Creating a Digital Twin of an Electric Utility
Reimagining building energy modeling in a world of high performance computing, big data, imagery, and advanced metering infrastructure

Presented at:
Argonne National Laboratory
Chicago, IL

Presented by:
Joshua New, Ph.D., C.E.M., PMP, CMVP
Building Technologies Research & Integration Center
Subprogram Manager, Software Tools & Models
Oak Ridge National Laboratory

September 25, 2018
Overview

- Jim Ingraham’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 project (Electric Power Board of Chattanooga, TN)
  - Utility-prioritized use cases
  - Developed capabilities
  - Preliminary results
Virtual EPB – bios

• Joshua New, Ph.D., C.E.M., PMP, CMVP
  • BTRIC “Software Tools & Models” responsible for development of DOE’s building simulation tools, HPC, and AI for big data mining.
  • Led 62 projects (9.4/year) totaling $10M/$28M ($1.3M/yr)
    • 133/133 deliverables (44/yr) on-time and on-budget; 100+ publications (13.8/yr)

• James (Jim) Ingraham, B.S. Finance
  • EPB, VP of Strategic Research; electric utility and broadband communications; market research and data modeling

• William (Bill) Copeland, B.S. Economics, MBA
  • EPB, Director of Business Intelligence, EPB business systems, visual analytics

• Hsiuhan (Lexie) Yang, Ph.D. Civil Engineering
  • Computer vision specializing in aerial imagery
  • Machine learning for large data: NASA, AIST, NSF, DOE

• Mark Adams, M.S. Ag&Bio, Mechanical Engineering
  • Building simulation expert, EnergyPlus/OpenStudio developer
AUTOBEM: New Age Energy Security You Can Trust

Jim Ingraham: EPB Vice President Strategic Research
A 21st Century Crossroads

Globalization
Technological Innovation
Climate Change
Technology Adoption Rates Accelerate

CONSUMPTION SPREADS FASTER TODAY

Nicholas Felton
Wireless Broadband IoT Age Is Upon Us

Papal Conclave 2005
Gigabit Speed Wireless Broadband Coming Soon in 2018-2019
A New Generation of Smart Energy Appliances

2011

$250
Artificial Intelligence

2015

$5000
5KWh
Commercial Customer Net-Zero That Works

OATI Microgrid Technology Center

- Combined Heat and Power
- Microturbine Generation
- Energy Storage
- Microgrid/Net Zero
- Renewable Technologies

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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

Bloomberg 3M ARUP
Sprint eBay Volvo
Hewlett Packard
Enterprise adidas
Etsy

Microsoft AMD P&G
LinkedIn Equinix

Samsung Hotel Group

novonordisk Adobe Digital Realty
STAPLES Walmart Intuit

Hilton Worldwide

Gap Inc. TD Bank

MARS REI

Johnson & Johnson

IKEA Yahoo!

DU PONT

Lockheed Martin

IRON MOUNTAIN

NASA Pernod Ricard

Autodesk IO GM

Target

Starwood Hotels and Resorts

Amazon VMware

Symantec

Google Starbucks Workday

Kellogg’s Intel

Genentech

Sealed Air

VMware

Symantec

Avery Dennison

EMC

Cisco

Salesforce

Nestle

Novotel

Switch

Akamai

HP

www.buyersprinciples.org
Some Partner With The Electric Company

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

50 MW SALT RIVER SOLAR FARM
ARIZONA

SIGNAL ENERGY
CONSTRUCTORS
WE HARNESS CREATIVE ENERGY
Strategic Research

Or Hire An Energy Service Company

Tenaska®

Caesars Entertainment®

Mandalay Bay® Resort and Casino, Las Vegas

MGM Grand,
Las Vegas

An MGM Resorts Luxury Destination
Energy Service Smoke And Mirrors Are Back

Who Can You Trust? DOE BTO AUTOBEM Can Be an Answer
Who Will Die

- Kodak
- BlackBerry
- Tower Records
- Borders
- Circuit City
- Sears
- Macy's
AUTOBEM Integrated With EPB Appliance Models

Power Heat Optimization & Electric Network Investment Model X

- EPB Data
  - Comm Service Rates
  - Transport Costs
  - Thermal Load
  - Customer Data
  - Electric Load
  - Electric Rates
  - Natural Gas Prices (Prophet X)
  - GPP/RSO Solar Data

- RFF Regional Fiber
- GGI Gas & CHP
- IoT
- Waste Heat Recovery
- AutoBEM
- EV Charging
- Wireless

- ORNL Data
  - Cartographic Data
  - Ground Level Images
  - Building Information Databases
  - Satellite & Airborne Imagery
  - Elevation Data
  - 3D Building Model Databases

- Assumptions & Inputs
- Forecasted Load, Technology Data
- Forecasted WS & RT Rates All Classes
- Financial Simulation & Metrics
- Exec Summary & Scenarios

Models
- Working Model
- Theoretical Model

Strategic Research
AUTOBEM Integrated With EPB Appliance Models
THE UTILITY OF THE FUTURE AT THE CUSTOMER PREMISE
Control and Manage Load Factor Is The Key

AUTOBEM = MANAGE LOAD FACTOR

ELECTRIC SYSTEM

EPB Control Center

111 SUBSTATIONS
336 FEEDERS
166,000 BUILDINGS

CIRCUITS

MICROGRID
UTILITY SCALE
GENERATION/STORAGE/
ENERGY EFFICIENCY

CUSTOMER

RESIDENTIAL
PUBLIC
COMMERCIAL
INDUSTRIAL
DARPA’S INTERNET CHANGED THE WORLD

AUTOBEM COULD BE THE NEXT GAME CHANGER
**ORNL/EPB Coordination**

- **ORNL**
  - Creates & maintains virtual building models
  - ORNL posts summary data

- **AutoBEM output**

- **EPB**
  - Receives data and analyzes output, driving business decisions
  - EPB Requests additional AutoBEM variables
  - EPB Connects to summary data for dashboards
EPB’s operational systems

Map showing premises, colored by AutoBEM attribute

Chart showing same data, in time series format

Use of filters create an interactive experience for business users, driving business decisions
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  – Developed capabilities
  – Preliminary results
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)
    - Urban Dynamics Institute, Resiliency Team member
  - 2012+ The University of Tennessee, Joint Faculty

- **Education**
  - The University of TN, (2004-2009), Knoxville; Ph.D. Comp. Sci.
    - M.S. Systems&Software Design, double-B.S. Computer Science and Mathematics, Physics minor

- **Professional Involvement**
  - IEEE, Senior Member
  - 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
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 & CO$_2$; 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
Energy Consumption and Production

Buildings consume 73% of the nation’s electricity

- Buildings consume 73% of the nation’s electricity
- 124 million U.S. buildings
- $395 billion/yr 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

- $9B/yr – ESCO
- $7B/yr – utility EE
- $14B/yr – DR management systems
- 0.3% modified, BEM < 10% of those
Building Energy Modeling +
Resilience of the Electric Grid +
ASHRAE’s Changing Climate Zones
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
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

Contemporary Period

Clustering-based Climate Zones (K=5): HadGCM A1FI 2050

Clustering-based Climate Zones (K=5): HadGCM A1FI 2100

CO₂ emissions (Gt C)

Scenarios
- A1B
- A1T
- A1FI
- A2
- B1
- B2
- IS92a
Building Energy Modeling +
Grid-interactive Efficient Buildings +
New Energy Market
(save $x \pm y$ at confidence level of $z$, time-sensitive value trades)
Building Energy Modeling

Optimal Return on Investment (for building energy savings)

Simulation Engine and Analysis Platform
U.S. Dept. of Energy
$93M, 1995–?

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

<table>
<thead>
<tr>
<th>Using Monthly utility data</th>
<th>ASHRAE G14 Requires</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV(RMSE)</td>
<td>15%</td>
</tr>
<tr>
<td>NMBE</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Using Hourly utility data</th>
<th>ASHRAE G14 Requires</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV(RMSE)</td>
<td>30%</td>
</tr>
<tr>
<td>NMBE</td>
<td>10%</td>
</tr>
</tbody>
</table>

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

Project Development Costs as % of Project Investment (based on sampling of federal ESPC projects)
### 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: HPC scalability for desktop software

<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

**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

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

<table>
<thead>
<tr>
<th>Residential home</th>
<th>Tuned input avg. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 30¢/day</td>
<td>Hourly – 8%</td>
</tr>
<tr>
<td>(actual use $4.97/day)</td>
<td>Monthly – 15%</td>
</tr>
<tr>
<td>3 bldgs, 8-79 inputs</td>
<td></td>
</tr>
</tbody>
</table>
Model America 2020 – 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

- Benchmark
- Reduce
- Offset

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
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 km(^2) 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+
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
3D Building Model Generation
LandScan USA – Amy Rose

- 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/lb•F</th>
<th>Density, lb/ft³</th>
<th>Thermal Conductivity, Btu/ft•h•°F</th>
<th>Emissivity Ratio</th>
<th>Surface Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum (alloy 1100)</td>
<td>0.21⁴</td>
<td>171⁴</td>
<td>128⁴</td>
<td>0.09⁶</td>
<td>Commercial sheet</td>
</tr>
<tr>
<td>Aluminum bronze (76% Cu, 22% Zn, 2% Al)</td>
<td>0.09⁴</td>
<td>517⁴</td>
<td>58⁴</td>
<td>0.20⁶</td>
<td>Heavily oxidized</td>
</tr>
<tr>
<td>Asbestos: Fiber</td>
<td>0.25⁵</td>
<td>150⁵</td>
<td>0.097⁵</td>
<td>0.09⁵</td>
<td>“Paper”</td>
</tr>
<tr>
<td>Asbestos: Insulation</td>
<td>0.27⁵</td>
<td>10⁵</td>
<td>0.097⁵</td>
<td>0.09⁵</td>
<td>“Paper”</td>
</tr>
<tr>
<td>Asbestos: wood</td>
<td>0.20⁵</td>
<td>50⁵</td>
<td>0.041⁵ (122)</td>
<td>0.30⁵</td>
<td>“Paper”</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.35⁵</td>
<td>81⁵</td>
<td>9.7⁵</td>
<td>0.30⁵</td>
<td>“Paper”</td>
</tr>
<tr>
<td>Bell metal</td>
<td>0.086⁶ (122)</td>
<td>0.376</td>
<td>0.93⁴</td>
<td>0.93⁴</td>
<td>“Paper”</td>
</tr>
<tr>
<td>Brick, building</td>
<td>0.2³</td>
<td>12³</td>
<td>0.4³</td>
<td>0.93⁴</td>
<td>“Paper”</td>
</tr>
</tbody>
</table>
Street-level imagery (Lexie Yang)

Façade Type

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

Window-to-wall ratio

Input image
Ground truth
Model output
Oak Ridge National Laboratory (interactive)
The University of Tennessee (2 days)
Virtual EPB – bios

- **Joshua New, Ph.D., C.E.M., PMP, CMVP**
  - BTRIC “Software Tools & Models” responsible for development of DOE’s building simulation tools, HPC, and AI for big data mining.
  - Led 62 projects (9.4/year) totaling $10M/$28M ($1.3M/yr)
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  - EPB, VP of Strategic Research; electric utility and broadband communications; market research and data modeling

- **William (Bill) Copeland, B.S. Economics, MBA**
  - EPB, Director of Business Intelligence, EPB business systems, visual analytics

- **Hsiuhan (Lexie) Yang, Ph.D. Civil Engineering**
  - Computer vision specializing in aerial imagery
  - Machine learning for large data: NASA, AIST, NSF, DOE

- **Mark Adams, M.S. Ag&Bio, Mechanical Engineering**
  - Building simulation expert, EnergyPlus/OpenStudio developer
Virtual EPB Summary

• DOE’s Building Technologies Office and Office of Electricity
  • Goal: create a digital twin of every building in EPB’s service area
  • Final Deliverable: Simulation-informed data and valuation report for energy, demand, emissions, and $ impact to EPB for each building in EPB’s service area for 5 prioritized use cases covering 9 monetization scenarios

• 2 projects, funded and tracked separately
• Total - $700k (OE-$450k, 41 tasks; BTO-$250k, 15 tasks + BTO: $400k FY19)
• 56 tasks, 12 milestones, 1 Go/No-Go (passed)
• On-schedule except for 1 technical input (High-res bldgs) and 1 task (QA/QC)
Utility Use Cases for Virtual EPB

- **Peak Rate Structure** - model peak segment customers in aggregate as disproportionate contributors to electric utilities’ wholesale demand charges for more equitable rate structures.

- **Demand Side Management** – identify DSM products and grid services for better distribution grid management that allow both utilities and rate-payers to share in peak reduction

- **Grid stability services** – quantify improved load models

- **Emissions** – accurately account for emissions contributed by each building, providing enhanced abilities for utilities to best comply with national emission policies.

- **Energy Efficiency** – accurate modeling/forecasting of every building energy profile virtually in a scalable fashion allows better follow-up and more targeted energy audits/retrofits.

- **Customer Education** - better understand building’s energy usage as a function of weather to provide better information during customer billing enquiries.

Energy, Demand, Emissions, and $ for 9 scenarios (Customer->EPB, EPB->TVA)
EPB buildings in Tennessee (166,944)
EPB buildings in Tennessee (166,944)
EPB buildings in Tennessee (166,944)
Chattanooga, TN (100,000+ buildings)
Scientific results

- 100+ page internal report NDA/OUO

- 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

<table>
<thead>
<tr>
<th></th>
<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><strong>Inputs</strong></td>
<td>458</td>
<td>3483</td>
<td>1072</td>
<td>760</td>
<td>1955</td>
<td>333</td>
<td>1823</td>
<td>887</td>
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<tr>
<td><strong>Inputs</strong></td>
<td>458</td>
<td>3483</td>
<td>1072</td>
<td>760</td>
<td>1955</td>
<td>333</td>
<td>1823</td>
<td>887</td>
</tr>
</tbody>
</table>

- 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
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)
• **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.
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
• Pre-heat/pre-cool 2 or 4 hours prior to peak demand hour each month
  • Single Heating or Single Cooling thermostat – up or down 4°F and 8°F
  • Dual Setpoint Thermostat – Average of baseline cooling and heating setpoints with a 0.5°C deadband

• Setback thermostat setpoint by 4°F or 8°F for peak demand hour and 4 hours after peak for each month

• Altered thermostat values affects 38 (1-4 per building type) thermostat schedules in 518 (3-118 per building type) thermal zones for 16 different building types

• The 4°F and 8°F runs are compared to baseline, unaltered simulation to determine demand reduction and energy savings potential
2a - Smart Thermostat: Maximum Demand and Energy Reduction Potential
Resiliency and Emissions Footprint

- **2b: Demand Side Management**
  - Resiliency of critically-loaded feeders and substations

**Circuit: Customer Information**

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Circuit Count: 1</th>
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</thead>
<tbody>
<tr>
<td>As of Date:</td>
<td>XFMR Count: 146</td>
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<tr>
<td></td>
<td>Meter Count: 703</td>
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<table>
<thead>
<tr>
<th>Circuit ID</th>
<th>Xmr Structure Number - Compressed</th>
<th>Premise Number</th>
<th>Account Number - Formatted</th>
<th>Premise Service Address</th>
<th>Meter Number</th>
</tr>
</thead>
</table>

- **3a: Emission Footprint for each building**
  - Carbon footprint (CO₂)
  - Nitrogen oxides (NOx)
  - Sulfur Dioxide (SO₂)
  - *Methane (CH₄)*
  - *Nitrous Oxide (N₂O)*
### 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>
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<tbody>
<tr>
<td><strong>Lighting</strong></td>
<td>Cost, Electric, Cost, Electric, Demand, Demand, Demand, Cost</td>
</tr>
<tr>
<td><strong>Infiltration</strong></td>
<td>Savings, Savings, Savings, Savings, Cost, Savings</td>
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<tr>
<td><strong>8F setback</strong></td>
<td>Savings</td>
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<tr>
<td><strong>HVAC Efficiency</strong></td>
<td>$, kWh, $, kWh, kW, $, kW, $</td>
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<td><strong>4F setback</strong></td>
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<tr>
<td><strong>Water heater</strong></td>
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<td><strong>Heat pump</strong></td>
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<tr>
<td><strong>Smart WH</strong></td>
<td>kWh, $, kWh, $, $, kW</td>
</tr>
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</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
Virtual EPB – interactive results

<table>
<thead>
<tr>
<th>ID</th>
<th>60246</th>
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<tbody>
<tr>
<td>DOE Building Type</td>
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<tr>
<td>Num Floors</td>
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<tr>
<td>Percentile</td>
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<td>Estimated wholesale vs retail cost</td>
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<td>CO2 emissions</td>
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<tr>
<td>Smart Thermostat - 4F cost savings</td>
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<td>Smart Thermostat - 8F cost savings</td>
<td>$ 2325.84</td>
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<td>TMY-&gt;AMY Smart Thermostat - 4F cost savings</td>
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<td>TMY-&gt;AMY Smart Thermostat - 8F cost savings</td>
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<td>HVAC Efficiency ECM</td>
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<td>Lighting ECM</td>
<td>$ 2898.95</td>
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</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), when the world’s fastest 27 petaflops, world’s 7th (top500.org)
Summit (ORNL), world’s fastest in June, 207 PF
Aurora (ANL), Frontier (ORNL)

Exascale...
Discussion

Joshua New, Ph.D., CEM, PMP, CMVP
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Oak Ridge National Laboratory
newjr@ornl.gov

HPC Tools for Modeling and Simulation
Capturing building energy consumption