Automatic building detection and Building Energy Model creation (AutoBEM): Reimagining BEM in a world with High Performance Computing, Big Data, Imagery, and Advanced Metering Infrastructure

Presented at:
University of Cambridge, UK
Hosts: Ruchi Choudhary and Yeonsook Heo

Presented by:
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Building Technologies Research & Integration Center
Subprogram Manager, Software Tools & Models
Oak Ridge National Laboratory

June 20, 2018
Joshua New, Ph.D., C.E.M., PMP, CMVP

• Career
  – 2009+ Oak Ridge National Laboratory, R&D staff
    • ETSD, Building Technology Research & Integration Center (BTRIC), Building Envelope & Urban Systems Research Group (BEUSR)
  – 2012+ The University of Tennessee, Joint Faculty

• Education

• Professional Involvement
  – AEE, Lifetime Member, Certified Energy Manager, Certified Measurement & Verification Professional
  – PMI, Member, Project Management Professional
  – IEEE, Senior Member
  – ASHRAE, defines international building codes
    • TC1.5, Computer Applications, Voting member and officer
    • TC4.7, Energy Calculations, 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
    • SSPC140 and ASHRAE Guideline 14 involvement
40 Years: Energy and Quality of Life
Energy Efficiency and Sustainability - global

• Buildings (China, India, US, UK, Italy) – 39% to 45% of primary energy
• Buildings in U.S.
  – 45% of primary energy & CO₂; 74% of electricity
• Buildings in China
  – 60% of building floor space in 2030 has yet to be built
• Buildings in India
  – 67% of building floor space in 2030 has yet to be built
US Energy Consumption

Estimated U.S. Energy Consumption in 2017: 97.7 Quads

Solar 0.775
Nuclear 8.42
Hydro 2.77
Wind 2.35
Geothermal 0.211
Natural Gas 28.0
Coal 14.0
Biomass 4.91
Petroleum 36.2

Electricity Generation 37.2
Net Electricity Imports 0.06

Residential 10.7
Commercial 8.99
Industrial 25.2
Transportation 28.1

Energy Services 31.1
Rejected Energy 66.7

Sources: LBNL, April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration’s analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated at 65% for the residential sector, 69% for the commercial sector, 23% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE’s analysis of manufacturing. Totals may not equal sum of components due to independent rounding.

Building Technologies Office
Energy Consumption and Production

Buildings consume 73% of the nation’s electricity

124 million U.S. buildings
€341.5 billion/year in energy bills
($395 billion/year energy bills)

Goal of the DOE
Building Technologies Office:
45% energy reduction per sq. ft.
by 2030 compared to 2010 baseline

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

€34.7 billion/year U.S. industry
$9B/yr – ESCO; $7B/yr – utility EE
$14B/yr – DR management systems
0.3% modified, BEM < 10% of those
ASHRAE Climate Zones

- Based on weather stations, most w/ 18+ yrs of quality data (1961-1990)

Updated every 4 years (2021)
Climate Zone 0 (extremely hot):
10,800 < CDD 50°F
Int’l Energy Conservation Code (IECC) adopts for 2018 code
Redefine CZs using model data

- Resolution: 2 km x 2 km grid cells
- Extent: Continental United States
- Present Conditions (1950-2000): WorldClim
- Future conditions (2050, 2100): PCM and Hadley GCMs; for multiple scenarios (IPCC AR4 A1FI, B1)

1. Precipitation during the hottest quarter
2. Precipitation during the coldest quarter
3. Precipitation during the driest quarter
4. Precipitation during the wettest quarter
5. Ratio of precipitation to potential evapotranspiration
6. Temperature during the coldest quarter
7. Temperature during the hottest quarter
8. Sum of monthly Tavg where Tavg ≥ 5 deg C
9. Integer number of consecutive months where Tavg ≥ 5 deg C (Length of potential growing season)
10. Solar interception
11. Day/night diurnal temperature difference
12. Elevation

- 12 energy-related variables
  - Temperature
  - Humidity
  - Radiation
  - Elevation
Building-adjusted CZ improvement

- What other (e.g. political) variables should be included?
- How could the nation's energy security and critical infrastructure resiliency be improved by incorporating future scenarios into the built environment?
- How much energy and $ could be saved by having a forward-looking climate-aware building code?
Climate Change Impacts
Building Energy Modeling Overview

Optimal Return on Investment (for building energy savings)

Simulation Engine and Analysis Platform
U.S. Dept. of Energy
€80 million – ($93M, 1995–?)

EnergyPlus
OpenStudio

Free, open-source (GitHub),
free support community (unmethours.com)

Project Development Costs as % of Project Investment
(based on sampling of federal ESPC projects)

- 3,000+ building survey, 23-97% monthly error

<table>
<thead>
<tr>
<th>Using Monthly utility data</th>
<th>CV(RMSE)</th>
<th>NMBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15%</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Using Hourly utility data</th>
<th>CV(RMSE)</th>
<th>NMBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30%</td>
<td>10%</td>
</tr>
</tbody>
</table>
HPC scalability for desktop software

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>
</tr>
<tr>
<td>64</td>
<td>18:34</td>
<td>22 GB</td>
<td>256</td>
</tr>
<tr>
<td>128</td>
<td>18:22</td>
<td>44 GB</td>
<td>512</td>
</tr>
<tr>
<td>256</td>
<td>20:30</td>
<td>88 GB</td>
<td>1,024</td>
</tr>
<tr>
<td>512</td>
<td>20:43</td>
<td>176 GB</td>
<td>2,048</td>
</tr>
<tr>
<td>1,024</td>
<td>21:03</td>
<td>351 GB</td>
<td>4,096</td>
</tr>
<tr>
<td>2,048</td>
<td>21:11</td>
<td>703 GB</td>
<td>8,192</td>
</tr>
<tr>
<td>4,096</td>
<td>20:00</td>
<td>1.4 TB</td>
<td>16,384</td>
</tr>
<tr>
<td>8,192</td>
<td>26:14</td>
<td>2.8 TB</td>
<td>32,768</td>
</tr>
<tr>
<td>16,384</td>
<td>26:11</td>
<td>5.6 TB</td>
<td>65,536</td>
</tr>
<tr>
<td>32,768</td>
<td>31:29</td>
<td>11.5 TB</td>
<td>131,072</td>
</tr>
<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>
</tr>
</tbody>
</table>
MLSuite: HPC-enabled suite of Artificial Intel.

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning

XML → MLSuite → PBS → Supercomputer #1 → Linux #1 → ... → Linux #218 → Supercomputer #2

Acknowledgment: Dr. Lynne Parker (NSF Div. Dir. Info. and Intel. Systems);
Dr. Richard Edwards (doctoral student, now Amazon’s ad analytics)
Calibration Performance – automated M&V

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

High Performance Computing
- Different calibration algorithms
- Machine learning – big data mining
- Large-scale calibration tests

Features
- Calibrate any model to data
- Calibrates to the data you have (monthly utility bills to submetering)
- Runs on a laptop and in the cloud
- 35 Publications:
- Open source (GitHub):

Results

<table>
<thead>
<tr>
<th></th>
<th>ASHRAE G14 Requires</th>
<th>Autotune Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly utility data</td>
<td>CVR 15%</td>
<td>1.20%</td>
</tr>
<tr>
<td></td>
<td>NMBE 5%</td>
<td>0.35%</td>
</tr>
<tr>
<td>Hourly utility data</td>
<td>CVR 30%</td>
<td>3.65%</td>
</tr>
<tr>
<td></td>
<td>NMBE 10%</td>
<td>0.35%</td>
</tr>
</tbody>
</table>

Results of 20,000+ Autotune calibrations (15 types, 47-282 tuned inputs each)

Other error metrics

| Residential home       | Tuned input          |
|                       | avg. error           |
| Within 30¢/day (actual use $4.97/day) | Hourly – 8% Monthly – 15% |
|                        | 3 bldgs, 8-79 inputs |
Energy I-Corps/Lab-Corps

• Multiple organizations and countries using Autotune

• 6-week training program, commercialization of calibration software
  – Scientific method applied to the business model canvas
  – 115 interviews, evolve business model
  – Customer Segments: ESCOs and Utilities

• Key technical gap:
  Utilities need a building energy model for every building in their service area
Model America 2020 – calibrated BEM for every U.S. building

Input Data

LandScan Population Model

Material Analysis via Thermal/IR

3D Energy Model Creation

Autotune Model Calibration

Calibrated Energy Model

Benchmarking

Download BEM via your street address

LIDAR

StreetView

Databases
Acknowledgements

• U.S. Department of Energy
• National Nuclear Security Administration
• Oak Ridge National Laboratory
• Building Technologies Office
• Office of Electricity
What matters most?

- 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

<table>
<thead>
<tr>
<th>Small Office</th>
<th>Outpatient</th>
<th>Large Office</th>
<th>Medium Office</th>
<th>Hospital</th>
<th>Warehouse</th>
<th>Small Hotel</th>
<th>Large Hotel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>458</td>
<td>3483</td>
<td>1072</td>
<td>760</td>
<td>1955</td>
<td>333</td>
<td>1823</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strip Mall</th>
<th>Retail</th>
<th>Quick Service Restaurant</th>
<th>Full Service Restaurant</th>
<th>Mid Rise Apt</th>
<th>High Rise Apt</th>
<th>Secondary School</th>
<th>Primary School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td>800</td>
<td>438</td>
<td>281</td>
<td>286</td>
<td>1464</td>
<td>4617</td>
<td>1621</td>
</tr>
</tbody>
</table>

- 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
## 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>Short Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite imagery, including panchromatic and multispectral images</td>
<td>Satellite imagery</td>
</tr>
<tr>
<td>Data type</td>
<td>Image</td>
</tr>
<tr>
<td>Company</td>
<td>N/A</td>
</tr>
<tr>
<td>Website</td>
<td>N/A</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>N/A</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>N/A</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+
Automatic Building Footprint Extraction

- 220,005 NAIP images
- 1 meter multispectral
- 2012-2014
- 5.8 TB compressed
- 9.8 trillion pixels

Portland, OR (25,393 m²)
Imagery: June – July 2012
Lidar: September 2010

Frankfort, KY (14,801 m²)
Imagery: June 2012
Lidar: June 2011

Part of Knox County, TN (18,527 m²)
Imagery: June 2012
Lidar: October 2014
Processing Street-Level Imagery

3D Building Model Generation
Neurophysiologically-based imaged fusion

\[ x'_y = -Ax_y + (B - x_y)(CI^e)_g \]
\[ -(D + x_g)(G_s * I^s)_g \]

Where:
- \( A \) – decay rate
- \( B \) – maximum activation level (set to 1)
- \( D \) – minimum activation level (set to 1)
- \( I^e \) – excitatory input
- \( I^s \) – lateral inhibitory input

\( C \) and \( G_s \) are as follows:

\[ G_{(x,y)} = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}} \]

\[ G_{(x,y,z)} = \frac{1}{4\pi^2\sigma^3} e^{-\frac{(x^2+y^2+z^2)}{2\sigma^2}} \]

3D Shunt Operator Symbol

Noise cleaning & registration if needed
Contrast Enhancement
Between-band Fusion and Decorrelation

![Diagram of neurophysiologically-based imaged fusion](image)
Image Fusion
(color night vision)

PD
GAD
T2
SPECT

Color Fuse Result
Retinal Fusion and Human/Computer Training (armored tank detection in satellite imagery)
Detection of Buildings (and properties) from StreetView imagery
LandScan USA

- 90-meter grid of daytime (commercial) and night time (residential) population
- ~14 different data sources (e.g. anonymized cell phone GPS)
- Building occupancy and schedule adaptation
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
Prototype and Reference Building Updates

- 70, 80 → 90% of U.S. commercial floor space
- 16 types, 16 climate zones, 3 vintages = 768 buildings
  - 17-19+ types, 16-17 climate zones, 5-16+ vintages = 1,360-5,168 models
- ~3,000 avg. parameters per building
  - Square footage, HVAC layout, infiltration (i.e. airflow)
  - Construction (e.g. wall, layers of envelope)
  - Material properties (ASHRAE Handbook of Fundamentals)
  - Equipment and occupancy schedules

### Physical Properties of Materials

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Specific Heat, Btu/ft^2 °F</th>
<th>Density, lb/ft^3</th>
<th>Thermal Conductivity, Btu/ft °F</th>
<th>Emissivity</th>
<th>Surface Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (alloy 1100)</td>
<td>0.214^a</td>
<td>171^c</td>
<td>128^d</td>
<td>0.09^e</td>
<td>Commercial sheet</td>
</tr>
<tr>
<td>Aluminum bronze (76% Cu, 22% Zn, 2% Al)</td>
<td>0.09^a</td>
<td>517^c</td>
<td>58^d</td>
<td>0.20^e</td>
<td>Heavily oxidized</td>
</tr>
<tr>
<td>Asbestos: Fiber</td>
<td>0.25^b</td>
<td>150^c</td>
<td>0.007^e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>0.20^b</td>
<td>36^c</td>
<td>0.02^e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ashes, wood</td>
<td>0.20^b</td>
<td>40^c</td>
<td>0.041^e (122)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.22^b</td>
<td>132^c</td>
<td>0.04^e</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bakelite</td>
<td>0.35^b</td>
<td>81^c</td>
<td>9.7^d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bell metal</td>
<td>0.086^b (122)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bimetallic tin</td>
<td>0.040^b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick, building</td>
<td>0.2^b</td>
<td>123^c</td>
<td>0.4^d</td>
<td>0.93^e</td>
<td></td>
</tr>
</tbody>
</table>
AutoBEM – Automatic Building detection and Energy Model creation

• 19 underlying Intellectual Properties (granted or in process)
  • Range from classified to open-source
  • AutoBEM-LiDAR
  • AutoBEM-Aerial – world’s best building footprint extractor
  • AutoBEM-Street
  • AutoBEM-3D DB
  • AutoBEM-Type
  • AutBEM-Gen – world’s fastest BEM creator
  • AutoSIM – world’s fastest buildings simulator
  • AutoDoEGen
  • AutoSTAT
  • Autotune – world’s best calibration algorithm
AutoBEM – ongoing work

- AutoBEM-Aerial/HVAC
- AutoBEM-Aerial/Chiller
- AutoBEM-scrape

AutoBEM Façade

AutoBEM WWR
Oak Ridge National Laboratory
Oak Ridge National Laboratory (interactive)
The University of Tennessee (2 days)
Overview

- Jim’s vision for Utilities of the Future
- Introduction and Context
- 2 Nation-Scale Use Cases
  - Climate zone assessment
  - GEB market creation
- Urban-Scale modeling
  - Automatic Building detection and Energy Model creation (AutoBEM)
- Virtual EPB progress
  - Utility-prioritized use cases
  - Developed capabilities
  - Preliminary results
AUTOBEM: New Age Energy Security You Can Trust

Jim Ingraham: EPB Vice President Strategic Research
Technology Adoption Rates Accelerate

CONSUMPTION SPREADS FASTER TODAY

Nicholas Felton
Wireless Broadband IoT Age Is Upon Us
Gigabit Speed Wireless Broadband
Coming Soon in 2018-2019

Papal Conclave 2013
ENERGY and INTERNET NETWORKS

Strategic Research

TVA

161 kv Transmission

Distribution Substation

46 kv Transmission

Communications Hub

Distribution Automation

Communications Hub

Distribution Substation

Distribution Automation

Transport Fiber

Source Station

System Control Center

Internet Switched Network

Home

Smart Meter

12 kv Transmission

ONT

LCP

Fiber Optics™

Voltage Control
Distribution Automation
Equipment Management

Energy Management
Meter Reading
Power Quality
Appliance Control
Outage Management

TV Content
A New Generation of Smart Energy Appliances

2011

$250
Artificial Intelligence

2015

$5000
5KWh
Why Tesla’s new solar roof tiles and home battery are such a big deal
The Fortune 500 Is All In - Customer Demand

CORPORATE RENEWABLE ENERGY BUYERS' PRINCIPLES:
INCREASING ACCESS TO RENEWABLE ENERGY

65 COMPANIES

48 MILLION MWH
OF DEMAND FOR
RENEWABLE ENERGY

$5 TRILLION IN
MARKET CAP

www.buyersprinciples.org
Some Partner With The Electric Company

AMAZON SOLAR FARM VIRGINIA - SOUTHWAMPTON - 100 MW (AC)
Southampton County, Virginia
Some Do It On Their Own

50 MW SALT RIVER SOLAR FARM
ARIZONA

We harness creative energy
Energy Service Smoke And Mirrors Are Back

Who Can You Trust? DOE BTO AUTOBEM Can Be an Answer
Where do Americans turn for answers we can trust?
Who Will Die

Kodak
BlackBerry
Tower Records
BORDERS
Blockbuster Video
Sears
City
Macy's
THE UTILITY OF THE FUTURE AT THE CUSTOMER PREMISE

- Television
- Internet of Appliances
- Energy Mgmt.
- Home Automation
- Virtual Reality
- Alt. Gen.

- Comfort and Convenience Service Model
  - Customers
  - Commercial
  - Mobile
  - Residential

- Storage
- Fuel Cell Gas Gen.

- CHP
- WHR
- TRI-GEN

- Small Cell
- 4G to 5G
- Internet

- Customer Service
- Cyber Defense
- Electricity
- Broadband
- Utility System Data
- Managed Services
Control and Manage Load Factor Is The Key

AUTOBEM = MANAGE LOAD FACTOR

ELECTRIC SYSTEM

111 SUBSTATIONS
336 FEEDERS
166,000 BUILDINGS

EPB Control Center

CIRCUITS

MICROGRID
UTILITY SCALE
GENERATION/STORAGE/
ENERGY EFFICIENCY

CUSTOMER

RESIDENTIAL
PUBLIC
INDUSTRIAL
COMMERCIAL
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

1.9 million EnergyPlus building energy models using AutoBEM technology, Titan, cloud,
and local servers to produce and analyze 10.7 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)
Use Case - Scenarios

• Preliminary building-specific estimates of energy, demand, and cost savings totaling €17.5 million/year ($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.
## Demand and EE opportunities

- Energy, demand, emissions, savings (customer and utility) for every building every 15 minutes

<table>
<thead>
<tr>
<th>ECMs</th>
<th>Different Fields Calculated for Each ECM</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>Total</td>
</tr>
<tr>
<td>Lighting</td>
<td>Cost</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Savings</td>
</tr>
<tr>
<td>8F setback</td>
<td></td>
</tr>
<tr>
<td>HVAC Efficiency</td>
<td>$</td>
</tr>
<tr>
<td>4F setback</td>
<td></td>
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<tr>
<td>Insulation</td>
<td>Annual</td>
</tr>
<tr>
<td>Water heater</td>
<td>Electric</td>
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<tr>
<td>Heat pump</td>
<td>Savings</td>
</tr>
<tr>
<td>Smart WH</td>
<td>kWh</td>
</tr>
</tbody>
</table>
Related Work

• **Combined Heat and Power (CHP)**
  • Sizing micro-CHP based on heating, cooling, and electrical demands

• **Transactive HVAC Control**
  • EnergyPlus models for transactive control

• **Microgrid**
  • Simplified model replaced with EnergyPlus
  • Run for area within EPB for considering microgrid

• **VOLTTRON Deployment**
  • B2G services deployment of hardware and control strategies
ORNL creates & maintains virtual building models.

EPB requests additional AutoBEM variables.

ORNL posts summary data.

EPB connects to summary data for dashboards.

EPB receives data and analyzes output, driving business decisions.
EPB’s operational systems

Map showing premises, colored by AutoBEM attribute

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

Chart showing same data, in time series format
1a – Peak contribution percentile by type

- Building ID
- Area (m²)
- Number of Floors
- **Color:** Energy Use Intensity (kWh/m²) by building type
- Min/Avg/Max by building type
Virtual EPB – interactive results

<table>
<thead>
<tr>
<th>ID</th>
<th>60246</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Building Type</td>
<td>SmallOffice</td>
</tr>
<tr>
<td>Num Floors</td>
<td>3</td>
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<tr>
<td>Percentile</td>
<td>87.70 %</td>
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<tr>
<td>Estimated wholesale vs retail cost</td>
<td>$9797.07</td>
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<tr>
<td>CO2 emissions</td>
<td>222052.32 lbs/year</td>
</tr>
<tr>
<td>Smart Thermostat - 4F cost savings</td>
<td>$1316.61</td>
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<td>Smart Thermostat - 8F cost savings</td>
<td>$2325.84</td>
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<tr>
<td>TMY-&gt;AMY Smart Thermostat - 4F cost savings</td>
<td>$204.99</td>
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<tr>
<td>TMY-&gt;AMY Smart Thermostat - 8F cost savings</td>
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<td>HVAC Efficiency ECM</td>
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<td>Gas HVAC ECM</td>
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<td>Gas Water Heater ECM</td>
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<td>Heat Pump Water Heater ECM</td>
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<tr>
<td>Lighting ECM</td>
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</tr>
</tbody>
</table>
Exascale Computing Project

- Coupling:
  - Transportation (CommuterSim)
  - Weather (WRF, Nek5000)
  - Buildings (OpenStudio/EnergyPlus)
  - Population (LandScan)
  - Socio-economics
  - Individual-person, agent-based models, fully-coupled simulations running on the fastest computers in the world

Titan (ORNL), nation’s fastest, 27 petaflops, world’s 5th (top500.org)

Summit (ORNL), world’s fastest in June, 207 PF

Aurora (ANL),  (ORNL)

Exascale...
Discussion

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Oak Ridge National Laboratory

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HPC Tools for Modeling and Simulation
Capturing building energy consumption