Performance of Energy Management Systems

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Performance of building Energy Management Systems (EMS) has been controversial in several studies due to lack of measured energy savings, changes in building use or operation, other changes that simultaneously affect building energy use, equipment malfunction, or weather normalization. This study evaluated energy savings in 20 buildings that have EMS installed to control HVAC. The buildings were selected to have currently available EMS models, and an absence of other factors that would significantly affect energy use. Utility energy bills were corrected for weather variations.

The EMS saved an average 13% of energy use per building, with a range from -10 (a 10% increase) to 29%. As a group the buildings' energy use declined 15%. The 11 schools achieved an average 8.7% savings, while the 9 non schools saved 18%. As a group, the average payback was 4.2 years with a range from 2.3 to 42 years.

The study attempts to correlate energy savings with building type, age, climate, installers, sophistication of operators, and number of EMS functions. Energy savings were higher when building operators maintained energy use records, made fewer adjustments to or overrides of the EMS, and when the building had less after-hours use. Strong correlations were also observed between EMS cost and annual dollar savings and floor area.

Introduction

Energy Management Systems (EMS) are computer-based control systems that operate building equipment. They can be expensive and don't always save energy. There are many studies and papers on EMS, but only a few include measurements of actual energy savings (or increases). There are reports of successes and failures, but there is generally little information on why they succeed or fail. Possible explanations for both successes and failures include hardware reliability, operator training, vendor support, operator sophistication, inappropriate applications, and too much or too little system.

The purpose of this study is to document the performance of selected EMS and to correlate success and failure with system characteristics and operation. We found successful and unsuccessful EMS applications. Energy savings as a percentage of use and simple payback are taken as the primary indicators of success.

We studied 20 buildings and found savings from -10% to 29%. We conducted half-hour phone interviews with all building operators, and visited 12 of the sites. The amount of information we could obtain depended on the knowledge of the people we interviewed, which varied significantly. Sometimes there were plans; often they were out of date. In spite of difficulties, we collected a significant amount of information.

The approach was to enter the data in a spreadsheet program, perform linear regression analysis to determine correlations, graph the significant variables, and try to understand the results. We didn't always find what we expected, and even found a few surprises. In any case, the small sample size limits the strength of conclusions, but the results are interesting both for the correlations we found and those not found.

Method

The approach had five main parts that will be discussed in the following sections: 1) A literature search was performed to find what was known and what was missing; 2) twenty sites were selected for follow-up; 3) utility bills were obtained and normalized for temperature and days in billing periods to determine changes in electricity and gas use before and after EMS installation; 4) all building operators were surveyed about their systems and operation; and 5) the data was analyzed.

Literature Search

We found many papers and books on the subject, but only five attempted to evaluate EMS performance. A North Carolina study (Buchamm 1989) listed three attributes that would contribute to demand and energy savings: 1) an informed building manager who can balance load management with occupant complaints; 2) the building can tolerate temperature swings, such as due to setback or load shedding; and 3) large open or common areas that can accommodate load shedding. With these attributes and a focus on reducing demand, schools and groceries were rated as good candidates, while offices were rated poorly.

An EPRI study (EPRI 1986) surveyed 38 commercial building owners and estimated an average energy savings of 17%, with a range of 3% to 33%. Utility bills were not analyzed.

An unpublished Oregon Department of Energy report (Smith 1988) studied ten commercial and institutional buildings with EMS. Utility bills provided savings estimates. However, energy use was not normalized for weather, and 9 of the 10 buildings had other factors that may have affected energy use, including 4 facilities in which the EMS was not functional or operating properly. The study concluded that projected energy savings were generally not realized.

The Washington State Energy Office (Kunkle 1990) undertook an extensive follow-up of energy conservation measures implemented under the Institutional Buildings Program. The study identified HVAC measures to be poor performers in general, with EMS being the most likely not to achieve expected savings. Of 14 EMS installations, 3 experienced partial failure while another 5 had poor performance. Therefore, 8 of 14 EMS were unsatisfactory.

The Bonneville Power Administration commissioned a follow-up study (Majewski 1989) of 22 buildings that participated in their Institutional Buildings Program. The publication described the buildings in detail, including observations, recommendations and operator comments. The study also included predicted energy savings, but did not analyze utility bills to determine actual savings.

The conclusion of all these studies is that EMS in general do not meet expectations. Consequently, the purpose of this study is to use normalized utility bills to quantify energy use, and to find out more about why EMS installations succeed or fail.

Building Selection

We used the following criteria to select buildings that we hoped would provide the most useful information:

1. EMS should be recent or current models of well known manufacturers that would be relevant to potential EMS users. Nineteen of the 20 EMS selected were provided by six well-known manufacturers, and were installed between 1987 and 1990.

2. Energy bills should be available before and after EMS installation

3. EMS should be the only major building modification that might affect energy use, although minor modifications are acceptable. The intention was to reduce uncertainty in attributing energy savings to EMS, although most of the buildings had added computers and printers.

The selected buildings include 11 schools, 5 offices, 2 banks, and 2 dormitories. For analysis purposes, the sites were characterized as either schools or nonschools. Schools are indicated with an “s” in the tables and graphs.

Utility Bills

Most of the energy use history was provided by utility companies. Energy use was normalized to 30 day billing periods and plotted monthly over several years. Then monthly energy use was corrected for temperature variations from the base year before EMS installation for both heating and cooling months.

Temperature correction was accomplished by plotting monthly energy use for each fuel versus average monthly temperature obtained from NOAA. The graphs included both heating and cooling curves. Linear regression analysis was performed to determine building heat loss (or gain) coefficients as the slope of the graphs. Thus energy use after installation was corrected by multiplying the building heat loss coefficient by the temperature difference from the base year.

Survey

In order to identify why some buildings performed better than others, we developed a survey for building operators. Answers were recorded from telephone conversations with all building operators that averaged about one half hour, and on-site visits to 12 of the facilities. Questions fell into eight categories: 1) energy use; 2) EMS operators, including ability, interest, and other responsibilities; 3) building envelope, including area, glazing, and insulation; 4) building occupancy and operating schedule; 5) HVAC equipment; 6) EMS manufacturer, installer, and features; 7) EMS operation, including frequencies of manual override and setpoint changes, and problems; and 8) maintenance program.

The survey asked about problems encountered with the EMS systems. All 20 respondents encountered initial problems: 14 of the problems were corrected within 2 weeks; 3 within 2 months; and the final 3 within 1 year. Eighteen of the 20 buildings currently report no problems. Two building operators say they have an inadequate number of zones or automatic valves to provide the desired control. No attempt was made during the study to verify proper equipment programming or operation.

Results

The results are extracted from an unpublished masters thesis (Thatcher 1992). The purpose of the study was to determine EMS performance. We selected percent energy savings and simple payback as measures of performance. Percent energy savings is related to dollar savings, but simple payback better reflects economic performance. These measures will be compared with building Energy Use Index (EUI), area, and age, and EMS cost and number of functions.

In the following sections, building and savings data are summarized. Not surprisingly there is a lot of scatter. Our approach was to average the values and calculate the standard deviation to quantify the variation. Then we performed linear regression analysis using internal spreadsheet routines to identift correlations. Regression analysis determines a straight line that best fits the data points in a sample. The Coefficient of Determination (R^2) is a measure of how well the data fits the line. An R^2 of 1.0 means that all the data points lie on the best-fit line. An R^2 of 0.0 means that there is no linear correlation.

Building and savings values are summarized in tables. Graphs show the relationships between performance and building or system attributes. Data points are indicated by symbols, while the best-fit line is drawn for comparison. We believe that the combination of the quantitative R^2 value and visual representation in the graph provide the reader with the best understanding of the analysis.

Building Summary

The building data is summarized in Table 1 for all 20 buildings. The buildings are listed in order by the percentage of total energy savings, from highest to lowest. Energy use was converted to British Thermal Units (Btu). Total Energy Use Index (EUI) represents energy use per square foot of building area. The average and standard deviation was calculated from the values for the individual buildings with no attempt to weight the result by energy use or other variable. Given the high standard deviations for most variables, the average values have low statistical significance. The total at the bottom of the table is for the group as a whole, and therefore gives more weight to the larger buildings. The group total also would be more representative of program effectiveness because total benefits and costs are compared.

EMS can have a wide range of sensors, control points, and functions. A simple EMS might only provide time-of-day scheduling (time clock), night set-back, and optimum start functions. A more complex system might add optimum stop, zone control, duty cycling, load shedding, temperature reset, and economizer control. In order to determine if performance depends on complexity, we also obtained the number and type of functions each EMS offered.

Savings Summary

Energy savings is summarized as a percentage of energy use before EMS installation in Table 2. Cost savings were based on energy costs of $0.045/kWh (3,413 Btu) and $0.50/therm (100,000 Btu). EMS cost was obtained from the building manager, vendor, or state program manager. Payback is only calculated for the 17 individual buildings that had positive payback. Payback does not apply (NA) to the other 3 buildings that had an increase in total energy costs. The group of 20 buildings had a 4.2 year payback.

Building Type

There were 11 schools and 9 nonschools in the sample. For purposes of analysis there were significant differences between the way these groups are operated and performed. Results are summarized for all buildings, and for schools and nonschools as separate groups in Table 3. We found that the average of our sample of 11 schools: 1) were 9 years older; 2) were 23% smaller; 3) were 11% less energy intensive (EUI); 4) had the same number of EMS functions; 5) saved half the percentage of energy at 2.4 times the payback period; and 6) paid 22% less per square foot for EMS than the group of 9 nonschools.

We also looked for differences between all electric buildings and buildings that used both electricity and gas. However, with this sample, only one school was all electric, and only two nonschools used gas. Therefore, there was no additional information obtained by summarizing data for these two groups.

Table 1. Building Summary - All Buildings

#	Type	Age (years)	Area (ft^2)	Energy Use (mmBtu) Gas	Electric	Total	EUI (mBtu/ft^2)	Functions
1	office	17	15000	0	2025	2025	135	5
2	office	10	25000	0	4350	4350	174	7
3s	middle school	10	106000	3074	3127	6201	59	6
4	bank	18	6840	0	855	855	125	3
5	office	18	300000	14490	24510	39000	130	7
6	bank	16	60900	0	5706	5706	94	4
7	office	9	225000	9383	12938	22320	99	5
8s	elem school	31	33400	3941	528	4469	134	5
9s	elem school	16	24200	0	1597	1597	66	5
10	dorm	60	10700	0	663	663	62	3
11s	middle school	30	78500	5793	2214	8007	102	4
12s	middle school	30	66000	4501	1280	5782	88	5
13s	high school	40	95400	10876	2194	13070	137	5
14	office	11	36000	0	2232	2232	62	5
15	dorm	60	10700	0	681	681	64	3
16s	high school	20	58500	2410	2574	4984	85	3
17s	middle school	60	60600	4727	1339	6066	100	2
18s	elem school	53	42100	1819	653	2471	59	3
19s	elem school	25	34000	1639	1047	2686	79	6
20s	elem school	45	46700	4782	635	5417	116	5
Average		29	66777	3372	3557	6929	98	4.6
StdDev		17	71531	4029	5530	8817	32	1.4
Group Total		579	1336	67434	71148	138583	104	91.0

Percent Energy Savings

In the following five sections, percent energy savings is graphed as a function of age, area, EUI, EMS functions, and cost per square foot.

Building Age. While older buildings might have greater potential for savings, particularly in the envelope, we did not observe that correlation. Figure 1 indicates a weak correlation ($R^2 = 0.36$) of savings with age, but the newer buildings achieved higher energy savings. This may be because the schools were an average 9 years older than nonschools, and had lower energy savings. However, the correlation is too weak to draw conclusions regarding age.

Building Area. Figure 2 indicates that savings do not depend on building size ($R^2 = 0.027$). This is equally true for schools and nonschools,

Energy Use Index. Annual EUI (Btu/yr-ft^2) indicates energy use intensity. One might expect that a large EUI would indicate potential for energy savings. However, Figure 3 does not support such a conclusion. Linear regression analysis yields $R^2 = 0.169$, which is a weak correlation. Schools yield no correlation ($R^2 = 0.006$), while nonschools yield a strong correlation ($R^2 = 0.812$) as can be seen in Figure 4.

This is the only case in which a sub-group (nonschools) reflects a different correlation than the group of all buildings. The result that nonschools show higher savings in buildings with higher energy intensity might be explained by the buildings' flexibility to adapt to changes in operation. For example, 10 of the 11 schools had occasional or frequent after-hours occupation, and seldom or never changed setpoints. Seven of the 11 schools seldom or never manually overrode the EMS. As a result there was no significant change in energy use with occupancy in schools.

Table 2. Savings Summary - All Buildings

#	Energy Savings (%) gas	electric	total	Savings $	EMS Cost ($1,000)	Payback (years)	EMS Cost ($/ft^2)
1		28.9	28.9	7713	17.8	2.3	1.19
2		25.9	25.9	14833	35	2.4	1.40
3s	3.4	44.4	24.1	18839	59	3.1	0.56
4		21.4	21.4	2417	6.6	2.7	0.96
5	26.9	15.9	20.0	70921	156	2.2	0.52
6		18.8	18.8	14132	35	2.5	0.57
7	34.5	4.7	17.2	24210	85	3.5	0.38
8s	25.7	-15.8	20.8	3959	32.3	8.2	0.97
9s		15.2	15.2	3191	20.5	6.4	0.85
10		11.0	11.0	959	10.2	10.6	0.95
11s	14.1	2.5	10.9	4807	65	13.5	0.83
12s	11.1	6.2	10.0	3552	24.3	6.8	0.37
13s	10.8	3.0	9.5	6748	46.7	6.9	0.49
14		9.4	9.4	2753	8.7	3.2	0.24
15		5.7	5.7	508	10.2	20.1	0.95
16s	8.7	1.8	5.2	1670	30.8	18.4	0.53
17s	13.9	-13.1	7.9	970	42	43.3	0.69
18s	1.2	-2.6	0.2	-117	5.35	NA	0.13
19s	7.3	-5.8	2.2	-212	26	NA	0.76
20s	-10.4	-10.3	-10.3	-3337	28	NA	0.60
Average	12.3	8.3	12.7	8926	37.2	9.2	0.70
StdDev	11.7	14.6	9.5	15801	34.0	10.1	0.31
Group	16.7	13.0	14.8	178516	744.5	4.2	0.56

Nine nonschools had an average energy savings of 17.6%. Five nonschools had occasional or frequent after-hours occupation with below average savings of 14%. However, the 4 nonschools that seldom had after-hours occupation saved 22%. Seven of the 9 nonschools never or seldom overrode the EMS, and the 4 that never or seldom changed setpoints saved 24% of total energy used. Therefore, nonschools had less after-hours occupation, were better able to adjust the EMS for occupancy, and achieved more of the potential savings.

EMS Functions. One might expect that a more sophisticated EMS with many functions would produce higher energy savings. While the best-fit line in Figure 5 does indeed show this trend, the scatter is great. The correlation is too weak ($R^2 = 0.128$) to support such a statement.

EMS Cost. Certainly one would hope that an expensive EMS would yield higher savings. EMS cost per square foot is shown in Figure 6. While the trend does support

Table 3. Building Type Summary

Building Type	Sample Size	Age (years)	Area (ft^2)	EUI (mBtu/ft^2)	Number of Functions	Energy Savings	Payback (years)	EMS Cost ($/ft^2)
All	20	29	66,777	98	4.6	12.7	9.2	0.70
Schools	11	33	58,673	93	4.4	8.7	13.3	0.62
Nonschools	9	24	76,682	105	4.7	17.6	5.5	0.80

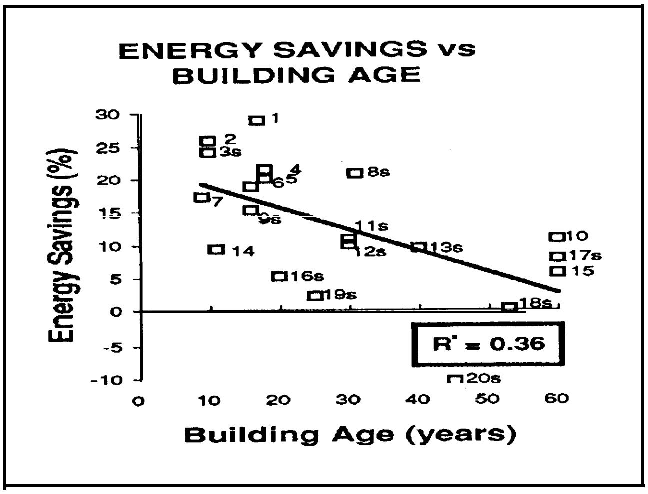

Figure 1. Energy Savings vs Building Age

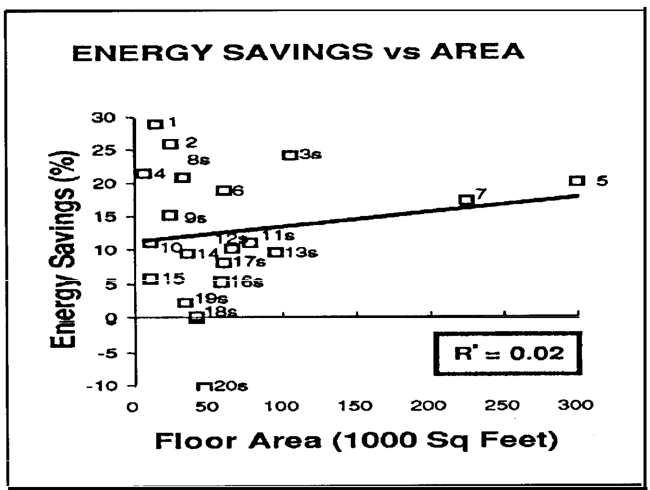

Figure 2. Energy Savings vs Bulldmg Area

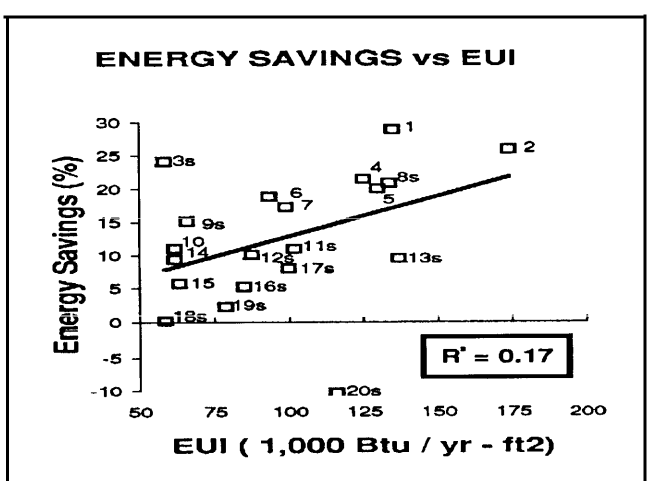

Figure 3. Energy Savings vs EUI

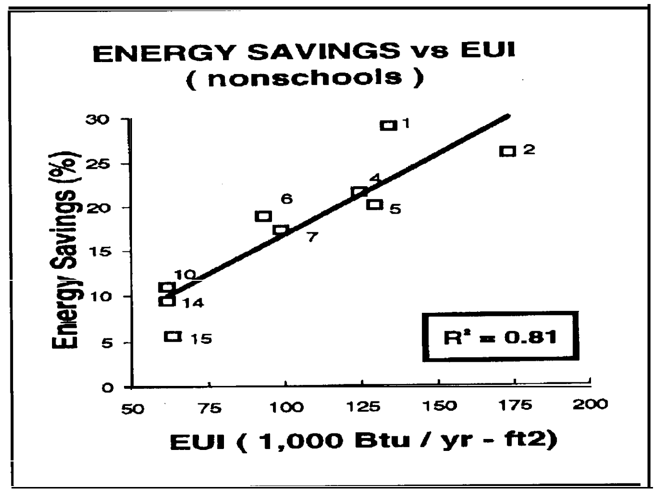

Figure 4. Energy Savings vs EUI (Nonschools)

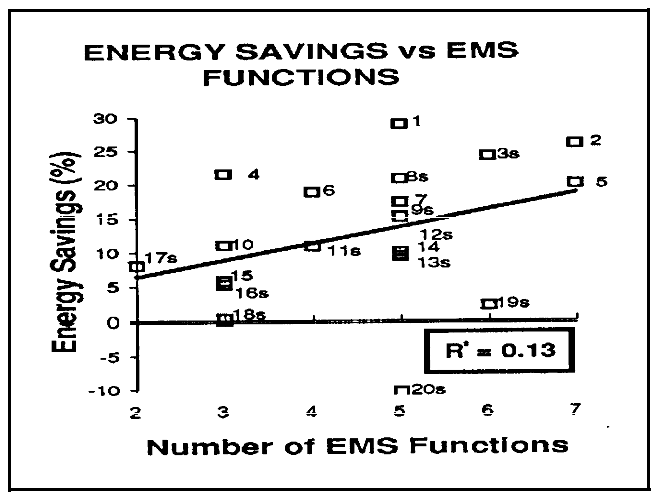

Figure 5. Energy Savings vs EMS hunctlon

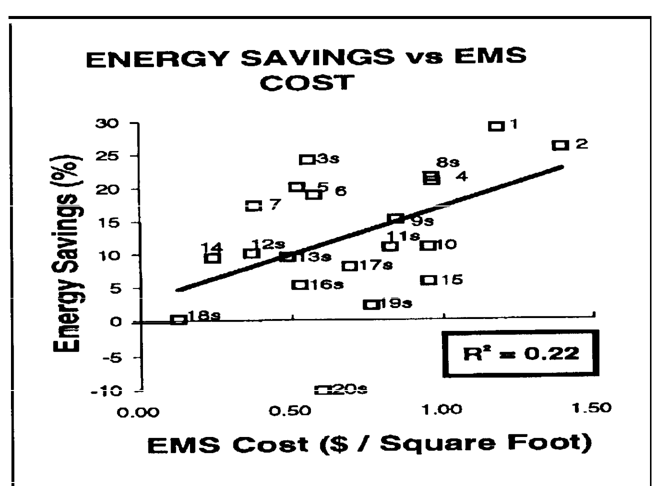

Figure 6. Energy Savings vs EMS Cost

that wish, there is significant scatter. The correlation is too weak ($R^2 = 0.22$) to state that more expensive systems result in higher savings. The same is true for schools and nonschools. The correlation is even weaker ($R^2 = 0.067$) when one considers total EMS cost, not normalized to building area.

Simple Payback. We chose to use simple payback as an economic indicator for this study rather than life cycle cost for several reasons. It is a simple and effective tool to compare many buildings with different types of equipment and control systems, different lifetimes, and different economic parameters, such as discount rate. Life cycle cost and cash flow analyses are better for making decisions for individual buildings.

Simple payback varied from negative for 3 buildings to 43 years. The average payback for the 17 buildings with positive payback was 9.2 years with a standard deviation of 10.2 years. When we summed the dollar savings and EMS cost for all 20 buildings as a group, we calculated the payback to be 4.2 years for the group. The reason the group payback is significantly lower is that the two largest buildings (both offices) had 2.2 and 3.5 year paybacks.

Payback was not correlated with area, EUI or EMS cost per square foot in our study of 20 buildings as shown in Table 4. The medium correlation with age is consistent with Figure 1 that shows that the newer buildings (nonschools in this study) performed better. The medium correlation with the percent of energy savings is not surprising, except perhaps the weakness of the correlation.

Table 4. Simple Payback Correlations

Attribute	R2
Age	0.513
Area	0.032
EUI	0.043
Savings%	0.369
Cost/ft^2	0

Financial Analysis. The preceding analysis considered the effects of building or EMS attributes on performance. In this section we consider how EMS cost relates to EMS complexity, building area, and cost savings. Bells and whistles (a.k.a. functions) generally cost more, but the computer modules are only a part of the system. When we looked at total system cost, we found only a weak correlation ($R^2 = 0.237$) with the number of functions offered.

Building Area. One would expect EMS cost to increase with building size because more sensors and actuators are required, as well as potentially more distributed control modules. Therefore, we were not surprised to find the strongest correlation of our study ($R^2 = 0.889$). EMS cost depends most strongly on building area as shown in Figure 7.

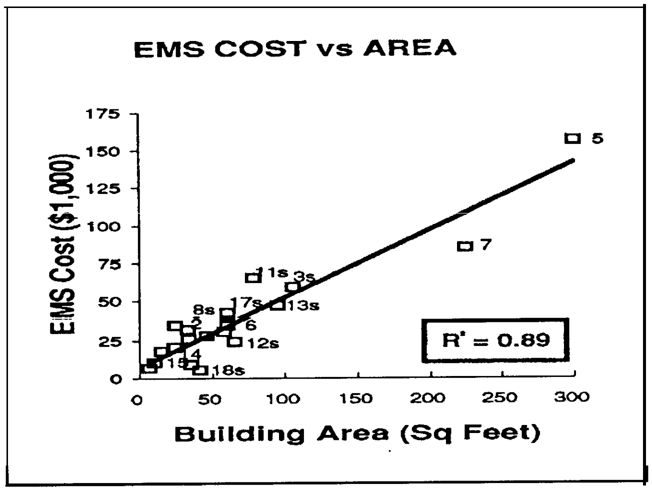

Figure 7. EMS Cost vs Building Area

Cost Savings. Here we find the dilemma of the chicken and the egg. Does higher EMS cost yield higher cost savings? Or does the potential for higher cost savings yield higher system costs? In either case a strong correlation ($R^2 = 0.815$) does exist as shown in Figure 8.

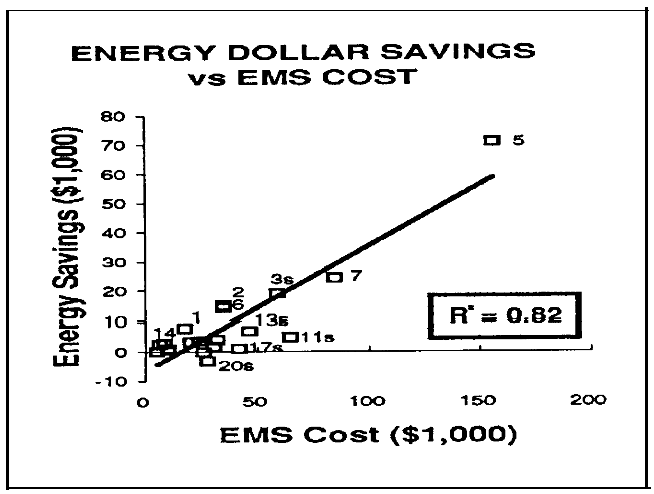

Figure 8. Energy Dollar Savings vs EMS Cost

Building Envelope. The survey asked questions about the building envelope, operator sophistication and responsibilities, EMS installation, problems, operation, and support. We then compared average savings of groupings based on the results of the survey:

Windows. Savings were higher in buildings with double glazed windows, but all of the schools had single glazing and lower savings. There was no significant difference between the 4 nonschools with single glazing and the 5 with double glazing. There was no correlation ($R^2 = 0.029$) between savings and window area as a percentage of wall area.

Insulation. Insulation was categorized as yes, partial, or none, with no attempt to quantify the amount of insulation. Eight buildings with insulation had the highest energy savings (19%), but six of the 8 were nonschools. Three uninsulated buildings had the next highest savings (12%), while 9 partially insulated buildings had the lowest savings (7%). No conclusions were drawn.

Building Operation. Previous Controls. Some of the buildings had major HVAC equipment controlled by time clocks prior to EMS installation. One might expect greater savings in buildings without previous controls. However, savings were higher (22%) for the 4 nonschools with time clocks than for the 5 without (14%). There was no significant difference for the schools. The existence of time clocks may be indicative of a higher level of operator sophistication.

Energy Consumption Records. Recording energy use implies a high level of interest in energy consumption. Energy savings for 5 schools that maintained records were three times (300%) as high as for the 6 schools that did not maintain records. For nonschools, those that maintained records saved about 20% more.

Summary

Data was averaged for the 20 individual buildings to obtain the average and standard deviations shown in Table 5. When the buildings were treated as a group, the larger buildings with higher energy use had more weight on the group average, also shown in Table 5 for comparison. The simple payback was averaged only for the 17 buildings that had positive payback, while the group average included all twenty buildings.

EMS performance in general was not correlated or only weakly correlated with expected building or system attributes, such as building age, area, Energy Use Index (EUI), and EMS functions and cost. The strongest correlations based on linear regression analysis between four variables and related building or system attributes are summarized in Table 6. The remaining correlations considered in the study were weak ($R^2 < 0.4$) except for payback versus building age ($R^2 = 0.513$).

Table 6. Significant Correlations

Variable	Attribute	Correlation (R^2)
EMS Cost	Area	0.889
Cost Savings	EMS Cost	0.815
Energy Savings %	EUI (nonschools)	0.812
Cost Savings	Area	0.762

Conclusions

We draw the following conclusions from the data presented in the summary section and from the results of the building operator survey:

- **Energy Savings.** EMS do save energy, but not in all cases. EMS reduced energy use in 20 buildings an average of 12.7%, or 14.8% taken as a group, Eleven schools saved 8.7% while 9 nonschools saved 17.6%. Energy use increased 10% in one school, and energy costs increased slightly in two other schools.

Table 5. Summary

Type	Age (years)	Area (ft^2)	EUI ($mBtu/ft^2$)	Savings (%)	Savings ($)	EMS Cost ($)	EMS Cost ($\$/ft^2$)	Payback (years)
Average	29	66,777	98	12.7	8,926	37.2	0.70	9.2
Std Dev	17	71,531	32	9.5	15,801	34.0	0.31	10.1
Group	29	66,777	104	14.8	8,926	37.2	0.56	4.2

- **Simple Payback.** Average payback for the 17 buildings with positive payback was 9.2 years. Payback for the group of all 20 buildings was 4.2 years.

- **EMS Cost.** EMS cost is strongly correlated with building floor area, with an average unweighed cost of $0.73/ft2. The overall average cost for the group of buildings was $0.56/ft^2.

- **Energy Records.** Schools that maintained energy use records had significantly higher savings than schools that did not.

- **EMS Adjustments.** Nonschools that seldom or never had changes to EMS setpoints or control parameters had significantly higher savings than nonschools with frequent changes.

- **After-Hours Occupancy.** Nonschools that seldom were occupied after normal working hours had significantly higher energy savings compared to those frequently occupied.

The small sample size of 20 buildings limited the number of building attributes that could be correlated with EMS performance. Also, the small sample size contributed to statistically large standard deviations.

There are other factors that affect building energy use, such as ventilation, infiltration, architecture, and people. Building occupants and operators both affect energy use and savings, but people are perhaps the most difficult to analyze. Further study with more buildings and more time on-site to optimize programming and verify proper equipment operation would better identify factors affecting EMS performance.

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