SIMPLE MODELING AND ANALYSIS OF HEATING VENTILATING AND AIR CONDITIONING SYSTEMS BY YOUR ENERGY MANAGEMENT SYSTEM

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The operations and maintenance engineer is challenged to use facility energy resources in the most efficient way. Computer based energy management systems (EMS)are the tools used in large facilities to implement efficient operation. In this paper I will discuss some techniques for automating a measurement of performance for your heating, ventilation, and air-conditioning (HVAC) components and systems using the EMS. By using simple models to quantify actual energy consumption, the choices for equipment replacement, maintenance, or facility modification can be based on your actual costs. At the end of the paper, I include an example of a contract specification requiring energy analysis models. If you are installing or upgrading your EMS, consider including the analysis models in the specification.

Computer models enjoy extensive use in engineering design. The kinds of models we operations and maintenance (O&M) engineers need just are not available as part of the standard software in energy management systems. Design models include many assumptions about how a facility system should work. O&M models must reflect how our HVAC systems actually work; the model must be verifiable when viewing the actual building performance today. Many of us are responsible for the management of facility plants with annual energy consumptions of millions of dollars. The question we must be able to answer is "How effective are we at the task of saving energy and dollars?" Answer the following questions for yourself:

a. Can you document how successful your energy management program is working? How many dollars are you saving?

b. What is the most efficient portion of your plant? (HVAC or facility envelope) Is your answer based on results from data gathered continually or estimates based on original design?

c. What is the least efficient portion of your plant? (HVAC or facility envelope) Do you know why? (The systems are old is not an acceptable answer.)

d. Do you know the actual operating efficiency for all your chillers and boilers?

Before we jump into a discussion about the use of models for energy management there are two points I think should be addressed. First, "What is a model?" And second, "What do we want to model?"

WHAT IS A MODEL?

A model for our purposes is a simple simulation of a real event. The model is a mathematical function, we choose the independent variables and the model finds the solution. Using a chiller as an example, we choose the ambient conditions and the performance data from the manufacturer will indicate the rated output for the chiller. Here the vendor provides the model. The model is useful when it adds to our understanding of the cause and effect relationship of any process. Conversely, if the model is so comprehensive that the process is obscured we have failed. Many point with pride to the design analysis programs (BLAST or TRACE for example) but my experience is that the data run in these programs is off the "blue line drawings" and the results are difficult to reconcile to actual values. Given those boundary conditions for our model we can look at what it is we want to model.

O&M ENGINEER APPROACH

As the O&M engineer, we want to be able to model chillers, boilers, and the facility. By modeling the devices supplying the heating and cooling we can determine operating efficiency. By modeling the facility we can determine if the load imposed on chillers and boilers is correct based on known conditions. Most of our models will be a composite of the individual components; the chiller, piping systems, and cooling towers for example.

DESIGN ENGINEER APPROACH

The approach to energy conservation has been very much from the perspective of the design engineer. The design engineer knows we can make the facility envelope more resistant to the heat gain or heat loss. This approach has spawned many insulation and window replacement projects. We do have less of a cooling load/heating load from the external forces on the envelope. But when we compute the air conditioning loads for a typical administrative facility, the interior electrical loads (including lighting) and personnel loads (including ventilation) are more significant than the transmission losses through the envelope. Today's higher quality envelopes make a situation where the internal heat loads become the driving force. To achieve the efficiency we need for today we must insure our facilities are actually operating as designed.

COMPUTER MODELING

The concept of computer modeling, while not new to any engineering discipline, has not been aggressively applied to the HVAC arena. There has been plenty of modeling done for new facilities and for retrofits in terms of additional insulation or changes in the HVAC system. The analysis starts with the design of the building as given. These are table top evaluations and do not actually look at the operation of the facility; these are open loop evaluations. Modeling as it is used by the O&M engineer relates to actual performance of the facility. The power of the model is the ability to go back and compare the actual consumption with values predicted by the computer model; closed loop evaluation. The computer models are required for the following reasons:

a. The computer model provides the ability to establish an expectation, that is we can establish what we expect to save in terms of dollars or energy for a given facility. Then we have the ability to reconcile our expectation with actual consumption for the facility.

b. The modeling allows us to document those savings which we have trouble quantifying. Those would be savings from many of the reset type programs using outside air for free cooling or changing deck temperatures to optimize the energy consumption.

c. We have the ability to establish a meaningful history on the operation of our facilities.

When we are trying to evaluate the performance of some particular HVAC system we must have a method to quantify the performance. It has been estimated (no source) that perhaps 70% of the savings of an energy management system exists in the start-stop function, basically those functions of the time clock. I would submit to you that perhaps on the order of 50% of the savings to be attributed to an energy management system come from the start-stop. (I will defend the 50% hypothesis in an example later) The other 50% would be available through proper operation of the facility during equipment "on" time and proper maintenance of the plant providing the heating and cooling. We have two time related functions, either the equipment is off (when its off we are certainly saving energy) or on. Many buildings are in use 50% of the hours in the week. Other facilities, hospitals and other 24 hour a day facilities have no savings from start-stop but tremendous savings from analysis of the equipment, analysis of airflows and just a wide range of diagnostic features. The key here is to keep our minds receptive to the savings to be attained. If we assume from the onset that start-stop functions are the only savings to be realized then we shall be blinded to other opportunities.

The concept of the modeling of devices, predominantly chillers and boilers, can be divided into two methods. The first method would evaluate the device over some specific time period and analyze the total energy input and the total product produced (average performance). The second method applies to devices which can be analyzed by taking a "snap shot" of the actual device performance (instantaneous performance).

COEFFICIENT OF PERFORMANCE

The analysis over time, six or eight hours, allows us to analyze the results of the average performance. This actual performance is compared to the manufacturer's stated performance. A report should be generated to document the results. The actual performance can be stated as a percent of rated output. I prefer to think of this as a coefficient of performance (COP). The key here is to have your EMS monitor the energy in and the product produced and document the results.

REAL TIME EVALUATION

The second method of evaluation we have is a real time evaluation (instantaneous). Our EMS can display the results of the product (chilled or heated water) produced through a calculated point in our EMS software. The energy input can also be displayed through the use of a calculated point in our EMS. With current EMS software we have difficulty setting up a calculated point for a family of curves, such as that required for a chiller. However, choosing the chilled water supply at a nominal temperature and typical outside air temperatures will provide a first cut for evaluating efficiency. This type of model is good for a chiller or boiler under steady state conditions. We currently measure,on some of our chillers, the actual energy or cooling produced. (For a chiller the output is a function of water flow and temperature differential.) Additionally, with the real time value we can actually demonstrate through the calculated point again what percent of performance the device is actually achieving. The results with this approach have been very encouraging. We have identified chiller performance as low as fifty percent of rated output.

The problem with this approach is that some devices are not well suited to real time evaluation. Centrifugal chillers certainly are; boilers may or may not be. The conventional sensors we have on a boiler are inadequate to measure the performance of the heat transfer when the boiler has cycled to make up for losses in the thermal jacket. Also we could measure the stack temperature but I do not support over instrumenting the devices. As I indicated in the beginning of this paper my intent is to develop simple models -- energy in (electricity and gas) against the product produced (hot water or chilled water). We seek to avoid situations where we are not in equilibrium conditions.

The evaluation over time is much more useful to the O&M engineer as it provides two distinct benefits. First, we show the actual transfer of energy through the device and second you see the efficiency over time. A device may have good COP (transfer ratio) but may be oversized for the application. For example a very large boiler may work well but the losses may cause the percentage of usable heat to be low.

For those readers that have not had an opportunity to evaluate chillers or boilers and actually look at component performance, it is very difficult to understand that the device could be installed and actually be functioning significantly outside of design performance. Only after you actually make a number of site inspections do you begin to see the magnitude of the problem. Our mechanical design has sufficient safety factor to tolerate a large reduction in actual output. In fact output may degrade to 70-60-50% of capacity. However, if the original sizing of the device was in fact 200% of actual load then we will not know there is a problem until we reach only 50% of the output. (If the chiller is sized for 200% of the existing load the O&M engineer would not know there is a problem until the occupant finally cannot be cooled.) Even when we have technicians on duty, the attitude exists that says run the plant with more units on line (large plants with multiple units).

THE EXAMPLE

In this example, we have an administrative facility with approximately 30,000 square feet of office area. The three floors of this facility are served by a multi-zone air handler with eleven zones. The air-conditioning is provided by a 70 ton reciprocating air cooled water chiller. The building HVAC controls were converted to direct digital control (DDC) in 1987. As part of the new control scheme we installed a flow meter on the chilled water. The chilled water supply and return temperatures were also monitored. A power meter was installed on the chiller. (Because of problems with our power meter, manual readings were made on the power input to the chiller during our load tests.)

On the first warm day after the new sensors were installed we set about running a load test. With the vendor's performance data in hand and outside air temperature at 90 degrees F., we increased the load on the chiller with outside air by direct operation of the outside air dampers. (The economizer cycle for the air handler is also under DDC.) We had started our test with the building internal temperatures in equilibrium. The chilled water was stable at 45 degrees F. We increased the percentage of outside air until the chiller could no longer maintain the 45 degree supply temperature.

The chiller actually developed 37 tons of cooling. A check of the part numbers on the two compressors indicated they were down sized by 5 horsepower on the last replacement. Some interpolation of the vendor's data indicated we could still expect to produce approximately 65 tons. The refrigerant gas pressure was low on the suction side. Since this unit was nearly ten years old we suspected scaling in the chiller barrel.

After the refrigeration shop had chemically treated the chiller barrel with a mild acid we again performed a load test. This time we were able to get 45 tons. The chiller is now scheduled for replacement as 45 tons is only working at 70 percent capacity.

The insight to be gained from this example is this:

a. As the output from this chiller decreased the hours of operation for the HVAC system were extended. Shop personnel incorrectly attributed the longer hours (over the years) to the addition of numerous computer systems in the building.

b. Approximately 40 percent of the HVAC load is made up of pumps and the air handler. These are fixed loads and the related energy consumption increases in direct proportion to the extended hours of operation. The remaining 60 percent is the compressor. When the output from the compressor is one half, our cost of operation is twice the proper amount.

c. To satisfy the temperature requirements for this building we have extended the hours of operation for the HVAC equipment by approximately 40 percent. These extended hours allow the building to start under required temperature control in the morning and eventually drift out of control by late afternoon under the hot Texas sun. The additional annual cost for this mode of operation is approximately $3,000/year.

TEST INSTRUMENTS ON WHEELS

One of the questions that surely will be asked is how can I afford all the hardware to monitor all those diagnostic points on the HVAC equipment? The decision to monitor certain HVAC systems is not without cost. However, the current state of EMS hardware facilitates a very cost effective approach. Current EMS vendors allow the field panels to be dialed up by phone. A properly outfitted smart field panel can be configured with all the type of sensors you want to gather data. These sensors can include clamp on current transducers and volt meters (to measure electrical load), temperature sensors (to temperature differential), flow meters, solar energy meters or any measurement device you want to install for a temporary period. With this approach you have the ability to record all your data into your EMS. Also, you can decide which sensors provide the characteristic information you need to model any particular type of facility and then permanently install only those sensors.

MAINTENANCE PROJECTS

The most over looked area in existing facilities for energy conservation is in the retrofit option. When we analyze a large military base approximately 70 percent of the buildings are good candidates for many of our reduction schemes. Some buildings have a requirement for 24 hour a day operation, those buildings are disqualified from some of the savings from start-stop or temperature resets. Those are the facilities that receive the most benefit from schemes which look at the actual operational efficiency of the boiler, chiller plant, air handlers, water distribution systems or facility envelope.

RETROFIT PROJECTS

The model can help us replace systems too. By establishing a COP for each of our devices we can develop a prioritized list for replacing systems. This list allows our mechanical devices and facilities to be rank ordered from efficient to inefficient. Imagine having the ability to assign your limited personnel assets against your verifiable worst system. This approach also provides us the data to
defend the life cycle cost for our action. When we calculate return on investment for projects that re-insulate or change windows the term of investment is long, perhaps 15 years. Certainly one of the key ingredients to any energy management system is recognizing what the return on investment is in terms of the actual operation.

THE MOVING ENERGY TARGET

Every day more and more computer equipment is being added to our buildings and the energy intensity per square foot for some facilities is actually increasing. The Department of Defense tried to relate the amount of energy used at the military bases to the amount of facility area (total metered base consumption / total heated or cooled base area). The energy plan required a reduction in the energy use per square foot from the baseline year. This seemed like a method to establish a baseline for consumption, however, this has turned out to be not a very valid measure of energy reduction efforts. Certainly mission change is going to reduce or increase energy consumption. These changes are outside the scope of what can be accomplished by the energy management system.

THE COMMITMENT

We are required to provide a level of service to our occupants, efficiently. The current tools that are available to energy management systems are insufficient to affect those savings. Modeling is the only way that we can identify real energy waste. A very large portion of the potential savings that energy management systems can deliver will be identified through modeling techniques.

SAMPLE SPECIFICATION FOR ENERGY MODELS

XX. ANALYSIS PROGRAMS:

XX.1 General: The purpose of this section is to take the EMS data and create an EMS information system through analysis of the data. The analysis programs evaluate the EMS operation and indicate how well, quantitatively, we are achieving our goals. Also, the analysis programs evaluate how well the various end items controlled by EMS are functioning. This analysis can be accomplished by comparing actual performance to manufacturers performance data, for individual items like chillers and boilers. In addition an interface will be required for a commercial spreadsheet program to obtain data telemetered by the EMS. The spreadsheet program shall be resident in an IBM personal computer (PC) compatible machine. The data may be transferred to the PC by diskette or by direct computer connection.

XX.2 Program Inputs: This program shall use historical or current trend files for actual data inputs. The data for all programs covered under this section will be gathered under the following methods: All data telemetered by the EMS computer shall be automatically available for use as inputs to the analysis programs without having to be reentered by the operator. Where data is not available or unreliable the programs shall default to normal engineering values for the process being modeled. The operator may override any values of telemetered or default data.

XX.2.1 The EMS computer will retain historical information on all start-stop devices. This information will consist of the previous

31 days of equipment run time retained by day. And also the previous 13 months by month. Any data that is unreliable should be tagged to indicate the error. Each piece of equipment with start-stop capability will have a record of 31 individual daily run times and 13 previous monthly totals for run time. This information will be automatically available to all programs covered in this section.

XX.2.2 Spreadsheet Inputs: A EMS program shall be provided to facilitate the conversion of EMS telemetered data into a format compatible with commercial spreadsheet programs. (this section will include any specific spreadsheet program requirements, for example, if you use LOTUS 123 then require the program interface)

XX.3 Program Outputs: The output shall be available in tabular form and in bar chart/plot format. The results shall include the actual measured values, the computed/theoretical values and the difference between the actual and computed values.

XX.4 Energy/Dollar Saver Program: This program shall totalize the actual energy and dollars saved by the EMS. The program shall accumulate all savings resulting from the shut down of any equipment connected to EMS. The program shall be implemented by the contractor for all on/off type devices connected to the EMS. The operator shall be able to define a single device or any number of devices as a subset for this program. The savings shall be defined for any subset or the total as specified by the operator. The program shall keep track of two separate types of loads; fixed loads (such as pumps) and variable loads (such as chillers). The cost saving will be the product of the kwh saved times the kwh cost. The provision shall be made to show savings from a reduction of total kw demand. This program shall be available to run at specific times as required by the operator and/or automatically run on a weekly basis.

XX.4.1 Program Inputs:

a. Device identification (building,unit,point)

b. kw fixed (normal running load for constant consuming devices)

c. kw variable (minimum load for variable load devices)

d. kwh cost

e. kw cost (the incremental cost per kw from the power company)

XX.4.2 Program Outputs: MBtuh and dollars actually saved.

XX.5 Chiller/Boiler Evaluation Program: This program shall allow the operator to enter the manufacturers performance curve for discrete devices. The performance data shall be entered in increments of five percent of load values. The manufacturers performance data shall be compared to actual run time samples from current data or from historical files. The program shall compute the actual performance from actual temperature differentials and flows.

XX.5.1 Program Inputs:

a. Type of device

b. Logical system name (building,unit).

c. Operator entered performance data (Btu/kw, Btu/Kcf, Btu/gal...etc.) from zero to 100% of load from the manufacturers performance data.

d. Chilled water flow rate.

e. Chilled water entering temperature.

f. Chilled water leaving temperature.

g. Condenser water entering temperature.

h. Condenser water leaving temperature.

i. Condenser water flow rate.

j. Boiler water flow rate.

k. Boiler fuel flow rates.

l. outside air temperature.

m. Boiler pressure.

n. Boiler supply water temperature.

o. Boiler return water temperature.

XX.5.2 Program Outputs: Actual Btuh delivered and operating efficiency.

XX.6 Building Load Analysis Program: This program shall allow HVAC modeling of a facility for comparison to actual data. Primary emphasis is placed on proper sizing of the A/C plant and the heating plant. The program shall determine the following loads: ventilation, personnel, equipment, lighting, and transmission load through the facility envelope. Solar loads will be measured by sensors or entered by the operator. The load program should be modeled along the lines of the ASHRAE cooling and heating load method. Walls and roof sections shall be chosen by the operator from a selection of typical sections, similar to the ASHRAE program. The program will be used to simulate actual facility performance during some chosen day and for a specified period of at least 8 hours (after the internal temperatures have reached equilibrium). During the same period the total energy consumed by the facility will be recorded for comparison against the simulation. The result of this analysis shall be reported as the coefficient of performance for the facility, a value of 100% would indicate the facility HVAC load equals the computed HVAC load.

XX.6.1 Program Inputs:

a. All physical parameters required in the ASHRAE cooling and heating load calculation method.

b. Trend file of the actual inside and outside temperatures for the test period by quarter hour.

c. Period for test (in hours)

d. Solar load values (may be operator entered if not metered)

e. Chiller load values (Btu/hr)

f. Boiler load value (Btu/hr)

XX.6.2 Program Outputs:

a. Actual Btu load/hour.

b. computed Btu load/hour.

c. Coefficient of Performance (COP) for the facility during the test period. COP will be defined as (COMPUTED LOAD/ ACTUAL LOAD) X 100 percent.