Whole-Building Energy Analysis
Through Wireless Networked Sensing

Gilman Tolle
Arch Rock
gtolle@archrock.com
# Reducing Energy Usage and Cost

## BILLING SUMMARY:

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Charges</td>
<td>$131.84</td>
</tr>
<tr>
<td>Demand Charges</td>
<td>$3,109.58</td>
</tr>
<tr>
<td>Energy Charges</td>
<td>$20,155.78</td>
</tr>
<tr>
<td><strong>TOTAL OF OAS:</strong></td>
<td><strong>$23,397.20</strong></td>
</tr>
<tr>
<td>Transmission</td>
<td>$768.64</td>
</tr>
<tr>
<td>Distribution</td>
<td>$2,966.21</td>
</tr>
<tr>
<td>Public Purpose Programs</td>
<td>$1,477.87</td>
</tr>
<tr>
<td>Nuclear Decommissioning</td>
<td>$72.22</td>
</tr>
<tr>
<td>DWR Bond Charge</td>
<td>$1,266.38</td>
</tr>
<tr>
<td>On-Going CTC</td>
<td>$1,539.76</td>
</tr>
<tr>
<td>Energy Cost Recovery Amount</td>
<td>$595.80</td>
</tr>
<tr>
<td>Generation</td>
<td>$14,710.32</td>
</tr>
<tr>
<td>Energy Commission Tax</td>
<td>$56.74</td>
</tr>
<tr>
<td>Electric Utility User Tax</td>
<td>$467.94</td>
</tr>
<tr>
<td><strong>TOTAL BILLED AMOUNT:</strong></td>
<td><strong>$23,921.88</strong></td>
</tr>
</tbody>
</table>
Your Commercial Building Spends

$30,000 / month
$360,000 / year

All 5.1 Million Commercial Buildings Spend

$10 billion / month
$123 billion / year
What did you spend that $30,000 on?
All Commercial Buildings

- Cooling: 15%
- Ventilation: 12%
- Refrigeration: 13%
- Water Heating: 1%
- Office Equipment: 7%
- Exterior Lighting: 6%
- Interior Lighting: 29%
- Air Compressors: 0%
- Misc: 6%
- Motors: 4%
- Cooking: 4%
- Process Heating: 2%

CEC CEUS 2006
Figure 3 - Typical Office Building Load Profile – Baseline Scenario

Assumptions
- High rise office building
- 250,000 square feet
- Centrifugal chiller / gas-fired hot water boiler
- 7:00am – 6:00pm, Mon-Fri
- Chicago, Illinois
- Typical summer day

National Action Plan for Energy Efficiency
Can you cut it by 15%?

Save us $54,000 / year
1 kW = $1,000 / year
Your Commercial Building
## BILLING SUMMARY:

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Charges</td>
<td>$123.60</td>
</tr>
<tr>
<td>Demand Charges</td>
<td>$3,574.66</td>
</tr>
<tr>
<td>Energy Charges</td>
<td>$22,256.12</td>
</tr>
<tr>
<td><strong>TOTAL OF OAS</strong></td>
<td><strong>$25,954.38</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>$1,061.39</td>
</tr>
<tr>
<td>Distribution</td>
<td>$3,139.63</td>
</tr>
<tr>
<td>Public Purpose Programs</td>
<td>$1,471.60</td>
</tr>
<tr>
<td>Nuclear Decommissioning</td>
<td>$71.91</td>
</tr>
<tr>
<td>DWR Bond Charge</td>
<td>$1,251.00</td>
</tr>
<tr>
<td>On-Going CTC</td>
<td>$1,533.24</td>
</tr>
<tr>
<td>Energy Cost Recovery Amount</td>
<td>$593.26</td>
</tr>
<tr>
<td>Generation</td>
<td>$16,802.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Commission Tax</td>
<td>$56.50</td>
</tr>
<tr>
<td>Electric Utility User Tax</td>
<td>$519.09</td>
</tr>
<tr>
<td><strong>TOTAL BILLED AMOUNT</strong>:</td>
<td><strong>$26,529.97</strong></td>
</tr>
</tbody>
</table>
Estimate
Measure
Act
Keep Measuring
Keep Acting
Preparing for Demand Response

Strategies for Demand Response, N. Motegi, M.A. Piette, D.S. Watson, S. Kiliccote, P. Xu
Why not shed it all the time?
Estimate
Measure
Act
Keep Measuring
Keep Acting
Meeting Environmental Mandates

LEED
EPACT Section 3
CA Assembly Bill 32
Estimate
Measure
Act
Keep Measuring
Keep Acting
Need Low Total Cost of Ownership

Capital Equipment Cost
Installation Labor Cost
Facility Manager’s Time Cost
So how are you going to do it?
Arch Rock Energy Optimizer (AREO)

AC Power Measurement Hardware
IP-based Wireless Networking
Web Application for Analysis
Related Systems

GE Enervista
Schneider PowerLogic ION
EnerNOC MBCx
Square-D
E-mon D-mon
…and many residential dashboards
Application Design Principles

Breakdown and Re-Aggregate Energy
Visualization and Annotation
Goal Setting and Tracking
15-MINUTE AVERAGE ENERGY DEMAND FOR APRIL 2009

Click and drag on the chart to zoom in. Click the check-marks to hide lines.

Peak demand for Apr 2009: 514.298 kW
15-MINUTE AVERAGE ENERGY DEMAND FOR APRIL 2009

Click and drag on the chart to zoom in. Click the check-marks to hide lines.

Peak demand for Apr 2009: 514,298 kW

- Lab
- IT
- Lab HVAC
- Other
Planning and Installation
<table>
<thead>
<tr>
<th>Electric Load Name</th>
<th>%</th>
<th>Spent</th>
<th>KWH</th>
<th>KW Now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>100%</td>
<td>$22,889</td>
<td>292,860</td>
<td>391.9</td>
</tr>
<tr>
<td>DP1</td>
<td>16%</td>
<td>$3,714</td>
<td>47,236</td>
<td>64.7</td>
</tr>
<tr>
<td>RGE</td>
<td>4%</td>
<td>$920</td>
<td>11,815</td>
<td>16.4</td>
</tr>
<tr>
<td>03DB</td>
<td>0%</td>
<td>$0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>DP2</td>
<td>84%</td>
<td>$19,175</td>
<td>245,625</td>
<td>327.2</td>
</tr>
<tr>
<td>03DCA</td>
<td>23%</td>
<td>$5,372</td>
<td>68,919</td>
<td>93.5</td>
</tr>
<tr>
<td>LB3</td>
<td>9%</td>
<td>$2,155</td>
<td>27,665</td>
<td>38.3</td>
</tr>
<tr>
<td>LB6</td>
<td>4%</td>
<td>$837</td>
<td>10,739</td>
<td>15.5</td>
</tr>
<tr>
<td>LB7</td>
<td>1%</td>
<td>$146</td>
<td>1,881</td>
<td>2.7</td>
</tr>
<tr>
<td>LB8</td>
<td>7%</td>
<td>$1,563</td>
<td>20,063</td>
<td>26.2</td>
</tr>
<tr>
<td>03DCB</td>
<td>33%</td>
<td>$7,626</td>
<td>97,911</td>
<td>136.2</td>
</tr>
<tr>
<td>LB1-2</td>
<td>10%</td>
<td>$2,402</td>
<td>30,841</td>
<td>41.4</td>
</tr>
<tr>
<td>LB4-5</td>
<td>21%</td>
<td>$4,850</td>
<td>62,262</td>
<td>90.6</td>
</tr>
<tr>
<td>Rack 49</td>
<td>0%</td>
<td>$71</td>
<td>913</td>
<td>1.3</td>
</tr>
<tr>
<td>03DC</td>
<td>27%</td>
<td>$6,177</td>
<td>78,795</td>
<td>97.5</td>
</tr>
<tr>
<td>RTU 14A</td>
<td>5%</td>
<td>$1,110</td>
<td>14,248</td>
<td>14.6</td>
</tr>
<tr>
<td>RTU 14B</td>
<td>5%</td>
<td>$1,037</td>
<td>13,309</td>
<td>14.3</td>
</tr>
<tr>
<td>RTU 14C</td>
<td>5%</td>
<td>$1,089</td>
<td>13,968</td>
<td>19.8</td>
</tr>
<tr>
<td>RTU 14D</td>
<td>2%</td>
<td>$474</td>
<td>6,053</td>
<td>14.2</td>
</tr>
<tr>
<td>03DCA DO</td>
<td>0%</td>
<td>$0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Electric Load Name</td>
<td>%</td>
<td>Spent</td>
<td>KWH</td>
<td>15Min KW</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----</td>
<td>--------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>Whole Building</td>
<td>100%</td>
<td>$22,889</td>
<td>292,860</td>
<td>391.1</td>
</tr>
<tr>
<td>Lab</td>
<td>52%</td>
<td>$11,907</td>
<td>152,898</td>
<td>214.7</td>
</tr>
<tr>
<td>LB1-2</td>
<td>10%</td>
<td>$2,402</td>
<td>30,841</td>
<td>41.4</td>
</tr>
<tr>
<td>LB3</td>
<td>9%</td>
<td>$2,155</td>
<td>27,665</td>
<td>38.4</td>
</tr>
<tr>
<td>LB4-5</td>
<td>21%</td>
<td>$4,850</td>
<td>62,262</td>
<td>90.6</td>
</tr>
<tr>
<td>Rack 49</td>
<td>0%</td>
<td>$71</td>
<td>913</td>
<td>1.3</td>
</tr>
<tr>
<td>LB6</td>
<td>4%</td>
<td>$837</td>
<td>10,739</td>
<td>15.5</td>
</tr>
<tr>
<td>LB7</td>
<td>1%</td>
<td>$146</td>
<td>1,881</td>
<td>2.7</td>
</tr>
<tr>
<td>LB8</td>
<td>7%</td>
<td>$1,563</td>
<td>20,063</td>
<td>26.1</td>
</tr>
<tr>
<td>IT</td>
<td>4%</td>
<td>$920</td>
<td>11,815</td>
<td>16.5</td>
</tr>
<tr>
<td>RGE</td>
<td>4%</td>
<td>$920</td>
<td>11,815</td>
<td>16.5</td>
</tr>
<tr>
<td>Lab HVAC</td>
<td>16%</td>
<td>$3,710</td>
<td>47,578</td>
<td>63.9</td>
</tr>
<tr>
<td>RTU 14A</td>
<td>5%</td>
<td>$1,110</td>
<td>14,248</td>
<td>13.8</td>
</tr>
<tr>
<td>RTU 14B</td>
<td>5%</td>
<td>$1,037</td>
<td>13,309</td>
<td>16.3</td>
</tr>
<tr>
<td>RTU 14C</td>
<td>5%</td>
<td>$1,089</td>
<td>13,968</td>
<td>19.7</td>
</tr>
<tr>
<td>RTU 14D</td>
<td>2%</td>
<td>$474</td>
<td>6,053</td>
<td>14.1</td>
</tr>
<tr>
<td>Other</td>
<td>27%</td>
<td>$6,351</td>
<td>80,569</td>
<td>96.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electric Load Name</th>
<th>%</th>
<th>Spent</th>
<th>KWH</th>
<th>KW Now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>100%</td>
<td>$22,889</td>
<td>292,860</td>
<td>391.9</td>
</tr>
<tr>
<td>DP1</td>
<td>16%</td>
<td>$3,714</td>
<td>47,236</td>
<td>64.7</td>
</tr>
<tr>
<td>RGE</td>
<td>4%</td>
<td>$920</td>
<td>11,815</td>
<td>16.4</td>
</tr>
<tr>
<td>03DB</td>
<td>0%</td>
<td>$0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DP2</td>
<td>84%</td>
<td>$19,175</td>
<td>245,625</td>
<td>327.2</td>
</tr>
<tr>
<td>03DCA</td>
<td>23%</td>
<td>$5,372</td>
<td>68,919</td>
<td>93.5</td>
</tr>
<tr>
<td>LB3</td>
<td>9%</td>
<td>$2,155</td>
<td>27,665</td>
<td>38.3</td>
</tr>
<tr>
<td>LB6</td>
<td>4%</td>
<td>$837</td>
<td>10,739</td>
<td>15.5</td>
</tr>
<tr>
<td>LB7</td>
<td>1%</td>
<td>$146</td>
<td>1,881</td>
<td>2.7</td>
</tr>
<tr>
<td>LB8</td>
<td>7%</td>
<td>$1,563</td>
<td>20,063</td>
<td>26.2</td>
</tr>
<tr>
<td>03DCB</td>
<td>33%</td>
<td>$7,626</td>
<td>97,911</td>
<td>136.2</td>
</tr>
<tr>
<td>LB1-2</td>
<td>10%</td>
<td>$2,402</td>
<td>30,841</td>
<td>41.4</td>
</tr>
<tr>
<td>LB4-5</td>
<td>21%</td>
<td>$4,850</td>
<td>62,262</td>
<td>90.6</td>
</tr>
<tr>
<td>Rack 49</td>
<td>0%</td>
<td>$71</td>
<td>913</td>
<td>1.3</td>
</tr>
<tr>
<td>03DC</td>
<td>27%</td>
<td>$6,177</td>
<td>78,795</td>
<td>97.5</td>
</tr>
<tr>
<td>RTU 14A</td>
<td>5%</td>
<td>$1,110</td>
<td>14,248</td>
<td>14.6</td>
</tr>
<tr>
<td>RTU 14B</td>
<td>5%</td>
<td>$1,037</td>
<td>13,309</td>
<td>14.3</td>
</tr>
<tr>
<td>RTU 14C</td>
<td>5%</td>
<td>$1,089</td>
<td>13,968</td>
<td>19.8</td>
</tr>
<tr>
<td>RTU 14D</td>
<td>2%</td>
<td>$474</td>
<td>6,053</td>
<td>14.2</td>
</tr>
<tr>
<td>03DCA-DQ</td>
<td>0%</td>
<td>$0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Circuit A: 30936 W  29222.417 / 0 kWh (In/Out)
-1618 VAR  1767.783 / 0.173 kVARh (Lead/Lag)
1:13:19 am

Circuit B: 31367 W  29424.003 / 0 kWh (In/Out)
-1669 VAR  1343.418 / 0.001 kVARh (Lead/Lag)
1:13:19 am

Circuit C: 30925 W  29573.724 / 0 kWh (In/Out)
-2009 VAR  1447.417 / 0.003 kVARh (Lead/Lag)
1:13:19 am
<Results offset="0" total="10494">
  <Result addr="00173b0011e56f7f" timestamp="1242103880.687790" seqNo="218" name="ElectricalDemand1">
    <Value typeName="nx_ippower_read_demand_t">
      <dvols>0</dvols>
      <dw>314413</dw>
      <dvar>-15369</dvar>
      <dva>314789</dva>
      <tstamp>1242103879</tstamp>
    </Value>
  </Result>
  <Result addr="00173b0011e56f7f" timestamp="1242103880.687990" seqNo="219" name="ElectricalSummation1">
    <Value typeName="nx_ippower_read_counters_t">
      <dwh_dlvd>283645555</dwh_dlvd>
      <dwh_rcvd>0</dwh_rcvd>
      <dvarh_lead>17268646</dvarh_lead>
      <dvarh_lag>1730</dvarh_lag>
      <tstamp>1242103879</tstamp>
    </Value>
  </Result>
  <Result addr="00173b0011e56f7f" timestamp="1242103880.688090" seqNo="220" name="ElectricalDemand2">
    <Value typeName="nx_ippower_read_demand_t">
      <dvols>0</dvols>
      <dw>318047</dw>
      <dvar>-19570</dvar>
      <dva>318648</dva>
      <tstamp>1242103879</tstamp>
    </Value>
  </Result>
  <Result addr="00173b0011e56f7f" timestamp="1242103880.688200" seqNo="221" name="ElectricalSummation2">
  </Result>
</Results>
Wireless Network
A Complete Implementation

- Layered architecture
- Patented low-power, responsive, robust link layer
- Reliable network-layer forwarding and routing
- Standard network-layer autoconfiguration (stateless & DHCPv6)
- Complete UDP and TCP transport protocol implementations
- Familiar application-layer protocols (e.g. HTTP, Telnet, SNMP, DNS, DHCPv6)
Industry’s *Smallest* Footprint

Production Quality
24,038 ROM
3,598 RAM
(including runtime)

courtesy of Jonathan Hui

<table>
<thead>
<tr>
<th></th>
<th>ROM</th>
<th>RAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDP</td>
<td>450</td>
<td>6</td>
</tr>
<tr>
<td>TCP</td>
<td>1674</td>
<td>48</td>
</tr>
<tr>
<td>6LoWPAN + IPv6</td>
<td>330</td>
<td>9</td>
</tr>
<tr>
<td>Checksums</td>
<td>1348</td>
<td>20</td>
</tr>
<tr>
<td>SLAAC</td>
<td>2550</td>
<td>0</td>
</tr>
<tr>
<td>DHCPv6 Client</td>
<td>134</td>
<td>0</td>
</tr>
<tr>
<td>DHCPv6 Proxy</td>
<td>216</td>
<td>32</td>
</tr>
<tr>
<td>ICMPv6</td>
<td>212</td>
<td>3</td>
</tr>
<tr>
<td>Unicast Forwarder</td>
<td>104</td>
<td>0</td>
</tr>
<tr>
<td>Multicast Forwarder</td>
<td>522</td>
<td>0</td>
</tr>
<tr>
<td>Message Buffers</td>
<td>0</td>
<td>2048</td>
</tr>
<tr>
<td>Router</td>
<td>2050</td>
<td>64</td>
</tr>
<tr>
<td>CC2420 Driver</td>
<td>3149</td>
<td>272</td>
</tr>
<tr>
<td>802.15.4 Encryption</td>
<td>1194</td>
<td>101</td>
</tr>
<tr>
<td>Media Access Control</td>
<td>330</td>
<td>9</td>
</tr>
<tr>
<td>Media Management Control</td>
<td>1348</td>
<td>20</td>
</tr>
</tbody>
</table>
Low Power, Reliable & Interactive

courtesy of Jonathan Hui

<table>
<thead>
<tr>
<th>Deployment</th>
<th>Year</th>
<th>Data Period</th>
<th>Duty Cycle</th>
<th>Latency</th>
<th>Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPv6</td>
<td>2008</td>
<td>1 min</td>
<td>0.65%</td>
<td>0.125 sec</td>
<td>99.98%</td>
</tr>
<tr>
<td>GDI</td>
<td>2003</td>
<td>20 min</td>
<td>2.2%</td>
<td>1 sec</td>
<td>28%</td>
</tr>
<tr>
<td>Redwoods</td>
<td>2004</td>
<td>5 min</td>
<td>1.3%</td>
<td>300 sec</td>
<td>49%</td>
</tr>
<tr>
<td>FireWxNet</td>
<td>2005</td>
<td>15 min</td>
<td>6.7%</td>
<td>900 sec</td>
<td>40%</td>
</tr>
<tr>
<td>WiSe</td>
<td>2006</td>
<td>30 min</td>
<td>1.6%</td>
<td>60 sec</td>
<td>33%</td>
</tr>
<tr>
<td>Dozer</td>
<td>2007</td>
<td>2 min</td>
<td>1.67%</td>
<td>15 sec</td>
<td>98.8%</td>
</tr>
<tr>
<td>SensorScope</td>
<td>2008</td>
<td>2 min</td>
<td>1.11%</td>
<td>120 sec</td>
<td>95%</td>
</tr>
</tbody>
</table>
Interoperable

- End-to-end with existing IP devices and WSN nodes
  - No stateful application gateways
  - Management Protocols: ping and traceroute
  - Transport Protocols: UDP, TCP
  - Application Protocols: Telnet, HTTP, SNMP, DNS, etc...

courtesy of Jonathan Hui
PhyNet Router
An Energy Optimizer Application

Time Correlation
Breakdown and Re-Aggregation
Open Data API
Graphs and Charts
Historical Data
Annotation
Goal Tracking and Prediction
Time Synchronization
<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>4%</td>
<td>$821</td>
<td>10,559</td>
<td>16.4</td>
</tr>
<tr>
<td>RGE</td>
<td>4%</td>
<td>$821</td>
<td>10,559</td>
<td>16.4</td>
</tr>
<tr>
<td>Lab HVAC</td>
<td>16%</td>
<td>$3,319</td>
<td>42,652</td>
<td>61.4</td>
</tr>
<tr>
<td>RTU 14A</td>
<td>5%</td>
<td>$990</td>
<td>12,741</td>
<td>20.4</td>
</tr>
<tr>
<td>RTU 14B</td>
<td>5%</td>
<td>$934</td>
<td>12,005</td>
<td>13.6</td>
</tr>
<tr>
<td>RTU 14C</td>
<td>5%</td>
<td>$969</td>
<td>12,465</td>
<td>19.8</td>
</tr>
<tr>
<td>RTU 14D</td>
<td>2%</td>
<td>$426</td>
<td>5,442</td>
<td>7.5</td>
</tr>
<tr>
<td>Unmetered</td>
<td>27%</td>
<td>$5,626</td>
<td>71,521</td>
<td>102.5</td>
</tr>
</tbody>
</table>
April 2009
<table>
<thead>
<tr>
<th>Month</th>
<th>Maximum Spending</th>
<th>Minimum Demand</th>
<th>Maximum Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2009</td>
<td>$30000.00</td>
<td>200 kW</td>
<td>400 kW</td>
</tr>
<tr>
<td>February 2009</td>
<td>$30000.00</td>
<td>200 kW</td>
<td>400 kW</td>
</tr>
<tr>
<td>March 2009</td>
<td>$35000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>April 2009</td>
<td>$30000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>May 2009</td>
<td>$35000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>June 2009</td>
<td>$30000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>July 2009</td>
<td>$30000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>August 2009</td>
<td>$30000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>September 2009</td>
<td>$30000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>October 2009</td>
<td>$25000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>November 2009</td>
<td>$25000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>December 2009</td>
<td>$25000.00</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td>2009 Total</td>
<td>$355,000.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BUDGET

SPENT $24,499 of $30,000  PREDICTED: $26,777 ($3,223 UNDER)
ACTIVITY LOG FOR APRIL 2009

Leave a note (up to 200 characters) now

Green: Energy Optimizer predicts the budget will be met - April 2009 spending of $26848.07 will be below $30000.00 12:04 PM Thu Apr 23

Gray: Decreased temp setting for RTU 14D to see if load on other 3 units decreases. 3:58 PM Wed Apr 22
Short Case Study
SPENDING BREAKDOWN

- HVAC $854 (17%)
- Line 1 $201 (4%)
- Line 2 $344 (7%)
- Line 3 $283 (6%)
- 2nd Op $1,160 (23%)
- Lighting $776 (15%)
- Other $1,413 (28%)
15-MINUTE AVERAGE ENERGY DEMAND FOR MAY 2009

Click and drag on the chart to zoom in. Click the check-marks to hide lines.
System for energy measurement, visualization, and analysis – nodes, network, application

Open standards-based system
Use our tools, build your own

The software should keep track of the details
Help you gain insight into what matters
An “Always-On” Link
While actually off >99% of the time

- Robust, interactive, easy-to-manage
- Low-Power Listening over 802.15.4
  - No global synchronization to establish or maintain
  - Low-latency communication (milliseconds) at any time
- Local optimizations (scheduling, streaming)

![Diagram of sender and receiver with unscheduled, scheduled, and packet stream labels with arrows pointing to times t] courtesy of Jonathan Hui
Network-Layer Autoconf

• Standard and familiar techniques:
  – Stateless: addresses locally derived from IEEE EUI-64 unique identifier
  – DHCPv6: addresses managed by stateful DHCPv6 server
Reliable Forwarding

• Reliable and efficient forwarding
  – Hop-by-hop retransmission
  – Hop-by-hop flow control
  – Streaming datagrams to same next-hop destination

• Responsive and manageable
  – Separate queues per flow guarantee minimal service
  – Urgent messages serviced before regular messages
Reliable Routing

• Distributed distance-vector protocol
• Maintain multiple next-hop routes
• Fuse different metrics
  – Estimated transmissions to destination (ETX)
  – Received signal strength indicator (RSSI)
  – Link-layer latency and power (listen-period of next-hop node)
  – Confidence in ETX and RSSI estimates

courtesy of Jonathan Hui
Transport & App Protocols

• Complete UDP and TCP transport implementations

• Enables any number of app protocols
  – Standard app protocols (e.g. HTTP, Telnet, DNS, DHCPv6)
  – New app protocols (no stateful application gateways to think about!)

courtesy of Jonathan Hui