Nailing the Peak: City-Scale, Building-Specific Load Factor and Contribution to a Utility’s Hour of Critical Generation

Presented at:
IBPSA Building Simulation Conference
Rome, Italy

Presented by:
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September 2, 2019
Technology Adoption Rates Accelerate
Wireless Broadband IoT Age Is Upon Us

Papal Conclave 2005
Gigabit Speed Wireless Broadband
Coming Soon in 2018-2019
Model America 2020 – BEM for every U.S. Building

1. Extract important inputs from available data
2. Create initial building energy model(s)
3. Make models available online

Goal: Stimulate private sector activity for efficient buildings

IGA
- Walkthrough Audit
- Calibration to measured data

Download BEM via street address
What matters and how much?

- **Sensitivity analysis for all building types**
  - 80% of commercial buildings - 16 climate zones, 16 building types, averaging 5.75 vintages
  - 281-4,617 building descriptors (e.g. thermostat, insulation level) were modified
  - Fractional Factorial (FrF2) resolution IV statistical design of experiments

- **Summarize 768 lists of impactful variables**
  - 254,544 annual simulations were completed on the nation’s fastest supercomputer (Titan)
  - 216 Excel spreadsheets were created listing the energy and demand impacts of each building property

- **Quantify Most Important Building Parameters**
  - Top 10 annual energy (kWh) and demand/peak-shaving (kW) variables for each of the 16 building types.
  - Publication in-review with supplemental Excel spreadsheets for each bldg. type, location, and vintage for 47-470 variables each.
Data Sources

- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

<table>
<thead>
<tr>
<th>Summary</th>
<th>Satellite imagery, including panchromatic and multispectral images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data type</td>
<td>Image</td>
</tr>
<tr>
<td>Company</td>
<td></td>
</tr>
<tr>
<td>Website</td>
<td></td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>Cities - 3-11 times per week</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>0.3 m</td>
</tr>
<tr>
<td>Measure accuracy</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>$11 per sq. km</td>
</tr>
<tr>
<td>Format</td>
<td>GeoTiff</td>
</tr>
<tr>
<td>Mapping to building input variables</td>
<td>Building footprints</td>
</tr>
<tr>
<td>Mapping to area properties</td>
<td>Vegetated areas, road surface, buildings, parking lots</td>
</tr>
<tr>
<td>Mapping to material properties</td>
<td>Road pavement materials (e.g., concrete, asphalt), parking lots (e.g., gravel, soil)</td>
</tr>
<tr>
<td>Coverage of US</td>
<td>Over 10 million km² of coverage of the contiguous US</td>
</tr>
<tr>
<td>Orientation</td>
<td>Aerial</td>
</tr>
<tr>
<td>Existing internal software</td>
<td>N/A</td>
</tr>
<tr>
<td>Existing expertise</td>
<td>Remote sensing data analysis tool</td>
</tr>
<tr>
<td>Restrictions</td>
<td>N/A</td>
</tr>
<tr>
<td>Comments</td>
<td></td>
</tr>
</tbody>
</table>
Manual Segmentation of DC
Automatic Road Extraction
Automatic Building Footprint Extraction

Algorithm: Deep Learning extended and using GPUs for fast building footprint and area extraction over large geographical areas.

Multi-company Competition Precision/Recall – 30/35; Current Precision/Recall – 60+/60+
Processing Street-Level Imagery (Jiangye Yuan)
Street-level imagery (Lexie Yang)

Façade Type

Windows (blue)
Façade (green)
Street/open (black)
Other building (red)

Window-to-wall ratio
Prototype Buildings

Small Office

Medium Office

Large Office

Warehouse

Strip Mall Retail

Standalone Retail

Primary School

Secondary School

Outpatient Healthcare

Hospital

Small Hotel

Large Hotel

Quick-service Restaurant

Full-service Restaurant

Mid-rise Apartment

High-rise Apartment
Oak Ridge National Laboratory
The University of Tennessee (2 days)
Use Case - Scenarios

- **Preliminary** building-specific estimates of energy, demand, and cost savings totaling $11-$35 million per year based on 9 scenarios prioritized by EPB.

1. **Peak Rate Structure**
   1. Scenario #1a, Peak contributions for each building
   2. Scenario #1b, Cost difference, in terms of dollars per year, for all building

2. **Demand Side Management**
   1. Scenario #2a, Monthly peak demand savings, annual energy savings, and dollar savings based on rate structure for all buildings.
   2. Scenario #2b, Location-specific deferral of infrastructure cost savings potential

3. **Emissions**
   1. Scenario #3a, Emissions footprints for each building

4. **Energy Efficiency**
   1. Scenario #4a, Optimal retrofit list of independent ECMs
   2. Scenario #4b, Optimal retrofit package of dependent ECMs

5. **Customer Education**
   1. Scenario #5a, Percentile ranking of each building’s EUI by building type and vintage
   2. Scenario #5b, Monthly peak demand savings, annual energy savings, and dollar savings based on rate structure for all buildings compared to AMY weather file scenario.
Chattanooga, TN (100,000+ buildings)
The AutoBEM technology “axe”

135,481 building models have been created and matched to EPB’s PremiseID
Limitations: limited building types, not calibrated, will improve quarterly
QA/QC: will show how close our simulations are to 15-min data

2.3 million EnergyPlus building energy models using AutoBEM technology, Titan, cloud, and local servers to produce and analyze 13 TB of simulation data.

1. Generate baseline building – OpenStudio (1.5-3h Amazon, 30h internal)
2. Run ECM measures – OS Measure (30 mins AWS, 2h internal), Custom (1m AWS, 5m intl.)
3. Copy data to Titan – 1 min (1.2GB tar.gz)
4. Submit to Titan – 0-2 hours in queue
5. EnergyPlus simulation time – 30-45 mins (5mins/sim = 1.4 years to simulate EPB on 1 core)
6. Data transfer – 40 mins (160GB tar.gz)
7. Uncompress – 10-15 mins
8. Reformat data – 20-30 mins
9. Analysis – 5-10 mins

Time for creation, annual simulation, and analyzing “all” EPB buildings
6.5 hours (6.1h – 36.5h)
Virtual EPB (provided by ORNL) shows the value of technology with interactive dynamic results.
Comparison to real data

• Empirical Validation
  • 15-minute whole-building electrical for 178,368 buildings
  • More accurate than BEM created by a human

Operational Use of BEM Simulations

Use Cases
• Peak rate structure
• Demand-side mgmt
• Emissions
• Energy efficiency
• Customer education

Measures
• Lighting, HVAC COP, infiltration, insulation
• Smart thermostats
• Water heaters
• PV/solar
• EV charging
• Future weather
• Dual-fuel HVAC
• Microgrids

Result: $11–35 million/year in potential savings identified via simulation-informed data and valuation for energy, demand, emissions, and cost impact to EPB and each customer for each building under five use cases covering nine monetization scenarios

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Clustering of (real) 15-min electrical data

180,000 buildings measured
Whole-building electricity

96d clustering (24h)

26,048 residential buildings with peaks typically between 5 and 7pm

9 residential clusters

8 commercial clusters (GSA1-3, 8am-5pm)
### Load Factor summary

- Utility load factor \( LoadFactor = \frac{Total(kWh)}{kWpeak \times numHours} \)
  - Close to 0, more opportunity for energy storage

<table>
<thead>
<tr>
<th>Vintage</th>
<th>Num Bldgs</th>
<th>% of all Bldgs</th>
<th>Avg. Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td></td>
<td></td>
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<tr>
<td>2006</td>
<td>16217</td>
<td>9.1%</td>
<td>0.170</td>
</tr>
<tr>
<td>2009</td>
<td>6357</td>
<td>3.6%</td>
<td>0.177</td>
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<tr>
<td>2012</td>
<td>149247</td>
<td>84.0%</td>
<td>0.163</td>
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<tr>
<td>Pre-1980</td>
<td>670</td>
<td>0.4%</td>
<td>0.405</td>
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<tr>
<td>1980-2004</td>
<td>1064</td>
<td>0.6%</td>
<td>0.296</td>
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<tr>
<td>90.1-2004</td>
<td>1478</td>
<td>0.8%</td>
<td>0.255</td>
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<tr>
<td>90.1-2007</td>
<td>268</td>
<td>0.2%</td>
<td>0.338</td>
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<tr>
<td>90.1-2010</td>
<td>1224</td>
<td>0.7%</td>
<td>0.208</td>
</tr>
<tr>
<td>90.1-2013</td>
<td>1808</td>
<td>1.0%</td>
<td>0.256</td>
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</table>

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Num Bldgs</th>
<th>% of all Bldgs</th>
<th>Avg. Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC Residential</td>
<td>171821</td>
<td>96.35%</td>
<td>0.164</td>
</tr>
<tr>
<td>Warehouse</td>
<td>799</td>
<td>0.45%</td>
<td>0.166</td>
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<tr>
<td>MidriseApartment</td>
<td>851</td>
<td>0.48%</td>
<td>0.261</td>
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<tr>
<td>SmallHotel</td>
<td>1557</td>
<td>0.87%</td>
<td>0.261</td>
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<tr>
<td>HighriseApartment</td>
<td>2068</td>
<td>1.16%</td>
<td>0.263</td>
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<tr>
<td>LargeHotel</td>
<td>408</td>
<td>0.23%</td>
<td>0.365</td>
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<tr>
<td>QuickServiceRest.</td>
<td>318</td>
<td>0.18%</td>
<td>0.380</td>
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<tr>
<td>Hospital</td>
<td>319</td>
<td>0.18%</td>
<td>0.399</td>
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<tr>
<td>Outpatient</td>
<td>59</td>
<td>0.03%</td>
<td>0.501</td>
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</tbody>
</table>
Database status (new):
AutoBEM Monthly Data joined with EPB System Data

Monthly AutoBEM Data
- Premise Number
- Improvement Type
- Total Cost Savings ($)
- Monthly Costs Savings ($)
- Monthly Demand Svgs (KW)

~2.1M records per year, all bldgs

Join on Premise Number

Data feeds to other EPB Systems

EPB System Attribute Data
- Premise Number
- Service Address
- Latitude/Longitude
- XFMR information (bank, structure, etc.)
- Circuit, Substation, Feeder

Data Visualization Tools

Customer Clustering & Demand Side Management Analytics

Distribution System Capacity Planning
EPB’s operational Business Intel. Dashboard

Map showing premises, sized by Demand Value

Chart showing monthly demand value

Use of filters create an interactive experience for business users, driving business decisions

GSA Analysis - Technology Improvements

Monthly Demand Savings (KW) for Smart Thermostat 4 degree

4°F
2.2°C

Improvement Type

Smart Thermostat 4 degree

Annual Demand Savings ($)

$3,052,571

Map showing premises, sized by Demand Value

Use of filters create an interactive experience for business users, driving business decisions
Discussion

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Bill Copeland
Director, Business Intelligence
Electric Power Board of Chattanooga, TN

HPC Tools for Modeling and Simulation
Capturing building energy consumption
Data source and software overview

**Automatic Detection and Building Energy Model Creation (AutoBEM)**

**Data Sources**
- Imagery (satellite, aerial)
- Street-level imagery
- Cartographic layers
  - Elevation, GIS
- Tax assessors
- Ranking of descriptors EE and Demand impacts (281–4,617 per building type)

**Software Tools**
- Occupancy (every 90m)
- Aerial - best footprints
- Street - height, type, WWR
- LiDAR - geometry
- GIS - database API
- Building type
- Model generator
- Fastest buildings simulator
- Web-based visual analytics

Result: Simulated buildings for any area of interest that match 15-minute electrical data more accurately than most manually created models
Virtual NYC – interactive results

<table>
<thead>
<tr>
<th>ECM</th>
<th>Annual Electricity/Savings</th>
<th>Jan Demand/Savings</th>
<th>Feb Demand/Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>41282530.14 kWh</td>
<td>8463.14 kW</td>
<td>8426.13 kW</td>
</tr>
<tr>
<td>Change Elec Base COP</td>
<td>0.09 kWh</td>
<td>155.27 kW</td>
<td>3232.78 kW</td>
</tr>
<tr>
<td>Change Lighting Power Density</td>
<td>2796916.23 kWh</td>
<td>975.65 kW</td>
<td>3597.39 kW</td>
</tr>
<tr>
<td>Change Roof Insulation</td>
<td>688072.96 kWh</td>
<td>267.15 kW</td>
<td>3348.45 kW</td>
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<tr>
<td>Change to Elec Water Heater</td>
<td>-24140.75 kWh</td>
<td>152.50 kW</td>
<td>3230.01 kW</td>
</tr>
<tr>
<td>Change to Gas Water Heater</td>
<td>0.09 kWh</td>
<td>155.27 kW</td>
<td>3232.78 kW</td>
</tr>
<tr>
<td>Change Space Intetration</td>
<td>411236.67 kWh</td>
<td>176.59 kW</td>
<td>3436.11 kW</td>
</tr>
<tr>
<td>Smart Thermostat 4 Degree</td>
<td>14573.47 kWh</td>
<td>155.27 kW</td>
<td>4155.11 kW</td>
</tr>
</tbody>
</table>
Savings across 152 buildings

E=energy (MWh), D=demand (kW), [min,avg,max]

1. **Smart thermostat 2.2C (4F) pre-condition**
   
   \[ E = [-72, 1.4, 525] \]
   
   \[ D = [-938, 918, 13907] \]

2. **Natural gas water heater (80% efficient)**
   
   \[ E = [0, 0, 0] \]
   
   \[ D = [0, 772, 13807] \]

3. **Heat pump water heater (COP 2.2)**
   
   \[ E = [-184, -16.4, -2] \]
   
   \[ D = [-30, 768, 13853] \]

4. **HVAC Efficiency (COP\_H 3.55 and COP\_C 3.3)**
   
   \[ E = [0, 0, 0] \]
   
   \[ D = [0, 772, 13808] \]

5. **Lighting Efficiency (0.85 W/ft\textsuperscript{2})**
   
   \[ E = [77, 784, 6757] \]
   
   \[ D = [23, 999, 14410] \]

6. **Infiltration (reduce 25%)**
   
   \[ E = [40, 774, 4648] \]
   
   \[ D = [-0.8, 840, 14200] \]

7. **Insulation (R16.12 to R28.57)**
   
   \[ E = [12, 204, 1600] \]
   
   \[ D = [1.9, 817, 13928] \]