without it. Inefficiencies in compressed air systems can be very significant, and energy-saving projects can range from 20 to 50% of electricity consumption [11]. Compressed air systems are categorized as supply side and demand side. The supply side of a compressed air system consists of a compressor, the prime mover, control system, air dryer, air filter, and storage. The compressor, prime mover (motor), and control system are all contained in the unit’s package. The compressor package also contains a cooling system, which can be either air-cooled or water-cooled. The air that is discharged from the compressor will normally flow through an air dryer and air filter before going to air storage prior to the demand side. The demand side of a compressed air system encompasses the piping distribution system, dedicated air receivers, pressure/flow controllers, filters, regulators, lubricators, and end uses. Normally, the air receiver is located close to the compressors, or immediately before the end use, and the filters, lubricators, and regulators are also in close proximity to the end uses [11].

3.1. Recommended assessment procedures

After the kick-off meeting, the team should install power and airflow data collection equipment and also retrieve power and airflow data from the data systems that are permanently installed into the compressed air systems [3]. While the data are being collected or before the end of the assessment visit, the collected data should be validated to assure all the data are accurate and accounted for. Production process operating data and plant functions should be gathered to establish a functional baseline for the plant [11]. While conducting the assessment, a comprehensive plan to observe and measure the supply-side performance of the compressed air system should be completed. Once the supply side is observed and measured, then the transmission from the supply side to the demand side should be observed and any required measurements should be taken [10]. Finally, the end-use applications (demand side) should be observed and measured.

The nameplate data are located on the side of the compressor and should be recorded in the assessment notes, and a picture should be taken of the nameplate if available. The “cut in” and “cut out” pressure should be recorded in the notes, and these pressure values can be found on the compressor’s display screen. The air pressure upstream and downstream of the cleanup equipment (i.e., filters, dryers, etc.) should be measured with a reliable gauge [10]. The operating pressure is assumed to be the midpoint between the cut in and cut out pressures or this pressure can be measured [12]. The plant-floor pressures should be measured with a reliable gauge at many different places on the plant floor. Next, the controls of the compressor should be identified from the control panel or from plant personnel. Plant personnel should also be able to explain how the schedule of the compressed air system is established, since the operating hours along with the non-operating hours are critical to assessing the energy usage. Knowing how the schedule is controlled is also critical, that is, whether the schedule is controlled by plant personnel or a sequencer [10].

The cooling method for the compressors needs to be recorded (whether it is air or water). The air storage should be determined by finding the sizes and number of air receivers from the plant personnel or from the tank, and the diameter and length of the header pipes should be measured. The number of compression stages and lubrication-type information should be given by plant personnel or can be found on the Compressed Air and Gas Institute (CAGI) data sheets [12]. CAGI data sheets may be produced by the manufacturer that develops the air compressors and can be found on the manufacturer's website using the model number of the compressor, which is found on the nameplate. For centrifugal compressors, a performance map that is created by the manufacturer is needed for the analysis of centrifugal compressors [12].

The last and most important information that is needed for the analysis of compressed air systems is the input power or airflow data. This current flow data can be provided by the plant personnel if the plant has a recording system. If the plant does not have such a data-logging system in place, current transducers with data loggers connected to them can be attached to the input power lines in the power cabinet on the compressors, or at the power disconnect, to measure the current draw of each compressor in the system [10]. Plant safety rules have to be taken into account before opening the power cabinet or disconnect box for each compressor. At least a week's worth of data needs to be measured (though more is better) to be able to model the compressed air system accurately.

Consistent with the American Society of Mechanical Engineer (ASME) protocol [13], the analysis of the assessment data begins by using the collected data and information to create a baseline profile of the compressed air system. The baseline profile should include power and energy profiles, air-demand profiles, supply efficiency, identify the different operating period types, and should include annual air demand and energy consumption. The annual energy consumption can be estimated by using the number of each type of compressor, the motor horsepower, the motor efficiency, the load factor, and operating hours [12]. After that, these numbers can be multiplied together to get the annual energy consumption of the compressed air systems. The system volume (effective volume) should also be calculated, along with a pressure profile of the system. The high-pressure demands on the system should be validated to be sure that the high pressure is required. Along with the pressure profile, an air-demand profile should also be created [13]. The critical air demands and the wasted compressed air should be analyzed. Critical air demands have to be met to assure that high product quality is being repeated, and the compressed air waste leaks, inappropriate uses, and artificial demand that can decrease the efficiency of the system. The air treatment equipment should be examined for optimization. The team should establish a target pressure for the system to increase the efficiency of the compressed air system [11]. Balancing the supply and demand is another recommendation that should be investigated for an increase in energy efficiency for the compressed air system. Assessing the maintenance opportunities and evaluating the heat-recovery opportunities are included in the final analyses.

3.2. Recommended assessment opportunities

The first and most common recommendation is lowering the overall system pressure in the compressed air system [10]. Discussion with facility personnel will help determine the highest needed pressure for the process equipment. By looking at the gauges on the compressor, the display screen on the compressor, and the flow control system that is in place, the operating pressure can be determined and can be compared with the needed pressure of the process equipment. This recommendation can be achieved by progressively reducing the discharge pressure at the compressor using the compressor controls, or by using a flow controller to equal out the system pressure at the required set point for the plant [11].

The next most common recommendation is reducing the amount of leaks in the compressed air system. An air-leak survey should be executed using an ultrasonic air leak detector, and the decibels of each leak should be recorded. Also, if power or airflow data can be recorded for times without any production in the facility, then a leak load can be found from this power or airflow data during this period. This assessment recommendation can be completed by implementing a maintenance program to check for compressed air leaks on a regular basis to keep the percentage of leaks down. Completely reducing the leaks in a compressed air system to zero is nearly impossible, especially for large systems, but with a well-implemented leak program, leaks in the system can be reduced to 10% of the average airflow of the system [11].

Another indication of a possible AR is the existence of inappropriate usages of compressed air, for example, tank sparging, part cleaning, and drying, which should be reduced or eliminated [13]. Discussion with facility personnel can help to determine some inappropriate uses that can be performed more efficiently with another energy source. For example, using compressed air for tank sparging (i.e., to mix up liquids) is very inefficient compared to using a pump or a stirrer. Using compressed air for part cleaning or drying is similarly inefficient compared to using some type of a blower system.

Using an automatic sequencer is another potential energy-saving AR. The need for this is indicated by having multiple compressors on a system without any automatic control, and only having manual control by facility personnel. Automatic operation controls will rotate compressors in and out of the system as needed and will alternate the backup compressors into the system [11].

Recovering waste heat from the compressor is another potential energy-saving AR. Indications of the need for this AR are having air-cooled compressors venting air to atmosphere, as well as a need for heat recovery in some process or space conditioning in the plant [14]. Recovering waste heat can improve the efficiency of a system that requires heat, but this AR does not increase the efficiency or reduce the energy consumption of a compressed air system. If the compressors are air-cooled and are located inside a conditioned space, then venting the heat out of the conditioned space during the summer months and into the conditioned space during the winter months will assist the HVAC system [14].

Using an optimum-sized compressor is another potential energy-saving AR. A compressor operating at the low end of its operational range is an indicator for this alternative [13]. An oversized compressor can be determined by measuring the electrical current flow and comparing the value to the motor nameplate data. The power should be plotted on the motor curve to check to see if the motor is operating at a high efficiency point. Using an oversized compressor motor at partial load will not be operating near its highest efficiency point, and therefore will be using more power than needed to produce the compressed air [12]. To calculate the optimal-size compressor, the required pressure and flow rate are needed to compare other compressor characteristics [11]. The energy savings will result from using less power to produce the required pressure and flow rate.

Another possible energy-saving AR regards using a dedicated air compressor. This may be indicated by having an end use at a considerable distance from the compressors, or having an end use that requires a higher pressure than the rest of the end users. Utilizing a dedicated compressor for end users with high-pressure requirements will reduce the cost to produce compressed air by making the lower-system pressure AR, discussed previously, viable [11]. The required airflow and pressure of the process equipment, which needs the dedicated compressor, are required to size the compressor properly.

Installing a variable frequency drive (VFD) compressor is another potential energy-saving AR. Variable frequency drives (VFDs, alternatively referred to as variable speed drives or VSDs) change the speed of the motor to increase or decrease the amount of power consumed, which is proportional to the output flow capacity. These drives can control the output flow capacity of a compressor from 15 to 100% of full flow [15]. Anything below 15% of full flow can result in the compressor being unloaded or shut off. The power factor of the motor while using a VFD is normally better than other conventional controls, and VFDs can yield a constant pressure band. Typically, compressors that are originally designed for VFDs have a higher benefit while using VFDs than compressors that have been retrofitted with VFDs [15]. An indicator for the need for this AR is having a variable load from the end users in a compressed air system, or a compressed air system that needs a trim compressor [10]. Using a VFD compressor will use less power more efficiently if the compressed air system has a variable load when the load is less than the full load of the compressor. Variable speed compressor curves are needed for the compressor to help determine the energy savings of a VFD [13].

Reducing the run time of the air compressor may also be considered, particularly if the compressor is being operated during non-production hours [10]. Setting the compressor controls to turn off when the compressed air system is not needed will save energy. The amount of time that the compressor can be shut off is the primary data needed to determine the resulting energy savings.

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If the compressor intakes are in locations where the ambient air temperature is high, then another possible AR is installing compressor intakes in the coolest location possible [12]. If the compressor is drawing air from an air-conditioned plant, then savings can be found by using outside air to reduce the load on the HVAC system. However, the energy savings or efficiency increase for compressors using cooler intake air is not easily calculated and is being researched by IAC personnel at this time [10].

4. Boilers and steam systems

Steam, along with electricity and direct-fired heat, is one of the three principle forms of energy that is used in industrial processes. Steam can range from 28 to 76% of the total onsite energy depending on the type of industry [16]. Boiler systems are divided into four different subsystem categories that include the generation, distribution, end uses, and recovery of steam. The steam is created with the generation components, which include boilers, pumps, and economizers. Once the steam leaves the boiler, it flows through the distribution system, which contains pipes, valves, and backpressure turbines. An efficient distribution system provides the appropriate amount of steam at the right temperatures and pressures to each end use. Steam can be used for numerous different processes and applications. Some end uses of steam are for process heating, mechanical drive, chemical reactions, and separation of hydrocarbon components. End-use components include heat exchangers, turbines, strippers, chemical reaction vessels, and fractionating towers. Finally, after the steam is used by the end uses, the condensate return system captures the condensate and sends it back to the boiler. The condensate is sent to a collection tank or to a deaerator tank to mix with the makeup water before the feedwater is pumped into the boiler. A deaerator tank is a vessel that is used to reduce the oxygen content in the boiler's feedwater. Deaerator tanks pressurize the feedwater, and the temperature is increased to the point of saturation, along with removing oxygen and other non-condensable gases [16].

Heat recovery, from the flue gases of natural gas or fuel oil boilers, can increase the efficiency of boilers by preheating the feedwater before it goes into the boiler. This heat can be recovered by heat exchangers in the exhaust stack of the boiler, and are referred to as economizers. In general, economizers usually can reduce fuel requirements by 5–10% [14].

Stack economizers are gas-to-liquid heat exchangers that are installed into the exhaust stack of the boiler, to recover sensible heat from the flue gases of natural gas or fuel oil boilers. Stack economizers can only recover sensible heat from the flue gases and can reduce the flue gas temperature down only to about 250 F (or 121°C). If the flue gases are reduced to a temperature below this value, then condensation can develop in the exhaust and this can decrease the life of the economizer [17]. Stack economizers can contain bare carbon-steel tubes or finned tubes depending on heat-recovery targets and the composition of the flue gases [14]. Condensing economizers can be used on large or small boilers and can be an attractive energy efficiency measure when stack economizers are not. Condensing economizers are heat exchangers that can recover sensible and latent heat from the flue gases of a natural gas boiler. More heat can be recovered using a condensing economizer than using a stack economizer [16].

4.1. Recommended assessment procedures

After the kick-off meeting and facility walk-through, the target equipment and components should be evaluated by measurement equipment, and identification and collection of essential data for the systems should recorded [10]. These essential data include temperature measurements of boiler makeup water, feedwater, shell, ambient air, stack gases, steam headers, and the distribution piping. The required data for pressure measurements include steam headers and branch lines, condensate return tank, deaerator, and points of usage before pressure reduction valves [3]. The flow measurement data that are required are the boiler fuel input rate, steam output rate, makeup water, blowdown, and the consumption of the end uses. Finally the last set of data that are needed is the chemical measurements (conductivity), which include the chemical concentrations (dissolved solids, chloride, and silica) for the makeup water, internal boiler water, condensate, and feedwater [16]. Once all of the data are measured and recorded, a system baseline can be established.

The number of different headers and the steam pressure at each header should be recorded in the notes, along with the process of each pressure reduction, for example, whether it is throttled or runs through a turbine. The fuel consumption is critical information that can be identified on a meter or from plant personnel. Similarly, the feedwater usage, obtained from a meter or from plant personnel, is also valuable information that is required. Other needed data include the percentage of condensate return, makeup water usage, the blowdown rate, the deaerator tank vent percentage and pressure, the feedwater usage, the load factor of the pump, the firing rate of the boiler, and the exhaust temperature and oxygen content in the exhaust stack [16]. The total number of steam traps on each header should be known, and the number of failed steam traps on each header, along with the number and size of leaks in the distribution system and the heat losses from the distribution system, should be identified [17].

If there is an economizer present in the system, it should be noted, along with the application that it is used for, and the exhaust temperatures before and after the economizer should be measured. The isentropic efficiencies of the steam turbines should be estimated, if a steam turbine is present in the system. The isentropic efficiency of a steam turbine can be calculated by dividing the actual turbine work by the isentropic turbine work [18]. The inlet and outlet pressures and temperatures of the steam should be measured, and then using the steam tables the enthalpy at each state can be found. Once the enthalpy at each state is found, the actual and isentropic turbine work can be found [19]. If the pressure and temperature cannot be measured, then the isentropic efficiency can be assumed to be between 70 and 90%. Where the larger turbines are closer to 90% and the smaller turbines are closer to 70%. Occasionally well-designed, large turbines can have an isentropic efficiency above 90%, and small turbines can be less than 70% if the turbine is not designed well [19].

During analysis of the assessment data, a final steam system baseline should be created using the collected data from the assessment visit. The annual energy consumption can also be estimated by using the number of boilers in each system, nameplate data (the rated input), the load factor, and operating hours of the boilers [10]. After that, these numbers can be multiplied together to get the annual energy consumption of the boilers. Once the baseline is created, then the energy-saving recommendations can be developed.

4.2. Recommended assessment opportunities

Recovering waste heat in the stack of the boiler presents one potential energy-saving AR. The exhaust gas analyzer should be used to take a measurement from the flue gases in the exhaust to determine this temperature. The higher the exhaust temperature the more heat can be recovered [14]. This recovered heat can increase the efficiency of a boiler system, process heat system, or HVAC systems. The heat is most commonly recovered by a stack or a condensing economizer and is used for preheating boiler feedwater [14].

Reducing the amount of leaks in the steam system via implementing a maintenance program is another potential energy-saving AR. Steam leaks are quite noticeable while observing the steam system. With normal circumstances, leaks can be minimized if a well-implemented maintenance program is used [1]. The sizes and number of leaks are the main data that are needed to determine the energy savings for decreasing the amount of leaks in a steam system [3].

When the oxygen content in the exhaust gases is higher than 3%, another potential energy-saving AR is reducing this oxygen content [16]. The exhaust gas analyzer should be used to take a measurement from the flue gases in the exhaust to determine the oxygen content in the flue gas. Reducing the oxygen content in the exhaust gases will increase the efficiency of the boiler. Frequently, installing an electronic oxygen trim control system on the boiler will reduce the oxygen content [18].

Exposed piping, valves, and fittings in a steam system's piping network indicate the need for addition insulation to these exposed surfaces. Taking thermal images will show the hot spots in the steam distribution system and will indicate the temperature of the hot spot [10]. Insulating the piping, valves, and fittings will decrease the heat loss of the steam system, therefore increasing the efficiency of the steam system. Similarly, insulating hot spots on the boiler surface will decrease the heat loss of the boiler, therefore increasing the boiler's efficiency.

Reducing the boiler pressure is another possible energy-saving AR. Steam produced at higher pressure and throttled for all end uses provides evidence for this potential energy-saving AR [12]. The facility personnel can provide the boiler pressure, and the highest pressure that is used by the processes. Reducing the boiler pressure will decrease the amount of work needed to produce the steam.

When steam is produced at higher pressure and throttled for all end uses, an alternative energy-saving AR involves installing a steam turbine into the steam system [18]. A steam turbine will produce electricity while replacing the throttling valve and decreasing the steam pressure in the system for the processes. The main required data are the current boiler pressure, steam pressure needed by the process, and the process of pressure change between the boiler and the next-level header.

Replacement of failed steam traps, as well as implementing an associated maintenance program, presents the final type of energy-saving AR. Thermal images will indicate which traps are working and which have failed [10]. Failed steam traps do not let the steam bypass back to the steam system. Replacing failed steam traps will increase the amount of condensate returned to the boiler.

5. Process-heating systems

Process heating is essential in the manufacture of most industrial and consumer products. Process-heating equipment is either fuel-fired, electric-based, or steam equipment. In the United States, fuel-fired process-heating equipment consumes approximately 17% of the total industrial energy consumption [20]. Process-heating equipment has many different names, which include furnaces, kilns, heaters, ovens, lehrs, incinerators, melters, and dryers, but all basically operate under the same rules as just heating a load to complete a task [20]. Heat-treating furnaces are used to create mechanical properties of metals, which includes strength, hardness, and flexibility. Heat-treating furnaces are used in the metal production industry mostly, but also in industries that anneal and temper ceramics and glass [20]. Drying ovens are used for water removal through direct or indirect heating. These ovens are used in industries that need dry raw materials or finished product that contains water. Drying ovens are common in glass, clay, food processing, textile, and chemical industries [20].

5.1. Recommended assessment procedures

Operational and maintenance requirements need to be identified by the assessment team members. Practical requirements of each process-heating system include the energy usage and emissions, production output, and the quality of the products [3]. If there are meters that measure the flow rate of the fuel and flue gas oxygen content, then these data should be recorded. Also, if any electrical power meters are installed on any equipment, this information should be recorded. Some facilities may have data-recording systems that can produce data that are needed for the energy assessment. The control systems and control strategies should be determined for each process-heating system. These can include the control of the heat input, temperature, and the air-to-fuel ratio.

The furnace type and fuel type of the furnace will need to be recorded, along with the number of burners for each furnace in each system. The nameplate data of the furnaces are located on the furnace or burners and should be recorded in the assessment notes, and a picture should be taken of the nameplate if available, consistent with the ASME energy assessment standard [21]. Plant personnel should be able to explain how the schedule of the process-heating system is set up; the operating hours along with the non-operating hours are critical to assessing the energy usage.

The nature of the material comprising the load or charge is very important for a process-heating system energy assessment. Along with the type of material, the feed rate of the load, initial charge temperature, and discharge temperature are also needed [21]. Next, an exhaust gas sample needs to be measured using a flue gas analyzer. This measurement instrument has a probe that needs to be inserted into the exhaust stack as close to the top of the furnace as possible, and should make a complete seal with the port on the exhaust to avoid dilution air in the exhaust [10]. The gas analyzer measures the exhaust gas temperature, ambient air temperature, and oxygen content of the exhaust gas, and then calculates the excess air, combustion efficiency, and carbon dioxide content of the exhaust gas.

After the load and exhaust gas information is found, the losses in the furnaces need to be determined and recorded [21]. To find the fixture losses, the fixture material, weight, initial temperature, and final temperature should be measured and recorded. The information that needs to be measured to find the losses in the walls includes surface area of the walls, average surface temperature, and the ambient temperature. For furnaces with special atmospheres inside the furnace for certain processes, the type of gas needs to be determined. Along with the type of gas, the initial temperature, final temperature, and flow rate of the special atmosphere gases need to be determined. Opening losses are one of the most common losses with a high magnitude [18]. To determine the losses through openings in the furnace, the type, shape, and size of the openings are needed along with the furnace wall thickness, inside temperature, ambient temperature, and percent of time open. For furnaces that use water for cooling, some losses will arise from this. To find the water-cooling losses, the water flow rate, inlet temperature, and outlet temperature are needed [3]. Finally, the heat storage of each furnace should be assessed and recorded. The furnace shape (rectangular or cylindrical), furnace size (height or diameter), furnace temperature, ambient temperature, and starting wall temperature are all required to determine the heat storage of the furnaces [3].

When analyzing the assessment data, each process-heating system requires an energy balance. This baseline should be portrayed in units of energy per production unit or energy per unit of time for each process-heating system [21]. The annual energy consumption can be estimated by using the number of furnaces in each process-heating system, the rated input for the burner, the load factor, and operating hours of the furnaces. After that, these numbers can be multiplied together to get the annual energy consumption of the furnaces [20]. Next, the assessment recommendations should be identified. These recommendations can include maintenance improvements, operation enhancements, control strategy upgrades, process improvement changes, and equipment replacements.

5.2. Recommended assessment opportunities

Consistent with the discussion of boilers in Section 4 of this chapter, heat recovery from the flue gases of fuel-fired process-heating equipment can increase the efficiency of furnaces by preheating the combustion air before it goes into the burner. In this case, heat can be recovered by heat exchangers in the exhaust stack of the boiler, referred to as air preheaters. In general, furnace efficiencies can be increased by approximately 20–30% for fuel-fired furnaces [14]. There are two types of air preheaters: recuperators and regenerators. A recuperator is fixed heat exchanger in the exhaust stack of a furnace. This air-to-flue gas heat exchanger is used to preheat combustion air using the flue gases. A regenerator is a container that is insulated and filled with metal or ceramic shapes that absorb thermal energy. Regenerators can store a moderately large amount of this thermal energy and then release that energy subsequently to preheat the combustion air of a furnace [14]. The exhaust gas analyzer should be used to take a measurement from the flue gases in the exhaust to determine the flue gas temperature. The higher the exhaust temperature the more heat can be recovered. This recovered heat can increase the efficiency of a process heat system, boiler system, or HVAC systems. The exhaust gas sample, preferably the exhaust temperature, is used to determine the type of heat-recovery method to be used, and then the energy savings will be calculated by finding the amount of heat that can be recovered from the exhaust temperature [14]. Once the amount of recovered heat is calculated, then the increase in combustion efficiency can be found for purchasing a heat exchanger and installing it in the furnace's exhaust stack.

Also consistent with the discussion of boilers, another potential energy-saving AR is reducing the oxygen content in stack gases. The exhaust gas analyzer should be used to take a measurement from the flue gases in the exhaust to determine the oxygen content in the flue gas. An indication of this AR is having oxygen content in the exhaust gases higher than 3% [18]. Reducing the oxygen content in the exhaust gases will increase the efficiency of the furnace.

Insulating the hot spots on the furnace walls is another potential energy-saving AR when such hot spots are observed via thermal imagery on the furnace walls [10]. This may be due to bare or inadequately insulated surfaces. Insulating these hot spots will decrease the heat loss of the furnace, therefore increasing the furnace's efficiency. Reducing the amount/size of openings to the atmosphere, in the furnaces, will similarly provide another possible energy-saving AR. These openings may be observed while examining the process-heating equipment. Reducing the area of these openings in a furnace will also reduce heat loss, and therefore increase the furnace's efficiency. The implementation of these last two ARs requires the purchasing and installing of insulation on the furnace walls.

6. HVAC systems

In 2003, heating, air conditioning and ventilation (HVAC) systems consumed about 30% of the energy consumption for commercial buildings. Space cooling represented about 44 of the 30% consumed by HVAC systems, while space heating and ventilation represented about 16 and 40%, respectively [22]. HVAC systems typically have one or more of four basic types of units to produce conditioned air, along with a duct system for the air distribution to the facility or a particular area in a facility. These four types of units are packaged units, air-handling units, split system air-conditioning units with gas furnaces, and split system heat pump units with auxiliary heat [23]. All HVAC units contain fans, filters, and coils. HVAC systems are used for cooling and heating of facilities, and keeping the humidity of an area or facility to a required level (since some processes have certain humidity or temperature requirements within a facility).

6.1. Recommended assessment procedures

A preliminary energy-use analysis (PEA) should be completed before any level of audits [24]. The PEA provides the essential background information for energy assessments of any level. It includes the following steps: defining the floor area of the facilities' conditioned space and recording the floor area. The next step is to collect at least a year's worth of utility bill data, and these data should be summarized to look at opportunities to change the rate schedule, if applicable. For the PEA, the utility use, peak demand, and costs should be analyzed, along with developing the energy cost index (ECI) of the building, which should be conveyed in dollars per floor area per year [24]. The energy utilization index (EUI) should be developed during the PEA, which should be expressed in energy use per floor area per year. The energy performance summary should be completed to develop the ECI and EUI for each energy (fuel) type and demand type. Once the ECI and EUI are developed, then these indices should be compared to similar buildings that contain comparable characteristics [24]. After the comparison is made, then the new energy, demand, and cost goals should be established, and then using the new values, calculate the energy and cost savings for each fuel type.

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [24], a level 1-walk-through analysis of HVAC systems consists of first performing a brief walk-through survey of the facility to become familiar with the building's construction, operation, equipment, and maintenance. The next step is meeting with facility personnel to learn of special problems or scheduled improvements and any maintenance issues that affect the overall efficiency of the HVAC systems. Subsequently, a space function analysis should be completed to determine whether or not the HVAC system efficiency has decreased due to different functions in the building [24]. If the current functions in the facility are different from the old functions, then the HVAC system may not be designed correctly. Finally, the energy reduction opportunities should be identified. These opportunities should be split into two categories: the low-cost or no-cost opportunities, and the capital investment opportunities. An initial rough estimate of energy and cost savings should be made for the opportunities.

The HVAC unit type and manufacturer should be recorded in the assessment notes along with the nameplate data of each unit, and a picture should be taken of the nameplate, if possible. The nameplate should be on the side of the outside panels of the unit. The thermostat set points should be recorded, facility personnel should be able to tell what these set points are, but it is good practice to double check by looking at the thermostats [24]. Identification of the types of thermostats that are used is important, that is, whether it is a basic thermostat or a programmable thermostat needs to be recorded. The plant could have a building management system that can control the set points automatically [23]. Plant personnel should be able to explain how the schedule of the HVAC systems is established; however, most of the time the operation only has to do with the set points and outdoor temperature. The operating hours for the HVAC systems can be found by using historical weather data for the region that the facility is located.

The fan sizes should be recorded if not on the nameplate data. The most important information that is needed for the analysis of the HVAC systems is the input power data for each HVAC unit. If the plant does not have a data-logging system in place, current transducers with data loggers connected to them can be attached at the power disconnect, to measure the current draw of each unit, as discussed in previous sections of this chapter. Also as noted previously, facility safety rules must be considered before opening the disconnect box for each unit. At least a few days of data need to be measured, a week's worth of data or more would be better, to be able to model the HVAC system accurately [23]. This power data will be used to calculate the energy usage of the HVAC systems.

The airflow rate data should be measured in the duct system, in different places, to determine if any major losses are affecting the airflow. The flow rate can be measured by a pitot tube in the duct, or a vane anemometer at an outlet of a duct. According to the Air Movement and Control Association International [25], measuring the flow rate using a pitot tube requires a specific technique, and is similar but not exactly the same for circular ducts and square ducts. These measuring points should be located at the center of equal area squares in the duct. The cross section of the duct should be divided into equal area squares, and the amount of squares should be equal to the amount of measuring points needed [25]. For good results, the pitot tube device should be placed in the duct at least 10 duct diameters away from the last fitting (or anything that creates a loss in the duct system) [25]. The facility duct system layout and duct diameters should be recorded, along with any places that have a potential loss in the duct network.

The uses of the system should be recorded along with the temperature and humidity requirements of each zone in the facility [24]. The annual weather data for the region should be researched and can be found online from the national weather service and other websites. The building construction materials used need to be described, and this information can be provided by facility personnel or building specification sheets [24]. The team members can measure and record the type of walls in the building, along with measuring the building dimensions. The sources of heat in the building should be recorded in the assessment notes. These sources of heat can include processes, machinery, furnaces, boilers, lighting, facility personnel, HVAC systems, air compressors, building envelope, infiltration, and plug loads.

Once all of these data are gathered, the analysis can calculate the annual energy consumption of the HVAC systems by using the number of each type of unit, the tonnage of the unit, the coefficient of performance (COP), the usage factor, and operating hours [23]. Subsequently, these values can be multiplied together to obtain the annual energy consumption of the HVAC systems.

6.2. Recommended assessment opportunities

Implementing a HVAC unit maintenance program is a potential energy-saving AR, if one does not already exist. Many factors can reduce the efficiency of the unit, and these factors include a reduction in evaporator airflow, refrigerant line restrictions, and refrigerant undercharging or overcharging [25]. Implementing a HVAC unit maintenance program will keep the units in top condition and will result in a lower efficiency loss over the lifetime of the unit. A maintenance program will also increase the lifetime of each unit.

Utilizing airside economizers provides another possible energy-saving AR. Airside economizers are able to take cool dry air from the outside atmosphere and use it to cool the facility. These economizers can be operated with either a temperature control or an enthalpy control to determine when the outside air is suitable for cooling [23]. The use of airside economizers will result in less power required for cooling because the compressor will not have to operate as often.

Another potential AR for consideration is the use of programmable thermostats and the subsequent adjustment of set points to an optimal temperature. Observation of the thermostat set points being lower in the summer months and higher in the winter months than needed, as well as having non-programmable thermostats, provides evidence supporting selection of this AR [3]. Adjusting the thermostat set points to an optimal setting will reduce the operational hours of the HVAC system, therefore reducing the energy consumption. Using programmable thermostats will allow a schedule to be established for the set points to be dialed back during nonworking hours, which will reduce the run time of the HVAC units while the facility is vacant [24].

Applying a new roof coating to the facility is another possible energy-saving AR. A new roof coating can reduce the run time of the HVAC system by increasing or reducing the heat gain of the building envelope [23]. For colder climates, where heat is needed the most, a black roof coating can be beneficial. However, for hot climates, a white roof can be more beneficial to reduce the heat gain. The implementation of this AR requires replacing the roof coating, by just simply either painting over existing coating or removing old material and replacing with new roofing material.

Adding insulation to the building is a potential energy-saving AR. Thermal images of the inside and outside of the building walls will help determine whether this AR is viable or not. Adding insulation to the building will reduce the heat gain into the building during the summer and reduce the heat losses in the winter [23]. Therefore, the HVAC system will have to operate less and decreases the overall energy consumption.

A building that needs dry/dehumidified air, rather than cool or warm air, should consider installing a desiccant dehumidification system. Discussion with the facility personnel about the temperature and humidity requirements for the areas in the building can support the practicality of this AR. Installing a desiccant dehumidification system can take air and reduce the humidity to a point that is suitable for the processes inside a building [24]. Desiccant units can be used in place of HVAC units to dehumidify the air while using less energy. Since these desiccant dehumidification systems do not heat or cool the air, and if special temperature requirements for the manufacturing process need to be met, then this AR may not be viable [23].

7. Pumping systems

Industrial motor systems are the single largest electrical end-use category in the United States, and pumps account for about 27% of the industrial motor energy consumption [26]. A pumping system contains one or more pumps with motors and a piping network that includes valves and fittings. These pumping systems are categorized as either closed-loop or open-loop systems. Closed-loop systems recirculate the water that is contained in the piping network, and open-loop systems contain a sump where the liquid is pulled from and the water is either discharged back into the sump or to the needed process. Pumping systems are used for facility HVAC processes and facility production processes [26]. In HVAC systems, heat exchangers use water to transfer heat to air for space conditioning, and for heat exchangers the flow rate from the pump is the critical performance characteristic. Process equipment use pumps to provide hydraulic power to machines, where pressure is the critical performance characteristic that is needed [26].

7.1. Recommended assessment procedures

An ASME level 1 assessment should include gathering information for each pumping system that is in the scope of the assessment [27]. The prescreening should include listing of the pumping systems, pump type, motor nameplate data, annual operating hours, applications of the pumps, and the control methods. During the prescreening, the systems that should be evaluated more closely should be determined, and any systems that can affect other systems should be noted to present the constraints on the systems [27]. The prescreening process should sort the systems by size, energy costs, and operational hours. Fixed speed centrifugal pumps and systems with throttling, recirculation, or by-pass controls should be a main focus of the assessment [3].

Recording the nameplate data of the pump and motor is a protocol of the ASME energy assessment standard [27]. The pump type and brand of the pump should be recorded also, which may be on the pump housing or on the nameplate. Plant personnel should be able to indicate the operating hours along with the non-operating hours, which are critical to assessing the energy usage [3].

Primary information that is needed for the analysis of the pumping systems regards the input power data. The procedure for obtaining these data follows the pattern from previous sections of this chapter. The next most important data to obtain while on an assessment are the flow rate data for the fluid in the system. Flow rate data can be given by the plant personnel if the plant has a recording system that properly records data or be taken from a flow rate-measuring device that is already in place on the piping network. If no flow rate-measuring device is in place, then an ultrasonic flow rate meter can be used to measure the flow rate [10]. This device can measure the flow rate in pipes of various diameters. For good results, the device should be placed on the pipe at least 10 duct diameters downstream from the last fitting, valve, or anything that creates a loss in the piping system and five duct diameters upstream [27]. Recording flow data this way is consistent with the ASME standard for measuring flow data. Pressure data should also be recorded at various points in the system, especially at places where large pressure drops could occur. Measuring pressure can be hard to accomplish if there are not any pressure measuring devices in the system already. If that is the case, then asking plant personnel may be the best way to get the pressure in the system. Data for calculating the system head are also needed, including the elevation difference in the piping network, pipe diameter, and the losses in the piping network [26]. The elevation difference and pipe diameter should be measured, and the losses should be counted and recorded along with the type of loss (valve, fitting, etc.). Pressure and head data are both an ASME standard [27]. The end uses of the system should be recorded along with the amount of fluid needed for each use.

The last piece of information needed to analyze a pumping system is the pump curves for each pump. These curves can be found on the manufacturer's website using the model number of the pump, or by contacting the manufacturer with the model number which is found on the nameplate. Pump curves include a head versus flow curve at particular impeller diameters, efficiency curves, power curves, and net positive suction head (NPSH) curves [26].

From the collected data, the ideal amount of energy required for the system to achieve the essential functions should be calculated by using the number of each type of pump, the motor horsepower, the motor efficiency, the load factor, and operating hours. Once the optimal amount of energy is calculated, then recommendations to increase system efficiency can be calculated. The system curve should be calculated for each pumping system in the facility. Only two points are needed to generate a system curve: the head at zero flow or static head point, and one operating point [27]. The system curve is required to completely understand the pumping system. As each recommendation is evaluated, a new system curve should be developed before deciding on the next recommendation. The energy-saving recommendations include reducing the system head, reducing the flow rate, confirming that pumping system components are operating close to the best efficiency point, and changing the operating hours of the pumping system. An optimal pumping system energy profile should be determined using the best recommendations, while the system requirements are reached [27].

7.2. Recommended assessment opportunities

Downsizing the existing pumps in a pumping system is a potential energy-saving AR. An indication of the possible AR is having a pump lightly loaded or flow throttled to desired rate. An oversized pump in a pumping system can be found by measuring the power or motor speed and plotting on the pump curve to check to see if the pump is operating at a point with high efficiency [27]. Using an oversized pump will use more power than needed to perform the job of the system.

Installing a VFD pump in a pumping system is a possible energy-saving AR for consideration. In the compressed air section of this chapter, VFDs are defined. Pumps use VFDs to increase efficiency and save energy by matching the flow rate to the requirements of the process. VFDs can be considered to be 95% efficient for pumps from 25 to 100% of full load [28]. VFDs on pumps offer minimum energy consumption over the entire speed range of the drive [29]. Evidence of the need for this potential AR is having a variable system flow with control by throttling or by-pass valve. If a flow control system (throttle valve or by-pass) is in place, and the controls are restricting the flow by more than 40% (60% closed), then VFD controls will result in energy savings [28]. Using a VFD will use less power more efficiently if the pumping system has a variable load.

Installing an automatic control in a pumping system is another potential energy-saving AR. Automatic operation controls will rotate pumps in and out of operation as needed by the system, and will alternate the backup pumps into the system [26]. The energy savings will vary from system to system depending on the quantity and size of the pumps in the system. The energy savings are based on the resulting reduction in power and operating hours in a pumping system. The implementation of this AR requires the installation of an automatic control system into the existing system, which will require sensors installed into the system including flow rate meters, temperature sensors, and pressure gauges [26].

Shutting off unneeded pumps in a pumping system is also a possible energy-saving AR. An indication of need for this AR is observing several pumps in parallel operating below their best efficiency point. An unneeded pump in a pumping system can be found by measuring the electrical current or motor speed, and plotting on the pump curves [26]. Unneeded pumps can be observed running at a very low efficiency, or even at dead head (which means the pump is operating at zero flow and only recirculating water in the pump housing) [27]. This can result in the pump overheating and subsequent damage. Shutting off unneeded pumps will reduce the power consumption of the pumping system. The energy savings will also vary from system to system depending on the quantity and size of the pumps.

8. Fan systems

Industrial motor systems are the single largest electrical end-use category in the United States, and fans use about 78.7 million kilowatt-hours of energy per year [30]. This 78.7 million kWh accounts for about 15% of the industrial motor energy consumption. Fans are used in nearly every manufacturing facility and are used for various HVAC purposes and facility process purposes [30].

Ventilation fans are one of the most common uses of fans in industrial facilities. They are used for heat control during the summer; the fan creates a draft through the plant to remove the heat from workers and machines. Local exhaust systems are designed to remove hazardous fumes or contaminates from chemical or mechanical process inside of a facility. They are generally located above or beside the process with a hood, and the fumes or contaminates are ducted out of the process area. These exhaust systems can include filters and dust collectors. Baghouses use fans and cloth bags to filter out dust particles by pulling air through the cloth bags to filter out the unwanted particles [31]. Another industrial application of fans is mechanical draft systems that move air through boilers and furnaces. Mechanical draft fans supply combustion air, deliver fuel to the burner, circulate gases for better heat transfer, and remove combustion products [31]. Air-blast drying and air-blast cleaning are two more applications of fans in an industrial facility. Parts that have been washed need to be dried and this can be done by air-blast drying. Parts that need particles cleaned off of them can be put under an air-blast cleaning fan to remove the excess or foreign particles [31]. Personnel cooling is the frequent use of fans other than ventilation fans in facilities. These fans range from small axial fans that are spread throughout a facility at workstations, or high volume low speed (HVLS) that are large ceiling fans that can cool large areas inside a facility.

Every HVAC system has to contain one or more fans to distribute the airflow throughout the zone that the system conditions. Packaged units and split system units have axial fans on the condenser side to pull air through the condensers to cool off the refrigerant and have centrifugal fans for the supply air fan that forces the air into the duct system [23]. Fan performance can be degraded due to pressure drops across filters and heat exchangers, air density can also alter the performance of a fan system [30].

8.1. Recommended assessment procedures

The nameplate data of the fan and motor are located on the respective housings, and should be recorded in the assessment notes, and a picture should be taken of the nameplate if available. The fan type, brand, and operating hours of the fan should be recorded also. The annual energy consumption can be estimated by using the number of each type of fan, the motor horsepower, the motor efficiency, the load factor, and operating hours [32]. Each duct system layout and duct diameters should be recorded, along with any places that have a potential loss in the duct network.

Similarly, the flow rate data for the gas in the system need to be recorded. A vane anemometer or a pitot tube can be used to measure this flow rate. The vane anemometer can measure the exit velocity in ducts of various diameters, and the pitot tube can also measure the flow rate anywhere in the duct system [25]. The procedure for measuring the flow rate and pressure data, using a pitot tube, is discussed in the HVAC section of this chapter.

The last piece of information needed to analyze a fan system is the fan curve for each fan. Similar to the pump curves discussed in the previous section, fan curves can be found on the manufacturer's website using the model number of the fan or by contacting the manufacturer with the model number which is found on the nameplate. Fan curves include a static pressure versus flow curve, power curves, and fan curves for different speeds can also be found [30].

8.2. Recommended assessment opportunities

Observing an excessive flow control to reduce volume indicates consideration of downsizing the existing fans as a potential energy-saving AR. An oversized fan in a fan system can be found by measuring the electrical current or motor speed and comparing them to the fan curves [30]. The power should be plotted on the fan curve to check to see if the fan is operating at a point with high efficiency. Using an oversized fan will use more power than needed to perform the job of the system.

Installing a VFD fan in a fan system is a possible energy-saving AR. Fans use VFDs to increase efficiency and save energy by matching the airflow to the process requirements and by being able to operate over a wide range of operating conditions [30]. VFDs are used for fan system controls when the load on the system is frequently changing or a continuously variable load is present [32]. VFDs can modulate the speed of a fan from full-design speed (100%) down to 20% of design speed [15]. Since VFDs can keep fan efficiencies high across many variations in the system, the operating costs can be reduced [30].

Replacing standard v-belts with cogged v-belts, on existing fan drives, is a possible energy-saving AR. Using a cogged belt can increase the drive efficiency of a fan by 2–3% [33].

Replacing the personal fans in the facility with high-volume low-speed (HVLS) fans is also a potential energy-saving AR. Using small personal cooling fans can add up if every employee or every workstation has one or more fans; HVLS fans use a small efficient motor to generate a high volume of air movement. Depending on the amount of area, the placement of the lights, and the placement of other objects close to the ceiling, a significant problem can be seen with the implementation of this AR. Lights or other objects that hang down far from the ceiling have the potential to be an obstruction that can make installing HVLS fans difficult [10].

9. Conclusions

Industrial energy assessments form a fundamental segment of energy management and conservation engineering. Conducting energy assessments can increase energy system efficiency and reduce energy costs for industrial facilities. Many systems in industrial facilities, including lighting, compressed air, steam, process heating, HVAC, and fans, can benefit from such an energy assessment. There are many opportunities for reducing energy costs for each of these systems, and these opportunities encompass a range of implementation costs. Some opportunities require very little or no capital to implement, while others can extend as far as replacing an entire system requiring a large amount of capital investment to implement.

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