A Commissioning Cost-Effectiveness Case Study

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A 75,000-square foot office building in the Pacific Northwest participated in a utility DSM program. The building was retrofitted with ECMs designed to use an estimated 30% less energy than a baseline building that meets Model Conservation Standard (MCS) code. The building was simulated with DOE2.lC and the model was tuned using monitored data and site weather. This building was unique in the program because it was commissioned. The commissioning was undertaken after the retrofit was completed and the building was occupied. Commissioning uncovered errors in ECM installation and poor maintenance practices. Some errors were corrected; most fixes were rejected as too expensive. In the final analysis, five out of eight installed measures were found to be not cost effective.

The tuned model was modified to simulate the ideal operation of the ECMs. The energy savings lost by not initiating commissioning at the project design phase are calculated. It is assumed that faulty measures would have been corrected during construction. The costs of such commissioning are estimated using the post-occupancy commissioning experience.

This paper discusses cost-effectiveness screening using three approaches. 1) The cost-effectiveness of the ECMs is recalculated with predicted energy savings between the *ideal* model and the MCS baseline. 2) The cost-effectiveness of commissioning *as a measure* is derived from the energy savings between the tuned model and the ideal model using the commissioning cost estimate. 3) The third approach looks at the ECMs and commissioning as a package and derives cost-effectiveness based on the energy savings between the baseline and ideal models and the incremental ECM cost plus commissioning costs.

Introduction

Background

This paper presents a case study of a building that participated in a large-scale research and demonstration project developed by a Pacific Northwest utility. The project was initiated to determine whether commercial buildings can be designed and constructed to use at least 30% less energy than estimates for baseline buildings that are designed to meet the current regional model energy code. The building was extensively monitored and modeled to accurately analyze the energy savings due to individual energy conservation measures (PECI, 1993). This building was also commissioned three years after occupancy. Commissioning uncovered a variety of problems in the building. Some of these were easily fixed but most were rejected as too expensive. The energy savings of the ECMs were calculated for the building with equipment as actually installed and operated. Due to disabled or malfunctioning measures, the building energy savings did not approach the design phase estimates of 40.1%. Final annual electric energy savings for the building were calculated to be 25.1%. This represents a reduction in the building's EUI from 38.1 kBtu/sf for the baseline building to 28.7 kBtu/sf.

Scope

Building commissioning is a systematic process of assuring by verification and documentation, ideally from the design phase to post-occupancy, that all building systems perform in accordance with the design intent and the owners' needs. Clearly the systems in this building fell short of the design intent. The question was asked, "What would the energy savings have been if the building had been commissioned from the design phase?"

This paper presents the extension of the original study to answer this question. In doing so the cost effectiveness of the building can also be addressed. The DOE2.lC model of the building, which had already been *tuned* to be an accurate simulation of the building as it was actually built and operated, was modified to fix the major problems discovered during post-occupancy commissioning. Commissioning costs are derived from the commissioning agent's experience in the building. The revised energy savings and commissioning costs are used to evaluate the economic benefits of building commissioning.

Building Description

General

The building is a remodeled, 92,000 gross square foot, historical building located in the downtown area of Portland, Oregon. A 1987 renovation added a two-story penthouse and rooftop terrace to the original seven-story building. The lower level of the building was converted into a parking garage. The ground floor and mezzanine are retail space, while the remainder of the building is made up of office space.

Energy Conservation Measures

Upgraded Lighting. Office area lighting consists mainly of three-lamp, 24-cell, parabolic fixtures containing either 32 Watt, T-8 fluorescent lamps with energy saving ballasts or 34 Watt, T-12 fluorescent lamps with energy saving ballasts. The T-12 lamps were included in the lighting design because the lamps and fixtures had already been purchased by the building owner.

The retail areas use low voltage, 55 Watt, MR-16 lamps or 130 volt, 50 Watt halogen lamps in track and recessed fixtures. Most of the downlighting and accent lighting in the building contains plug-in style compact fluorescent lamps. High-pressure sodium lamps provide lighting for the parking garage.

Occupancy Sensors. Occupancy sensors were used throughout the building in restrooms, conference areas, storage rooms and many offices. The sensors collectively controlled a connected load of 12,745 Watts, which is 11.5% of the total connected lighting load.

Envelope Measures. The walls are constructed of heavy timbers and 16-inch to 20-inch thick brick with a plaster finish. This basic wall structure was furred out and R-7 batt insulation installed on all perimeter walls and finished with gypsum. The original roof insulation was increased from R-11 to R-30. Two-inch wide horizontal reflective blinds were installed on the third through ninth floor windows.

Hydronic Loop Heat Pump System. A closed-loop, water-to-air heat pump system provides conditioned air to the building. A 30-ton air-to-water heat pump, located in the parking garage, provides heating for the loop, and a cooling tower provides cooling for the loop. When the 30-ton heat pump fails to maintain the required loop temperature, a gas-fired boiler supplies auxiliary heat to the loop. A schematic of the main HVAC system components is shown in Figure 1. A mixture of console, horizontal, and vertical type unitary water source heat pumps are located in the tenant spaces. There are 2 to 23 heat pumps per floor, with a total of 93 for the building. The average COPS for the units are 3.76 for heating and 3.43 for cooling. The COPS were taken from manufacturers' product sheets using entering water temperatures of 85F for cooling and 70F for heating and leaving water temperatures of 95F for cooling and 63F for heating.

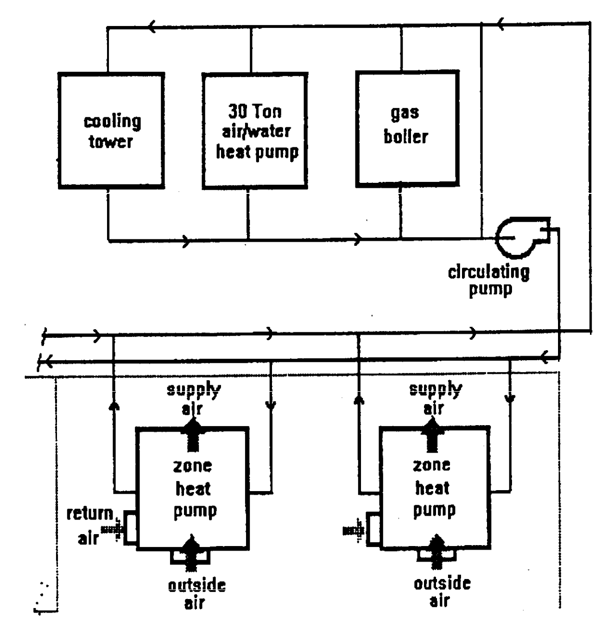

Figure 1. H VAC Schematic

Energy Management Control System. An energy management control system (EMCS), which is part of the fire, life safety and security system, is capable of monitoring time of day control for lighting and HVAC equipment. Night low-limit thermostats should control temperature during unoccupied hours.

The EMCS was also intended to control the building's lighting system, however, few of the control points were connected and the measure was only partially implemented.

Other Measures. The garage exhaust fan is a two-speed unit with carbon monoxide sensors and controls. It runs at low speed twenty-four hours a day, except when the carbon monoxide levels exceed a preset limit. Monitoring showed that the fan very rarely ran at high speed.

In keeping with the historical nature of the building, operable single-pane windows were retained. These were weatherized and fitted with closure devices to minimize infiltration.

Three-step daylighting controls were installed to control perimeter lighting on the north and west sides of the third floor.

DOE2.1 Building Simulation and Model Tuning

This project combined extensive, long-term monitoring with sophisticated modeling techniques. Tuning is the process of adjusting a simulation to match monitored data. For this project, the model was tuned for each end use and the building as a whole on both a monthly and a seasonal basis (Kaplan and PECI, 1992). The model goes through several iterations until it agrees with the monitored data within some stated tolerances. These tolerances were ±30% for monthly end-use consumption and ±20% for seasonal end-use consumption.

By providing extensive data to properly tune the model, actual building performance can be measured against simulated baseline performance. Also, once tuned, the model can better determine the interactive effects and the cost effectiveness of individual ECMs as they actually operate in the building.

The standard tuning methodology (Kaplan and PECI, 1992) included the following main tasks:

1. Standardize an as-built model by inputting the building schedules as derived from the monitored data. Separate weekday and weekend schedules were used for each month. Data were averaged from hourly readings over the month.

2. Input the weather data monitored at the building site. Site weather data included outside temperature, outside relative humidity, wind speed and horizontal insulation. Additional details of the weather packing can be found in the tuning methodology report (Kaplan and PECI, 1992).

3. “Tune” the standardized model to the monitored data.

4. Replace the site-specific weather data with statistically valid average weather data (TMY) for the site.

5. Derive the “tuned baseline” model by subtracting all ECMs from the tuned TMY model.

6. Individually model each ECM against the tuned baseline.

7. Calculate the levelized cost for each ECM.

Over 225 channels were monitored hourly in this building. The energy consumption of each end use was monitored. The monitoring also provided detailed information on loop temperatures and flow rates, space temperatures, fan and heat pump duty cycles and outside air flows. Detailed lighting and receptacle schedules were entered into the model from monitored data. The end-use categories to be tuned were selected in accordance with the monitoring categories and the limitations of the DOE2.1 C software.

Baseline

The baseline building is defined as the building that would have been built if the Model Conservation Standards Equivalent Code (February, 1985) had been observed and no funded or non-funded ECMs that exceed code had been installed. The baseline model has the same footprint, architectural features, occupancy and operating schedules as the tuned model, unless any of these aspects is modified by an ECM.

Model Tuning Results

The tuned model showed a good correlation with monitored data. The building heating and cooling energy could not be separated since the monitored data was not differentiated. The results for the unitary heat pumps are within 20% for every month and 15% seasonally. The total HVAC was within 19% for every month and 8% seasonally. The cooling tower, loop circulation pump and 30-ton heat pump were difficult to tune individually, but tracked the monitored data well as a system. Figures 2, 3, and 4 are graphical representations of these results.

Building Commissioning

The object of the commissioning portion of this building study was to test a set of building commissioning guidelines and to try to determine the effect of commissioning on the building’s energy performance. According to the guidelines, the ideal commissioning effort would begin during the predesign phase of the construction process with the selection of a commissioning agent (CA). During

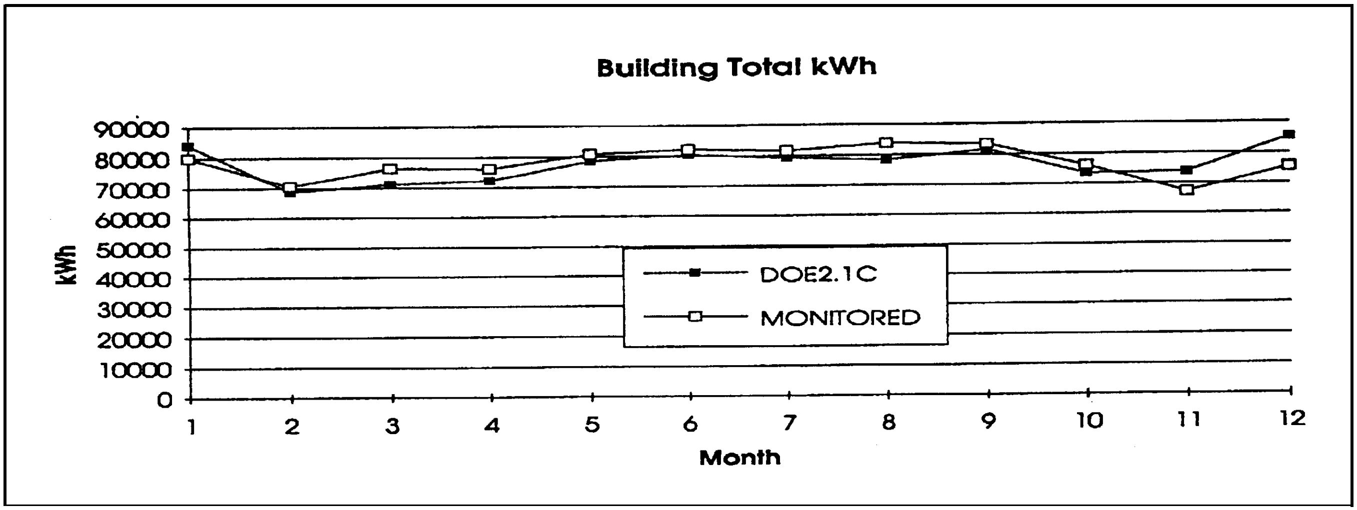

Figure 2. Building Total Electric Use: Monitored Data vs. D0E2.lC Simulation with Site Weather

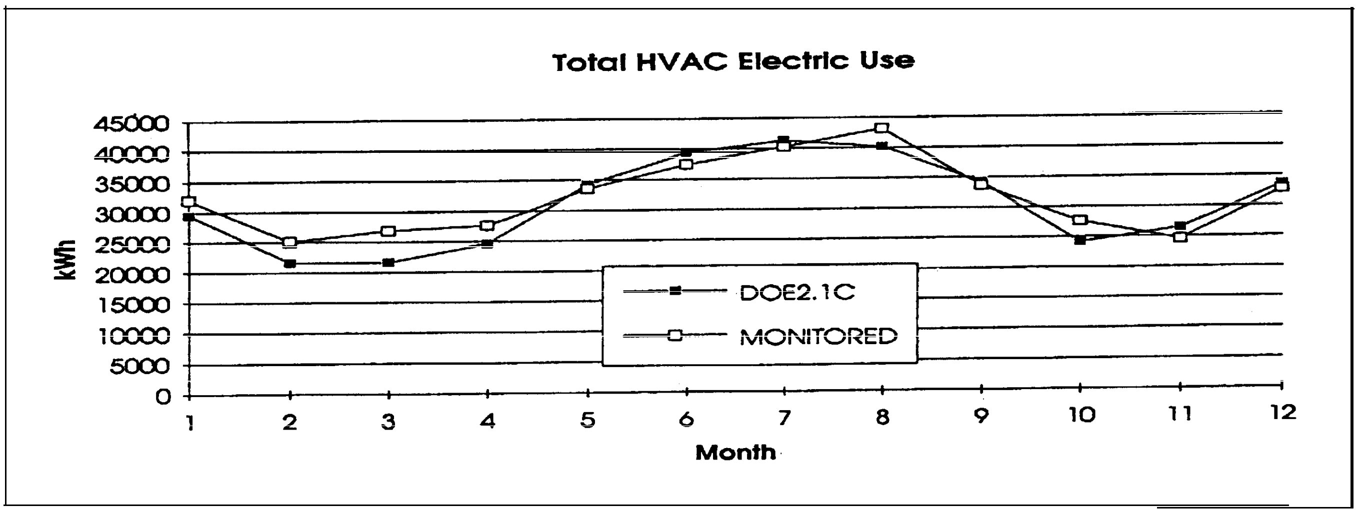

Figure 3. Total HVAC Electric Use: Monitored Data vs. DOE2.lC Simulation with Site Weather

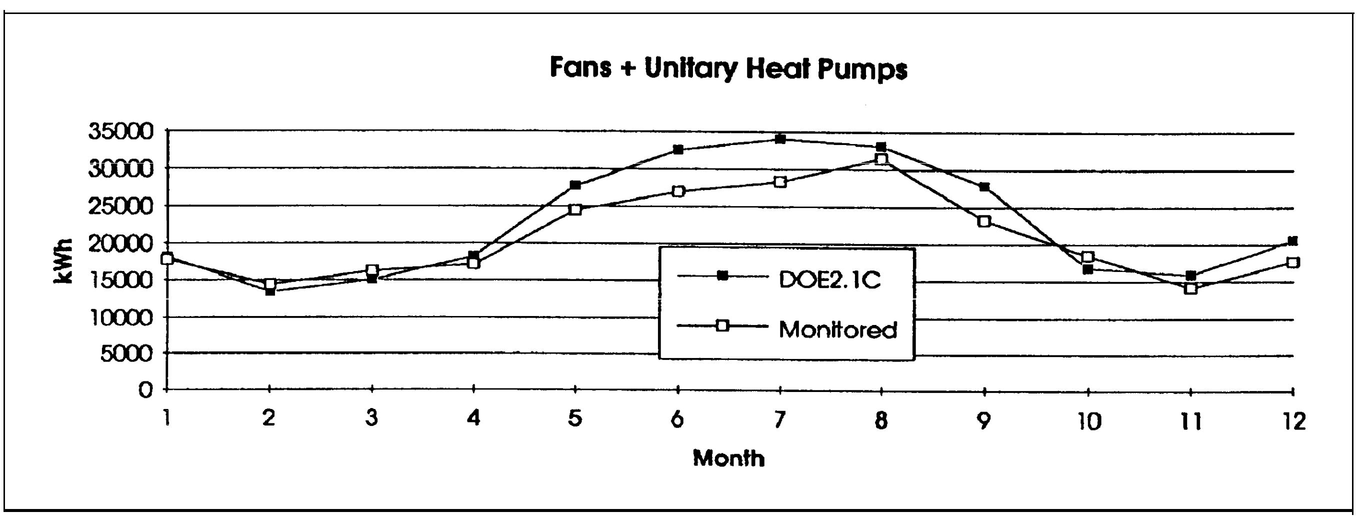

Figure 4. Unitary Heat Pump Electric Use: Monitored Data vs. DOE2.lC Simulation with Site Weather

the design phase the CA would attend design team meetings, gather and review the design intent documentation, and identify potential ECM performance problems.

Because the building renovation was completed and the building occupied prior to the decision to use it as a case study, the commissioning process focused on those commissioning activities that normally take place during the acceptance phase. They are as follows: performance testing of the utility-funded energy conservation measures and the systems which affect those measures, development of the operation and maintenance manual, and an educational session for the facility manager. To a limited extent, design intent documentation was reconstructed.

The following is a list of the funded conservation measures and related systems that were tested:

- Carbon monoxide monitor and the related exhaust fan
- Hydronic heat pumps, cooling tower, circulating pumps and related motors
- Back-up 30-ton heat pump
- Lighting controls
- Energy management control system
- Back-up gas boiler

Commissioning Findings

The commissioning process revealed a range of problems regarding documentation, operating and maintenance practices, equipment and system performance, and equipment installation. Details of this post-occupancy commissioning can be found in the commissioning report (PECI, 1992), which is available from the sponsoring utility. The impact of deficiencies on overall building energy performance varies. For this cost effectiveness study, only the directly quantifiable deficiencies and fixes related to the ECMs were considered. For instance, the effect of poor maintenance practices, such as dirty coils and clogged strainers, on the performance of the water loop heat pump system are elusive to measure or to model. In contrast, the effect of a lighting control, which sweeps off lights in the building at designated times, on lighting end use is easily demonstrated by monitored data.

Carbon Monoxide Monitor and Garage Exhaust Fan. Performance testing revealed that the sensor for the carbon monoxide monitor was out of calibration. Also, the time-delay switch in the CO monitor was not enabled, allowing the fan to short cycle. Both were corrected before performing the functional performance test. The measurements of power draw by the fan motor showed that the motor was probably incorrectly sized and was operating at about 20% efficiency at the low speed. This was not corrected.

Hydronic Heat Pump System and Related Equipment. The only HVAC equipment integrated into the energy management control system was 41 unitary heat pumps out of the total of 93. The remaining HVAC equipment is controlled by other means, causing scheduling conflicts. The EMCS program for scheduling run times for the unitary heat pumps was disabled. Two-speed fan controls in the unitary heat pumps either did not function as designed or were not installed. In addition, the 30-ton heat pump had a refrigerant leak.

The EMCS program to control the connected heat pumps was enabled and tested on a trial basis during the commissioning period. The 30-ton heat pump was properly charged with refrigerant, but this was not a lasting repair.

The performance testing also found that the efficiency of the backup gas boiler was below specifications. The manifold pressure was raised to the manufacturer's recommended pressure which slightly increased the efficiency.

Lighting Control. A lighting sweep, using local override control switches, was installed as part of the EMCS. Two control points were added to the EMCS to accommodate the lighting sweep, one point for the 3rd floor and one point for the 6th through 9th floors. Prior to the lighting sweep, tenants were responsible for turning off the lights on floors 3, and 6 through 9. As a result the lights were often left on all night and on weekends. The remaining floors were not considered for the lighting sweep because they are controlled either by time clocks or occupancy sensors.

Commissioning Simulation

Building commissioning uncovered a number of problems. Some were corrected, but many were rejected as too expensive. This study focused on three problems that directly affected the performance of identified ECMs and could be quantified and modeled with data from monitoring or performance testing. The *ideal* commissioned building was simulated using the tuned model and making adjustments based on this data. The assumption was made that if commissioning were begun at the design stage, these problems would have been discovered prior to acceptance and corrected by the contractors. The specific "fixes" simulated are 1) the institution of lighting sweep control on five floors and night setback for all unitary heat pumps, 2) repair of the refrigerant leak in the 30-ton heat pump which was then assumed to operate per the manufacturer's specifications, 3) proper sizing of the garage exhaust fan motor.

Commissioning Costs

From our experience in commissioning the building as a research project, we felt that the costs of commissioning from the design phase could be realistically estimated. The commissioning of this building went smoothly with good cooperation among all members of the commissioning team. The owner was supportive and appreciative of the commissioning process, although reluctant to implement all of the recommendations due to financial constraints.

For the purpose of this case study, it is assumed that commissioning would focus on the mechanical systems, including the EMCS. The scope of the commissioning includes the following components:

- Writing of the overall commissioning plan
- Scoping meeting
- Gathering of design intent documentation
- Writing performance test plans for conservation measures and related systems
- Construction inspection
- Functional testing
- Environmental compliance
- Generation of an operations and maintenance manual

There are a variety of rules of thumb in estimating commissioning costs: a Northeast utility uses $0.20-0.67 per square foot; a Northwest utility uses 6% of the total measure cost; commissioning agents cite costs of 1-4% of the total measure cost or $0.01-0.10 per square foot. For this project, as scoped, the cost estimates using these general guidelines range from $6,000 to $15,000. The average cost is $9,500 which translates to a total of 211 hours for the commissioning process. Based on our experience, this would have been an adequate budget for commissioning this building. The cost of the data acquisition system was not included since it was a research tool used primarily for the simulation tuning and not vital to the commissioning. The building commissioning relied on data from the EMCS, field measurements and inspections.

Economic Analysis

This study uses levelized cost as the sole criterion for ECM cost-effectiveness. It is an estimate of how much it actually cost to get each kWh of savings realized by an individual ECM or package of ECMs. The levelized cost of a measure accounts for its initial cost, annual energy savings, expected life, and assumptions about long-term financing, inflation, and nominal and real discount rates. The lower the levelized cost, the more cost-effective the measure. In northwest energy planning, $0.056 per kWh saved, per year, (56 mills) has been a widely used upper limit to qualify a measure as cost-effective. The levelized cost is based on the following assumptions:

- Long-term financing rate: 8.35%
- Inflation rate: 5.00%
- Discount rate: 3.00%
- Nominal discount factor: 8.155
- Measure life: as defined by utility guidelines

The measure costs were already documented. The cost of commissioning for this analysis will be used to evaluate commissioning as an energy conservation measure. This total cost was divided between the three affected ECMs in proportion to the ECM cost and added to the original costs to evaluate each measure with commissioning included.

The items for comparison are: 1) the cost effectiveness of the building ECMs recalculated with predicted energy savings between the *ideal* model and the baseline, 2) the levelized cost of commissioning as a conservation measure based on the increased savings shown by the simulation of the commissioned, fully functional building and the estimated commissioning cost, and 3) ECM levelized cost with commissioning costs added to the original measure cost .

The assignment of measure life for commissioning as an ECM is a complicated issue worthy of a separate study. A measure life of five years was used for this analysis. This assumes that the building would need to be recommissioned at five year intervals.

Results

Table 1 lists the results of the first comparison. The parametric analysis shows the cost effectiveness of each individual measure compared to the baseline. The interactive analysis adjusts the parametric energy savings to account for interactions between the measures and then

Table 1. Summary of Economic Analysis of Building ECMs in the Existing and the *Ideal* Commissioned Buildings

			Parametric Analysis		Interactive Analysis	
ECM	Life (years)	Incremental Cost (dollars	Lev. Cost, Existing (mills/kWh)	Lev. Cost w/Cx (mills/kWh)	Lev. Cost, Existing (mills/kWh)	Lev. Cost w/Cx (mills/kWh)
Efficient Lighting	9	$136,566	400	same	372	432
Wall Insulation	24	$14,883	29	same	27	31
Roof Insulation	24	$3,640	54	same	50	58
Occupancy Sensors	10	$10,493	81	same	75	87
Window Shading	14	$400	22	same	20	24
Hydronic Loop	19	$33,639	22	14	21	15
Ex. Fan Control	11	$6,326	NA	38	NA	38
EMCS	13	$69,091	205	51	191	56
All ECMs	17	$275,037	NA	NA	80	55

recalculates the levelized cost. For each type of analysis, the levelized cost is shown for the existing and the ideal commissioned building. For the hydronic loop, the exhaust fan control, and the EMCS, the levelized costs dropped dramatically in each comparison. The original levelized cost of the exhaust fan control was infinite because the measure showed zero savings. The levelized cost of the other measures rose slightly because fewer energy savings were attributable to them with the more efficient systems and controls. For the commissioned, fully functional building, five of the eight measures now would meet the cost-effectiveness criterion of 56 mills or less. The roof insulation went from 54 to 58 mills. The occupancy sensors and efficient lighting measures remained above the limit. [1]

Figure 5 graphically compares the parametric electric energy savings between the tuned model of the existing building and the *ideal* commissioned building.

Table 2 shows a levelized cost of 16 mills when commissioning is considered as an energy conservation measure. For this measure, the baseline was the tuned model of the existing building. This low levelized cost is very encouraging, particularly since the savings, cost and measure life were chosen conservatively. It should also be noted, however, that the more problems building commissioning reveals, the more cost effective it will prove to be.

Also in Table 2 are the levelized costs for the hydronic loop, exhaust fan control and EMCS with the cost of commissioning prorated between them and added to the original incremental cost. The complete package of eight ECMs comes in at one mill under the limit.

Conclusions

The commissioning of this building, beginning at the project design phase, would have been cost effective by significantly increasing the electric energy savings. The levelized cost of a building commissioning measure was calculated as 16 mills. When the cost effectiveness of the package of eight building ECMs is evaluated for the commissioned building excluding the commissioning cost, the levelized cost drops from 80 mills to 55 mills. When including the commissioning cost with the measure incremental cost, the ECM package has a levelized cost of 57 mills.

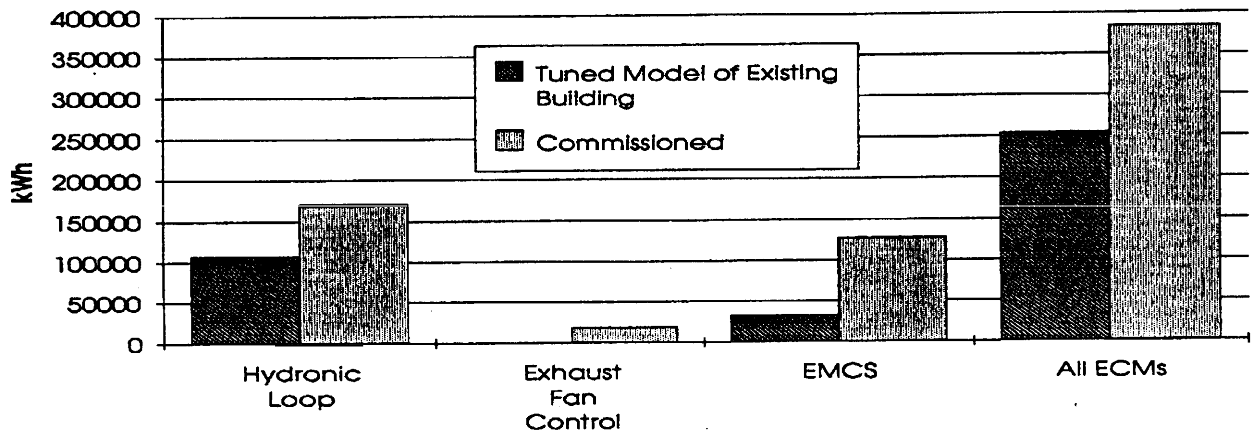

Figure 5. Parametric Savings for Commissioned Measures vs. the Existing Building

Table 2. Summary of Economic Analysis of Commissioned Measures

ECM	Life (years)	Incremental Cost w/Cx (dollars)	Parametric Lev. Cost w/Cx (mills/kWh)	Interactive Lev. Cost w/Cx (mills/kWh)
Building Commissioning	5	$9,500	NA	16
Hydronic Loop	19	$36,109	15	16
Ex. Fan Control	11	$6,801	40	40
EMCS	13	$75,646	56	61
All ECMs	17	$284,537	NA	57

Endnote

1. The 400 mill levelized cost for the lighting upgrade in the building is largely the result of three factors: 1) the installed lighting power density was higher than designed, 2) the measure life of nine years used in the study is lower than that used in most ECM analyses 3) the incremental cost was high for this building.

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