Commissioning Existing Buildings: A Program Perspective

David Jump, Ph.D., P.E. Adan Rosillo, P.E., CEM Asim Tahir

Quantum Energy Services and Technologies, Inc.
Berkeley, California

ABSTRACT

Since September 2002, the Oakland Energy Partnership's Large Commercial Building Tune-Up Program has recruited managers and operators of existing large commercial buildings in the City of Oakland for program participation. The Tune-Up Program is an aggressive effort to obtain 16.7 GWh in energy savings in over 10 Mft^2 in office, institutional, healthcare, hotel, educational, and retail buildings. Sponsored under the California Public Utility Commission's 2002 Local Program initiative, the Tune-Up program provides retro commissioning (r-Cx) teams to help building owners and operators thoroughly investigate the operations and performance of their existing building systems, identify measures that improve energy performance, assist with measure installation and verification, and provide documentation to operators on optimum system performance.

Great importance has been placed on the initial assessment of each building, in order to answer important questions from the program's and owner's perspectives. These issues include: condition of building's systems and equipment, amount of savings potential, skill sets of r-Cx teams, assurance that measures will be installed, persistence of installed measures.

This paper describes how the program recruits buildings, assesses the potential for savings, and assigns engineering teams. The type and size of buildings, their HVAC and lighting configurations, common r-Cx measures found, and their savings are described Results for each building are described, and the program's cost-effectiveness is reviewed. Currently, six buildings totaling 2.8 million square feet have been recruited, for an expected savings of approximately 2.4 GWh. This is 14% toward our program goal.

INTRODUCTION

Since September 2002, the Oakland Energy Partnership's Large Commercial Building Tune-Up Program ("Tune-Up Program") has recruited managers and operators of existing large commercial buildings in the City of Oakland. The Tune-Up Program is an aggressive effort to obtain 16.7 GWh in energy savings in over 10 Mft^2 in office, institutional, healthcare, hotel, educational, and retail buildings. Sponsored under the California Public Utility Commission's 2002 Local Program initiative, the Tune-Up Program provides retro commissioning (r-Cx) teams to help building owners and operators investigate the operations and performance of their existing building systems, identify measures that improve energy performance, assist with measure installation and verification, and provide documentation to operators on optimum system performance.

Large energy savings are achievable through retro-commissioning California's buildings. One study [1] reported that 690 MBtu and $9.5M could be saved if 2% of the building stock were retro-commissioned. It reported that most measures had a simple payback of 1.8 years, which is under the expected measure life of 3 to 6 years. R-Cx case studies [2,3] show 5 to 20% savings in buildings in California. In Oakland, where weather conditions are milder, savings are expected to be lower. The Tune-Up Program targets 10% electric and gas savings in each facility.

To ensure the program meets it goals, a thorough building screening process has been developed. There are several issues to consider in selecting buildings into the program: building energy use, condition of HVAC and lighting systems, capabilities and extent of building control system, and so on. This paper describes the screening process and its findings. For one building where data are available, the number and type of r-Cx measures identified during the screening process are compared with results from the detailed investigations.

The role of building benchmarks in the screening process is discussed in this paper. Three benchmarking tools are used to determine a candidate building's energy performance, and to compare the performance with similar buildings. The usefulness of each tool to the program is discussed. The methods each tool uses to develop benchmarks and compare are discussed.

PROGRAM DESCRIPTION

The Tune-Up Program adopts the retro-commissioning (r-Cx) processes as described in several guidelines [4,5]. These four phases are: planning, investigation, implementation, and hand-off. A marketing phase and an evaluation, measurement and verification (EM&V) phase have been added. The following summarizes the activities in each of the program phases:

- Marketing Phase. This phase includes development of marketing materials, promotion of the program, and recruitment meetings held with potential program participants.
- Planning Phase. A screening process is applied to determine whether the building is a good candidate for the program. Good building candidates show potential for savings and a number of readily identified measures that, if implemented, would save energy. A Memorandum of Understanding (MOU) is signed between the building owner and the Tune-Up Program. R-Cx service providers are selected.
- Investigation Phase. The r-Cx service providers collect detailed building documentation, assess control systems, identify service contractors, and talk to operators. Testing and monitoring plans are developed and implemented. Deficiencies in equipment and system operation are identified, and savings and costs for recommended measures are quantified. This list can include design or installation flaws in building systems and equipment, set point or schedule changes, or needed maintenance. The Tune-Up Program offers rebates to install these "r-Cx" measures. A list of recommended major equipment retrofits and replacements is also developed. These capital improvements are documented in an Energy Management Plan.
- Implementation Phase. R-Cx providers assist the building owners implement the measures by providing measure specifications, and review of bid documents. Installed measures are inspected.
- Hand-off Phase. Data is collected after the r-Cx measures are installed, and the measure savings and costs are updated. A systems manual is delivered to the building operators. It describes the findings of the r-Cx project, and the recommended settings, schedules, and sequences of operation of the building systems in order to maintain their performance.
- EM&V Phase. An EM&V contractor is provided with documentation on the participant buildings, recommended measures, data collected, and savings analysis. The EM&V contractor surveys a sample of buildings, reviews measures and analysis, and provides independent verification of estimated savings.

SCREENING PROCESS

A set of eligibility criteria and a building screening process was developed in order to ensure that the buildings admitted into the program generate significant savings within the program's time frame. The screening process is used to assess the following items:

1) Program eligibility
2) Building energy use
3) Condition of building systems and equipment
4) Type of building mechanical and electrical equipment
5) Number of typical r-Cx and retrofit measures identified during a short audit
6) Building energy management system (EMS) capabilities

7) Owner/management understanding of r-Cx value
8) Building operator availability and commitment
9) Owner/management commitment (sign MOU, install measures)
10) Owner's capital resources to install recommended measures

The assessment of a building for program participation depends partly on its energy savings potential, and partly on the non-technical issues 7 to 10 cited above. Discussion of the non-technical issues has been presented in [6]. This paper focuses on the assessment of the energy savings potential through retro commissioning, as this is of current interest to the industry. Building owners may use the following discussion to assess their building's energy performance, and consider whether a tune-up would be beneficial for their facility.

Figure 1 shows a flowchart of the screening process. General information is collected during an initial recruitment meeting. Electric and natural gas bills, as well as whole-building 15-minute interval electric demand data, are collected. Depending on the availability of the 15-minute data, detailed or simple weather-dependent models are developed, and daily load profiles are reviewed. The whole-building energy use intensity (EUI) is determined. After analyzing and reviewing the collected data, program representatives tour the building and inspect the mechanical and electrical systems, and interview the operator on building history and system operation.

The energy savings potential is assessed in two parts: (1) analysis of the building's energy use characteristics, and (2) assessment of savings opportunities in the building's existing equipment.

ANALYSIS OF BUILDING ENERGY USE CHARACTERISTICS

Benchmarks

The total on-site annual electric and gas consumption is calculated and normalized by the total square footage of the building (excluding parking garages). The resulting energy use intensity (EUI) in kBtu/ft^2 is an indicator of the building's overall energy performance. For the purpose of screening candidate buildings for the program, we want to know how well a building's energy performance compares to its peer buildings. Further, we want to know what a typical EUI for a building in Oakland is, as well as what the EUIs for the best performers are. Buildings with high EUI's are considered to have good energy savings potential, although good savings opportunities may be identified in buildings with EUIs close to the average.

Without any data available for buildings in Oakland, we used established benchmarking tools. These are: Cal-Arch, Energy Star's Portfolio Manager, and EZ Sim. The EUI for calendar year 2002 is calculated from each tool.

- Cal Arch [7] calculates the EUI and compares it to a population of similar type and size buildings in the same climate zone. It compares buildings with those described in Pacific Gas & Electric's Customer End-Use Survey Database.
- EZ Sim [8] creates a simplified model of building energy use. It calculates an EUI and corrects it for local weather. It compares the building with similar buildings in a database of buildings in the Pacific Northwest (Bonneville's ELCAP project).
- ENERGY STAR's Portfolio Manager [9] calculates an EUI based on monthly utility bills and compares it to buildings of the same type across the country (US DOE's CBECS database). The tool generates a percentile ranking by normalizing for significant drivers of EUI – square footage, weather, building occupancy, hours of operation, and number of desktop computers. For those buildings with a score of 75 or more, EPA may award an ENERGY STAR label that recognizes exceptional building energy performance, to the owners.

Daily Load Profiles

Daily load profiles are used to identify problem areas, and potential savings measures, before visiting the building. Load profiles can show whether building nighttime electric loads are high, the existence of unusual peaks in demand, excessive operation hours, or warm-up periods that are too early, and so on. Figure 2 shows an example that has excessive operation hours: building start up is at 3:30 in the morning, while the fist occupants arrive at 7 am.

Detailed Model

Detailed weather-dependent models are developed when 15-minute electric data is available. Average hourly demand data is plotted against average hourly outside temperature data for each hour of the year. Data from weekdays are separated from weekends and holidays. On the resulting weekday plots, several distinct “data swarms” are identified. Separating the data swarms by operating and non-operating hours is insightful, and identifies additional savings opportunities, such as proper use of economizers (both air and water-side), and high use during non-operation hours. Figure 3 provides an example taken from one of the participating buildings.

Simple Model

Monthly utility bills and monthly average ambient temperatures are used to develop simple models of electric and gas use in buildings. The EZ Sim Tool is used to develop simple models. Figure 4 shows results for an 180,000 ft^2 office building. The monthly energy use per square foot is plotted against average ambient temperature for both gas and electric usage. Tool users adjust factors affecting the model (e.g. cooling effectiveness, baseload, etc.) until a good fit between actual data and the model is obtained. The model is compared with models derived from ‘typical’ buildings (note: the ‘typical’ building is not that represented by dotted lines on the second chart) and the tool makes recommendations of areas to investigate. These recommendations are shown in the table below the figures. The typical building’s characteristics are derived from a database of building characteristics compiled from a survey in the Pacific Northwest.

Savings Target

The annual 2002 gas and electric consumption and costs are determined. Ten percent of the annual energy use is target for each building. The magnitude of the target savings sets the expectations for the project, as well as helps determine the amount of program funds to allot for engineering services and rebates. After the r-Cx measures are determined, these target savings are compared to actual savings to see if the original expectations were realistic.

ASSESSMENT OF BUILDING EQUIPMENT AND SYSTEMS

After the utility data is analyzed, program representatives meet with facility operators to tour the building and inspect the HVAC, lighting and control systems. Important factors noted during these visits are the configuration of the HVAC system, the capabilities and extent of the building energy management system, existence and capabilities of the lighting control system, and general equipment condition.

The survey staff discusses the building operation with the site engineers in order to become familiar with its operation and determine whether there are any apparent flaws in its systems. These may include design, installation, maintenance, and operational flaws. The survey personnel are experienced engineers who are familiar with building systems and equipment and who can identify typical flaws in building equipment and operation. The survey staff documents as many potential r-Cx measures, and EEMs as possible during the brief tour of the building. Table 2 provides a list of the r-Cx measures identified from preliminary audits for each building surveyed.

Buildings accepted into the program have a high energy intensity in comparison to their peer buildings, have high target savings potential, and have a large number of r-Cx measures noted from the preliminary audit. These factors are considered along with the assessment of the owner’s or operator’s willingness to participate, resources for installing measures.

RESULTS

Benchmark Comparisons

Each tool has a unique method to compare EUIs and to define similar buildings. The methods have advantages and disadvantages for use within the program. These are discussed below.

Cal-Arch’s method of calculating EUIs and comparing to similar buildings in the same climate zone eliminates the need to make adjustments for weather. The comparison buildings are selected from a database of buildings in the local utility’s service area, so that buildings are truly compared with their neighbors. The comparisons are made for the total energy consumption, and for electricity and natural gas consumption separately. Percentile rankings of each building’s EUI among its peer buildings are made. A building’s total energy use may be quoted as being higher than a specified percentage of comparison buildings. Bar charts of the comparison population are also shown.

Cal Arch does not account for differences in occupancy, plug loads, type of equipment, and so on, which allows, for example, a lightly occupied building to appear to be a better performer than its peers. Cal-Arch is available through a website, and does not archive data.

ENERGY STAR's Portfolio Manager adjusts EUI's based on many factors, including weather, occupancy, hours of operation, and plug loads (represented by the number of personal computers in the building). Since we use the tool before we have surveyed the building, and do not collect the required information, we rely on the tool's default values. The tool makes adjustments based on the default values. Results for office buildings are shown in Table 2. EUIs reported by Portfolio Manager for office buildings differ from those reported by Cal-Arch, as shown by the CV(RMSE) of 8%.

The results from Portfolio Manager are presented to the property managers, and the ENERGY STAR building program is introduced. This provides an extra incentive for owners to participate. For buildings that sign up in the program, we collect the necessary information and perform a more detailed analysis. A few buildings have expressed interest in the ENERGY STAR label; some buildings qualify at their current performance levels.

EZ Sim also adjusts the annual energy consumption of a building in order to compare it with other buildings. Simple menu selections also allow the user to characterize a few building factors: such as envelope construction, number of floors, and heating fuel. EZ Sims compares the building's benchmark with the lowest, the mean, and the highest benchmark of similar buildings in its database. More detailed information may be collected during audits of the facility. Again, because we do not collect this information until detailed investigations have begun, we rely on the tools default inputs. Table 2 also shows the benchmarks for each office building generated from EZ Sim. These show a larger variation from that of Cal-Arch at 13%.

EZ Sim is advantageous for use later in the program, after detailed investigations have begun. Once more data is collected and the building is properly characterized with the tool, it allows users to enter different data for 'comparison' buildings. Comparison building models are used to estimate differences in energy use from the baseline model. EZ Sim thus has the capability to help with the analysis of different r-Cx measure and EEMs.

As our database of EUI's increased, the variance between the EUIs given by Cal-Arch and the weather-adjusted EUIs became apparent. Table 2 summarizes EUIs for office buildings. The rows with site numbers correspond to those in Table 1, which are buildings that are participating in the program. The buildings without site numbers were either screened out (i.e. Owner-Occ. #5, Govt. #4), or the MOU has not been signed. The buildings with high EUIs that were screened did not present savings opportunities during the preliminary audit. In these buildings, we found that the operators were utilizing every opportunity to conserve energy, leaving little to cost-effectively identify through the program. Even though the EUI's were high, the configuration and current needs of the building coupled with the extent of control through the EMCS put a limit on how much energy can be saved.

On the other hand, buildings with low EUIs (i.e. PM Comm. #1) showed enough savings opportunities during the audit that we believed they would be good for the program. A few buildings have artificially low EUIs due to reduced occupancy. However if the audit and operator interviews reveal many r-Cx opportunities, the building can still be included in the program.

For office buildings, the simple EUI calculation from Cal-Arch indicates an average benchmark for the Oakland office buildings is about 68 kBtu/ft^2, with a deviation about the mean of 20%.

VALIDATING PRELIMINARY FINDINGS – RESULTS FROM ONE BUILDING

The focus of our program is on the most cost effective savings measures. The screening process identified specific building systems with good energy savings potential. Focusing on these systems was an efficient use of time and effort. In most cases additional measures were identified once the investigation phase began, but these were either retrofit projects or had long payback periods.

Similar measures identified during the screening process (air and water-side economizer problems, boiler controls) were present in many buildings. The load shapes, and the simple and detailed models helped identify many of the performance issues. The root causes of the performance problem were investigated during the site visit. For example; a gas usage benchmark in an office building that is higher than in its peer buildings (identified from Cal-Arch) or a flat usage profile across the year (EZ Sim simple model) would indicate that boilers are running in the summer when space heating is not required. This could mean that there is something wrong with the way the boilers are being controlled. Similarly, a change point at 50 ºF in Figure 3 points to inefficient use of an economizer. For a mild climate like Oakland, outside air can meet cooling loads up to 65 ºF.

In addition to models and bill analysis, engineers relied on their experience to add measures to the initial list. For instance, technology advances in variable speed drives (VFDs) enable them to control air flow than inlet guide vanes, a modern technology at the time of the building's construction. The team would include that measure on the preliminary list for investigation. Later, detailed investigations may show that the range of fan operation is limited, and not enough savings would be generated to justify the cost of replacing the vanes.

A recently completed project was used to review the r-Cx measures identified from the preliminary audit, with those actually recommended for implementation. Table 3 provides such a comparison. Those that we found to yield savings are indicated, along with their estimated savings percentage and payback period.

CONCLUSION

The screening process shows promise in providing guidance to assessing a building's energy savings potential, and identifying building systems where the potential measures may lie. Results are inconclusive, as few buildings are far enough along in the investigation phase to compare recommended measures with those found in the preliminary audits. This issue will be revisited as results come in, and improvements to the process will be made.

To date, the program has recruited 17 facilities (buildings and college campuses), for a total of 5.5 Mft^2. This includes two community college campuses, two hotels, and 13 office buildings. The expected savings in these facilities is 6.7 GWh and 169,500 therms, approximately 40% of our program goal. An additional 1.7 Mft^2 of commercial office space in 6 buildings are in the screening process.

The Tune-Up Program supports the efforts of the California Commissioning Collaborative to develop and promote the commissioning industry in California [10]. Its goals include: providing case studies, determining qualifications for retro commissioning service providers, developing standardized work descriptions, and developing screening criteria to help owners understand whether r-Cx services can help improve their building's performance.

REFERENCES

1. Portland Energy Conservation (PECI) Inc., Nov. 2000. "California Commissioning Market Characterization Study," a report prepared for Pacific Gas and Electric Company.

2. L. Luskay, T. Haasl, L. Irvine, PECI, D. Frey, Architectural Energy Corporation, proc. 2nd Int. Conf. For Enhanced Building Operations, Oct. 14-18, 2002. "Retro Commissioning Case Study - Applying Building Selection Criteria for Maximum Results."

3. A. Kahn, Inst. For Market Transformation, A. Potter, and T. Haasl, PECI, proc. ACEEE Summer Study, Pacific Grove, CA, 2002. "Retro Commissioning of Two Long Term Health Care Facilities."

4. T. Haasl, Portland Energy Conservation, Inc., and T. Sharp, Oak Ridge National Laboratory. See ORNL/TM-1999/34 document: "A Practical Guide for Commissioning Existing Buildings."

5. See the FEMP Building Commissioning Guideline at: http://www.eere.energy.gov/femp/techassist/bldguide.pdf

6. D. Jump, J. Flanagan, A. Rosillo, and J. Cavalli, "Retro-Commissioning Buildings with Public Goods Funds – Learning Lessons in Oakland," 11th National Conference on Building Commissioning, Palm Springs, CA, May 20 – 22, 2003

7. Cal-ARch is available on-line at: http://poet.lbl.gov/cal-arch/

8. EZ Sim is available through: http://www.ezsim.com/

9. ENERGY STAR's Portfolio Manager is available at: http://www.energystar.gov
10. Information on the California Commissioning Collaborative may be found at: http://www.cacx.org

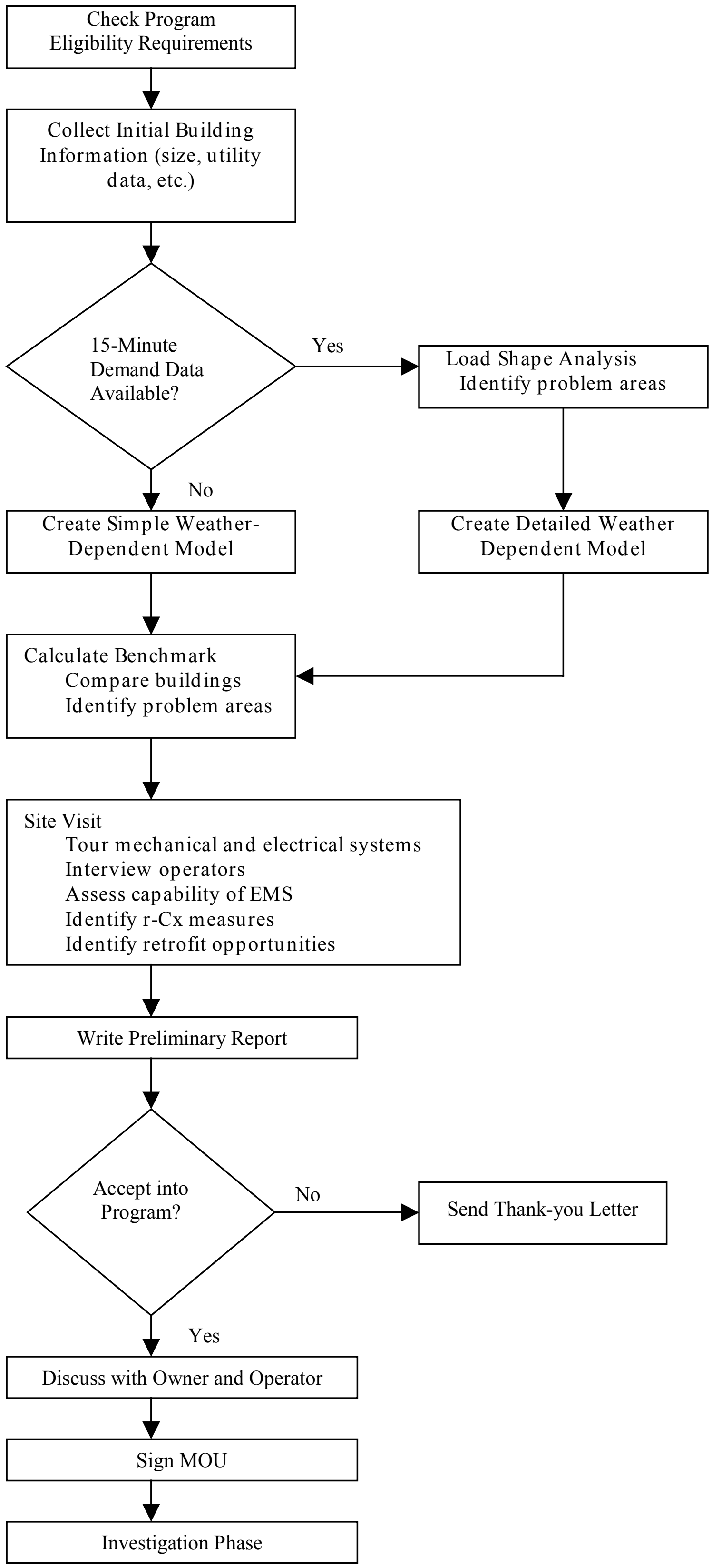


Figure 1. Screening process flowchart.

Figure 2. Example Daily Load Profile. This example is taken from 15-minute data for a courthouse.

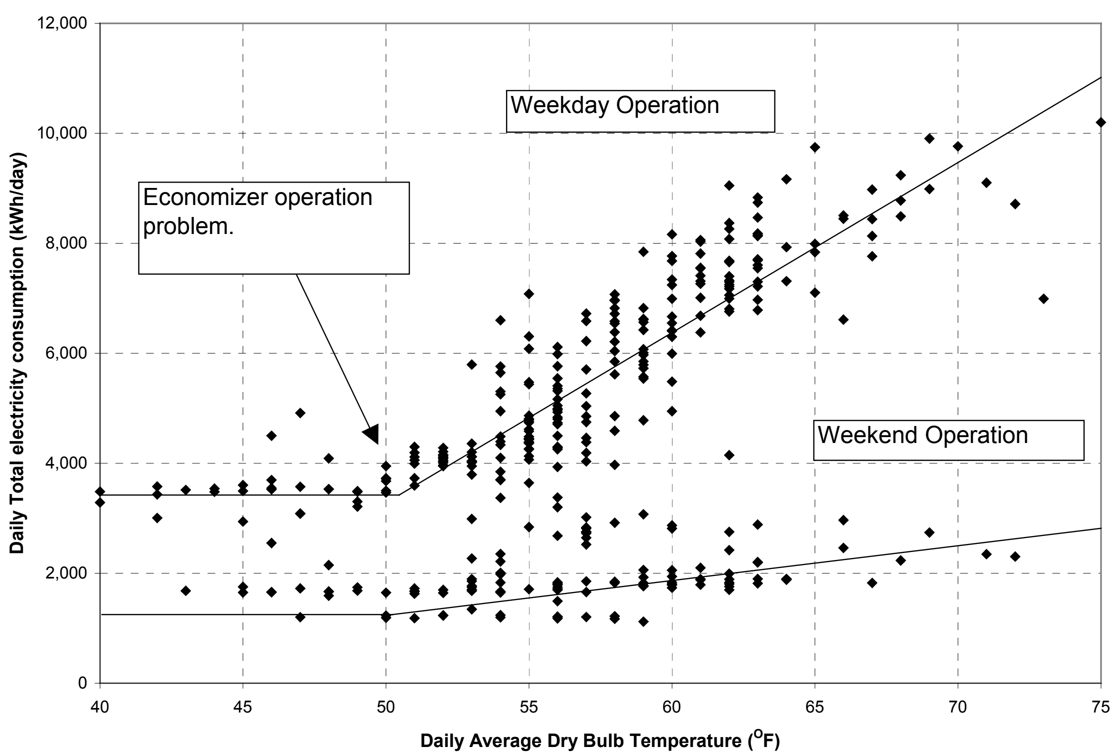
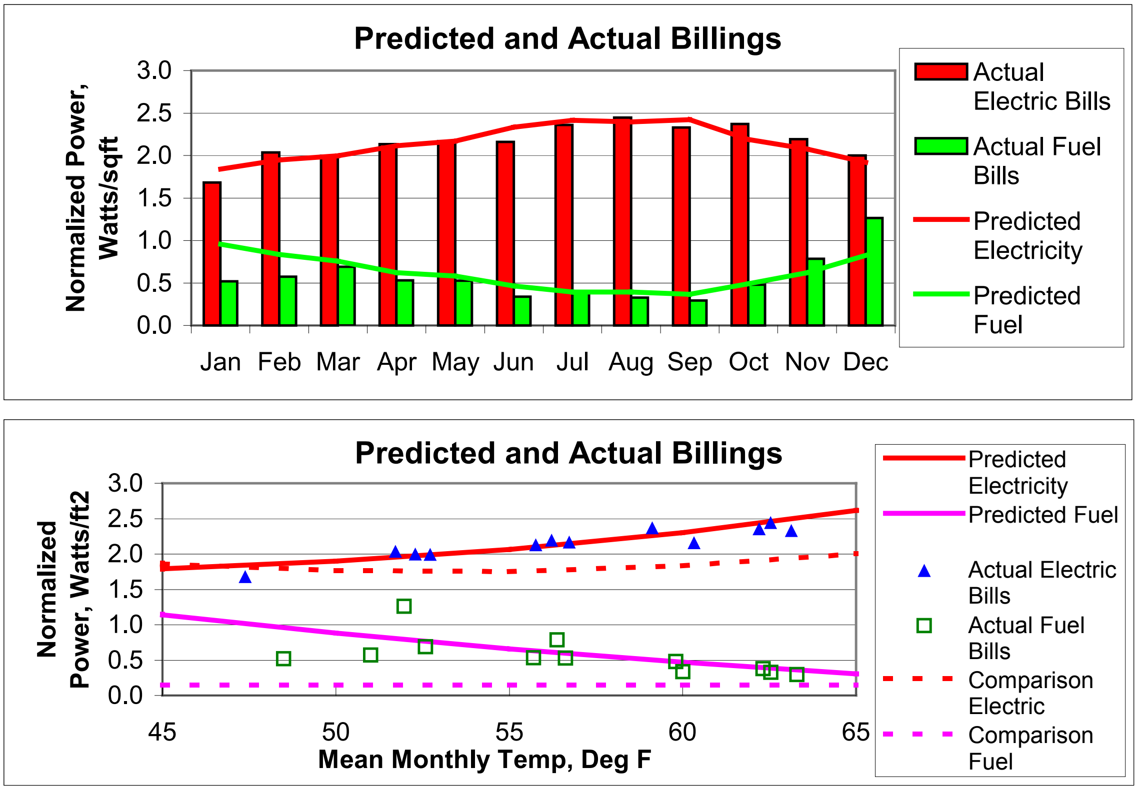


Figure 3. Detailed building model. The 15-minute interval data has been totaled for each day of the year and plotted against average outside temperature.



Heating Slope Modifier: **Look for:**
Heating slope is greater than usua Poor insulation levels, heating efficiency, or distribution losses.
Fuel Baseload:
Fuel process load is typical.
Baseload Modifier:
Internal gain is greater than usua High lighting/plug loads, extra equipment, extended operating hours, extra equipment or process loads, exterior lights (or pumps) left on.
ACH Modifier:
ACH is typical.
Cooling Slope Modifier:
Cooling slope is typical.

Right/left Balance Modifier:
Solar gain is typical.

Figure 4. Simple Model from EZ Sim.

Table 1. List of r-Cx measures found for 12 sites.

Site 1 - 300,000 ft² Office Building	**Site 6 - 100,000 ft² Office Building**
Water-Cooled DX Units	**Central CHW/HW, CAV w/ Reheat**
Optimize air side economizer	Replace hot water coils and fix leaks in ducts – then reduce boiler operating hours
Optimize water-side economizer	Eliminate long morning warm-up
Low speed fans on cooling tower not working	Program holidays in EMCS
Tune up boiler controllers	**Site 7 200,000 ft² Hotel**
Site 2 - 100,000 ft² Office Building	**Water Cooled Heat Pumps**
Central CHW/HW, CAV w/ Reheat	Add front end to EMS
Optimize air side economizer	Investigate cooling tower and boiler sequences of operations & set-points
Tune up boiler controllers	**Site 8 - 750,000 ft² Hotel and Convention Center**
Eliminate long morning warmup	**Central CHW/HW, Fan-Coil Units + CAV**
Optimize air compressor operation (leaks in pneumatic control lines)	Add chilled water reset capability
Site 3 - 140,000 ft² Office Building	Add relays to existing EMS to control water-side economizer
Water-Cooled DX Units	Install temperature controls to run fans based on water temperature
Move the reference pressure out of the fan room to provide a reliable reading for VFD control.	Add stop/start controls to condenser water pumps
Valve off water-side coils - pumps run on weekends/	Add lead/lag control to pump operation
AHU fans VFDs running at 60 HZ 100% of time	Tune-up boiler combustion controls and blower.
Investigate condenser water fouling	Replace AHU door seals
Site 4 - 170,000 ft² Office Building	Replace filters and repair frames
Water-Cooled DX Units	Replace valves
Reduce high nighttime baseloads	Repair pneumatic control
Lower CWT for effective water-side economizing	Eliminate inlet vanes (no VAV operation).
Add VFDs to supply fans	Repair/replace broken dampers
Site 5 - 460,000 ft² Courthouse/Office Building	Install new OAT sensor.
Central CHW/HW, VAV/CAV/Reheat (many mods.)	Inspect installed point-by-point and compare with front end for proper operation
Tune up boilers	Inspect local control loops for proper operation. Repair wherever is possible
New boiler controls	**Site 9 - 240,000 ft² Courthouse**
Inspect and repair steam traps	**Central CHW/HW, VAV w/ Reheat**
Repair pipe and equipment insulation	Stop running chiller when cleaning crews on site
Repair and recalibrate damper controls in all air economizers	Eliminate long morning warm-up – move HVAC start closer to operation hours.
Recalibrate terminal boxes	Eliminate excess equipment operation hours on Monday after 6 pm, unless this interferes with nightcourt.
Clean cooling and heating coils	Verify operation of three-way valves
Replace motor V-belts	Determine proper duct pressure for this configuration
Reduce fan speed and duration of building morning warm up period	Examine economizer schedule
Add chillers, cooling towers, auxiliary equipment to EMS	Check sensor calibration
Optimize main equipment schedule according to occupancy	Determine hot water requirements and reduce # boilers in operation
Calibrate pneumatic controls/ establish semi-annual calibration strategy	Check and verify existing control sequences.
Implement optimum start/stop control strategies	Apply a hot water reset schedule based on OAT to the boiler control.
Implement load curtailment strategies during peak hours	
Clean existing fixtures and lenses	
Clean reflective surfaces and walls and ceilings	
Reduce lighting levels on hallways/corridors/stairwells	

Table 1. List of r-Cx measures found for 12 sites, cont.

Site 10 - 650,000 ft^2 Community College Campus	**Site 11 - 211,000 ft^2 Community College Campus**
Central Plant: Primary/Secondary/Tertiary System	**Central Plant: Primary/Secondary System**
Tune hot water boilers	Repair and recalibrate damper controls in all air economizers / fresh air dampers
Repair and recalibrate damper controls in all air economizers / fresh air dampers	Clean cooling / heating coils
Clean cooling / heating coils	Clean air ducts
Clean air ducts	Eliminate simultaneous heating and cooling by increasing dead band
Replace v-belts	Develop standard equipment operating schedules based in occupancy
Eliminate simultaneous heating and cooling by increasing dead band	Implement HW&CHW loop temperature reset strategy
Develop standard equipment operating schedule strategies based on occupancy	Implement optimum start/stop control strategies
Plug leaky air tubing	Relocate/ add zone temperature sensors. Implement averaging control strategies
Eliminate one 25-HP air compressor	Photocell/ astronomic clock/ schedule strategy for exterior lighting
Replace leaky diaphragms	Clean existing fixtures and lenses
Implement HW&CHW loop temperature reset strategy	Clean reflective surfaces and walls and ceilings
Implement optimum start/stop control strategies	Reduce lighting levels on hallways/corridors/stair wells
Relocate/add zone temperature sensors. Implement averaging control strategies	Install occupancy sensors on selected areas
Photocell/ astronomic clock/ schedule strategy for exterior lighting	
Clean existing fixtures and lenses	
Clean reflective surfaces and walls and ceilings	
Reduce lighting levels on hallways/corridors/stair wells	
Install occupancy sensors on selected areas	

Table 2. Benchmark Comparison for Office Buildings

Site #	Building	Size (Kft^2)	Type	CalArch kBtu/ft^2-yr.	EZ-Sim kBtu/ft^2-yr.	EnergyStar kBtu/ft^2-yr.	EnergyStar Score
1	PM Commercial #1	242	Office	57	64	56	88
	Owner-Occupied Comm. #2	600	Office	66	73	59	65
2	Government #1	101	Office	81	62	88	68
6	Government #2	103	Office	93	92	87	61
	Government #4	80	Office	73	72	75	63
3	Government #5	142	Office	66	63	56	69
	Owner-Occupied Comm. #5	225	Office	55	56	52	73
4	PM Commercial #4	170	Office	69	83	66	60
	PM Commercial #7	300	Office	53	65	53	88
			Average	68	70	64	
			Mean Bias Error	-	1.94	-2.28	
			CV(RMSE)	-	13%	8%	

Table 3. Comparison of Preliminary Audit Results to Investigation Phase Results.

HVAC Configuration: Central CHW/HW, Fan-Coil Units + CAV	Scoping Phase	Detailed Investigation	Savings (% of electric or gas consumption)
Add chilled water reset capability	X	X	0.5%
Add relays to existing EMS to control water-side economizer	X	X	0.5%
Install temperature controls to run fans based on water temperature	X	X	1.8%
Add stop/start controls to condenser water pumps	X	X	0.3%
Add lead/lag control to pump operation	X		
Tune-up boiler combustion controls and blower.	X	X	0.7%
Replace AHU door seals	X	X	0.03%
Replace filters and repair frames	X		
Replace valves	X		
Repair pneumatic control	X	X	0.02% (e), 4.3% (g)
Eliminate inlet vanes (no VAV operation).	X		
Repair/replace broken dampers	X		
Install new OAT sensor.	X	X	0.4% (e), 5.1% (g)
Inspect installed points and compare with front end for proper operation	X		
Inspect local control loops for proper operation. Repair wherever is possible	X	X	0.3% (e), 3.9% (g)
Implement control strategies for CHW, HW, optimum start/stop, etc.	X	X	0.2% (e), 2.7% (g)
Total Electric Savings	339,390 kWh (5.8%)		
Total Gas Savings	49,055 therms (20.5%)		
Total Cost Savings	79005 (7.8%)		