USING EMCS DATA TO DOCUMENT and IMPROVE AIR HANDLER PERFORMANCE

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ABSTRACT

Traditionally, energy monitoring and control systems (EMCS) have been used, as the name implies, to monitor and control heating, ventilating and air conditioning systems, however, this paper will identify other benefits of an EMCS. Recording EMCS data on a periodic basis, typically once an hour, and analyzing it using a commercial off the shelf database program has proven to be an effective method to improve and document indoor air quality, energy savings; and provide continuous controls commissioning and performance diagnostics. Identification of system problems is the key to having an efficient and reliable EMCS. Once identified they can be scheduled to be repaired and system integrity will be maintained. Specific diagnostic and functionality programming include:

- Identifying leaking heating and cooling control valves
- Identifying simultaneous heating and cooling operation
- Identifying proper air side economizer operation
- Identifying faulty components
- Identifying cooling and heating system problems
- Calculating ventilation rates
- Calculating energy wastes and savings

Finally, using EMCS data in the non-traditional manner has saved thousands of dollars in operation and maintenance costs by providing a hands-off "tool" to diagnose air handler performance.

INTRODUCTION

As Government downsizing continues to be the norm for the future, the need to optimize and maximize performance from automation systems such as an EMCS will combat declining maintenance staffs and resources. The Facilities Department at The National Security Agency and Facility Dynamics Engineering developed this diagnostic methodology and applied it, with great success, to an EMCS controlling 36 house air handlers in a 1,200,000 square foot, multi-use Government building at Ft. Meade, Maryland. This program has identified over $200,000 of energy waste, during a three month period, by identifying faulty control components and poor control sequencing as previously mentioned. In addition, the program uses carbon dioxide and temperature measurements to calculate fresh air quantities to ensure ASHRAE 62-89 ventilation requirements are met.

The methodology presented in this paper allows building operators and engineers the opportunity to perform an examination on the health of their system and eliminate waste due to faulty controls components and /or programming. What is not covered in this paper, but has equal merit, is a reality check or optimization of mechanical systems. Typically, design calculations represent a conservative approximation of equipment size and performance. Based on extreme weather data and building usage, many heating, ventilating, and air conditioning (HVAC) systems operate at part load much of the time. Using EMCS data, building operators will be able to predict system part load performance and load trends; therefore, optimizing energy efficiency and system operation. For example, by recording static pressure and air temperatures and flow rates in a variable air volume distribution system, an operator could more accurately establish the static pressure requirement for the system which could save energy and improve occupant comfort.

This paper presents a methodology that can be used to improve air handler performance in any type of facility regardless of EMCS manufacturer.

METHODOLOGY

Data Capture

The first step is to capture the system data and store it for subsequent analysis. All EMCS systems allow establishing trends. Typically, trend data is captured and initially stored in the field control panel. Based on the memory available, the field panels allow a certain amount of data to be stored in the buffer. Typically, when you establish a trend, only the data stored in buffer is available. Older data is discarded to make room for the new data. Therefore, to capture the data for a long term, you must typically configure the EMCS to archive the data to disk. This is usually a separate step in the setup of the trend and sometimes a separate software module is required for this. When establishing the storage format, many options may be available. Frequently, the data is stored in "comma separated value" format (.csv). Other EMCS systems will allow you to select the format as a database or spreadsheet file format. Any of these formats are portable and can be used by almost any analysis tool. Be sure that you are storing the data in a contiguous data stream and not as formatted pages.

Relative to the quantity and quality of the points available, this obviously depends on what is connected to the EMCS and how well it is maintained. The more points available for diagnostics the better the analysis will be. In some cases, where desirable points are not monitored such as the energy consumption of a variable speed fan, you can take representative measurements and incorporate the characteristics into the calculations. It is also important to make sure the points are calibrated. In reality, one of the initial efforts will be to identify points that are in need of calibration. Towards this end, the initial analysis will be to look for values outside expected ranges. This will help identify where to start with the calibration effort. In our case, air handler performance data, such as control valve position, outdoor air damper position, coil leaving temperatures, air pressure, on/off status, outside air, supply air and return air carbon dioxide levels, and time and date stamps are recorded on an hourly basis. Data is archived in csv format. This data is then imported into a relational database where the data is processed. The data is imported and appended to a table in the database. Similarly, the outdoor temperature and humidity are recorded and imported into a table in the database.

Data Processing

One of the realities of dealing with large, 10 year old EMCS' such as the one at NSA is that there are some hours when the system is in non-response. Therefore, queries are executed which find and purge these bogus records so as not to invalidate the calculations. Sometimes individual points can go to non-response. Therefore, another series of queries cleans up the data.

User Interface

To facilitate application of filters such as for specific time frames, buildings, air handlers, temperature ranges, etc. forms are developed to provide the user-friendly interface. Forms can also be developed to provide a simple means for executing queries and generating reports. Assuming the analysis tool is being used routinely, development of these forms is recommended as it will save time and allow a user unfamiliar with database concepts to use the tool.

DIAGNOSTIC FEATURES

Various queries and reports are generated based on the processed data to document system and component characteristics, efficiencies, costs, and to identify problems or system anomalies. The following are samples of these analytical tools.

Leaking Heating and Cooling Control Valves

This diagnostic feature identifies leaking chilled water, steam and/or hot water heating coil control valves. Leaking valves are determined by recording valve position and coil entering and leaving air temperatures on a periodic basis and this information is entered in the database. These data are filtered and averaged to eliminate inaccurate recordings. Once into the database, the valve signal corresponding to a closed valve position is sorted along with the coil entering and leaving air temperatures. If the valve is closed and the entering and leaving coil air temperature difference is greater than three degrees will typically indicate a faulty control valve and should be replaced or calibrated.

Wasted energy costs for the heating system are determined by the following equation, which can be programmed in the database:

$$\text{energy cost (\$)} = (T_{\text{coil leaving air}} - T_{\text{coil entering air}}) \times \text{CFM} \times 1.1 \times \text{steam}_{\text{cost}} \quad \text{Eq. (1)}$$

where:

$T_{\text{coil leaving air}}$ = the air temperature leaving the coil
$T_{\text{coil entering air}}$ = the air temperature entering the coil
CFM = the air flow rate across the coil
$\text{steam}_{\text{cost}}$ (\$) = the energy cost to produce steam at the site

Wasted sensible cooling energy costs for the cooling system are determined by the following equation, which can be programmed in the database:

$$\text{energy cost (\$)} = (T_{\text{coil leaving air}} - T_{\text{coil entering air}}) \quad \text{Eq.(2)}$$

$\times CFM \times 1.1 \times 3.41 \times CHW_{eff} \times kwh_{cost}$

where:

$T_{coil\ leaving\ air}$ = the air temperature leaving the coil
$T_{coil\ entering\ air}$ = the air temperature entering the coil
CFM = the air flow rate across the coil
CHW_{eff} (Kw/ton) = the overall chilled water system and/or chiller efficiency
kwh_{cost} ($/kwh) = the cost for electric at the site

This formula can be programmed in the database to calculate energy cost or waste for each hour, using the local utility rate structure for a more accurate cost savings. In order to calculate latent energy wastes, additional points such as coil entering and leaving air wet bulb or humidity must be added to the air handler.

Some of the faults identified by this diagnostic feature include: misadjusted pilot positioners, dirt on valve seat, poor close off capability of actuators, wear on actuators, untuned and unstable control loops and improper stroke setup.

Simultaneous Heating and Cooling Operation

This diagnostic feature identifies simultaneous heating and cooling air handler operation. This diagnostic feature sorts the recorded values for both heating and cooling valve positions open at the same time. Equations (1) and (2) can be used to calculate energy savings.

Table 1 **Recorded EMCS Data for Simultaneous Heating and Cooling Operation**

Fl	C	Date	Time	Outside Air Temp	Pre-Heat Valve	Pre-Heat Temp	Mixed Air Temp	Cooling Valve Signal	Cooling Coil Temp	Reheat Valve Signal	Discharge Air Temp
2	5	3/1/9	0	51.1	0	54.9	70.62	25	56.7	60	70.5
2	5	3/2/9	0	52.0	0	58.8	70.53	25	57.7	40	64.7
2	5	3/3/9	0	49.9	0	58.5	70.67	25	57.1	16	64.7
2	5	3/4/9	0	36.6	0	46.0	69.79	25	55.4	31	64.1
2	5	3/5/9	0	45.1	0	50.7	70.48	25	57.1	54	68.9
2	5	3/6/9	0	47.4	0	53.9	71.11	25	57.4	28	64.7

Table 1 shows actual recorded EMCS data for an air handler. After looking at the data, it can be readily seen that both the reheat coil control valve and cooling coil control valve are operating at the same time. In the table, the symbols Fl (Floor) and C (Core) identify the location of the air handler in the database. In this case, the cooling coil was fixed to a 25 percent open setting to provide a flow bypass for a chilled water pump. Unfortunately, the pump was removed from the system a long time ago and the valve's minimum setting was never adjusted.

Other causes for faults identified by this diagnostic feature include: misadjusted pilot positioners, dirt on the valve seat, poor close off capability of actuators, wear on actuators, faulty programming, untuned and unstable control loops and improper stroke setup.

Table 2 **Simultaneous Heating and Cooling Operation Cost Savings**

Floor	Core	Date	Time	Mixed Air Temp	Cooling Coil Air Temp	Discharge Air Temp	kWh Wasted	Therms Wasted	Total Wasted Energy Cost
3	8	3/1/97	0	70.48	57.2	79.2	50	7.50	$4.25
3	8	3/1/97	1	71.89	58.4	78.5	45	6.77	$3.83
3	8	3/1/97	2	71.99	67.2	74.8	13	1.95	$1.11
3	8	3/1/97	3	66.03	56.1	81.2	58	8.72	$4.94

Table 2 illustrates recorded EMCS data for a specific air handler and calculates wasted energy cost due to simultaneous heating and cooling operation. This diagnostic feature identifies both operational and programming or logic errors. Operational errors include component failures, poor commissiong or set up, cooling and reheat valve calibration problems and human error.

Faulty Economizer Operation

This diagnostic feature determines faulty economizer operation on an air handler. It sorts the data for outside air temperatures between 40° F and 65° F, mixed air temperatures greater than 68 ° F and corresponding outside air damper signal or position. Table 3 shows real time EMCS data for this feature. The outside air damper signal ranges from closed (0 output signal) to full open (100 output signal). Looking at the first line of data in Table 3, the OA temperature is within the temperature parameters for economizer cycle operation on the air handler. For economizer operation the outside air damper should be open greater than 35%, therefore indicating faulty economizer operation. Another indication is that the mixed air temperature is greater than 68 ° F which shows that there is not much fresh air entering the air handler. This particular unit had poorly sequenced return, outside and relief air dampers causing the mixed air plenum to be pressurized by the return air fan, therefore allowing only a small amount of fresh air to enter the unit.

There are many reasons for an economizer cycle to be bypassed or disabled. Some of these include a history of freezestat nuisance trips, humidity problems, frozen and ruptured coils, causing operators disabled the economizer.

Table 3 **Recorded EMCS Data for Identifying Faulty Economizer Operation**

Floor	Core	Date	Time	Status	Outside Air Temp	Mixed Air Temp	Return Air Temp	Outside Air Damper Signal
B	2	11/9/96	0	On	48.4	70.5	76.2	35
B	2	11/9/96	1	On	48.4	70.5	76.2	35
B	2	11/9/96	2	On	48.1	68.5	76.2	35
B	2	11/9/96	3	On	48.2	68.5	76.2	35
B	2	11/9/96	4	On	46.0	68.5	76.2	35
B	2	11/9/96	5	On	45.1	68.5	76.2	35

Faulty Components

This feature identifies faulty or inaccurate control devices such as sensors requiring calibration. Table 4 shows that the mixed air temperature is greater than both the return and outside air temperatures. Since the mixed air is a product of the outside and return air streams it is physically impossible for the mixed air temperature to be greater than the return air temperature. Therefore, it can be concluded that the return or mixed air temperature sensor is out of calibration.

Table 4 **Recorded EMCS Data Faulty Component**

Floor	Core	Date	Time	Status	Outside Air Temp	Mixed Air Temp	Return Air Temp	Outside Air Damper Signal
3	3	10/29/96	0	On	49.6	76	71.4	-25
3	3	10/29/96	1	On	47.2	76	71.4	-25
3	3	10/29/96	2	On	46.3	76	71.4	-25
3	3	10/29/96	3	On	46.2	76	71.4	-25
3	3	10/29/96	4	On	46.2	76	71.4	-25

Heating and Cooling System Problems

Coil capacity problems can be identified using EMCS data. This feature, as shown in Table 5, sorts the data for cooling coil control valve signals greater than 100 or full open. The query in Table 5 identifies a potential flow problem or dirty airside or waterside coil, since the valve is full open and the air side temperature difference (Mixed Air Temp minus Cooling Coil Temp) is relatively small. The next step could be to group and average the valve signal to determine the frequency of struggling performance and plot those values to the corresponding outside air temperature. This would focus on where the problem lies. If its a flow problem in a two-way valve chilled water system, then some of the problems could be a plugged strainer, bad actuator or lack of a configuration management system for tying into the chilled water system, etc. If its a three-way valve distribution system, then some of the problems could be lack of flow or balancing problem, plugged strainer or dirty coils.

Table 5 **Recorded EMCS Data for Struggling Cooling System**

Floor	Core	Date	Time	Status	Mixed Air Temp	Pre-Heat Air Temp	Cooling Coil Temp	Cooling Cool Valve Signal
B	2	11/26/96	14	On	69	35	63.2	100.9
B	2	11/26/96	15	On	69	35	63.2	100.9
B	2	11/28/96	6	On	56	35	51.2	103.2
B	2	12/1/96	14	On	72	35	62.8	101.5

Documenting Ventilation Rates

This feature calculates the percentage of fresh air entering the air handler by using a temperature balance equation on the air streams. The outside, mixed and supply air temperatures are recorded by the EMCS and then imported into the database were the fresh air percentage is calculated. Table 6 shows actual recorded EMCS data for percentage outside air diagnostic feature. The same formula can be used with carbon dioxide readings in the same air streams. The percentage of outdoor air intake is given by the following equation:

$$\%OA = 100 \times \frac{(T_{ra} - T_{ma})}{(T_{ra} - T_{oa})} \qquad \text{Eqn. (3)}$$

where:

$\%OA$ = percent outdoor air intake

T_{ra} = temperature in the return airstream of the air handler

T_{ma} = temperature in the supply airstream of the air handler

T_{oa} = temperature in the outside airstream of the air handler

It should be noted, however, that this equation should be used with caution when return air temperatures and outside air temperatures are within 10°F of each other due to the inaccuracy of each sensor. Therefore, taking carbon dioxide measurements at the same points in the airsream and using the same equation would provide an accurate result.

Table 6 Recorded EMCS Data for Percent Outside Air Diagnostic Feature

Floor	Core	Date	Time	Outside Air Temp	Pre-Heat Coil Air Temp	Mixed Air Temp	Return Air Temp	% Outside Air
B	2	3/1/97	0	51.1	54.3	67.9	71.6	25%
B	2	3/2/97	0	52.0	56.9	68.2	71.7	29%
B	2	3/3/97	0	49.9	55.5	68.2	71.7	26%
B	2	3/4/97	0	36.6	47.3	67.3	71.7	21%
B	2	3/5/97	0	45.1	52.1	67.9	71.6	23%

SUMMARY

Using recorded EMCS data can be an extremely useful tool to identify efficiency and performance problems in HVAC systems. This paper discusses a methodology for identifying fault detection and diagnostic features for air handlers. The main objective for this methodology is to ***identify*** system and component problems so they can be repaired. As downsizing continues and less and less resources are made available to the building operator, the EMCS system will be a major tool for the operators to satisfy the needs of his building occupants. The payback of an EMCS system will be much greater than normal if its used to perform the fault detection and diagnostic features outlined in this paper.