Performance in the Commercial Sector 1980-2010

The long-term impact of codes and engineering practice

David Baylon
Objectives

• Describe the commercial building performance in the PNW
  • Buildings built over ~50 years
  • Sampled at random using various sampling approaches
  • Compared to historic data
  • Focus on four building types
  • Assess current energy performance trends

• Performance based on EUI in Kbtu/sf
  • Conditioned floor area
  • Site energy based on complete utility bills

• Describe performance goals of the WA State Energy Code
  • Legislative mandate, 2009
  • Progress to date in the performance estimates

• Propose programs to significantly improve performance
Databases

• CBSA 2008 (2014 buildings, 1188 EUIs):
  • Developed from a series of commercial building audits from 1987 to 2008
    • About 9 separate stratified random samples
    • Sampled from various geographic areas across the regions.
  • Large new construction sample (2006-2007)
  • Complex sample designs make any weighting scheme very problematic
  • Utility energy use collected on 60% of the sample from 2008-9 utility records

• CBSA 2014 (1380 buildings, 593 EUIs):
  • A sample commercial buildings as available in 2012.
  • Sample corrupted by complexity and significant recruiting difficulties
  • Characteristics survey designed to be consistent with CBSA 2008
  • Utility energy use collected on about 43% of the sample
Comparison Datasets

• 2003 and 2012 CBECS:
  • National summary in two major data collection efforts,
  • About 5000 buildings each sample
  • Summaries mapped to CBSA building types.

• 1985 CAP Audits (~1700 buildings--Office, Retail, Groceries, Schools)
  • Sample of convenience drawn from utility sponsored audits
  • Database not available, data summaries from 1988
  • Energy bills and EUIs calculated for 1984-1985
EUI Summary Development

• Combined CBSA samples with all available data
• Reviewed EUI information to assess the validity of the data entered
  • Buildings with modeled energy use removed (about 45% of the samples)
  • Building types reset to a single definition across all samples
• Sample weights and climates ignored (over 80% in Climate “4C”)
• Building type based on “use” when the audit was conducted
  • Updated in older samples with a phone survey
• Buildings categorized by vintage of initial occupancy
  • 2005 on is used as the modern building sample
  • Vintage cohorts in decade bins from 1980
  • Treated as stratified sample by building type and vintage.
• No weightings applied
### CBSAs Building Type Sample Sizes

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Audits</th>
<th>EUI sample</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly</td>
<td>177</td>
<td>84</td>
<td>47</td>
</tr>
<tr>
<td>College</td>
<td>119</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Education (K-12)</td>
<td>343</td>
<td>161</td>
<td>47</td>
</tr>
<tr>
<td>Grocery</td>
<td>289</td>
<td>155</td>
<td>54</td>
</tr>
<tr>
<td>Other Health</td>
<td>217</td>
<td>137</td>
<td>63</td>
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<tr>
<td>Hospital</td>
<td>131</td>
<td>45</td>
<td>32</td>
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<tr>
<td>Institution</td>
<td>134</td>
<td>75</td>
<td>56</td>
</tr>
<tr>
<td>Office</td>
<td>533</td>
<td>342</td>
<td>64</td>
</tr>
<tr>
<td>Other</td>
<td>149</td>
<td>74</td>
<td>50</td>
</tr>
<tr>
<td>Lodging</td>
<td>173</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>Restaurant/Bar</td>
<td>296</td>
<td>140</td>
<td>47</td>
</tr>
<tr>
<td>Retail</td>
<td>521</td>
<td>287</td>
<td>55</td>
</tr>
<tr>
<td>Warehouse</td>
<td>292</td>
<td>172</td>
<td>59</td>
</tr>
<tr>
<td>Total</td>
<td>3374</td>
<td>1794</td>
<td>53</td>
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</tbody>
</table>
Comparison of EUI Averages

Distribution of EUIs by Vintage Years
...and Restaurants

Distribution of EUI by Vintage Year

<table>
<thead>
<tr>
<th>Vintage Year</th>
<th>Total EUI (Kbtu/SF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1980</td>
<td></td>
</tr>
<tr>
<td>1980-1989</td>
<td></td>
</tr>
<tr>
<td>1990-1999</td>
<td></td>
</tr>
<tr>
<td>2000+</td>
<td></td>
</tr>
</tbody>
</table>
Energy Use Trends

• In some building types comparisons across buildings are less meaningful
  • Process loads depend on occupancy not on building construction
    • Hospitals/Labs
    • Warehouse becomes manufacturing
    • Restaurants: EUI dominated by food prep not building characteristics
• Master metered and district steam
  • Colleges/Universities
• Diverse categories with building that are not comparable
  • Assembly and Other: Catch all categories with very diverse building types
EUI analysis

• Building type “case studies”: Office, Retail/Grocery, Schools
  • About 55% of the buildings in the sample
  • About 60% of the total conditioned area

• Benchmarks
  • CBECS (2003, 2012):
    • Nationwide sample, almost 5000 buildings each survey
    • Traceable sample design and weights
  • BPA (CAP), SCL (~1985 Audits)
    • Region-wide audits with EUIs
    • Most comprehensive survey of 1980s baseline
    • Most building types represented, compiled from secondary sources
    • Original data not available
  • Energy code requirements (lighting power)
    • WSEC, 1986-2006
    • OSEC, 1989-2000
Determinants of EUI

• For most building types: new buildings like old buildings
• Size?
  • Overall size doesn’t matter for EUI comparison
  • In the target buildings the EUI relation to size has an $R^2<0.02$
• LPD Improvement?
  • Utility programs over 30 years have reduced the LPD comparably with Codes
  • Balanced by other building characteristics
    • Increased ventilation,
    • Simultaneous heating and cooling (especially VAV)
• Heat loss rates, Reduced UA
  • 30 to 50 percent reduction in envelope heat loss rate
  • Little evidence of an impact on EUIs in most building types
• Sloppy engineering,
  • Oversized and expensive systems,
  • Consistent whining about someone else’s issues.
Building Types

- Office
- Retail/Grocery
- Schools (K-12)
Office

- Similar HVAC systems across the sector
- EUIs uncorrelated to building size ($R^2<0.02$)
- Similar lighting throughout the sector
  - Substantial lighting change outs over time (T12 to T8)
  - Consistent LPD in all vintages
  - LPDs will be further reduced by LEDs
- Heat loss rate (UA/sf) reduced almost 50% from the pre 1980 buildings
  - Mostly in the first decade of code enforcement
- About an 8% site energy reduction from historic averages (pre 1980) in the 2005+ buildings
Office EUIs, 1980 to 2010

Distribution of EUI by Vintage Year
Office LPDs, 1980-2010

Distribution of LPD by Vintage Year

- 1985 Audits
- 1989 WSEC
- 2006 WSEC

Interior LPD (W/SF)
Office: Heat Loss Rate (UA/sf)

Distribution of Heat Loss Rate by Vintage Year

excludes outside values
• Changes with the advent of Big Box stores.
  • Dominated by RTUs in all size ranges
  • Grocery (refrigeration) removed as much as possible for “Retail” Classification

• Retail includes dry goods retail as well as “super stores” which appeared mostly since 2000.

• Grocery: Food Store with Deli
  • Comparable to historic definitions

• Grocery EUIs are more than double retail even with the expanded definition

• Lighting retrofit and modernization typical in across this sector
  • Groceries and retail are comparable but presented separately
  • Consistent pattern across the sector and across vintages

• Lighting power in modern buildings influenced by increasing LEDs

• Retail/Grocery: Heat loss reduced by over 50% between 1980 and present
  • Most of the reduction was between 1980 and the mid 1990s.
Retail EUIs, 1980-2010

Distribution of EUI by Vintage Year

Total EUI (Kbtu/SF)


CBEC2003 CBEC2012 1985 Audits
Retail LPDs, 1980-2010

Distribution of LPD by Vintage Year

- 1985 Audits
- 1986 OSEC
- 2006 WSEC

Interior LPD (W/SF)
Retail: Heat Loss Rate (UA/sf)

Distribution of Heat Loss Rate by Vintage Year

- Pre 1980
- 1980-1989
- 1990-1999
- 2000+

excludes outside values
Grocery EUIs, 1980-2010

Distribution of EUI by Vintage Year

excludes outside values
Grocery LPDs, 1980-2010
Grocery: Heat Loss Rate (UA/sf)

Distribution of Heat Loss Rate by Vintage Year

excludes outside values
School (K-12)

- Consistent improvement until 2005
  - Advent of cooling in HVAC design
  - More summer programs
- Overall a 25% reduction from historic averages in the 2005+ building
- Lighting upgraded modern standards over time
  - Consistent target of utility and public retrofit programs
  - Lighting power cut in half from historic averages in all vintages
- Small “improvements” beyond lighting
  - Increased ventilation
  - Better insulation and glazing
  - Reduced WWR especially in early vintages
  - Lighting control
- Heat loss rates reduced by 60% since 1980.
School (K-12) EUIs, 1980-2010

Distribution of EUI by Vintage Year

- Pre-1980
- 1980-1989
- 1990-1999
- 2000-2004
- 2005+

- 2003 CBECS
- 2012 CBECS
- 1985 Audits

Total EUI (Kbtu/SF)

0 50 100 150
School (K-12) LPDs, 1980-2010

Distribution of LPD by Vintage Year

- 1985 Audits
- 1989 OSEC
- 2006 WSEC

Box plots showing the distribution of interior LPDs by vintage year from 1980 to 2010.
School (K-12) Heat Loss Rates (UA/sf)

Distribution of Heat Loss Rate by Vintage Year

excludes outside values
Commercial Sector Results

- Reduced LPD by a factor of 2 since 1985 across building types.
- Improved Building Envelope Components by 50%
- Improved Controls
  - Lighting
  - HVAC scheduling
- Stable energy use across buildings despite improvements
  - Reduced mechanical system (HVAC) efficiency
  - Careless applications of ventilation standards
  - Oversized equipment
  - Simultaneous heating and cooling
  - Large quantities of outdoor air beyond ventilation requirements (pressurization)
- Minimal impact on energy use from 30 years of energy codes and utility programs
- No real impact from jawboning in the Architecture and Engineering professions
Washington State Performance Goals (2009)

- Designed to help achieve carbon reduction agreements
  - Energy reduction of 70% over 2006 code by the 2031 code cycle
  - Legislative mandate to code writing agency
  - Delivers a near net zero building stock
- This analysis uses the 2005+ sample as a baseline
- Some code initiatives since 2011
  - DOAS
  - Zone definition
  - Equipment sizing initiative
  - 25% reduction in LPD (with the advent of LEDs)
  - Building leakage testing
  - Back sliding on building shell
- Probably a reduction of 25% to date
## Performance Goals for 2031 (WSEC)

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Base</th>
<th>70% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KBTU/sf</td>
<td>KBTU/sf</td>
</tr>
<tr>
<td>Education</td>
<td>67</td>
<td>20</td>
</tr>
<tr>
<td>Other Health</td>
<td>89</td>
<td>27</td>
</tr>
<tr>
<td>Institution</td>
<td>79</td>
<td>24</td>
</tr>
<tr>
<td>Office</td>
<td>80</td>
<td>24</td>
</tr>
<tr>
<td>Lodging</td>
<td>86</td>
<td>26</td>
</tr>
<tr>
<td>Retail</td>
<td>86</td>
<td>26</td>
</tr>
<tr>
<td>Grocery</td>
<td>260</td>
<td>80</td>
</tr>
<tr>
<td>Warehouse</td>
<td>23</td>
<td>7</td>
</tr>
</tbody>
</table>
Outcome Code targets

- Major improvements in building performance is required
- Primary target should be the HVAC system
  - Eliminate simultaneous heating and cooling (VAV)
  - Improve zone separations
  - Reduce substantially building pressurization with outdoor air
  - Size equipment to reflect the calculated loads (believe your calcs)
  - Separate required ventilation air from heating and cooling delivery (DOAS)
    - Heat recovery, demand control
- Reduce lighting 30% from 2015 WSEC code
  - LED provides a path for this goal
- Improve envelope
  - Decrease allowable envelope leakage (.25 CFM/sf)
  - Decrease component heat loss by 30%
  - Improve window performance
- 60% to 70% reduction over the 2005+ cohort
  - Roughly equivalent to WSEC legislative goals for 2031
Outcome Based Program (utilities):

• Set an operating EUI target and base the incentives on this target.
  • Track EUI performance over time
• Set the target consistent with Energy code goals
  • Low enough so you get good engineering design
  • About 25 KBTU/sf/yr or about 7 kWh/sf/yr
  • Schools with partial occupancy periods about 16 KBTU/sf/yr or about 5 kWh/sf/yr
  • Develop custom targets for building types with specific process loads or occupancy loads
    • Restaurants
    • Hospitals
    • Assembly (Casinos, Churches, Community Centers)
    • Etc.
• Incentives based on performance after full occupancy and sufficient billing history
Outcome Based Program (code)

• Code based performance codes can be developed based on utility experience
  • Performance modeling inadequate by itself
  • Engineered gaming typical
  • EUI performance requirement would “focus the mind”

• Develop public “benchmarking” for new buildings
  • Public tracking of building performance
  • Key code metrics such as building size and equipment type

• Ongoing code development focused on design to achieve performance goals.
Questions,
Comments
Other Slides
System Comparison (KCHA)
Is it possible? Yes

- Engineering the mechanical systems for efficiency reduces the predicted EUI by a factor of three:
  - 27 Kbtu/sf/yr for KCHA Office building
  - 22 Kbtu/sf/yr for RFM office building
  - 29 Kbtu/sf/yr for Issaquah fire station
  - 14 Kbtu/sf/yr for Westside school