Post-retrocommissioning HVAC Operations Monitoring using Enterprise-wide Energy Management System

N. “Amar” Amarnani

&

Brian Roberts

County of Los Angeles - ISD
Overview

- Process of HVAC retro-commissioning
- eQUEST energy model to create baselines and estimate savings
- Tactical use of EEMIS for optimized HVAC operations
- 3-Prong approach for sustainable savings
  - Equipment monitoring using data from EEM Suite
  - Utility bill analysis by means of Utility Accountant
  - System-level benchmarks using UCE+ module to help detect deviations from the optimized state
What is Cx/RCx?

Cx: New building commissioning provides documented confirmation that building systems function according to design.

RCx: Retrocommissioning existing buildings is a systematic process for improving building HVAC operation and maintenance.
Retrocommissioning (RCx)
Project Funding

- **CPUC 04/05:**
  - 11 Facilities (1.6 million GSF)

- **LACo-CEO 06/07:**
  - 3 Facilities (1.5 million GSF)

- **CPUC 06/08:**
  - 18 Facilities (3.6 million GSF) ongoing

  Facilities maintained and operated by the County
Adopted RCx Process

1. Benchmarking - Whole Building
2. Planning
3. Investigation
4. Corrections
5. eQuest
6. EEMs
7. FPT
8. Benchmarking - System Level
9. Training
10. Optimized/Persistence

Figure 1. Retro-commissioning (RCx) process adapted by SCE/SCG/County of LA Partnership Program.
HVAC RCx Measures

- Improved Chiller and Pump Sequencing
- Improved Boiler Combustion Efficiency
- Installed Boiler Hot Water Temp Reset Controls
- Performed Diagnostic Air and Hydronic Testing
- Optimized Economizer Controls
- Installed Discharge Air Temp Reset Controls
- Improved VAV Static Pressure Controls
- Selective air balancing and terminal box repairs
- Tested and calibrated all existing controls
- Control programming upgrades
Bellflower Courthouse
eQUEST Model Savings

Bellflower Courthouse Energy Use Density

- Baseline
- EEM 1-AHU/EF Ctr Blr S/S
- EEM 2-OA Econ DB
- EEM 3-DAT Reset
- EEM 4-TAB
- EEM 5-Ctr Blr LO
- EEM 6-Blr OAT Reset
- EEM 7a-Boiler Tuneup (70 to 80%)
- EEM 7b-Boiler Tuneup (80 to 84%)

EUI (kBtu/sf-yr)
Public Library Headquarters
Simultaneous Heat/ Cool

Chiller is operating at 60 deg outside air temperature.

Boiler is operating at higher than 80 deg outside temperature.

Public Library HQ - Chilled vs Hot Water $\Delta T$ - Baseline

There is a large number of bin hours when simultaneous heating and cooling occurred. Reheat is not necessary at higher outside air temperatures. Note the low heating $\Delta T$ above 75°F OAT.
Energy (electric + gas) Utilization Pre- & Post-RCx

Energy Utilization Index (gas+electric) kBtu/GSF

EUI-Pre-RCx  EUI-Post-RCx  %Diff
**RCx Utility Bill Saving**  
**First Year**

![RCx $ Savings](image)

Figure 21: Post-RCx operational savings ($).

- Library HQ
- Belflower
- Beverly Hills
- Compton
- Downey
- East LA
- Rio Hondo
- MlkU CC
- Santa Monica
- San Fern
- Whittier
- Total

**RCx $ Savings**

- $ saved (therm)
- $ saved (kWh)
RCx kWh Savings Against Baseline

Figure 22: Post-RCx electric energy (kWh) savings.
RCx Therm Savings Against Baseline

Figure 23: Post-RCx gas energy (therms) savings.
RCx + EEMIS + M&O = Optimized HVAC

- HVAC RCx Project
  - Funding
  - Contract w/ RCx Provider
  - Optimize buildings

- EEMIS
  - Automation
  - System-level Benchmarks
  - Monitoring
  - M&O Support

- Maintenance & Operations
  - Continue optimized operations

- Optimized HVAC Building Operations
Los Angeles County covers more than 4000 square miles
What is EEMIS?

- A network of discrete facility systems, hardware and data streams that are accessible through a centralized data-base using presentation & analytical tools for operational and management functions

- Real Time - Ethernet LAN / WAN based communications

- EEMIS is comprised of four main Sub-Systems
  - Teletrol’s BAS for the County’s HVAC operations in 65 facilities
  - Cutler Hammer’s PowerNet Metering Systems in 125 facilities
  - Square D’s PowerLink Lighting Panels. 165 Panels each with it’s own controller, installed in 12 Facilities
  - Itron’s Energy Suite Software Application
LA County EEMIS Network

Figure 4: County of Los Angeles Enterprise Energy Management Information System (EEMIS) configuration.
**Enhanced Monitoring 3-Prong Approach**

O&M Personnel studying weekly graphs from EEMIS to monitor equipment operation and defined parameters to ensure persistence of energy savings.

Energy Analyst comparing optimized state electric and gas performance metrics against benchmarked data.

Pre-programmed system level benchmarks alert designated ISD personnel about threshold being exceeded.

*Figure 3: Three-prong approach for persistence of RCx savings.*
Hot Water Pump Operation

Data summary

<table>
<thead>
<tr>
<th>Point name</th>
<th>Minimum</th>
<th>Minimum time stamp</th>
<th>Maximum</th>
<th>Maximum time stamp</th>
<th>Average</th>
<th>Units</th>
</tr>
</thead>
</table>

Multi-Point Trend report

Downey Library Hwp amps vs Osa Temp

Report date: 5/1/2006 8:21:38 AM
Total days: 5

HWP off on warm day
Cold Deck Temperature Reset

Figure 8: Supply air vs. return air temperature.
eQUEST Energy Modeling

- eQUEST® is a building energy use analysis tool
- eQUEST = enhanced DOE-2 + Wizards + Graphics
- Free download from http://www.energydesignresources.com
- System-level benchmarks are based on hourly output
  - Ton vs. OSAT
  - kW vs. Ton
  - Run-hours against timescale
  - kWh against timescale
  - Therms against timescale
## eQUEST Output - Bin Data

### OSAT Vs. Chiller kW

#### Table 4-2: Data Set - Average Chiller Demand vs. OAT (Including Confidence Intervals)

<table>
<thead>
<tr>
<th>OAT</th>
<th>Average kW</th>
<th>Number of Samples</th>
<th>Std Dev</th>
<th>Avg kW StdDev</th>
<th>Avg kW</th>
<th>Avg kW 2*StdDev</th>
<th>Avg kW 2*StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
<td>36.5</td>
<td>82</td>
<td>12.4</td>
<td>48.9</td>
<td>24.1</td>
<td>61.3</td>
<td>11.7</td>
</tr>
<tr>
<td>59</td>
<td>36.5</td>
<td>108</td>
<td>11.3</td>
<td>47.9</td>
<td>25.2</td>
<td>59.2</td>
<td>13.9</td>
</tr>
<tr>
<td>60</td>
<td>43.1</td>
<td>129</td>
<td>17.1</td>
<td>60.2</td>
<td>26.9</td>
<td>77.4</td>
<td>8.8</td>
</tr>
<tr>
<td>61</td>
<td>40.8</td>
<td>151</td>
<td>19.0</td>
<td>60.8</td>
<td>27.0</td>
<td>84.4</td>
<td>8.5</td>
</tr>
<tr>
<td>62</td>
<td>50.3</td>
<td>151</td>
<td>19.1</td>
<td>69.3</td>
<td>31.2</td>
<td>88.4</td>
<td>12.2</td>
</tr>
<tr>
<td>63</td>
<td>50.3</td>
<td>140</td>
<td>18.9</td>
<td>66.3</td>
<td>31.4</td>
<td>88.2</td>
<td>12.5</td>
</tr>
<tr>
<td>64</td>
<td>54.9</td>
<td>143</td>
<td>18.1</td>
<td>73.1</td>
<td>35.8</td>
<td>91.2</td>
<td>18.7</td>
</tr>
<tr>
<td>65</td>
<td>57.8</td>
<td>122</td>
<td>17.7</td>
<td>75.6</td>
<td>40.1</td>
<td>93.3</td>
<td>22.4</td>
</tr>
<tr>
<td>66</td>
<td>60.2</td>
<td>120</td>
<td>19.1</td>
<td>79.4</td>
<td>41.1</td>
<td>98.5</td>
<td>21.9</td>
</tr>
<tr>
<td>67</td>
<td>60.5</td>
<td>100</td>
<td>16.9</td>
<td>77.4</td>
<td>43.5</td>
<td>94.4</td>
<td>26.6</td>
</tr>
<tr>
<td>68</td>
<td>69.1</td>
<td>93</td>
<td>18.7</td>
<td>87.8</td>
<td>50.3</td>
<td>106.5</td>
<td>31.6</td>
</tr>
<tr>
<td>69</td>
<td>65.2</td>
<td>86</td>
<td>15.7</td>
<td>80.8</td>
<td>49.5</td>
<td>96.5</td>
<td>33.9</td>
</tr>
<tr>
<td>70</td>
<td>71.9</td>
<td>80</td>
<td>17.1</td>
<td>88.2</td>
<td>54.1</td>
<td>109.7</td>
<td>36.9</td>
</tr>
<tr>
<td>71</td>
<td>72.7</td>
<td>81</td>
<td>17.1</td>
<td>89.8</td>
<td>55.5</td>
<td>106.9</td>
<td>38.4</td>
</tr>
<tr>
<td>72</td>
<td>68.4</td>
<td>73</td>
<td>15.0</td>
<td>83.5</td>
<td>53.4</td>
<td>98.5</td>
<td>38.4</td>
</tr>
<tr>
<td>73</td>
<td>70.9</td>
<td>78</td>
<td>13.3</td>
<td>84.7</td>
<td>57.0</td>
<td>98.6</td>
<td>43.2</td>
</tr>
<tr>
<td>74</td>
<td>76.4</td>
<td>54</td>
<td>13.9</td>
<td>89.3</td>
<td>61.5</td>
<td>103.2</td>
<td>47.6</td>
</tr>
<tr>
<td>75</td>
<td>78.0</td>
<td>70</td>
<td>14.7</td>
<td>92.7</td>
<td>63.3</td>
<td>107.4</td>
<td>48.6</td>
</tr>
<tr>
<td>76</td>
<td>80.7</td>
<td>52</td>
<td>13.6</td>
<td>94.3</td>
<td>67.1</td>
<td>107.9</td>
<td>53.5</td>
</tr>
<tr>
<td>77</td>
<td>81.0</td>
<td>59</td>
<td>11.9</td>
<td>93.0</td>
<td>69.1</td>
<td>104.9</td>
<td>57.2</td>
</tr>
<tr>
<td>78</td>
<td>82.7</td>
<td>70</td>
<td>12.8</td>
<td>95.5</td>
<td>70.8</td>
<td>106.5</td>
<td>57.8</td>
</tr>
<tr>
<td>79</td>
<td>86.6</td>
<td>58</td>
<td>13.9</td>
<td>100.5</td>
<td>72.7</td>
<td>114.4</td>
<td>58.8</td>
</tr>
<tr>
<td>80</td>
<td>88.2</td>
<td>52</td>
<td>12.6</td>
<td>100.8</td>
<td>75.5</td>
<td>113.5</td>
<td>60.0</td>
</tr>
<tr>
<td>81</td>
<td>88.7</td>
<td>54</td>
<td>13.7</td>
<td>102.4</td>
<td>75.1</td>
<td>116.0</td>
<td>61.4</td>
</tr>
<tr>
<td>82</td>
<td>94.1</td>
<td>47</td>
<td>9.0</td>
<td>103.1</td>
<td>85.1</td>
<td>112.1</td>
<td>70.1</td>
</tr>
<tr>
<td>83</td>
<td>97.8</td>
<td>45</td>
<td>11.4</td>
<td>105.1</td>
<td>94.1</td>
<td>117.2</td>
<td>75.8</td>
</tr>
<tr>
<td>84</td>
<td>93.6</td>
<td>37</td>
<td>13.0</td>
<td>106.8</td>
<td>80.7</td>
<td>119.5</td>
<td>67.7</td>
</tr>
<tr>
<td>85</td>
<td>94.8</td>
<td>42</td>
<td>10.8</td>
<td>105.2</td>
<td>83.7</td>
<td>116.0</td>
<td>72.9</td>
</tr>
<tr>
<td>86</td>
<td>98.7</td>
<td>32</td>
<td>10.4</td>
<td>109.1</td>
<td>88.4</td>
<td>119.4</td>
<td>78.0</td>
</tr>
<tr>
<td>87</td>
<td>100.2</td>
<td>30</td>
<td>11.0</td>
<td>112.0</td>
<td>88.3</td>
<td>123.0</td>
<td>79.5</td>
</tr>
<tr>
<td>88</td>
<td>101.1</td>
<td>34</td>
<td>13.2</td>
<td>114.3</td>
<td>87.9</td>
<td>127.4</td>
<td>74.7</td>
</tr>
<tr>
<td>89</td>
<td>106.4</td>
<td>27</td>
<td>8.6</td>
<td>115.1</td>
<td>97.8</td>
<td>123.7</td>
<td>39.1</td>
</tr>
<tr>
<td>90</td>
<td>102.8</td>
<td>22</td>
<td>9.9</td>
<td>112.7</td>
<td>92.9</td>
<td>122.7</td>
<td>32.9</td>
</tr>
<tr>
<td>91</td>
<td>101.7</td>
<td>20</td>
<td>10.4</td>
<td>112.2</td>
<td>91.3</td>
<td>122.6</td>
<td>30.9</td>
</tr>
<tr>
<td>92</td>
<td>100.9</td>
<td>10</td>
<td>10.4</td>
<td>114.5</td>
<td>94.1</td>
<td>127.2</td>
<td>33.5</td>
</tr>
<tr>
<td>93</td>
<td>104.3</td>
<td>11</td>
<td>8.7</td>
<td>113.0</td>
<td>95.8</td>
<td>121.7</td>
<td>36.9</td>
</tr>
<tr>
<td>94</td>
<td>101.4</td>
<td>6</td>
<td>7.2</td>
<td>108.6</td>
<td>94.3</td>
<td>115.8</td>
<td>37.1</td>
</tr>
<tr>
<td>95</td>
<td>103.9</td>
<td>8</td>
<td>7.6</td>
<td>111.5</td>
<td>96.4</td>
<td>119.1</td>
<td>38.8</td>
</tr>
<tr>
<td>96</td>
<td>104.7</td>
<td>5</td>
<td>6.4</td>
<td>113.4</td>
<td>100.3</td>
<td>119.3</td>
<td>39.9</td>
</tr>
<tr>
<td>97</td>
<td>106.6</td>
<td>5</td>
<td>6.4</td>
<td>113.0</td>
<td>100.3</td>
<td>119.4</td>
<td>39.9</td>
</tr>
<tr>
<td>98</td>
<td>112.8</td>
<td>1</td>
<td>0.0</td>
<td>112.6</td>
<td>112.6</td>
<td>112.6</td>
<td>112.6</td>
</tr>
<tr>
<td>99</td>
<td>104.0</td>
<td>2</td>
<td>0.5</td>
<td>104.5</td>
<td>103.6</td>
<td>105.0</td>
<td>103.1</td>
</tr>
</tbody>
</table>
System Level Benchmark
Chiller kW Vs. OAT

Figure 4-2. Chiller Energy Performance – Representation with Equations
Weather Corrected eQUEST Equation

Library HQ - Tons vs. OSAT

\[ y = 0.0033x^3 - 0.8286x^2 + 71.019x - 1988.1 \]

\[ R^2 = 0.9967 \]
System-level Benchmarking
EEMIS UCE+ Example

**RCx Persistence Process**

- **eQuest Model**
  - \( F(x) = -0.0001X2 + 0.629X - 0.0917 \)
  - **eQuest Model Output**
    - equation for upper limit
  - \( F(x) = -0.0002X2 + 0.602X - 2.5604 \)
  - **eQuest Model Output**
    - equation for lower limit

- **Data Points from Building Systems**
  - \( F(x) = AX1 \times BX2 \times CX3 \times DX4 \)
  - **UCE+**
    - Universal Calculator Engine - Plus

- **EEMIS**

![Graphical representation](image)

Figure 20: RCx persistence process utilizing Universal Calculation Engine Plus (UCE+).
Optimized eQUEST Output

Electric Consumption (kWh)

Gas Consumption (Btu)

Electric Consumption (kWh x000)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Cool</td>
<td>10.5</td>
<td>2.0</td>
<td>9.0</td>
<td>5.1</td>
<td>12.3</td>
<td>16.9</td>
<td>47.6</td>
<td>46.9</td>
<td>39.4</td>
<td>25.5</td>
<td>3.7</td>
<td>2.0</td>
<td>211.8</td>
</tr>
<tr>
<td>Heat Reject.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Space Heat</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HP Supp.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hot Water</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vents. Fans</td>
<td>11.0</td>
<td>9.8</td>
<td>11.5</td>
<td>11.1</td>
<td>12.0</td>
<td>12.9</td>
<td>13.8</td>
<td>15.0</td>
<td>13.2</td>
<td>12.9</td>
<td>10.7</td>
<td>10.3</td>
<td>144.3</td>
</tr>
<tr>
<td>Pumps &amp; Aux.</td>
<td>1.4</td>
<td>0.8</td>
<td>1.4</td>
<td>1.1</td>
<td>1.5</td>
<td>1.8</td>
<td>2.3</td>
<td>2.4</td>
<td>2.1</td>
<td>1.9</td>
<td>0.9</td>
<td>0.9</td>
<td>18.4</td>
</tr>
<tr>
<td>Ext. Usage</td>
<td>4.5</td>
<td>4.0</td>
<td>4.5</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>4.5</td>
<td>4.5</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>52.6</td>
</tr>
<tr>
<td>Misc. Equip.</td>
<td>28.8</td>
<td>26.1</td>
<td>29.1</td>
<td>28.1</td>
<td>28.9</td>
<td>28.2</td>
<td>28.8</td>
<td>29.1</td>
<td>28.1</td>
<td>28.6</td>
<td>27.9</td>
<td>28.9</td>
<td>340.9</td>
</tr>
<tr>
<td>Task Lights</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Area Lights</td>
<td>45.3</td>
<td>41.0</td>
<td>45.3</td>
<td>43.9</td>
<td>45.4</td>
<td>44.0</td>
<td>45.3</td>
<td>45.3</td>
<td>45.9</td>
<td>45.3</td>
<td>43.9</td>
<td>45.4</td>
<td>534.3</td>
</tr>
<tr>
<td>Total</td>
<td>101.5</td>
<td>83.7</td>
<td>100.9</td>
<td>93.6</td>
<td>104.5</td>
<td>108.1</td>
<td>142.2</td>
<td>143.5</td>
<td>122.0</td>
<td>118.9</td>
<td>91.5</td>
<td>91.9</td>
<td>1302.3</td>
</tr>
</tbody>
</table>
### 7th ICEBO, Nov 1-2, San Francisco, CA

### eQUEST vs Actual - kWh

#### Single-level Bill Scenario Variance

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NW Regional HQ</td>
<td>Electricity</td>
<td>kWh</td>
<td>eQUEST</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
<td>40,800.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Actual</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
<td>40,000.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Variance</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
<td>-800.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CuSum</td>
<td>-800.00</td>
<td>-1,600.00</td>
<td>-2,400.00</td>
<td>-3,200.00</td>
<td>-4,000.00</td>
<td>-4,800.00</td>
<td>-5,600.00</td>
<td>-6,400.00</td>
<td>-7,200.00</td>
<td>-8,000.00</td>
</tr>
</tbody>
</table>

Note: Data is prorated to fiscal periods
Recap:
HVAC Retro-commissioning and EEMIS Monitoring

- HVAC Retro-commissioning
  - Investigate and resolve operational deficiencies
  - Install and test Energy Efficiency Measures
  - Develop system-level benchmarks

- 3-Prong approach to sustain RCx savings
  - Facility operation monitoring
  - Utility bill analysis with whole building benchmarks
  - System-level benchmarks to detect deviations
Partnership Credits

Southern California Edison
- Michael Lo, Program Manager

Southern California Gas Co.
- Paulo Morais, Project Manager

County of Los Angeles – Internal Services Dept.
- Howard Choy, Division Manager, ISD, Los Angeles County
- Nora Hernandez, Section Manager, ISD, Los Angeles County
Contact Information

County of Los Angeles - Internal Services Department

Brian Roberts
323-267-3010
E: broberts@isd.lacounty.gov

N. “Amar” Amarnani
323-267-2441
E: namarnani@isd.lacounty.gov