Barney L. Capehart, University of Florida EADC/IAC
Lynne C. Capehart, University of Florida EADC /IAC

A frequent criticism of energy audits is that they overestimate the savings potential available to the customer. This paper addresses several problem areas which can result in over-optimistic savings projections, and suggests ways to prevent mistakes.

Performing an energy and demand balance is the initial step a careful energy analyst should take when starting to evaluate the energy use at a facility. These balances allow one to determine what the largest energy users are in a facility, to find out whether all energy uses have been identified, and to check savings calculations by determining whether more savings have been identified than are actually achievable.

Some analysts use the average cost of electricity to calculate energy savings. This can give a false picture of the actual savings and may result in over-optimistic savings predictions. This paper discusses how to calculate the correct values from the electricity bills, and when to use these values. Finally, the authors discuss several common energy-savings measures which are frequently recommended by energy auditors. Some of these may not actually save as much energy or demand as expected, except in limited circumstances. Others have good energy saving potential but must be implemented carefully to avoid increasing energy use rather than decreasing it.

Critics of energy audit recommendations often say that auditors overestimate the savings potential available to the customer. This possibility of overestimation concerns utilities who do not want to pay incentives for demand-side management programs if the facilities will not realize the expected results in energy or demand savings. Overestimates also make clients unhappy when their energy bills do not decrease as much as promised. The problem multiplies when a shared savings program is undertaken by the facility and an Energy Service Company. Here, the difference between the audit projections and the actual metered and measured savings may be so signifi-cantly different that either there are no savings for the facility, or the Energy Service Company makes no profit.

More problems are likely with the accuracy of the energy audits for industrial and manufacturing facilities than for smaller commercial facilities or even large buildings since the equipment and operation of industrial facilities is more complex. However, many of the same problems discussed here in terms of industrial and manufacturing facilities can occur in audits of large commercial facilities and office buildings. Based on our auditing experience for industrial and manufacturing facilities over the last five years, we have identified a number of areas where problems are likely to occur, and a number of these are presented and discussed. In addition, we have developed a few methods and approaches to dealing with these potential problems, and we have found a few ways to initiate our energy audit analyses thanti f onefacilie it

When we perform an energy survey (audit), we inventory all of the major energy-using equipment in the facility. Then we list the equipment and estimate its energy consumption and demand using the data gathered at the facility such as nameplate ratings of the equipment and operating hours. We develop our energy balance by major equipment category such as: lighting, motors, HVAC, air compressors, etc. We also have a category called Miscellaneous to account for loads that we did not individually survey such as copiers, electric typewriters, computers, and other plug loads. We typically allocate 10 percent of the actual energy use and demand to the Miscellaneous category in the demand and energy balances. (For an office building instead of a manufacturing facility, this Miscellaneous load might be 15 to 20 percent). Then we calculate the energy and demand for each of the other categories.

The first major category we analyze is lighting because this is usually the category that we have the most confidence in for knowing the actual demand and hours of use. Thus, we believe that our energy and demand estimates for the lighting system are the most accurate, and can then be subtracted from the total actual use to let us continue to build up the energy and demand balance for the facility. We record the types of lamps and number of lamps used in each area of the facility, and ask the maintenance person to show us the replacement lamps and ballasts used. With this lamp and ballast wattage data, together with a good estimate of the hours that the lights are on in the various areas, we can construct what we believe to be a fairly accurate description of the energy and demand for the lighting system.

There is generally no other "easy" or "accurate" category to work on, so we proceed to either air conditioning or motors. In most facilities there will be some air conditioning, even if it is just for the offices that are usually part of the industrial or manufacturing facility. Many facilities - particularly here in the hot and humid southeast - are fully air conditioned. Electronics, printing, medical plastics and devices, and many assembly plants are common ones that we see that are fully air conditioned. Boats, metal products, wood products, and plastic pipe manufacturing facilities are most often not air conditioned. Air conditioning system name plate data is usually available and readable on many units, and efficiency ratings can be found from published ARI data[1], or from the manufacturers of the equipment. The biggest problem with air conditioning is to get run time data that will allow us to determine the number of full-load equivalent operating hours for the air conditioning compressors or chillers. From our experience in North and North-Central Florida, we use about 2200 to 2400 hours per year of compressor run time for facilities which have air conditioning that responds to outdoor temperature. Process cooling requirements are much different, and would typically have much larger numbers of full-load equivalent operating hours. With the equipment size, the efficiency data, and the full-load equivalent operating hours, we can construct a description of the energy and demand for the air conditioning system.

Turning next to motors, we begin looking at one of the most difficult categories to deal with in the absence of fully metered and measured load factors on each motor in the facility. In a one day plant visit, it is usually impossible to get actual data on the load factors for more than a few motors. Even then, that data is only good for the one day that it was taken. Very few energy auditing organizations can afford the time and effort to make long-term measurements of the load factor on each motor in an industrial or manufacturing facility. Thus, estimating motor load factors becomes a critical part of the energy and demand balance, and also a critical part of the accuracy of the actual energy audit analysis. Motor name plate data shows the horsepower rating, the manufacturer, and sometimes the efficiency. If not, the efficiency can usually be obtained from the manufacturer, or from standard references such as the Energy-Efficient Motor Systems Handbook,[2] or from software data bases such as MotorMaster produced by the Washington State Energy Office.[3] We inventory all motors over one hp, and sometimes try to look at the smaller ones if we have time.

Motor run time is another parameter that is very difficult to get. When the motor is used in an application where it is constantly on, that is an easy case. Ventilating fans, circulating pumps, and some process drive motors are often in this class because they run for a known, constant period of time each year. In other cases, facility operating personnel must help provide estimates of motor run times. With data on the horsepower, efficiency, load factor and run times of motors we can construct a detailed table of motor energy and demands to use in our balances. Motor load factors will be discussed further in a later section of this paper.

Air compressors are a special case of motor use with most of the same problems. Some help is available in this category since some air compressors have instruments showing the load factor, and some have run time indicators for hours of use. Most industrial and manufacturing facilities will have several air compressors, and this may lead to some questions as to which air compressors are actually used, and how many hours they are used. If the air compressors at a facility are priority scheduled, it may turn out that one or more of the compressors are operated continuously, and one or two smaller compressors are cycled or unloaded to modulate the need for compressed air. In this case, the load factors on the larger compressors may be unity. Using this data on the horsepower, efficiency, load factor and run times of the compressors, we develop a detailed table of compressor energy use and demand for our energy and demand balances.

Specialized process equipment must be analyzed on an individual basis since it will vary tremendously depending on the type of industry or manufacturing facility involved. Much of this equipment will utilize electric motors and will be covered in the motor category. Other electrically-powered equipment, such as drying ovens, cooking ovens, welders, laser and plasma cutters are non-motor electric uses and must be treated separately. Equipment name plate ratings and hours of use are necessary to compute the energy and demand for these items. Process chillers are another special class that are somewhat different from the comfort air conditioning equipment because the operating hours and loads are driven by the process requirements and not the weather patterns and temperatures.

Once the complete energy and demand balances are constructed for the facility, we check to see if the cumulative energy/demand for these categories plus the miscellaneous category is substantially larger or smaller than the actual energy usage and demand over the year. If it is, and we are sure we have identified all of the major energy uses, we know that we have made a mistake somewhere in our assumptions. As mentioned above, one area that we have typically had difficulty with is the energy use by motors. Measuring the actual load factors is difficult on a one-day walkthrough audit visit, so we use our energy balance to help us estimate the likely load factors for the motors. We do this by adjusting the load factor estimates on a number of the motors to arrive at a satisfactory level of the energy and demand from the electric motors. Unless we do this, we are likely to overestimate the energy used by the motors, and thus overestimate the energy savings from replacing standard motors with high efficiency motors.

As an example, we performed an energy audit for one large manufacturing facility with a lot of motors. We first assumed that the load factors for the motors were approximately 80 percent, based on what the facility personnel told us. Using this load factor gave us a total energy use for the motors of over 16 million kWh/year and a demand of over 2,800 KW. Since the annual energy use for the entire facility was just over 11 million kWh/year and the demand never exceeded 2,250 kW, this load factor was clearly wrong. We adjusted the average motor load factor to 40 percent for most of the motors which reduced our energy use to 9 million kWh and the demand to just under 1,600 kW. These values are much more reasonable with motors making up a large part of the electrical load of this facility.

After we are satisfied with the energy/demand balances, we use a graphics program to draw a pie chart showing the distribution of energy/demand between the various categories. This allows us to visually represent which categories are responsible for the majority of the energy use. It also allows us to focus our energy savings analyses on the areas of largest energy use.

Over the course of performing 120 industrial energy audits, we have identified a number of problem areas. One lies with the method of calculating energy cost savings: whether to use the average cost of electricity or break the cost down into energy and demand cost components. Other problems include instances where the energy and demand savings associated with specific energy efficiency measures may not be fully realized or where more research should go into determining the actual savings potential.

One criticism of energy auditors is that they sometimes overestimate the dollar savings available from various energy efficiency measures. One way overestimation can result is when the analyst uses only the average cost of electricity to compute the savings. Because the average cost of electricity includes a demand component, using this average cost to compute the savings for companies who operate on more than one shift can overstate the dollar savings. This is because the energy cost during the off-peak hours does not include a demand charge. A fairly obvious example of this type of problem occurs when the average cost of electricity is used to calculate savings from installing high-efficiency security lighting. In this instance, there is no on-peak electricity use, but the savings will be calculated as if all the electricity was used on-peak.

The same problem arises when an energy efficiency measure does not result in an expected - or implicitly expected -

demand reduction. Using a cost of electricity which includes demand in this instance will again overstate the dollar savings. Examples of energy efficiency measures which fall into this category are: occupancy sensors, photosensors, and adjustable speed drives. Although all of these measures can reduce the total amount of energy used by the equipment, there is no guarantee that the energy use will only occur during off-peak hours. While an occupancy sensor will save lighting kWh, it will not save any kW if the lights come on during the peak load period. Similarly, an ASD can save energy use for a motor, but if the motor needs its full load capability - as an air-conditioning fan motor or chilled water pump motor might - during the peak load period, the demand savings may not be there. The reduced use of the device or piece of equipment on peak load times may introduce a diversity factor that produces some demand savings. However, even this savings will be overestimated by using the average cost of electricity in most instances.

On the other hand, some measures can be expected to provide their full demand savings at the time of the facility's peak load. Replacing 40 watt T12 fluorescent lamps with 32 watt T8 lamps will provide a verifiable demand savings since the wattage reduction will be constant at all times, and will specifically show up during the period of peak demand. Shifting loads to off peak times should also produce verifiable demand savings. For example, putting a timer or energy management system control on a constant load, electric drying oven to insure that it does not come on until the off-peak time will result in the full demand savings. Using high efficiency motors also seems like it would also produce verifiable savings because of its reduced kW load, but in some instances there are other factors that tend to negate these benefits. This topic is discussed later on in this paper.

To help solve the problem of overestimating savings from using the average cost of electricity, we divide our energy savings calculations into a demand savings and an energy savings. In most instances, the energy savings for a particular piece of equipment is calculated by first determining the demand savings for that equipment and then multiplying by the total operating hours of the equipment. To calculate the annual cost savings (CS), we use the following formula:

$$\begin{aligned} CS = & [\text{Demand Savings} \times \text{Average Monthly Demand Rate} \times 12 \text{ mos/yr}] \\ & + [\text{Energy Savings} \times \text{Average Cost of Electricity without Demand}] \end{aligned}$$

If a recommended measure has no demand savings, then the energy cost savings is simply the energy savings times the average cost of electricity without demand (or off-peak cost of electricity). This procedure forces us to think carefully about which equipment is used on-peak and which off-peak.

To demonstrate the difference in savings estimates, consider replacing a standard 30 hp motor with a high-efficiency motor. The efficiency of a standard 30 hp motor is 0.901 and a high efficiency motor is 0.931. Assume the motor has a load factor of 40% and operates 8760 hrs/yr (three shifts). Assume also that the average cost of electricity is \$0.068/kWh, the average demand cost is \$3.79/kW/mo, and the average cost of electricity without demand is \$0.053/kWh. The equation for calculating the demand of a motor is:

$$D = HP \times LF \times 0.746 \times 1/Eff$$

The savings on demand (or demand reduction) from installing a high-efficiency motor is:

$$\begin{aligned} DR &= HP \times LF \times 0.746 \times (1/Eff_S - 1/Eff_H) \\ &= 30 \text{ hp} \times .40 \times 0.746 \text{ kW/hp} \times (1/.901 - 1/.931) \\ &= 0.32 \text{ kW} \end{aligned}$$

The annual energy savings is:

$$\begin{aligned} ES &= DR \times H \\ &= 0.32 \text{ kW} \times 8760 \text{ hrs/yr} \\ &= 2803.2 \text{ kWh/yr} \end{aligned}$$

Using the average cost of electricity above, the cost savings (CS_1) is calculated as:

$$\begin{aligned} CS_1 &= ES \times (\text{Average cost of electricity}) \\ &= 2803.2 \text{ kWh/yr} \times \$0.068/\text{kWh} \end{aligned}$$

= \$190.62/yr

Using the recommended formula above:

CS = [Demand Savings × Average Monthly Demand Rate × 12 mos/yr] + [Energy Savings × Average Cost of Electricity without Demand]

= (0.32 kW × \$3.79/mo × 12 mos/yr) + (2803.2 kWh/yr × \$0.053/kWh)

= (\$14.55 + \$148.57)/yr
= \$163.12/yr

In this example, using the average cost to calculate the energy cost savings overestimates the cost savings by \$27.50 per year, or 17 percent. Although the actual amount is small for one motor, if this error is repeated for all the motors for the entire facility as well as all other measures which only reduce the demand component during the on-peak hours, then the cumulative error in cost savings predictions can be substantial.

Many of us in the energy auditing business started off assuming that motors ran at full load or near full load, and based our energy consumption analysis and energy savings analysis on that premise. Most books and publications that give a formula for finding the electrical load of a motor do not even include a term for the motor load factor. However, since experience soon showed us that few motors actually run at full load or near full load, we were left in a quandary about what load factor to actually use in our calculations because we rarely had good measurements on the actual motor load factor. A recent paper by R. Hoshide shed some light on the distribution of motor load factors from his experience.[4] In this paper, Hoshide noted that only about one-fourth of all three-phase motors run with a load factor greater than 60%; with 50% of all motors running at load factors between 30% and 60%, and one-fourth running with load factors less than 30%. Thus those of us who had been assuming that a typical motor load factor was around 70% or 80% had been greatly over-estimating the savings from high efficiency motors, adjustable speed drives, high efficiency belts, and other motor-related improvements.

The energy and demand balances discussed earlier also confirm that overall motor loads in most facilities cannot be anywhere near 70% to 80%. Our experience in manufacturing facilities has been that motor load factors are more correctly identified as being in the 30% to 40% range. With these load factors, we get very different savings estimates and economic results than when we assume that a motor is operating at a 70% or greater load factor as shown in our example earlier.

One place where the motor load factor is critical - but often overlooked - is in the savings calculations for adjustable speed drives. Many motor and ASD manufacturers provide easy-to-use software that will determine savings with an ASD if you supply the load profile data. Usually a sample profile is included that shows calculations for a motor operating at full load for some period of time, and at a fairly high overall load factor - e.g. around 70%. If the motor only has a load factor of 50% or less to begin with, the savings estimates from a quick use of one of these programs may be greatly exaggerated. If you use the actual motor use profile with the load factor of 50%, you may find that the ASD will still save some energy and money, but often not as much as it looks like when the motor is assumed to run at the higher load factor. For example, a 20 hp motor may have been selected for use on a 15 hp load to insure that there is a "safety factor." Thus the maximum load factor for the motor would be 75%. A typical fan or pump in an air conditioning system that is responding to outside weather conditions may only operate at its maximum load about 10% of the time. Since that maximum load here is only 15 hp, the average load factor for the motor might be more like 40%, and will not be even close to 75%.

Another interesting problem area is associated with the use of high-efficiency motors. In Hoshide's paper mentioned earlier, he notes that in general, high-efficiency motors run at a faster full load speed than standard efficiency motors.[4] This means that when a standard motor is replaced by a high efficiency motor, the new motor will run somewhat faster than the old motor in almost every instance. This is a problem for motors that drive centrifugal fans and pumps, because the higher operating speed means greater power use by the motor. Hoshide provides an example where he shows that a high efficiency motor that should be saving about 5% energy and demand actually uses the same energy and demand as the old motor. This occurs because the increase in speed of the high efficiency motor offsets the power savings by almost exactly the same 5% due to the cube law for centrifugal fans and pumps.

Few energy auditors ever monitor fans or pumps after replacing a standard motor with a high efficiency motor; therefore, they have not realized that this effect has cancelled the expected energy and demand savings. Since Hoshide noted this feature of high efficiency motors, we have been careful to make sure that our recommendations for replacing motors with centrifugal loads carry the notice that it will probably be necessary to adjust the drive pulleys or drive system so that the load is operated at the same speed in order to achieve the expected savings.

We have developed some significant questions about the use of cogged and synchronous belts, and the associated estimates of energy savings. It seems fairly well accepted that cogged and synchronous belts do transmit more power from a motor to a load than if standard smooth V-belts are used. In some instances this should certainly result in some energy savings. A constant torque application like a conveyor drive may indeed save energy with a more efficient drive belt because the motor will be able to supply that torque with less effort. Consider also a feedback-controlled application such as a thermostatically-controlled ventilating fan or a level-controlled pump. In this case, the greater energy transmitted to the fan or pump should result in the task being accomplished faster than if less drive power were supplied, and some energy savings should exist. However, if a fan or a pump operates in a non-feedback application - as is very common for many motors - then there will not be any energy savings. For example, a large ventilating fan that operates at full load continuously without any temperature or other feedback may not use less energy with an efficient drive belt because the fan may run faster as a result of the drive belt having less slip. Similarly, a pump which operates continuously to circulate water may not use less energy with an efficient drive belt. This is an area that needs some monitoring and metering studies to check the actual results.

Whether efficient drive belts result in any demand savings is another question. Since in many cases the motor is assumed to be supplying the same shaft horsepower with or without high efficiency drive belts, a demand savings does not seem likely in these cases. Possibly using an efficient belt on a motor with a constant torque application which is controlled by an ASD might result in some demand savings. However, for the most common applications, the motor is still supplying the same load, and thus would have the same power demand. For feedback-controlled applications, there might be a diversity factor involved so that the reduced operation times could result in some demand savings - but not the full value otherwise expected. Thus, using average cost electricity to quantify the savings expected from high efficiency drive belts could well overestimate the value of the savings. Verification of the cases where demand savings are to be expected is another area where more study and data are needed.

We would like to close this discussion with a return to ASDs, since these are devices that offer a great potential for savings, but have far greater complexities than are often understood or appreciated. Fans and pumps form the largest class of applications where great energy savings is possible from the use of ASDs. This is a result again of the cube law for centrifugal fans and pumps where the power required to drive a fan or pump is specified by the cube of the ratio of the flow rates involved. According to the cube law, a reduction in flow to one-half the original value could now be supplied by a motor using only one-eighth of the original horsepower. Thus, whenever an air flow or liquid flow can be reduced, such as in a variable air volume system or with a chilled water pump, there is a dramatic savings possible with an ASD. In practice there are two major problems with determining and achieving the expected savings.

The first problem is the one briefly mentioned earlier, and that is determining the actual profile of the load involved. Simply using the standard profile in a piece of vendor's software is not likely to produce very realistic results. There are so many different conditions involved in fan and pump applications that taking actual measurements is the only way to get a very good idea of the savings that will occur with an ASD. Recent papers have discussed the problems with estimating the loads on fans and pumps, and have shown how the cube law itself does not always give a reasonable value.[5,6,7] The Industrial Energy Center at Virginia Polytechnic Institute and Virginia Power Company have developed an approach where they classify potential ASD applications into eight different groups, and then estimate the potential savings from analysis of each system and from measurements of that system's operation.[8] Using both an analytical approach and a few measurements allows them to get a reasonable estimate of the motor load profile, and thus a reasonable estimate of the energy and demand savings possible.

The second problem is achieving the savings predicted for a particular fan or pump application. It is not enough just to identify the savings potential and then install an ASD on the fan or pump motor. In most applications, there is some kind of throttling or bypass action that results in almost the full horsepower still being required to drive the fan or pump most of the time. In these applications, the ASD will not save much unless the system is altered to remove the throttling or bypass device, and a feedback sensor is installed to tell the ASD what fraction of its speed to deliver. This means that in many air flow systems, the dampers or vanes must be removed so that the quantity of air can be controlled by the ASD changing the speed of the fan motor. In addition, some kind of feedback sensor must be installed to measure the temperature or pressure in the system to send a signal to the ASD or a PLC controller to alter the speed of the motor to meet the desired condition. The additional cost of the alterations to the system and the cost of the control system needed greatly change the economics of an ASD application compared to the case where only the purchase cost and installation cost of the actual ASD unit is considered.

For example, a dust collector system might originally be operated with a large 150 hp fan motor running continuously to pick up the dust from eight saws. However, because production follows existing orders for the product, sometimes only two, three or four saws are in operation at a particular time. Thus, the load on the dust collector is much lower at these times than if all eight saws are in use. An ASD is a common recommendation in this case, but estimating the savings is not easy to begin with, and once the costs of altering the collection duct system and the cost of adding a sophisticated control system to the ASD is considered, the bottom line result is much different than the cost of the basic ASD with installation. Manual or automatic dampers must be added to each duct at a saw so that it can be shut off when the saw is not running, In addition, a PLC for the ASD must be added to the new system, together with sensors added to each damper so that the PLC will know how many saws are in operation and therefore what speed to tell the ASD for the fan to run to meet the dust collection load of that number of saws. Without these system changes and control additions, the ASD itself will not save any great amount of energy or money. Adding them in might well double the cost of the basic ASD, and double the payback time that may have originally been envisioned.

Similarly, for a water or other liquid flow application, the system piping or valving must be altered to remove any throttling or bypass valves, and a feedback sensor must be installed to allow the ASD to know what speed to operate the pump motor. If several sensors are involved in the application, then a PLC may also be needed to control the ASD. For example, putting an ASD on a chilled water pump for a facility is much more involved, and much more costly, than simply cutting the electric supply lines to the pump motor and inserting an ASD for the motor. Without the system alterations and without the feedback control system, the ASD cannot provide the savings expected.

New energy auditors often do not have the experience to have engineering judgment about the accuracy of their analyses. That is, they cannot look at the result and immediately know that it is not within the correct range of likely answers. Because our EADC program has a fairly steady turnover of students, we find the same type of errors cropping up over and over as we review our draft audit reports. To help new team members develop the engineering judgment that they will eventually gain through experience, we are developing "rules of thumb" for our energy analyses. The rules of thumb are intended to provide a ballpark estimate of the expected results. For example, if our rule of thumb for the percent for installing high efficiency motors says that the savings range is 3-5% of the energy use by the motors, then a student who comes up with a savings of 25% will immediately know that the calculations are wrong and will know to check the assumptions and data entry to see where the error lies. Without these rules of thumb, the burden for checking these results is shifted to the team leaders and program directors. Although this does not obviate the need for report review, it minimizes the likelihood that errors will occur. We suggest that other organizations who frequently utilize and train new energy auditors consider developing such rules of thumb for the major types of facilities and/or geographic areas that they audit.

Energy auditing is not an exact science, but a number of opportunities are available for improving the accuracy of the recommendations. Techniques which may be appropriate for small-scale energy audits can introduce significant errors into the analyses for large complex facilities. We began by discussing how to perform an energy and demand balance for a company. This balance is an important step in doing an energy use analysis because it provides a check on the accuracy of some of the assumptions necessary to calculate savings potential. We also addressed several problem areas which can result in over-optimistic savings projections, and suggested ways to prevent mistakes. Finally, several areas where additional research, analysis, and data collection are needed were identified. Once this additional information is obtained, we can all produce better and more accurate energy audit results.

1. Air-Conditioning & Refrigeration Institute, ARI Unitary Directory, published every six months.

2. S. Nadel, M. Shepard, S. Greenberg, G. Katz., A. de Almeida, Energy-Efficient Motor Systems: A Handbook on Technology !rogram and !olicy "##ort$nities. American Council for an Energy-Efficient Economy, 1992.

3. Washington State Energy Office, MotorMaster Electric Motor Selection Software and Database, updated annually.

4. Robert K. Hoshide, Electric Motor Do's and Don'ts, Energy Engineering, Vol 91, No.1, 1994.

5. Wayne L. Stebbins, Are You Certain You Understand the Economics for Applying ASD Systems to Centrifugal Loads?, Energy Engineering, Vol. 91, No. 1, 1994.

6. R. R. Vaillencourt, Simple Solutions to VSD Pumping Measures, Energy Engineering, Vol. 91, No. 1, 1994.

7. Gene Kempers, DSM Pitfalls for Centrifugal Pumps and Fans, Energy Engineering, Vol. 92, No. 2, 1995.

8. Personal communication with Mr. Mark Webb, Senior Engineer, Virginia Power Company, Roanoke, VA, January 1995.