Using Utility Bills and Average Daily Energy Consumption to Target Commissioning Efforts and Track Building Performance

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ABSTRACT

This paper discusses using basic utility data that is readily available from utility bills to both focus and target commissioning efforts. It also discusses how to use this information to spot emerging problems related to how the building is using energy. This sort of analysis can be done using relatively simple techniques such as a hand calculation or a spreadsheet and is the type of thing that any facility engineer or operator could handle and would be interested in. Techniques are also discussed which allow the data to be further refined to target specific energy uses.

INTRODUCTION

Most Facilities Departments and Commissioning Agents are privy to the utility bills associated with the facilities they are operating or otherwise involved with. Usually, Facilities Departments review the bills for approval purposes and many groups track billing period consumption from month to month for record and comparison. Commissioning agents use this information for similar purposes as well as to understand building consumption patterns and flag potential areas requiring attention. In many cases, little analysis is done beyond looking at the information as presented in the billing statement, and a great deal of benefit can be realized by simply reviewing the information in this manner. However, by a little bit of additional analysis via hand calculations or a simple spreadsheet it is possible to glean even more information about the building and its energy use patterns from the utility data. By looking at the data on an average daily consumption basis, normalized to match the calendar months, it is possible to identify patterns that will not be noticed by simply tracking total consumption per billing period or even average daily consumption per billing period. Once developed, the techniques and calculations required for this additional work would quite literally require only a few minutes of an operator's or engineer's time. But the insights gained can often save thousands of dollars in utility costs and commissioning labor either by identifying an abnormal consumption pattern early on or by more finely focussing commissioning efforts funded from a limited budget.

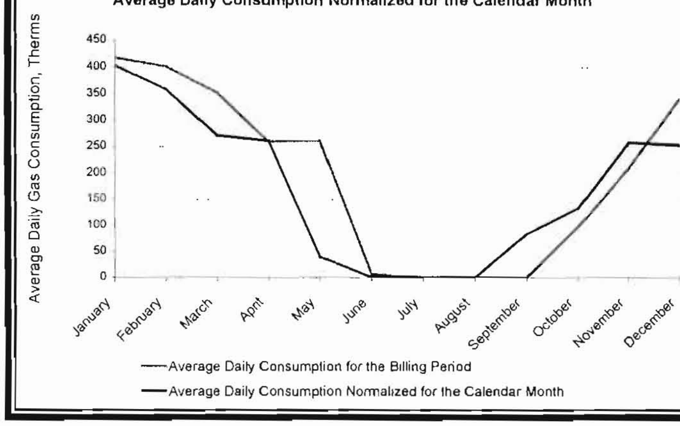
WHY TAKE THE EXTRA STEPS?

Operators and commissioning agents who already are monitoring monthly consumption or even average daily consumption for the billing period (many utilities have started to present this information as a standard part of their bill) may wonder what additional value is to be gained by further refining the information. The benefits are as follows:

- Gross billing period consumption data, while somewhat related to season, is also influenced by the length of the billing period and the dates the meter is read. Meters are often read on a specific day of the month rather than on a regular interval based on a certain number of days. This means that two months with identical operating schedules, weather patterns and other factors, but differing numbers of days would show different consumption totals. This would simply be because one billing period had more days than the other, not because of any particular pattern associated with the season or building.

- Meter reading dates seldom fall on the first day of the month, thus the consumption data usually is related to two different calendar months. For instance, a bill for a meter reading taken on the 10th of May and received later that month would most likely be posted as the May consumption. In fact, from a calendar basis, it is more likely that it reflects energy utilization patterns associated with the weather and use of the building in April rather than May. But, the information is also influenced by what happened in May since the reading was taken on the 10th of the month. Attempting to correlate this data to weather and utilization information for either of the calendar months could be misleading and may be irrelevant. Even if the data is looked at as average

Figure 1 - Average Daily Consumption for the Billing Period vs. Average Daily Consumption Normalized for the Calendar Month



daily consumption data to over come the problem discussed in the preceding bullet, it still cannot be correlated with calendar month based data with any degree of confidence as to the results. Figure 1 illustrates the differences between average daily data that has been normalized for the calendar month vs. data that is based on the billing period.

- Once the metered data has been normalized to match calendar months, it can be correlated and compared to other data that is available in calendar month format. Heating and cooling degree data are good examples. We will discuss this topic further in a later section.

GENERATING THE NORMALIZED DATA

Once you have been through the process and understand it, performing and average daily energy consumption analysis is surprisingly easy, even with the normalization of the data that is required. This is especially true if you set up a spreadsheet to do the calculations for you. Once the spreadsheet it set up, it can often be filled in and updated by less technically oriented people, allowing the more technically oriented folks to focus on identification and correction of the issues uncovered by the analysis. To perform the analysis, you will need at least one year's worth of utility bills for each energy source that the facility uses. It is even better if you can get several years worth of bills. The bills need to have the following information at a minimum.

- *Date of reading:* This is the actual date that the meter was read, as shown on the bill, not the date the bill was received or the date it was approved or the date it was posted by accounting. This is important information that will allow you to normalize the data in a subsequent step.
- *Consumption for the billing period:* This is often shown as the current meter reading, the previous meter reading, and the difference, which is the actual consumption for the billing period. For gas meters, this figure is often adjusted to correct for factors such as temperature and pressure. Variations in pressure and temperature change the density of the gas. If the density of the gas changes, then the volume that moved through the meter will be different than what the meter would have measured under standard conditions. The measured consumption needs to be corrected to reflect this to allow the bill to be in terms of standard cubic feet of gas. Gas meter bills also will often contain a btu correction factor which adjusts the actual energy content of the gas that was sold to you based on its make-up at the time of the sale as compared to a standard cubic foot of standard gas. Gas from different well sources often has a different btu content or heating value and this is the factor that adjusts for that difference. You want to base your analysis on the final adjusted values, just like the utility company does when it generates your bill. If the data on the bill is in therms (100,000 btus), then all of the necessary conversions will have been done for you. On the other hand, if the bill is in terms of cubic feet, then you may need to use some of the adjustment and conversion factors to provide the data you are looking for in terms of btus.
- *Charges for the billing period:* This information is not essential for the analysis, but it does allow you to report the results of the analysis in terms of dollars and cents rather than btus or kWhs. Business people and accountants can make much more sense of information presented to them in business terms (i.e. dollars) rather than engineering terms.

If at all possible, you should obtain copies of the raw utility bills rather than information from accounting journals. This will allow you as the technical person to interpret the technical data and will eliminate any transcription errors. In addition, the utility bills may contain other information that you can use such as the number of heating or cooling degree-days in the billing period.

Once you have the bills, you can convert the information into average daily consumption for the billing period. To do this, divide the billing period consumption by the number of days in the billing period for each bill. The result is the average daily consumption *for the billing period.* If your billing periods happen to correspond exactly to the calendar month, then you are done with the data reduction and can proceed to the graphing function, which is the heart of the analysis. However, in most cases, you will need to normalize the data to correlate with the calendar months. Do this using the following steps.

- Step 1 – perform the following multiplication and division operations for each calendar month.

(Number of days in the month in billing period 1) x
(average daily billing period 1 consumption)

plus

(Number of days in the month in billing period 2) x
(average daily billing period 2 consumption)

- Step 2 - Divide this result by the number of days in the month.

- Result - Average daily consumption normalized for the calendar month.

Now comes the fun part. Plot this data to make a air handling systems to work against the economizer control system, resulting in a lot of unnecessary steam consumption. The indicator of the problem was the fact that the energy use seemed to lag behind the degree-day data (the degree days dropped off, but the consumption didn't) until June, when the boilers were shut down for the summer. A more normal pattern emerged in the fall after the problem had been corrected. It is important to understand that the difference between the curves did not lead the retrocommissioning team to the exact problem. Discovering and correcting the programming error took additional research and effort in the form of reviewing and revising program code and control system hardware. What is important is that the observed difference caused the team to realize that something might not be quite as it should be, which then led them to discover and diagnose the problem.

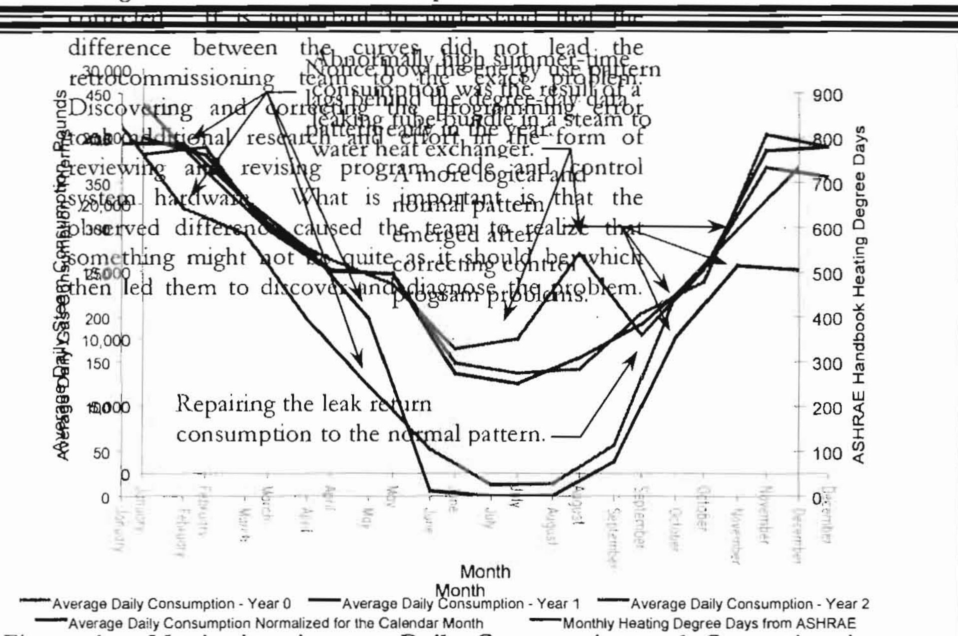


Figure 4 – Monitoring Average Daily Consumption and Comparing it to Previous Years Reveals Problems

Figure 3 Average Daily Consumption for the Month vs. Heating Degree Days for the Month.

Continued monitoring of the average daily consumption allowed them to confirm their diagnosis via a closer match in the shape of the curves in the fall months.

Obviously, this is not an exact science. Variables include:

- The characteristics of the building may result in a pattern that is not logical, but normal for that particular building. For instance, the processes in some buildings may result in a pattern similar to that in the early months of the graph in Figure 3 as a normal pattern.
- Heating and cooling degree data are good indicators of a trend in the requirement for heating or cooling in a building, but are not an exact indicator. Variations in the ambient humidity levels, outdoor air quantities, building envelope characteristics, building operating schedule, and requirements of the loads in the building, and the actual basis and source of the degree data itself can skew the actual consumption patterns from what would be expected based on the degree day data. This is particularly true for cooling degree data.

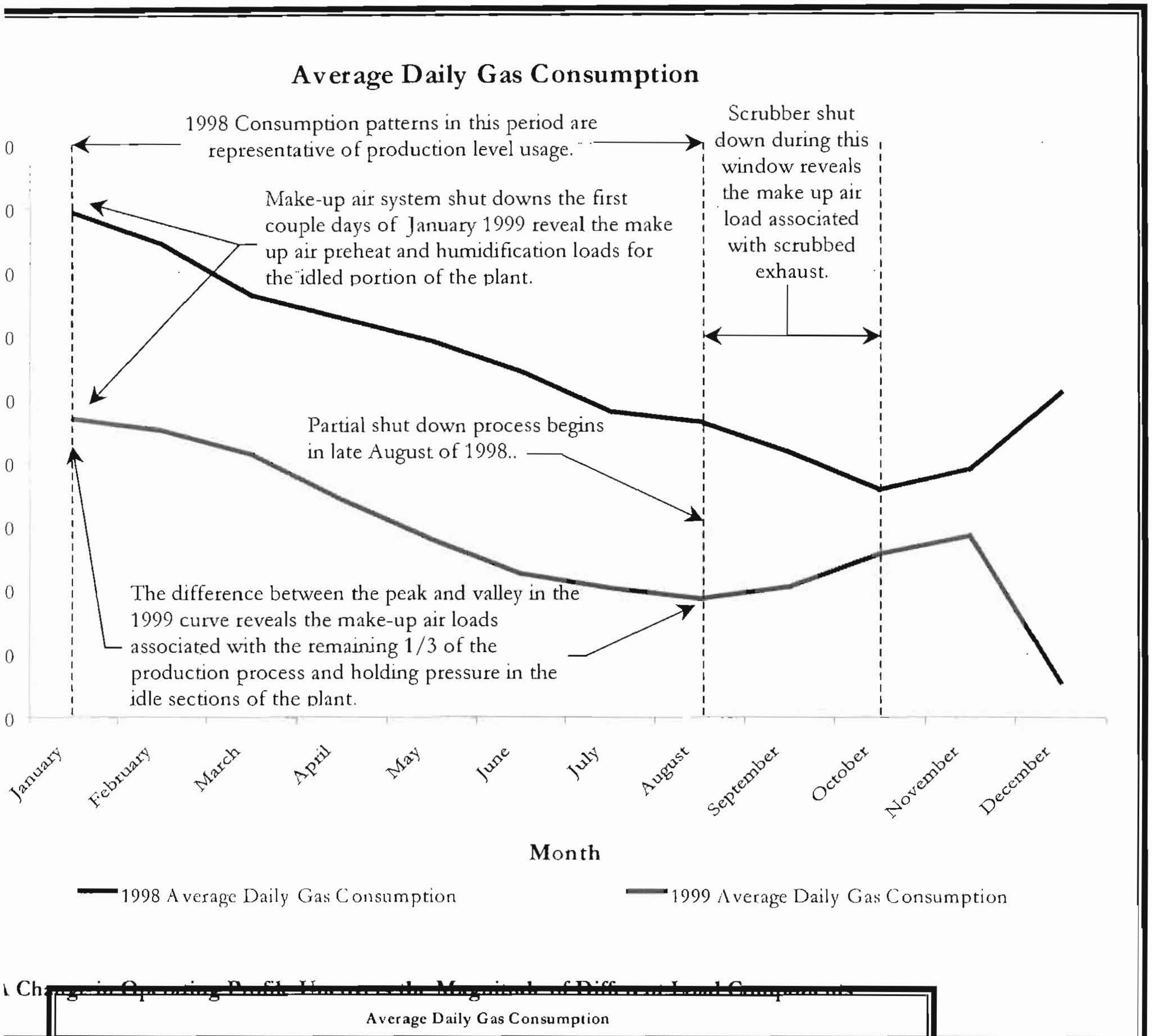
Despite these shortcomings, this technique can be a useful approach to guide the user towards potential opportunities to improve the energy consumption patterns in a facility.

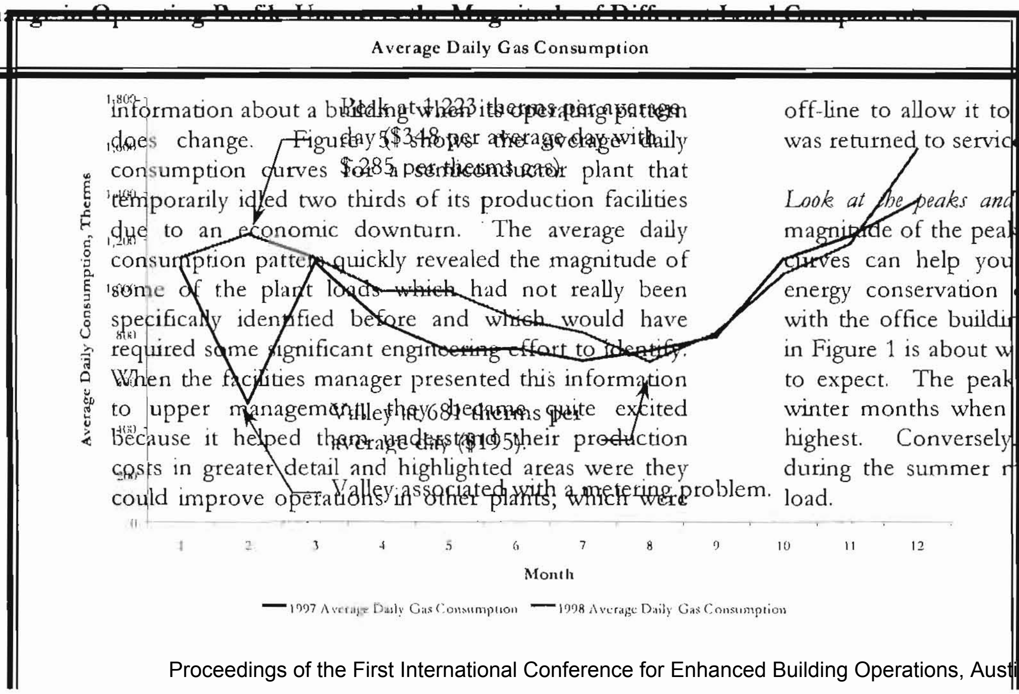
Compare the shape of the curves for different years. Comparing current average daily consumption trends with those for previous years can also provide some interesting insights. If the operating patterns for the building and the loads it contains do not vary much from year to year, then generally, the average daily consumption pattern should be fairly consistent, with only minor deviations from the norm attributable to variations in the weather pattern from year to year. Significant deviations may be an indicator of an emerging problem.

Figure 4 illustrates the consumption patterns for a building where this type of ongoing monitoring proved to be quite beneficial. In this particular case, the retro commissioning provider had been retained by the building manager to provide analysis and trouble-shooting services on an as needed basis. This included reviewing the building's utility bills regularly. Typically, the consultant received the bills about a month after the fact. In July, when the June data came in, the consultant was suspicious of some sort of problem since the consumption trend was a little higher than in the preceding years. Upon receiving the July data (in August), he was convinced there was something wrong since the reheat and kitchen steam loads in the building were unchanged from the previous years, but the summer time steam consumption was starting to skyrocket. About half a day's worth of investigation and troubleshooting revealed that the excessive consumption did not really exist. The real problem was a leak in a steam to water heat exchanger. Since steam consumption was measured based on the condensate discharge rate from the building, the leak in the heat exchanger resulted in a flow in the condensate return system that was not due to condensed steam but due to water loss from the reheat system. Thus, the building appeared to be using energy that it was not actually using. Repairing the leak eliminated the leakage water from the condensate system so the condensate meter was once again measuring only condensed steam, and the indicated energy use returned to a more normal pattern.

Neither the building manager nor the accounting department had noticed this problem when they approved and paid the bill. They were used to paying large utility bills with escalating energy costs and only looked at them in terms of the bottom line dollars rather than in terms of the energy use relative to previous years and previous months. However, by taking an energy related, pattern oriented view of the usage, the consultant quickly identified the abnormality. In addition to allowing the heat exchanger leak to be identified and corrected, the analysis and accumulated data allowed the Owner to go to the utility and obtain a refund for some of the July and August utility costs. This is because the data, along with the documentation of the heat exchanger repair and the building operating schedule allowed the building manager to easily demonstrate to the utility representative that the information from the condensate meter had included a false load.

Comparing average daily consumption for different years can also provide interesting and useful





information about a building when its operating pattern does change. Figure 5 shows the average daily consumption curves for a semiconductor plant that temporarily idled two thirds of its production facilities due to an economic downturn. The average daily consumption pattern quickly revealed the magnitude of some of the plant loads which had not really been specifically identified before and which would have required some significant engineering effort to identify. When the facilities manager presented this information to upper management, they became quite excited because it helped them understand their production costs in greater detail and highlighted areas were they could improve operations in other plants, which were still running. It also paved the way for improvements and additional analysis at the idled plant while it was off-line to allow it to operate more efficiently when it was returned to service.

Look at the peaks and valleys in the curves. Often, the magnitude of the peaks and valleys in the consumption curves can help you target retrocommissioning and energy conservation efforts. The pattern associated with the office building gas consumption curve shown in Figure 1 is about what your intuition would lead you to expect. The peak in the curve occurs during the winter months when the need for heat would be the highest. Conversely, there is no gas consumption during the summer months when there is no heating load.

Compare the curve in Figure 1 to the one shown in Figure 6, which is also from an office building in the Northwest region. This curve shows a very high baseline gas consumption for the building, indicating that on a summer day the building uses gas at nearly 50% of the rate that it does on the coldest winter day, despite the fact that there is no heating load in the summer. Armed with this sort of information up front, on your first visit to a site you can try to determine if this pattern is normal for the building or indicative of a problem or energy conservation opportunity. Things that can cause a high baseline like the one in Figure 6 include:

- Energy used for cooking in a large kitchen or cafeteria. If the kitchen appliances burn the gas directly, little can typically be done to reduce the consumption. If the kitchen uses steam for some of the cooking operations, then it may be possible to target boiler efficiency improvements, steam trap maintenance, and modifications to reduce the parasitic loads on the system as retrocommissioning and energy conservation opportunities[1].
- Energy used to serve some sort of process load in a production facility or a hospital laundry. There may be an opportunity to reduce energy consumption in this area by improving the efficiency of the process itself. Often, this can be difficult to accomplish because production facilities stay in business by making a product they can sell. Anything that would upset the production process or otherwise shut it down is seen as a loss of revenue rather than an improvement. If the achievable savings are significant, it may be possible to convince the production managers to make the changes during a scheduled outage or maintenance shut down.
- Energy associated with some sort of reheat process in an HVAC system. The obvious systems associated with this are reheat systems, but any system that by design, simultaneously uses heating and cooling for environmental control purposes can cause this type of consumption pattern. Examples would include multizone systems and double duct systems. A subcategory of this is scheduling; i.e. if a reheat HVAC process is necessary, it may not be necessary 24 hours per day and thus simply scheduling the equipment to match the occupancy requirements could reduce consumption. There are often significant, easily achievable opportunities in this area when dealing with HVAC systems. It turned out that this type of operation was the cause of the high baseline consumption for the building associated with Figure 6. The initial site visit, conducted in July, led to the discovery that the boilers were firing on a 30% to 50% duty cycle, and thus, where the direct cause of the high baseline consumption. High reheat loads caused this high summertime firing rate. Further investigation revealed that the reheat loads were due to:

  - Minimum flow settings that were based on a design occupant level that was approximately three times the actual occupant level.
  - Control sequences that increased the minimum flow setting as the terminal equipment went into its reheat cycle.
  - Minimum flow settings that were based on perimeter heating requirements[2].
  - Round the clock operation of all systems due to the need to maintain conditions in isolated areas scattered through-out the building on a round the clock basis, even though the majority of the building was used on a "9 to 5" schedule.

Consumption was significantly reduced by some relatively simple retrocommissioning efforts which:

- Adjusted minimum flow settings to match the current occupant load.
- Reprogrammed terminal equipment to reheat at a constant minimum flow setting.
- Reprogrammed perimeter terminal equipment to operate at a lower, ventilation rate based

gure 6 – NW Office Building with a High Baseline Gas Consumption

[1] Parasitic loads are loads that consume steam but provide no useful benefit. Keeping the piping up to temperature is one example of a parasitic load. Large piping systems serving small loads can often consume more energy than the load they serve. If a boiler must fire all summer to serve a small kitchen steam load, and to do that, it must also keep the entire steam piping system up to temperature, then there may be significant savings available if the piping circuit can be re-arranged to provide a small independent main to the year round load while the remainder of the system is valved off.

[2] Many perimeter zones required more air in the heating mode than they did in the cooling mode. The minimum flow settings were based on the heating requirement and resulted in continuous reheat during summer months.

minimum flow setting during the summer months.
 - o Implemented scheduling at the zone level rather than the system level[3].

- System malfunctions that are simply wasting energy. Often, the arrangement and control of HVAC systems allows a malfunction of one subsystem to be hidden or compensated for by another subsystem. On one project, a less than optimal design coupled with calibration errors allowed a make up air unit to preheat the outdoor air from 81°F to 110°F, over cool and dehumidify it to 40°F (saturated), reheat it to 46°F and then humidify it to saturate the 46°F in an effort to maintain close environmental tolerances in the clean room it served. Since the clean room environment was ideal, this problem went undetected for months until a newly hired facilities engineer with an energy conservation background investigated the cause of the high steam consumption that he observed when he arrived at the site. Fixing the problem required the application of relatively low cost, standard, commissioning techniques. It saved thousands of dollars per month in operating costs. This type of problem is alarmingly common. High baseline consumption is often a clue that this type of problem is occurring.

The electrical consumption curve show in Figure 2 has a significant base line. It also has a significant peak in the summer. Again, this is what your intuition would lead you to expect in a building where the cooling equipment was served by electricity and which contained significant lighting and office equipment loads. Contrast this with the electrical consumption curve shown in Figure 7. This curve was also for an office building, but you will notice that the peak associated with the seasonal cooling load is insignificant when compared to the base load. Thus it was concluded that initial retrocommissioning efforts should be targeted at making the base-load systems and equipment more efficient since that would probably yield bigger cost savings than efforts targeted at the cooling plant. This didn't mean that the cooling plant wouldn't be considered since it could have opportunities for valuable improvements to its efficiency. It meant that the work on the plant would be targeted to occur after work on the base load systems and equipment. If budgets are tight, then efforts directed at the based load systems may yield the most bang for the buck in this type of situation.

In the case of the building associated with Figure 7, further analysis and investigation revealed that there were significant opportunities to reduce the base load consumption via scheduling, trimming pump impellers[4], correcting some control system interactions that were causing simultaneous electric heating and cooling operation, and reducing the winter time humidification load which was served by electrically powered humidifiers. These modifications saved tens of thousands of dollars per year in energy costs and were accomplished via programming and operational changes and some minor equipment modification. Paybacks were less than 6 months in most instances even though the programming was outsourced to the site control system contractor. There were also opportunities in the central cooling plant, but they were capital intensive and much more difficult to implement with paybacks that were anticipated to be in the 3 to 8 year range.

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[3] Terminal equipment in areas that were unoccupied at night was programmed to go to a no flow position (0 cfm) based on a schedule. The control systems on the variable volume fan systems allowed the existing systems to simply follow this reduction in load and operate at a significantly lower capacity to serve the round the clock loads. This saved fan energy as well as reheat energy. Night set back and set up routines temporarily activated the unoccupied zones as necessary to keep temperatures with-in reasonable limits at night and over weekends and holidays.

[4] It is not uncommon to find the discharge service valve on a pump partially throttled. Even though this saves some energy by reducing the flow of the pump to design levels, opportunities for further savings may exist by eliminating the pressure drop through the throttled valve. Impeller trimming can reduce the pumps flow rate to design with-out the need for throttling. The *Bell and Gossett Engineering Design Manual* is an additional source of information on this topic.

FURTHER REFINING AVERAGE DAILY CONSUMPTION INFORMATION

Frequently, it is possible to use simple a simple spread

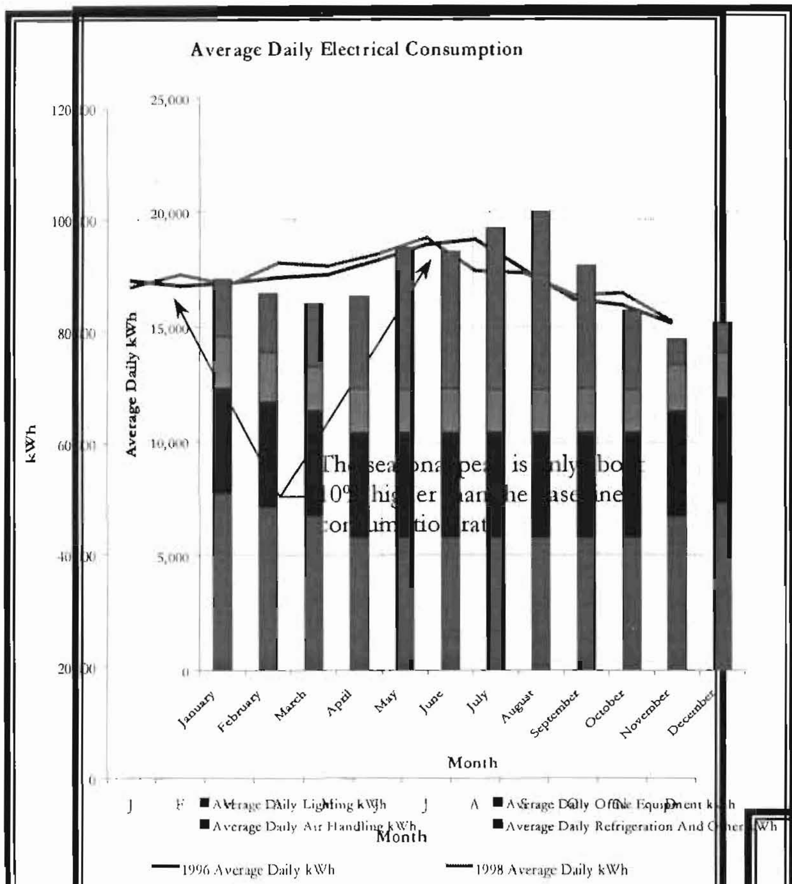

Figure 8 – Electrical Consumption for the Building Associated with Figure 7, Broken Down by Use
Figure 7 – NW Office Building with Relatively Insignificant Seasonal Peak vs. Baseline Consumption

sheet or even hand calculations to refine the average daily consumption information based on field observations and/or information that is readily available from equipment schedules. This process will allow you to further focus your retrocommissioning, energy conservation, and operation and maintenance efforts.

Lighting consumption is one of the easiest loads to identify in this manner. The power requirements and fixture counts are readily obtainable from the drawings or via inspection in the field. Interviewing the operators, visual observation, or datalogging will usually reveal the hours of operation. Calculation of the consumption associated with the lights is simply a matter of multiplying the number of fixtures times the watts per fixture times the number of hours of operation per month. The average daily consumption is then obtained by dividing the monthly total by the number of days in the month.

A similar calculation can be performed for motors and other equipment. When calculating motor loads, there are several important considerations to take into account.

- The power calculation should be based on field measurements of the motor power or on the scheduled brake horsepower (bhp), not the motor name plate horse power. Motors are frequently applied and operated at settings that are less than their name plate rating. Using the nameplate data rather than the actual load can introduce significant, unnecessary errors into the approximation you are trying to make.
- Variable flow systems, like Variable Air Volume (VAV) air handling units, do not operate at a constant power level by design. Therefore, you cannot simply multiply the motor brake horse power by the number of hours of operation to get the motor power consumption. Some technique must be used to reflect the actual motor operating profile. There are several approaches to this. One involves dividing the total operating hours into increments that mimic the observed load profile (i.e. 2 hours at 20% bhp, 4 hours at 50% bhp, 1 hour at 75% bhp and 1 hour at 100% bhp[5]) calculating the consumption for these increments,

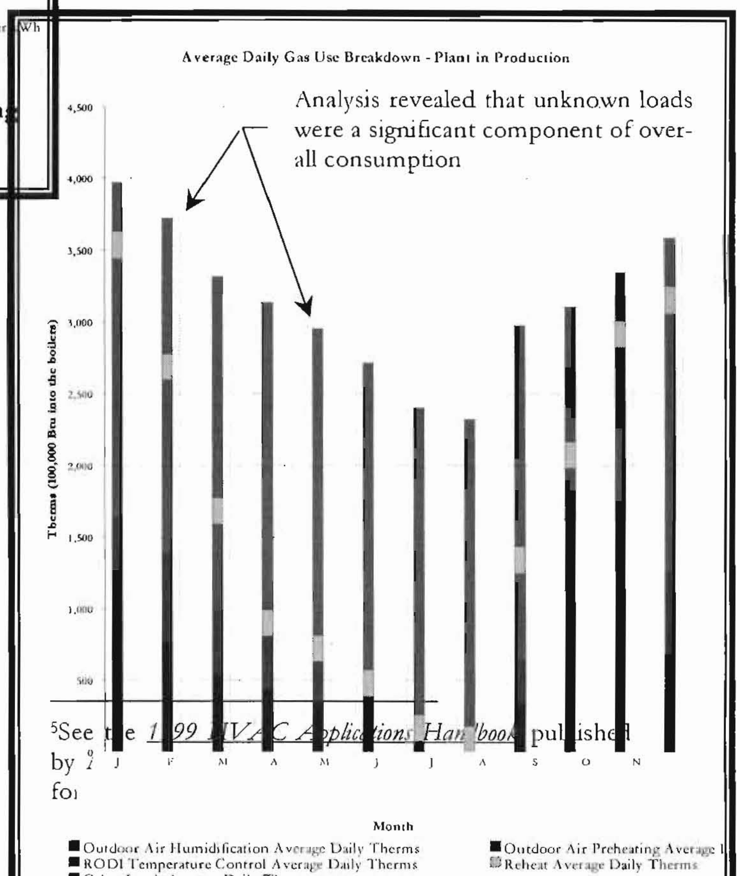

Figure 9 – Gas Consumption for a Semi Conductor Plant, Broken Down by Use

[5] See the 1999 HVAC Applications Handbook published by ASHRAE for

and then summing the results. A less calculation intensive approach, which is equally valid given the approximate nature of the calculation you are doing is to simply assume all hours occur at some representative percentage of the full load bhp. For example, experience and field observation might indicate that using a value of 60% to 70% of design flow for all hours of operation for VAV systems will often yield a reasonably accurate result for a typical office environment[6].

It is also possible to gain a sense of the order of magnitude of the outdoor air ventilation loads using bin weather data and the system operating characteristics[7]. This is a more calculation intensive process than those discussed in the preceding paragraphs, but lends itself to a spreadsheet solution. Once the spreadsheet is developed, it can be reused fairly quickly for estimates on other projects. Figure 9 is an example of using this technique to break down the gas loads on the semiconductor plant that was mentioned previously. In the case of this plant, going through this process revealed that there appeared to be significant gas consumption in the form of "other loads". These were loads that obviously existed since the boilers were using the energy, but could not be accounted for based on the plant operating data and the local environment. Identifying and minimizing these loads became particularly important with the plant running in the idle state where costs were incurred to maintain the plant in a clean condition, but no revenue was being produced. The exact nature of the other loads is still under investigation, but thus far, significant components have been found in the form of the parasitic burden of the steam system and control programming problems that cause many of the support systems required to maintain pressurization and cleanliness to use unnecessary reheat.

[6]Note that this is stated in terms of percentage of flow. Brake horsepower can be calculated from the flow and static pressure information but if you are doing this, you need to remember to derate the static pressure you are using from the design value based on the fan laws and augmented by the requirements of the terminal equipment. See the *2000 HVAC Systems and Equipment Handbook,* published by ASHRAE, Chapter 18, for a discussion of the fan laws and their application.

[7]The details of bin type energy estimating techniques are beyond the scope of this paper. However. Information regarding this procedure can be found in the *1997 Fundamentals Handbook* published by ASHRAE, Chapter 30. Bin weather data is available in *Engineering Weather Data, AFM 88-29* which is available from the government printing office.

Other techniques can also be used to identify and break out components of a building's energy consumption pattern. In one instance, an engineer confronted with an immediate need to know the steam production rate associated with a boiler wired an inexpensive electric clock purchased at the local drugstore across the 120vac feedwater pump starter coil. The pump accumulated the minutes and hours of feedwater pump operation. Since the boiler pressure was relatively constant, the feedwater pump flow rate was fairly constant and could be read directly from the pump curves. The feedwater pumping rate at a constant boiler pressure, multiplied by the number of hours of operation in a 24 hour period resulted in a fairly accurate estimate of the average boiler load and steam production for that day. Since the boiler was the only gas load in the building, the engineer was also able to develop and accurate estimate of average boiler efficiency by converting the steam production into btus and dividing it by the gas in put in btus.

The point is that some fairly simple, practical, and innovative techniques can be used in the field to analyze a buildings energy consumption patterns and then target commissioning and maintenance efforts so that the work of the commissioning agent and facilities staff can yield the biggest bang for the buck. The purpose of the techniques outlined in the preceding paragraphs is to allow the user to quickly identify the order of magnitude of the various components of the energy consumption pattern. They are not intended to yield exact results and should not be portrayed as providing exact information or used as if the information provided is precise. In addition, if you find yourself spending a lot of time trying to break out a consumption component from the data that you have, it may be worth stopping and asking yourself if the effort is justified in terms of what you think you might learn and/or if there is a simpler way to approach the problem.

CONCLUSION

Developing the practice and technique of monitoring and analyzing building utility data can furnish commissioning providers and facilities groups with valuable insights into the day to day operations of the buildings they are involved with. This information can be used to improve efficiency, target retrocommissioning efforts, and focus operations and maintenance work. The average daily consumption analysis calculations are straightforward and can be easily implemented by operators and engineers using simple spread sheets or hand calculations. With a little more effort, additional information can be developed using slightly more sophisticated engineering techniques.