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Creating a Virtual Utility: Energy and Demand Opportunities via Automatic Building Energy Modeling (AutoBEM)

Presenter

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Senior R&D Staff, Oak Ridge National Laboratory
Oak Ridge, TN

Date

January 30, 2020
Joshua New, Ph.D., C.E.M., PMP, CMVP, CSM

• Career
  – 2009+ Oak Ridge National Laboratory, R&D staff
    • ETSD, Building Technology Research & Integration Center (BTRIC), Building Integration & Control Research Group
    • Climate Change Science Institute, Urban Dynamics Institute
  – 2012+ The University of Tennessee, Joint Faculty

• Education
    M.S. Systems & Software Design, double-B.S. Computer Science and Mathematics, Physics minor

• Professional Involvement
  – IEEE, Senior Member (top 8%)  
  – ASHRAE, defines international building codes
    • TC1.5, Computer Applications, Voting member and officer
    • TC4.2, Climatic Information, Voting member and officer
    • SSPC169, Weather Data for Building Design Standards (24% of page count of building code), Voting member
    • TC4.7, Energy Calculations, Voting member and officer
    • SSPC140 and ASHRAE Guideline 14 involvement

• Certifications
  – AEE, Lifetime Member
    • Certified Energy Manager
    • Certified Measurement & Verification Professional
  – PMI, Member
    • Project Management Professional
  – Certified Scrum Master

Artificial Intelligence
  • President’s National S&T Council’s Machine Learning and Artificial Intelligence Subcommittee’s Artificial Intelligence Consortium
Energy and Buildings Overview

Buildings consume 73% of the nation’s electricity
80% of peak energy use is from buildings

124 million U.S. buildings
$395 billion/yr energy bills

Goal of the DOE
Building Technologies Office:
30% energy reduction per sq. ft.
by 2030 compared to 2010 baseline

Building Energy Modeling – building
descriptions + weather = estimated
building energy consumption

$9B/yr – ESCO; $7B/yr – utility EE
$14B/yr – DR management systems
0.3% modified, BEM < 10% of those

Commercial Site Energy Consumption by End Use

HVAC 32%

Lighting 25%

Electronics & Computers 12%

Water heating 6%

Refrigeration 4%

Cooking 2%

Other 13%

Space heating 45%

Water heating 18%

Space cooling 9%

Other 7%

Motivation: BEM for every U.S. Building by 12/31/2020
Methodology: Scalable compute, data, simulation, and empirical validation

1. Quantitatively rank most important building inputs
2. Time on world’s #1 fastest HPC resources
3. Identify and compare data sources for important inputs
4. Establish partnerships and APIs for scalable data retrieval
5. Algorithms to extract bldg properties
6. Create OpenStudio, EnergyPlus models
7. Make models freely available

Potential use cases:
• Load management
• Utility program formulation
• Sales/market leads
• Incentive structure
• EaaS business model
• IGA walkthroughs
• Automated financing
• Simulation-informed analysis

Goal: Stimulate private sector activity and academic research for a sustainable built environment
Acknowledgements

• U.S. Department of Energy
• National Nuclear Security Administration
• Oak Ridge National Laboratory
• Building Technologies Office
• Office of Electricity
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 building type, location, and vintage for 47-470 variables each.
Keeping ORNL at the forefront in Computing: #1 Jaguar, Titan, Summit, Frontier?

Titan is the world’s fastest buildings energy model (BEM) simulator

>500k building simulations in <1 hour

130M US buildings could be simulated in 2 weeks

8M simulations of DOE prototypes (270 TB)

<table>
<thead>
<tr>
<th>CPU Cores</th>
<th>Wall-clock Time (mm:ss)</th>
<th>Data Size</th>
<th>EnergyPlus Simulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>18:14</td>
<td>5 GB</td>
<td>64</td>
</tr>
<tr>
<td>32</td>
<td>18:19</td>
<td>11 GB</td>
<td>128</td>
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<td>64</td>
<td>18:34</td>
<td>22 GB</td>
<td>256</td>
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<tr>
<td>128</td>
<td>18:22</td>
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<td>256</td>
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<td>88 GB</td>
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<td>512</td>
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<td>176 GB</td>
<td>2,048</td>
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<td>1,024</td>
<td>21:03</td>
<td>351 GB</td>
<td>4,096</td>
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<td>2,048</td>
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<td>4,096</td>
<td>20:00</td>
<td>1.4 TB</td>
<td>16,384</td>
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<td>8,192</td>
<td>26:14</td>
<td>2.8 TB</td>
<td>32,768</td>
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<td>16,384</td>
<td>26:11</td>
<td>5.6 TB</td>
<td>65,536</td>
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<tr>
<td>32,768</td>
<td>31:29</td>
<td>11.5 TB</td>
<td>131,072</td>
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<tr>
<td>65,536</td>
<td>44:52</td>
<td>23 TB</td>
<td>262,144</td>
</tr>
<tr>
<td>131,072</td>
<td>68:08</td>
<td>45 TB</td>
<td>524,288</td>
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</tbody>
</table>
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>Short Title</th>
<th>Satellite imagery, including panchromatic and multispectral images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>Satellite imagery, including panchromatic and multispectral images</td>
</tr>
<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>
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<tr>
<td>Restrictions</td>
<td>N/A</td>
</tr>
<tr>
<td>Comments</td>
<td></td>
</tr>
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</table>
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
Building Footprints from Satellite Imagery

Open Competition Precision/Recall – 30/35
ORNL Current Precision/Recall – 60+/60+
Processing Street-Level Imagery (Jiangye Yuan)

3D Building Model Generation
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
The University of Tennessee (2 days)
Digital Twin of a Utility
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.
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 Utility – interactive results

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

1. Lighting Efficiency (0.85 W/ft$^2$)
   \[ E= [77, 784, 6757] \]
   \[ D= [23, 999, 14410] \]

2. Infiltration (reduce 25%)
   \[ E= [40, 774, 4648] \]
   \[ D= [-0.8, 840, 14020] \]

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

4. Smart thermostat 2.2C (4F) pre-condition
   \[ E= [-72, 1.4, 525] \]
   \[ D= [-938, 918, 13907] \]
Accuracy compared to real 15-minute data for each building

• Empirical Validation
  – 15-minute whole-building electrical for 178,368 bldgs
  – More accurate than BEM created by a human\(^1\)
    • ½ error of the average manually-created BEM when compared to measured data

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

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 $\text{LoadFactor} = \frac{\text{Total}(kWh)}{\text{kWpeak} \times \text{numHours}}$
- 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>
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</thead>
<tbody>
<tr>
<td>Residential</td>
<td></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>
</tr>
<tr>
<td>2012</td>
<td>149247</td>
<td>84.0%</td>
<td>0.163</td>
</tr>
<tr>
<td>Commercial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-1980</td>
<td>670</td>
<td>0.4%</td>
<td>0.405</td>
</tr>
<tr>
<td>1980-2004</td>
<td>1064</td>
<td>0.6%</td>
<td>0.296</td>
</tr>
<tr>
<td>90.1-2004</td>
<td>1478</td>
<td>0.8%</td>
<td>0.255</td>
</tr>
<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>
</tr>
</tbody>
</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>Midrise Apartment</td>
<td>851</td>
<td>0.48%</td>
<td>0.261</td>
</tr>
<tr>
<td>Small Hotel</td>
<td>1557</td>
<td>0.87%</td>
<td>0.261</td>
</tr>
<tr>
<td>Highrise Apartment</td>
<td>2068</td>
<td>1.16%</td>
<td>0.263</td>
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<tr>
<td>Large Hotel</td>
<td>408</td>
<td>0.23%</td>
<td>0.365</td>
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<tr>
<td>QuickService Rest.</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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Load Factor summary

**Monthly AutoBEM Data**
- Premise Number
- Improvement Type
- Total Cost Savings ($)
- Monthly Cost Savings ($)
- 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**

**Distribution System Capacity Planning**

**Customer Clustering & Demand Side Management Analytics**
Virtual Utility integration

Map showing premises, sized by Demand Value

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

Chart showing monthly demand value

Map showing premises, sized by Demand Value

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

Chart showing monthly demand value
Presenter

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