Low Cost Building Automation System for Small- and Medium-Sized Commercial Buildings

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Outline

- Definition small- and medium-sized commercial building
- Definition Building Automation System (BAS)
- How prevalent are BASs in commercial buildings?
- What can BAS do in small- and medium-sized buildings?
- Potential savings from use of BAS
- Case study
- Recommendations
Definition of Small- and Medium-Sized Commercial Buildings

- Commercial Building Energy Consumption Survey (CBECS) defines
  - Small-sized buildings – 1,000 to 5,000 sf
  - Medium-sized buildings – 5,000 to 50,000 sf

- Building Automation System (BAS)
  - A system designed to monitor and control major end-uses, such as, heating, ventilation and air conditioning systems and lighting systems, from a central location
  - Some times referred to as energy management and control system
Prevalence BAS in Commercial Building Sector

► According to CBECS, approximately 10% to 15% of the buildings have EMCS serving 30% to 40% of the building area.

► Most of the buildings served by EMCS are large, i.e. greater than 100,000 sf.

► Some small- and medium-sized buildings may have time clocks and programmable thermostats.

■ However, it is not clear how many of these are properly used!
What can a BAS do?

- BAS can provide both monitoring and control capability

- Control capability includes:
  - Scheduling major end-use loads, such as, air conditioners, heat pumps, furnaces, lights, exhaust fans
    - Weekdays, weekend and holiday
  - Resetting heating and cooling set points during unoccupied periods
  - Enabling “optimal” start and stop times for HVAC systems
  - Could also make major equipment demand responsive

- Monitoring capability will ensure proper operations

Source: KMC Controls
How is this Technology Different …

► It is more than a time clock
► It does more than a wall mounted programmable thermostat
► It does more than a communicating thermostat
► It does more than a web-enabled RTU controller
Why is BAS not Widely used in Small- and Medium-Sized Buildings

► Not because of lack of vendors or technology
  ▪ There are a number of vendors of components needed for monitoring and controlling buildings

► Primary reason is lack of
  ▪ Split incentives between owners and tenants
  ▪ Awareness of the benefits from use of central controls
  ▪ Packaged cost-effective solutions, and
What is need for Widespread Adoption of the Technology?

- Identification/development of low-cost packaged solutions
- Education of building owners on the benefits of building controls
- Market transformation effort by utilities
- Case studies
Potential Energy Savings from the Technology

- A number of studies have indicated that 10% to 30% of energy in commercial buildings is wasted.

- Most of the waste is due to inability to control end-uses during unoccupied hours, weekends and holidays.
## Potential Energy Savings

Electricity EUI in small- and medium-sized buildings is – 40 kBtu/sf/yr -> 12 kWh/sf/yr

<table>
<thead>
<tr>
<th>EUI (kWh/sf/yr)</th>
<th>11.72</th>
<th>11.72</th>
<th>11.72</th>
<th>11.72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (sf)</td>
<td>5,000</td>
<td>5,000</td>
<td>20,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Savings (%)</td>
<td>10</td>
<td>30</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Electricity Price ($/kWh)</td>
<td>0.05</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Savings ($/yr)</td>
<td>293</td>
<td>1,758</td>
<td>1,172</td>
<td>7,032</td>
</tr>
</tbody>
</table>

Installed cost assuming 3 yr payback ($) | 879 | 5,274 | 3,516 | 21,096 |
The graphs show electric load profile for two identical 20,000 sf office buildings. Building on the left has about 80+ occupants, while the building on the right has 90+. The building on right also has a building automation system that is managing the operations of the rooftop units and few other equipment (exhaust fans and exterior lighting), it also has a good weekend and holiday operational schedules. The building on the left only has thermostats that control the rooftop units, there are no holiday schedules that can be programmed.
Summary

- Energy - significant savings (up to 30%) are possible, if buildings adopt controls and use them effectively.
- Non-energy - controls also have the potential of improving comfort and indoor air quality – non-energy benefit.
- Technology – it exists, but need there is need for better packaging.
- Adoption - solution may have to be tailored by building size and type, for example, for buildings:
  - less than 1,000 sf may only need an easily programmable thermostat.
  - between 1,000 sf and 5,000 sf may afford a networked programmable thermostat so central monitoring is possible.
  - between 5,000 sf and 20,000 sf may afford a networked programmable thermostat and a good replacement advanced RTU controller.
  - greater than 20,000 sf a true BAS will be cost-effective.
Recommendations

- Identify vendors and product that meet our needs
- If we find products that meet our requirement
  - Develop cost-effective packaged solution(s) for small- and medium-sized buildings
- If we do not find products that meet our requirements
  - Develop a specification and issue a “Control Challenge”
- Engage utilities to provide incentives to building owners who install the packaged solution
- Launch an awareness campaign to educate the benefits from use of building controls in the target market
- Address split incentive – for example, rate the asset making energy label mean something
CASE STUDY
Energy Use Intensity of Small- and Medium-Sized Buildings

<table>
<thead>
<tr>
<th>Energy Use Intensity (kBtu/sf/yr)</th>
<th>Gas</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO_CBECs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO_CBECs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO_PNNL_Avg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO_PNNL_Avg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO_PNNL_Seattle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MO_PNNL_Seattle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: CBECS 2003 and PNNL Post-1980 Prototype Buildings

- **SO** – Small Office
- **MO** – Medium Office
- **Avg** – National Average
- **PNNL** – Pacific Northwest National Laboratory Prototypical Buildings
Four Identical Office Buildings

► Building I
  ▪ 20,000 sf, 12 Roof Top Units (all electric)
  ▪ 80 Occupants

► Building II
  ▪ 20,100 sf, 12 Roof Top Units (all electric)
  ▪ 79 Occupants

► Building III
  ▪ 20,090 sf, 13 Roof Top Units (all electric)
  ▪ 80 Occupants

► Building IV
  ▪ 20,530 sf, 10 Roof Top Units (all electric)
  ▪ 85 Occupants
Existing Building HVAC Controls

- 10-13 rooftop units/building (most heat pump design, with 2nd stage electric heat)
- Programmable thermostats (Honeywell/Trane)
- No holiday scheduling
- No optimal start/stop sequence
- No networking or central monitoring capability
- No remote diagnostic or trending capabilities
- Schedules generally set too early (3 to 5 a.m. start times) and too late (7 to 9 p.m. stop times)
- Weekend scheduling configured for 4 to 8 hours (just in case)
- Some lighting controls with time clock
- Exhaust fans running 24x7
- No ability to monitor from a central location
Building Automation System Addition

- Buildings II, III and IV retrofitted with BAS in 2009/2010
- Installed new networked, programmable thermostats
- Wireless sensors (4 to 6 per heat pump) added to improve comfort (averaged sensor values)
- Holiday scheduling added (8 holidays/year)
- Optimal start added
- Remote diagnostic and data trending added
- Schedules tightened up (5 to 6 a.m. staggered start times) and (6 p.m. stop times)
- Removed weekend operations
Building Automation System Addition (cont)

- Automatic outside air low temperature override added (25°F)
- New thermostats accept outdoor air temperature sensor input (allows for cooling/heating lockout)
- Created 4°F throttling range (dead band) between heating and cooling (was 2°F before)
- Other
  - bathroom exhaust fan
  - exterior lights
  - DHW tank control also added
Project Costs Per Building

- New programmable thermostats ($250 each x 12) = $3K
- New wireless sensors ($50 each x 60) = $3K
- New wireless sensor integrator w/repeater (1) = $1.5K
- Network infrastructure (hub/switch, computer, network integrator [JCI NCM], cabling) = $6K
- Labor to install new thermostats, network infrastructure = $5K
- Total cost = $18.5K per building
Unique Control Sequences

► Heat pumps (HPs) control sequence
  - Uses 4 or more hardwired and wireless temperature sensor measurements averaged – better comfort
  - Configured such that the heating and cooling set points are driven from one master set point
  - If the wireless sensor(s) stop working (battery failure, sensor removed, fails, etc), the control algorithm that calculates the average room temperature will force a reading of from 71°F up to 75°F (depending upon which wireless sensor failed)
Unique Control Sequence (cont)

► Optimal start

■ Configured for the perimeter HPs only
■ Will pre-start HP before occupancy time when OAT (outside air temperature) is below 45°F (heating) or above 65°F (cooling)
■ Program looks at OAT after midnight and starts calculating (based upon OAT and normal scheduled start time) how many minutes to pre-start
■ Pre-start is up to 120 minutes and is based upon a sliding scale related to OAT below or above the 45/65°F OAT limits
■ At 25°F, the heating will pre-start 2 hours before occupancy and at 85°F, the cooling will also pre-start 2 hours before occupancy

► Automatic low OAT override is configured for the perimeter heat pumps

■ When OAT drops below low limit (25°F), the perimeter heat pumps will run 24/7
■ Once OAT increases 2°F above the OAT low limit, the heat pump operation will revert to the scheduled start/stop time
Unique Control Sequence (cont)

► When the heat pumps are in their unoccupied modes, the night low and high limit set points will determine when the heat pump activates heating or cooling to maintain the low or high limit, respectively.

► The night low limit and high limit set points are adjustable and are currently configured for 64 to 65°F (low limit) and 81 to 82°F (high limit).

► Setting the low limits lower or the high limits higher will save more energy.

► Optimal start and automatic low OAT control strategies should mitigate most recovery problems due to long weekends or extreme (cold) weather conditions.

► Bathroom exhaust fans are controlled via occupancy schedule to match the building occupancy.
Unique Control Sequence (cont)

- Interior HPs are configured to have their 2nd stage of heating (auxiliary electric heat) locked out when outside air temp is above 30°F
- Perimeter HPs are configured to have their 2nd stage of heating (auxiliary electric heat) locked out when outside air temp is above 40°F
Unique Control Sequence: Future Enhancements

- Each thermostat has remote push-button override capability
- Currently, operations staff must add schedules to accommodate odd shifts, etc, and this results in needless extra HVAC operations for minimal staff
- Each thermostat will put their respective HVAC unit into a 2 hour occupied mode, when the thermostat “sees” a momentary contact closure occur at the terminals dedicated for such a function
- 2 hour event is also adjustable (up to 8 hours), but it is recommended from an energy perspective, to keep this as low as possible (force staff to get up and push the button if they really need the comfort beyond normal occupancy)
Comparing Pre- and Post-Consumption

Cumulative whole building electricity consumption during the pre-retrofit period (2008)

Cumulative whole building electric consumption during the post-retrofit period (2011)
Comparison of cumulative whole building energy consumption between pre- and post-retrofit periods (2008/2011)
Comparison of cumulative whole building energy consumption between pre- and post-retrofit periods (2008/2011)
Comparison of Actual Energy Use Intensity and Annual Cost

<table>
<thead>
<tr>
<th>Energy Intensity (kBtu/sf/yr)</th>
<th>Annual Energy Cost ($/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY07 FY08 FY09 FY10</td>
<td>FY07 FY08 FY09 FY10</td>
</tr>
<tr>
<td>Building I</td>
<td></td>
</tr>
<tr>
<td>Building II 63 59 56 44</td>
<td>17,527 16,359 15,494 12,590</td>
</tr>
<tr>
<td>Building III 57 55 51 51</td>
<td>17,709 16,762 17,862 14,763</td>
</tr>
<tr>
<td>Building IV 81 64 61 53</td>
<td>23,271 19,425 17,497 15,365</td>
</tr>
</tbody>
</table>
Lessons Learned

- In the case of Buildings II, III, and IV, when the setbacks were implemented, we began to see energy reductions, but no cost savings because the increase in peak demand cost from simultaneous RTU startup in the morning was offsetting the kWh savings.

- Recognizing this unintended consequence of our initial setback implementation and correcting it by staggering the start times, leads to reduced energy use AND cost savings, which is the desired result.
QUESTIONS?
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