Agenda

• Pre-cooling and demand response control in extreme hot weather climates
• Demand response quick assessment tool for large commercial building
  – Demo
  – Modeling and calibration
• Demand response quick assessment tool for small commercial building
• Discussion and future work
Pre-cooling and demand response control in extreme hot weather climates

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May 5, 2008

Sponsored by the California Energy Commission through the Demand Response Research Center
Executive Summary

• Pre-cooling and demand shed strategies worked well in the office buildings tested under extreme hot weather and were able to reduce cool load significantly (20~30% in hot days).

• Compared to the baseline days, the test days show a slight decrease in the percentages of persons who rated their productivity as ‘enhanced’.

• Properly controlled exponential temperature setup in the shed period can maximize the load reduction.

• Pre-cooling strategies were more effective in extreme hot days than in cool days.
Demand Shifting With Thermal Mass

- Precool at night during off-peak hours
- Adjust daytime setpoints to control discharge
- Cooled structure reduces daytime, on-peak cooling loads
- Savings due to
  - Reduced on-peak energy and demand usage
  - High COP at night and early morning
  - Night ventilation
## Field Test Summary

<table>
<thead>
<tr>
<th>Year</th>
<th># of Sites</th>
<th>Peak reduction</th>
<th>% (whole building)</th>
<th>Strategies</th>
<th>Comfort</th>
<th>Peak outside temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1 (Santa Rosa)</td>
<td>2.3 W/ft²</td>
<td>~60%</td>
<td>Preclg + temp set up (one step)</td>
<td>No complaints</td>
<td>90-95 ºF</td>
</tr>
<tr>
<td>2004</td>
<td>2 (Santa Rosa, Sacramento)</td>
<td>0.5~2.0 W/ft²</td>
<td>10~66%</td>
<td>Preclg (w/o) + temp set up (one step)</td>
<td>Comfort survey</td>
<td>85-90 ºF</td>
</tr>
<tr>
<td>2005</td>
<td>2 (Oakland)</td>
<td>0.5~1.0 W/ft²</td>
<td>10~25%</td>
<td>Preclg (w/o) + various shed and recovery strategies</td>
<td>Comfort survey + indoor monitors</td>
<td>80-85 ºF</td>
</tr>
<tr>
<td>2006 2007</td>
<td>2 (Visalia, San Bernardino)</td>
<td>0.5~1.0 W/ft²</td>
<td>20~30%</td>
<td>Preclg (w/o) + various shed and recovery strategies</td>
<td>Comfort survey + indoor monitors</td>
<td>100-110 ºF</td>
</tr>
</tbody>
</table>
Case study in mild climate

Limited and Extended Precooling (warm days)

- **baseline**
- **Limited precooling**
- **Extended precooling**

Whole building power W/sqft

Time (hour)

1.4 W/sf shed
The building was pre-cooled at 68°F from midnight to 5am, and at 70°F from 5am to 12pm. After 12pm, the temperature was gradually raised to 76°F. The maximum shed period was from 3pm to 6pm (high price CPP period).
Case study in hot climate

Questions to answer

• Will the strategies work equally well in extreme weather conditions?
  – Critical peak pricing would typically be invoked on extreme hot days
  – Will the comfort reaction be different?
  – Will load shed be large enough?
  – Will sheds last long enough?
Demand Shed Strategies

- Current
- Precooling + Linear Set Up
- Precooling + Exp Set Up
- No Precooling + Exp Set Up

<table>
<thead>
<tr>
<th>Temp (°F)</th>
<th>Unoccupied Hours</th>
<th>Occupied Hours</th>
<th>Unoccupied Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>68</td>
<td></td>
<td></td>
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<td>70</td>
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<td></td>
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<tr>
<td>80</td>
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</tr>
</tbody>
</table>

Floating
Zonal Set Up
Web based comfort survey

- Sent survey request emails twice a day
- Two self-assessed questions

Please answer the following questions based on your experience right now:

**How would you rate the current temperature in your workspace?**
- Much too warm
- Too warm
- Comfortably warm
- Comfortable (and neither cool nor warm)
- Comfortably cool
- Too cool
- Much too cool

**Does the current temperature in your workspace enhance or interfere with your ability to get your job done?**
- Enhances
- Interferes

**Any additional comments or recommendations about the current temperature?**
Cigna Building in Visalia

- Met all basic criteria
  - Required some minor programming changes to their existing EMS system
  - 130,000 Sq. Ft.
  - Single Occupant
  - Very motivated and cooperative property manager
Precooling + linear temp reset

![Graph showing cooling power over time with two lines: Baseline and night & morning precooling + linear temp set up. The x-axis represents time from 0:00 to 22:31, and the y-axis represents cooling power in kW from 0 to 350. The graph shows fluctuations in cooling power throughout the day.](image-url)
Precooling + exp temp reset

The graph shows the cooling power in kW over time from 0:00 to 22:31. There are two lines represented:

- **Baseline**
- **morning precool + exp temp set up**

The baseline line is shown in blue, and the morning precool + exp temp set up line is shown in purple.
Precooling versus no precooling

Graph showing cooling power kW over time:
- **Morning precooling + temp set up**
- **No precooling + temp set up**

Time scale: 0:00 to 4:00

Cooling power kW scale: 0 to 400
9.20.2006 Test: Sensation
Office Building in San Bernardino

- AutomatedLogic Control, Full DDC at zone level
- 99,000 Sq. Ft.
- Single Occupant
- Built in 2005
- Three rooftop Units & VAV
Test schedule

<table>
<thead>
<tr>
<th>Number</th>
<th>Date</th>
<th>Strategies</th>
<th>Peak OA temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8/14/2007</td>
<td>no-pre-cooling + zonal reset</td>
<td>104°F</td>
</tr>
<tr>
<td>2</td>
<td>8/15/2007</td>
<td>pre-cooling + linear zonal reset</td>
<td>104°F</td>
</tr>
<tr>
<td>3</td>
<td>8/16/2007</td>
<td>pre-cooling + exponential reset</td>
<td>104°F</td>
</tr>
<tr>
<td>4</td>
<td>8/17/2007</td>
<td>Baseline, no comfort survey</td>
<td>101°F</td>
</tr>
<tr>
<td>5</td>
<td>8/28/2007</td>
<td>Baseline, comfort survey</td>
<td>103°F</td>
</tr>
<tr>
<td>6</td>
<td>8/29/2007</td>
<td>pre-cooling + exponential reset</td>
<td>111°F</td>
</tr>
<tr>
<td>7</td>
<td>9/18/2007</td>
<td>pre-cooling + exponential reset</td>
<td>84°F</td>
</tr>
</tbody>
</table>

Note: Peak Outside Air Temperature is measured from the DDC system
Precooling on hot days (104 °F)
Precooling in hot days (104°F)

![Graph showing rooftop units total demand with baseline and precooling with exponential temp set up. The graph plots time against demand in kilowatts (kW).]
No precooling in hot days (104 °F)
Precooling in extreme hot days (110 °F)
Return air temperature

Return Air Temp    °F

6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00

- no precooling with zonal temp set up
- precooling with linear temp set up
- precooling with exponential temp set up
Thermal comfort survey

Breakdown of sensation votes for 8/28/2007 baseline day and combined votes from 8/15/2007 and 8/16/2007 test days.
Electricity usage – extreme hot days

- Baseline
- Precooling with exponential temp reset

Energy Use kWh

- On-peak
- Mid-peak
- Off-peak
- Sum

0 1000 2000 3000 4000 5000 6000 7000 8000
Conclusions

• Precooling and demand shed strategies worked well under both mild and extreme hot weather conditions and were able to reduce cooling loads significantly (20~30% on hot days).

• No noticeable change in thermal comfort if the temperatures are under control.

• Properly controlled exponential temperature setup in the shed period can maximize load reduction.

• The night precooling results are mixed. It worked well in heavy mass buildings and buildings with undersized HVAC system.
Future work

- Develop guidelines for appropriate control strategies according to building characteristics
- Assess the market potential and barriers
- Field study to quantify building thermal mass
- Support pre-cooling strategy implementation
  - 11 buildings in Tri-city corporate center