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Chattanooga - The Smart City - How a National Laboratory and a City heralded a digital transformation: The Electric Grid and Buildings

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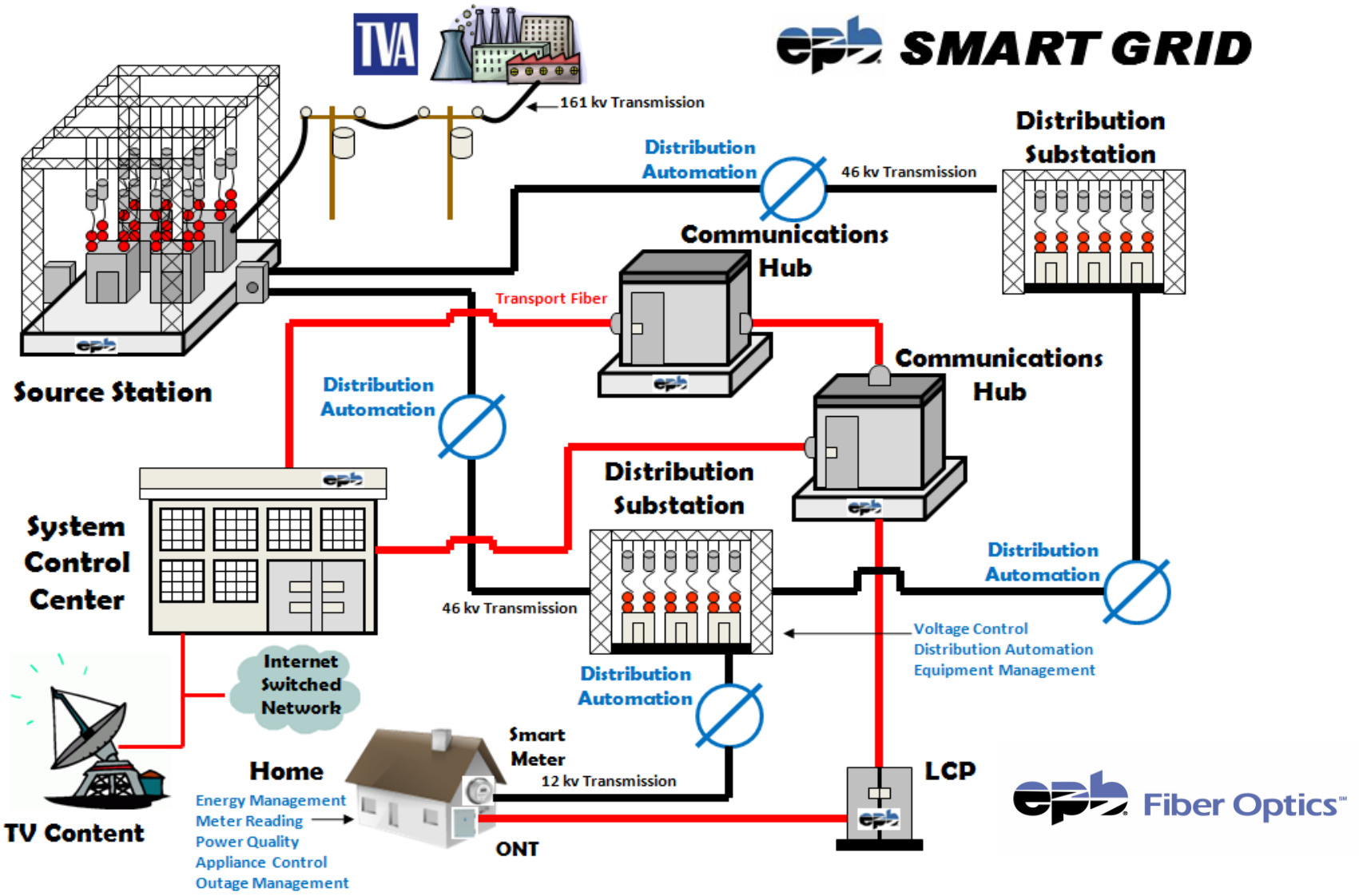
Presented for: Global Smart Cities Council Plenary Session

Recorded: October 8, 2020

Strategic Research

ENERGY and INTERNET Networks



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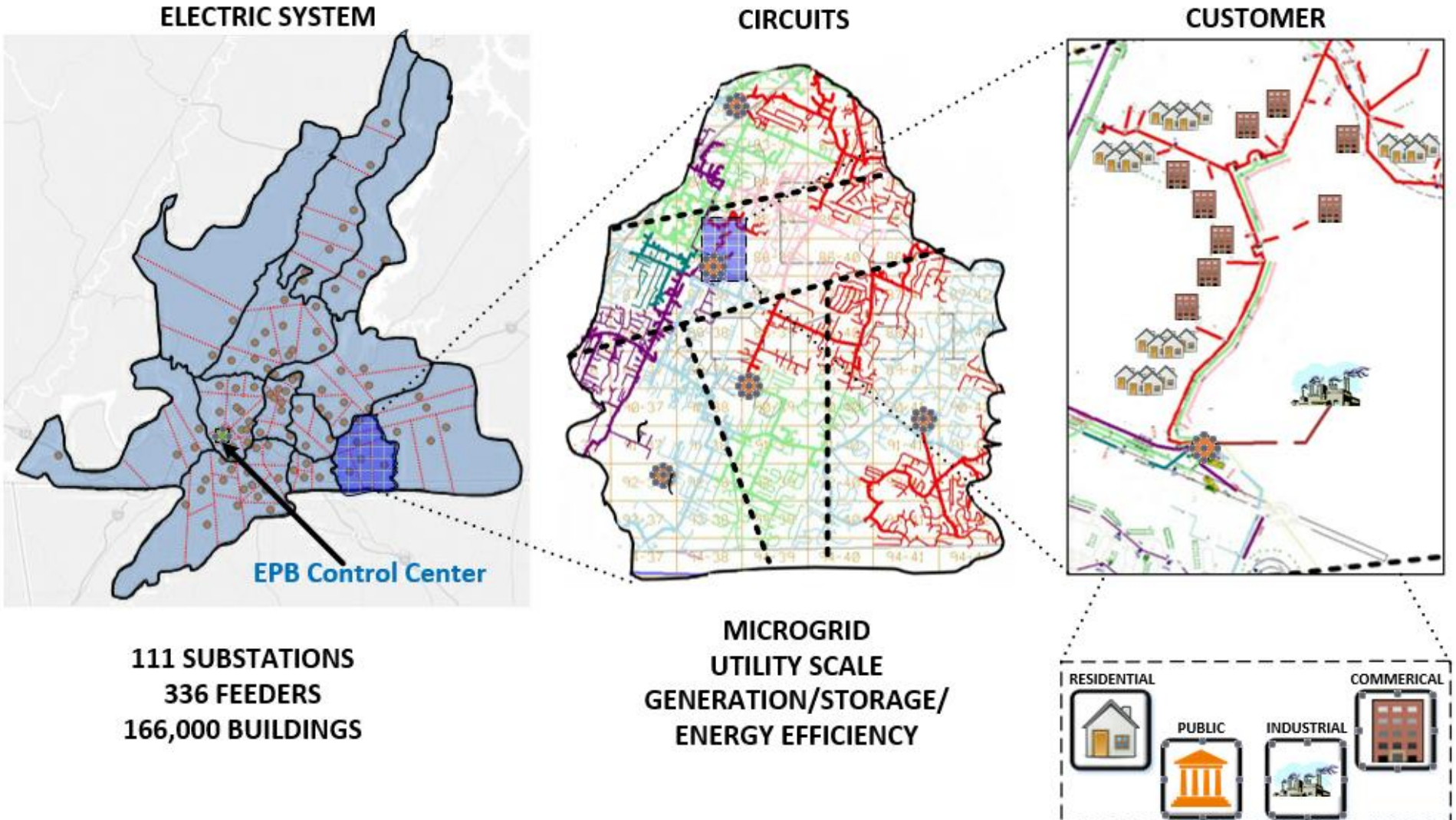
Strategic Research

Control and Manage Load Factor Is The Key

AUTOBEM = MANAGE LOAD FACTOR



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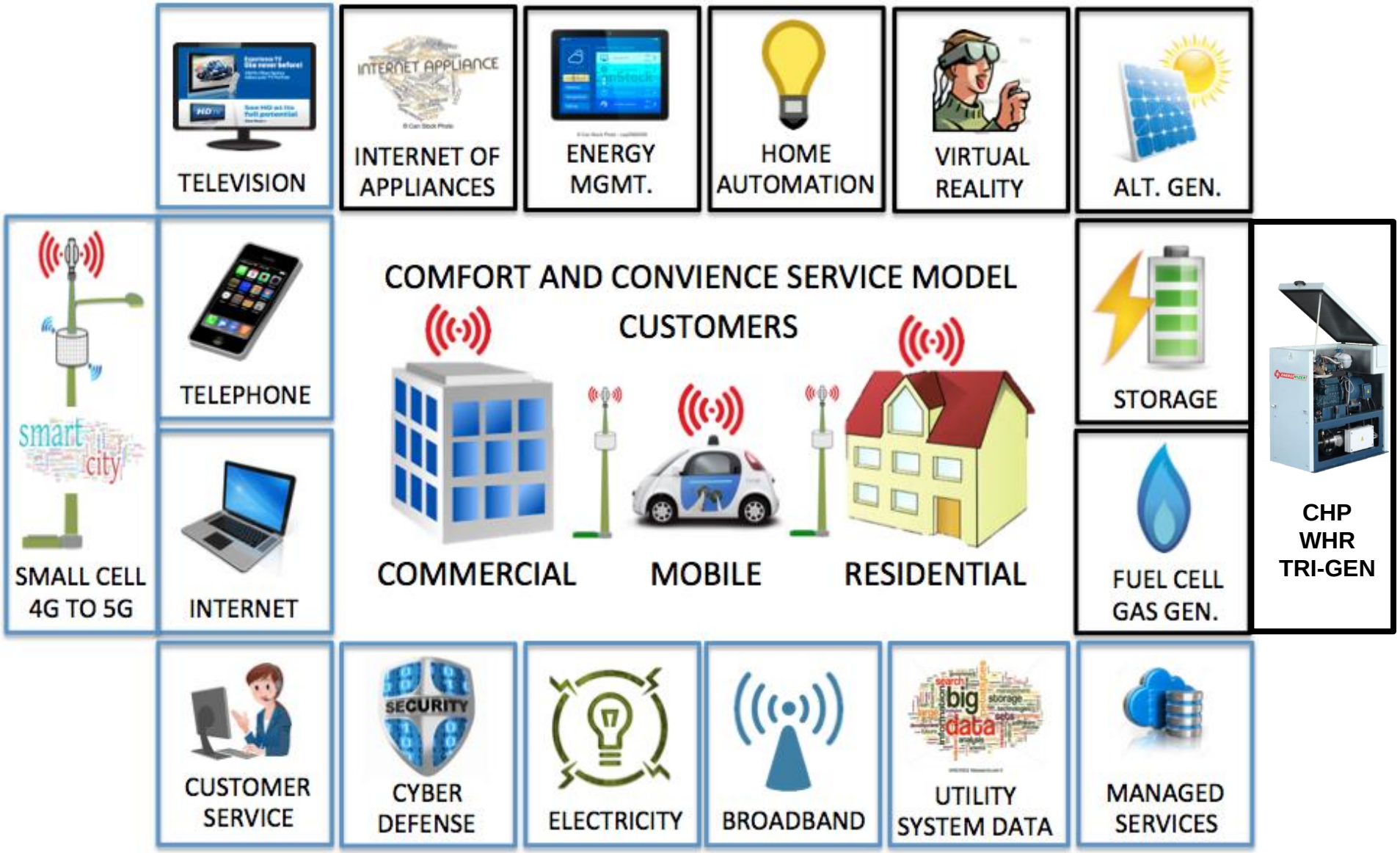
Strategic Research

Utility of the Future at the Customer Premise



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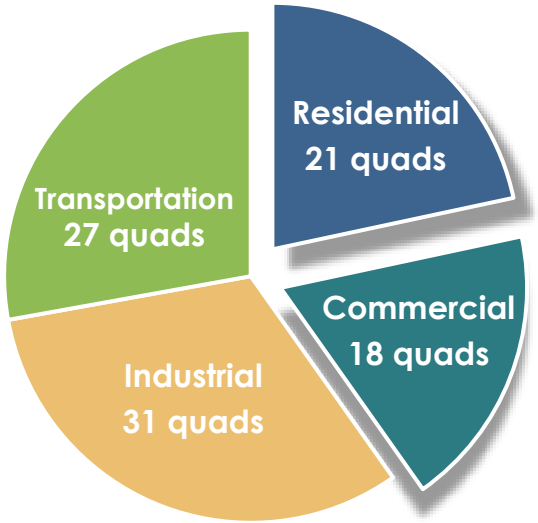
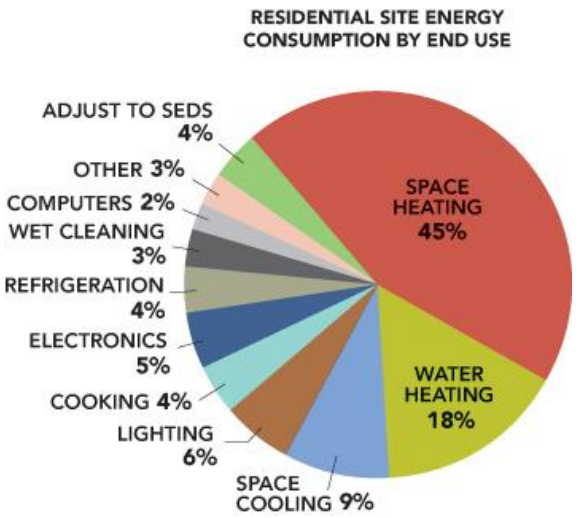
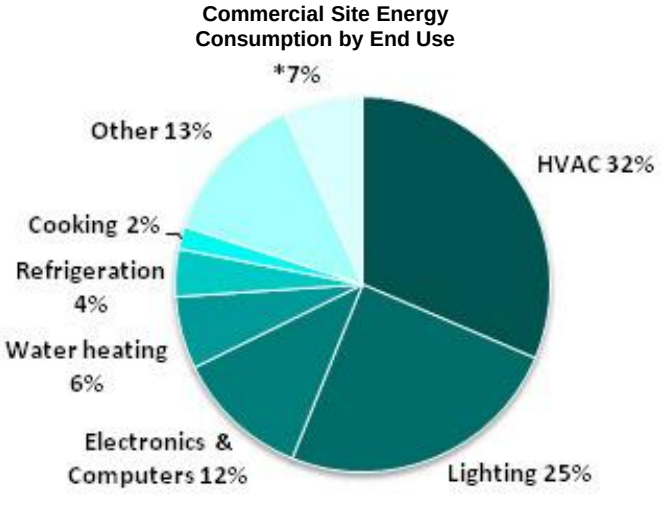
Energy and Buildings Overview



40% Buildings

125 million buildings
$412 billion in 2019 energy bills





Buildings consume 73% of the nation's electricity
80% of energy during peak hours

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

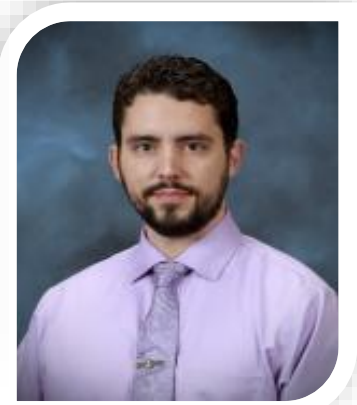
Office of Electricity vision:
Harness innovation for a stronger, more resilient and reliable North American energy system while maintaining energy independence.

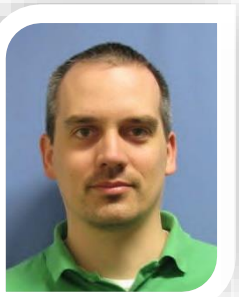
Building Energy Modeling – building descriptions + weather = estimated building energy consumption

Grid-interactive Efficient Buildings (GEB) Vision: integration and continuous optimization of DERs for the benefit of building owners, occupants, and the grid.

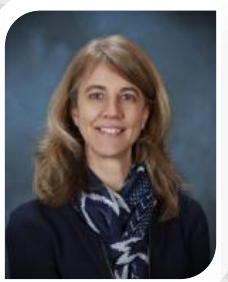
Acknowledgements

- EPB/ORNL partnership
- U.S. Department of Energy
  - EERE/Building Technologies Office
  - Office of Electricity
  - National Nuclear Security Administration
- Oak Ridge National Laboratory

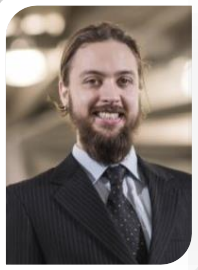
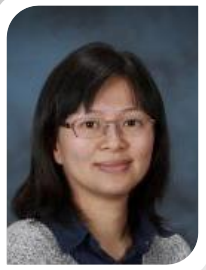








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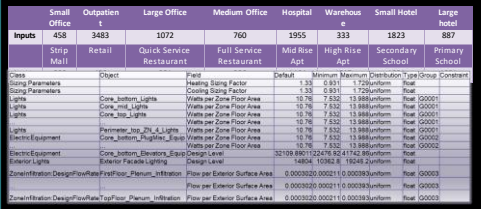
Technical overview

Digital Twin of every U.S. building

Methodology: Scalable compute, data, simulation, and empirical validation

1. Quantitatively rank most important building inputs

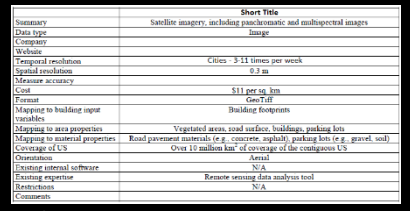


Sensitivity Analysis

2. Time on world's #1 fastest high-performance machines

Supercomputers

3. Identify and compare data sources for important inputs



Comparison Matrix

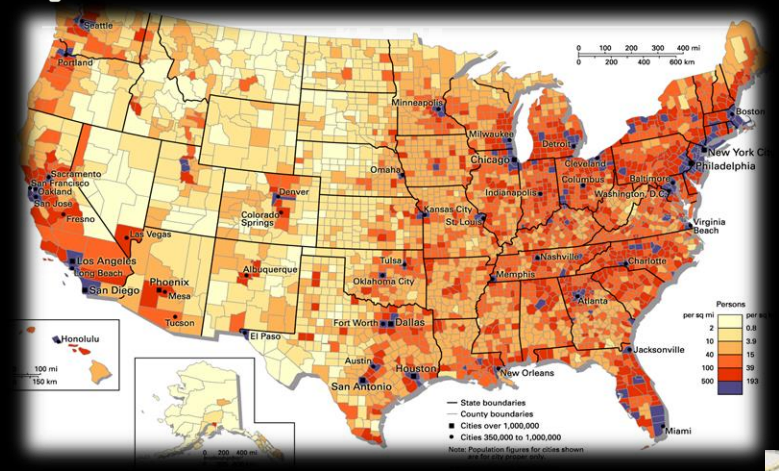
4. Establish partnerships and APIs for scalable data retrieval

Satellite/Aerial Imagery

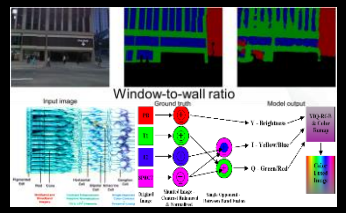
StreetView

LIDAR

Databases

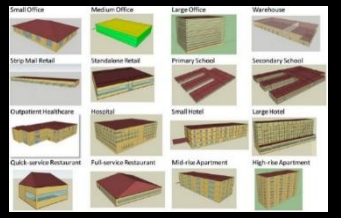


5. Algorithms to extract building properties



Computer Vision

6. Create OpenStudio & EnergyPlus models



DOE Prototype Buildings

Demonstrate and stimulate GEB opportunities toward a sustainable built environment

7. Make models freely available

Download BEM via street address

Use cases:

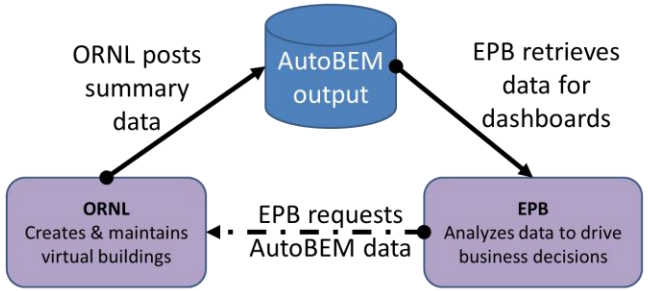
- Simulation-informed analysis
- Sales/market leads
- Utility program formulation
- Rate structures
- Resilience
- Automated financing
- Business model evaluation

Overview – uses and building technologies

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

Energy Conservation Measure: Insulate Roof, Seal space

Improve airtightness of the building envelope (i.e. reduce the gaps at the doors and windows).

Reduce by 25% (EnergyStar whole-house).

https://www.idi-insulation.com/wp-content/uploads/2018/08/Creating-a-Seal.png

Adding insulation layer to the existing roof structures following the latest ASHRAE 90.1 Appendix G guidelines.

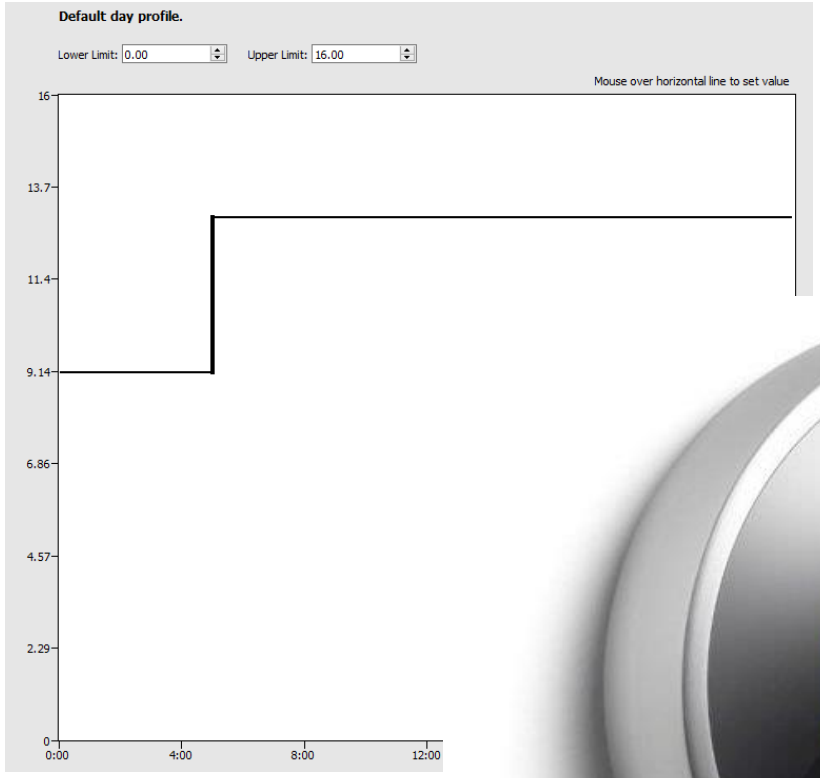
R-value: 16.12 (avg) to 28.57 (IECC-2012).

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.dea5.net%2Ftips-on-how-to-choose-the-best-local-insulation-specialist%2F&psig=AOvVaw0jfTQxBkhHEpxCrh7FOIcU&ust=1591106479177000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCIjoptbj4OkCFQAAAAAdAAAAABB5

Energy Conservation Measure: Adjust Thermostat Setpoint (4-8°F)

Buildings as thermal batteries

Pre-conditioning the space by
4°F two hours before, or
8°F four hours before the peak demand hour.



https://gearmoose.com/wp-content/uploads/2019/05/nest-2-thermostat1.jpg

Overview of Building Technologies (simulated in every building)

#	Description	Category	Value	Source
1	Insulate Roof	Envelope	R-16.12 to R-28.57	IECC-2012
2	Reduce Space Infiltration	Envelope	Reduce 25% from vintage	EnergyStar whole-house
3	Adjust Thermostat Setpoint (4F)	HVAC	4°F 2 hrs prior to peak	EPB
4	Smart Thermostat (8F)	HVAC	8°F 4 hrs prior to peak	EPB
5	Change Electric HVAC COP	HVAC	COP to 3.55 (heating) 3.2 (cooling)	IECC-2012
6	Change Lighting Power Density	Lighting	LPD 0.85 W/ft^2	IECC-2012
7	Change to Gas Water Heater	Water	Efficiency 80% (assumes electric)	IECC-2012
8	Change to Gas HVAC	HVAC	Efficiency 80% (assumes electric)	IECC-2012

Automatic Detection and Building Energy Model Creation (AutoBEM)

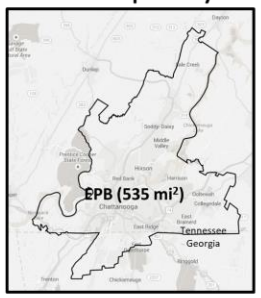
Data Sources

- 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)

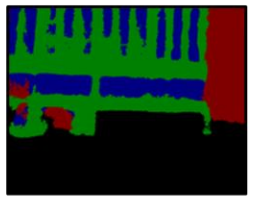
Data comparison matrix

	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
Mapping to area properties	Vegetated areas, road surface, buildings, parking lots
Mapping to material properties	Road pavement materials (e.g., concrete, asphalt), parking lots (e.g., gravel, soil)
Coverage of US	Over 10 million km^2 of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A

Occupancy

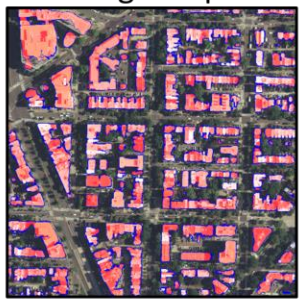


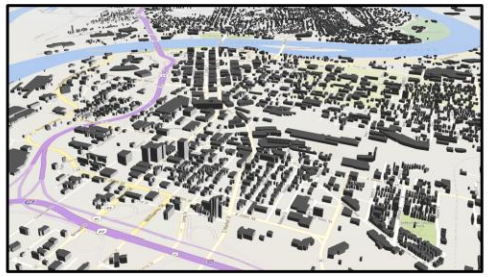
Street-level data

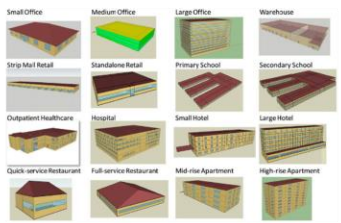


Window-to-wall ratio

Building footprints







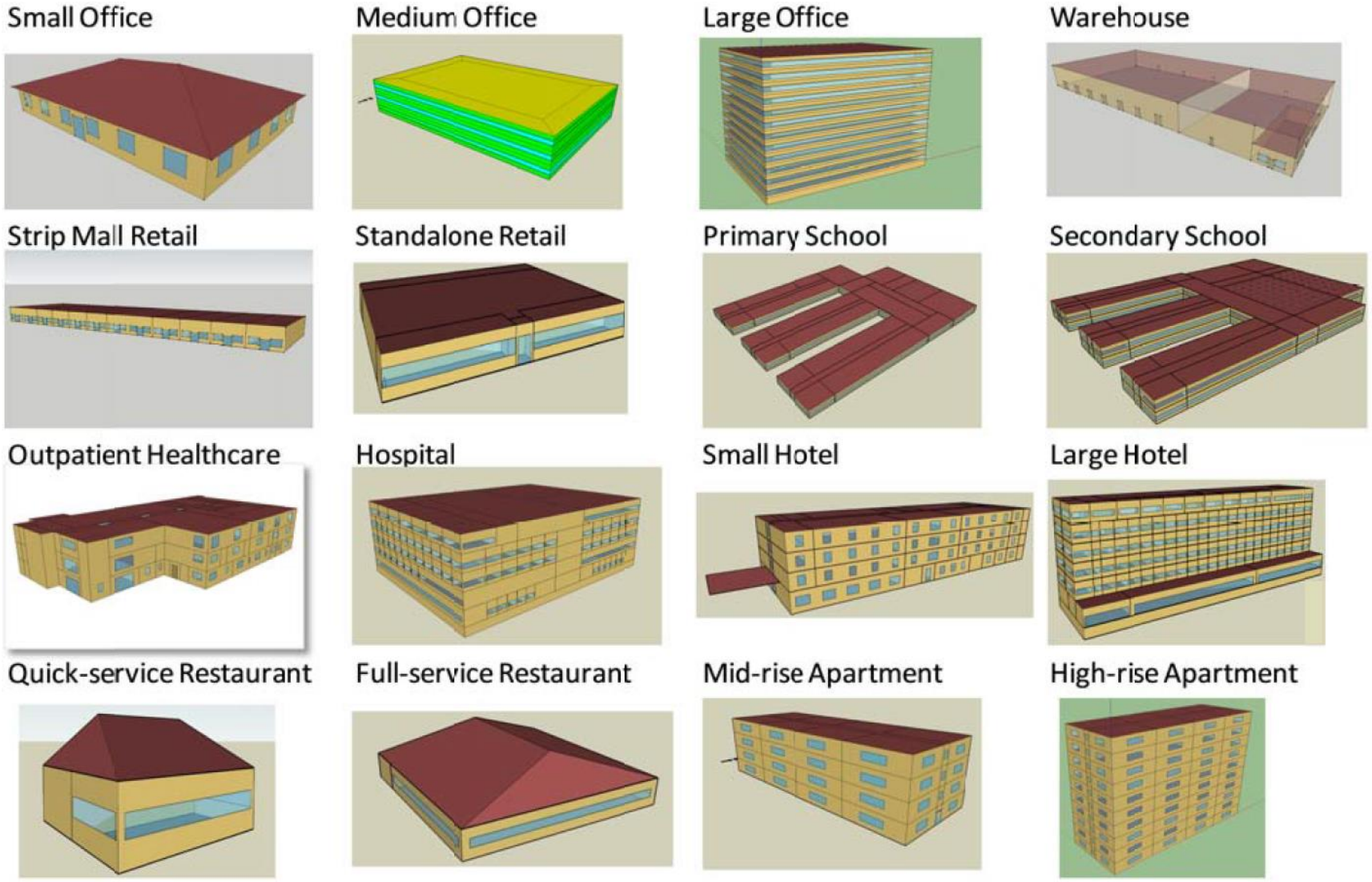
Class	Object	Field	Default	Minimum	Maximum	Distribution	Type	Group	Constraint
Sizing:Parameters		Heating Sizing Factor	1.33	0.931	1.729	uniform	float		
Sizing:Parameters		Cooling Sizing Factor	1.33	0.931	1.729	uniform	float		
Lights	Core_bottom_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0001	
Lights	Core_mid_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0001	
Lights	Core_top_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0001	
...	...	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0001	
Lights	Perimeter_top_ZN_4_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0001	
ElectricEquipment	Core_bottom_PlugMisc_Equip	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0002	
		Watts per Zone Floor Area	10.76	7.532	13.988	uniform	float	G0002	
ElectricEquipment	Core_bottom_Elevators_Equip	Design Level	32109.89011	22476.92	41742.86	uniform	float		
Exterior:Lights	Exterior Facade Lighting	Design Level	14804	10362.8	19245.2	uniform	float		
ZoneInfiltration:DesignFlowRate	FirstFloor_Plenum_Infiltration	Flow per Exterior Surface Area	0.000302	0.000211	0.000393	uniform	float	G0003	
...	...	Flow per Exterior Surface Area	0.000302	0.000211	0.000393	uniform	float	G0003	
ZoneInfiltration:DesignFlowRate	TopFloor_Plenum_Infiltration	Flow per Exterior Surface Area	0.000302	0.000211	0.000393	uniform	float	G0003	

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

Prototype Buildings – surveys for internal details



ORNL at the forefront in Computing: #1 Jaguar, Titan, Summit

Theta 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)

ALCC Award
19M core-hours
June 2, 2020

OLCF's Titan

CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
16	18:14	5 GB	64
32	18:19	11 GB	128
64	18:34	22 GB	256
128	18:22	44 GB	512
256	20:30	88 GB	1,024
16,384	26:11	5.6 TB	65,536
32,768	31:29	11.5 TB	131,072
65,536	44:52	23 TB	262,144
131,072	68:08	45 TB	524,288

ALCF's Theta

CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
57,344	20:44	440 GB	229,376
114,688	28:20	880 GB	458,752

Capabilities – flexible digital twin for buildings

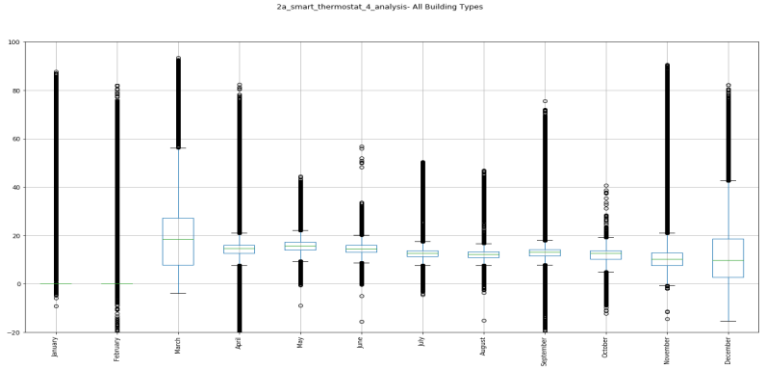
178,368 building models have been created and matched to EPB's PremiseID

3+ million EnergyPlus building energy models using AutoBEM technology, Titan, cloud, and local servers to produce and analyze 15+ TB of simulation data.

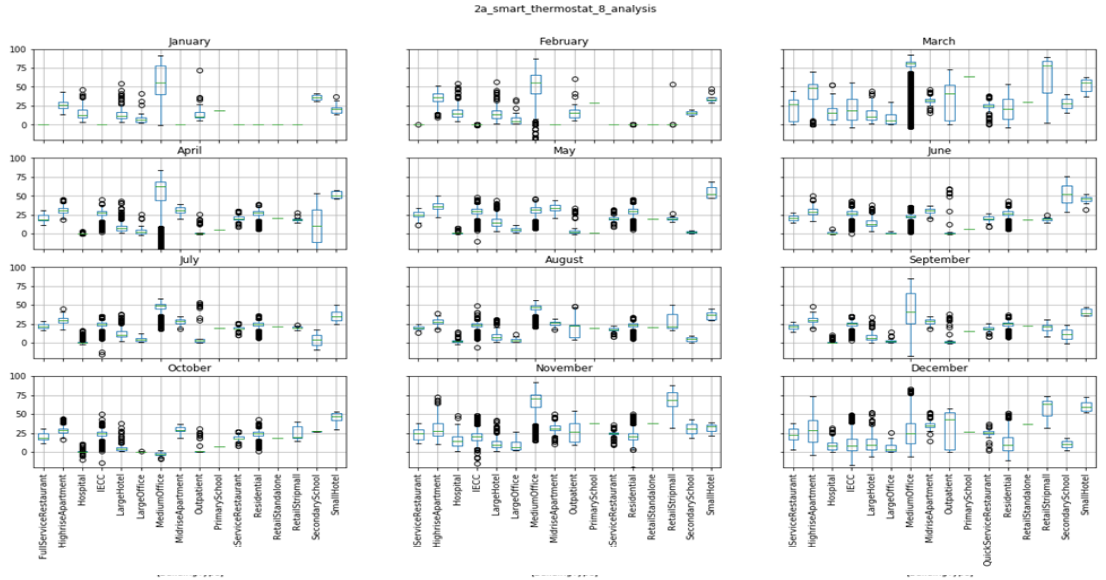
1. Generate baseline building – 1.5-3h Amazon, 30h internal
2. Run ECM measures – OS Measure (30 mins AWS, 2h internal), Custom (1m AWS, 5m intl.)
3. Copy data to Titan – 1 min (1.2GB tar.gz)
4. Submit to Titan – 0-2 hours in queue
5. Simulation time – 30-45 mins (5mins/sim = 1.4 years to simulate EPB on 1 core)
6. Data transfer – 40 mins (160GB of tar.gz)
7. Uncompress – 10-15 mins
8. Reformat data – 20-30 mins (pickle)
9. Analysis – 5-10 mins (64-node AWS instance with solid state drives)

Time for creation, annual simulation, and analyzing "all" EPB buildings
6.5 hours (6.1h –36.5h) **; 3.7 ECMs for every building simulated in 28.3 mins!**

Potential Demand Reduction via Smart Thermostats in a Simulated Utility



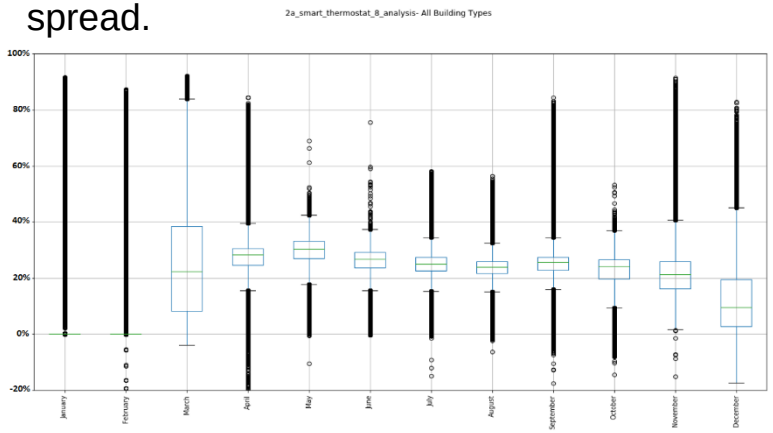
4°F pre-conditioning shows an average **13%** peak demand reduction across 178,368 residential and commercial buildings.



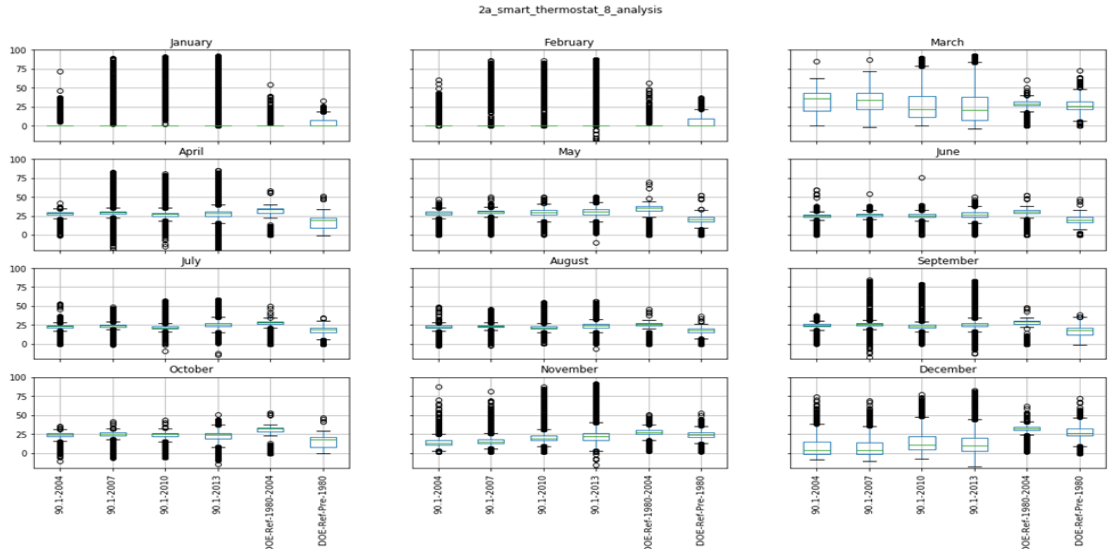
8°F breakdown of quartiles by **building type** for each calendar month with medium offices and strip malls as high, but time-sensitive, value deployments.

Analysis: Demand Reduction Breakdowns

8°F shows an average **22%,** significant spread.



8°F breakdown of quartiles by **vintage** (age) for each calendar month shows slight increases with newer vintages.



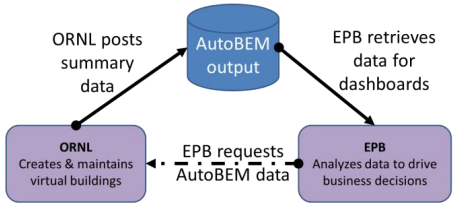
Accuracy compared to real 15-minute data for each building

- Empirical Validation
  - 15-minute whole-building electric use for 178,368 buildings
  - More accurate than uncalibrated 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

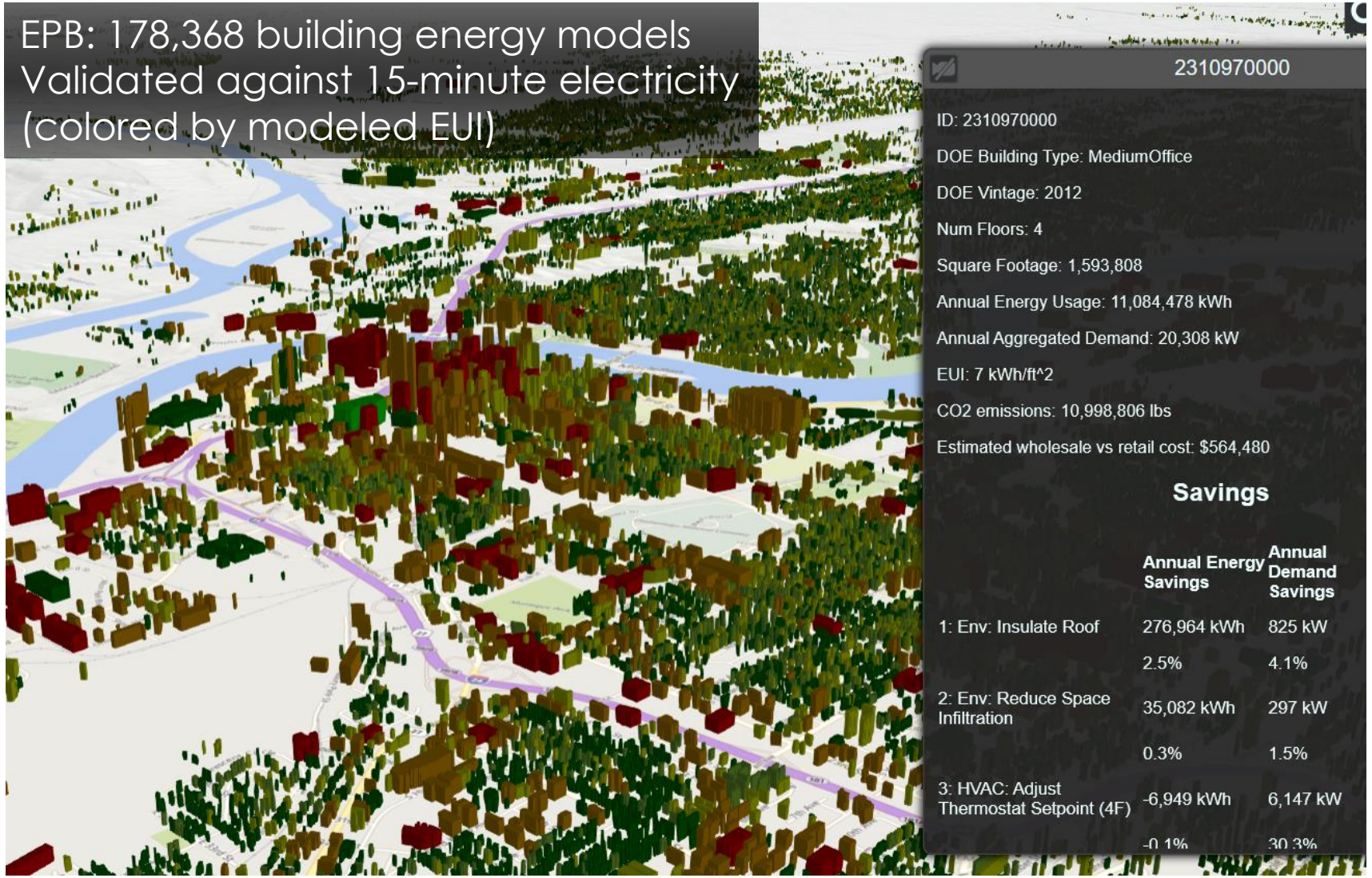
- Lighting, HVAC COP, infiltration, insulation
- Smart thermostats
- Water heaters
- PV/solar
- EV charging
- Future weather
- Dual-fuel HVAC
- Microgrids

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

[1]Garrison, Eric, New, Joshua R., and Adams, Mark (2019). "Accuracy of a Crude Approach to Urban Multi-Scale Building Energy Models Compared to 15-min Electricity Use." Best PhD Student Paper award. In *Proceedings of the ASHRAE Winter Conference*, Atlanta, GA, Jan. 12-16, 2019. [PDF] [PPT]

Results: Digital Twin of a Utility (every building)

EPB: 178,368 building energy models
Validated against 15-minute electricity
(colored by modeled EUI)



bit.ly/virtual_epb

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Load Factor summary

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

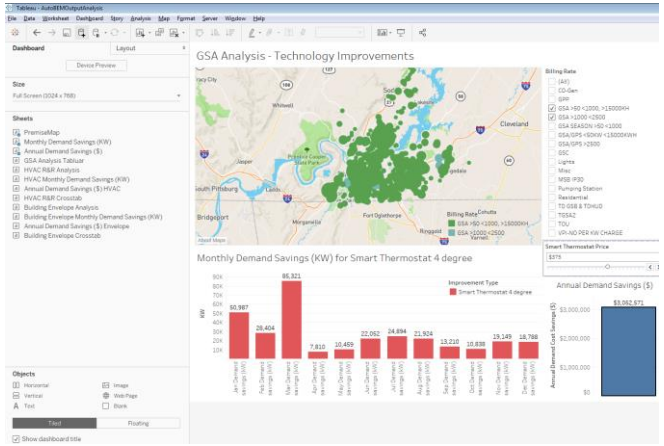
Data feeds to other EPB Systems

EPB System Attribute Data

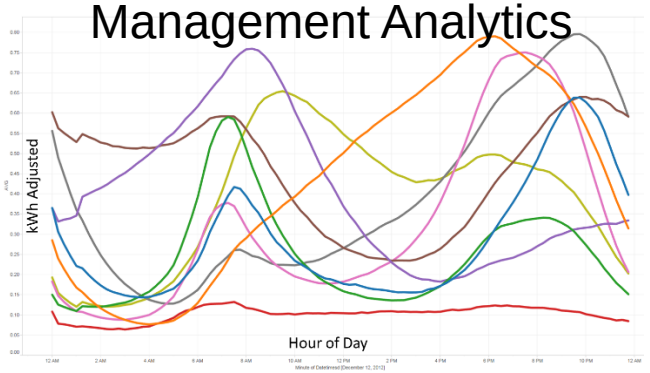
- **Premise Number**
- **Service Address**
- **Latitude/Longitude**
- **XFMR information (bank, structure, etc.)**
- **Circuit, Substation, Feeder**

Distribution System Capacity Planning

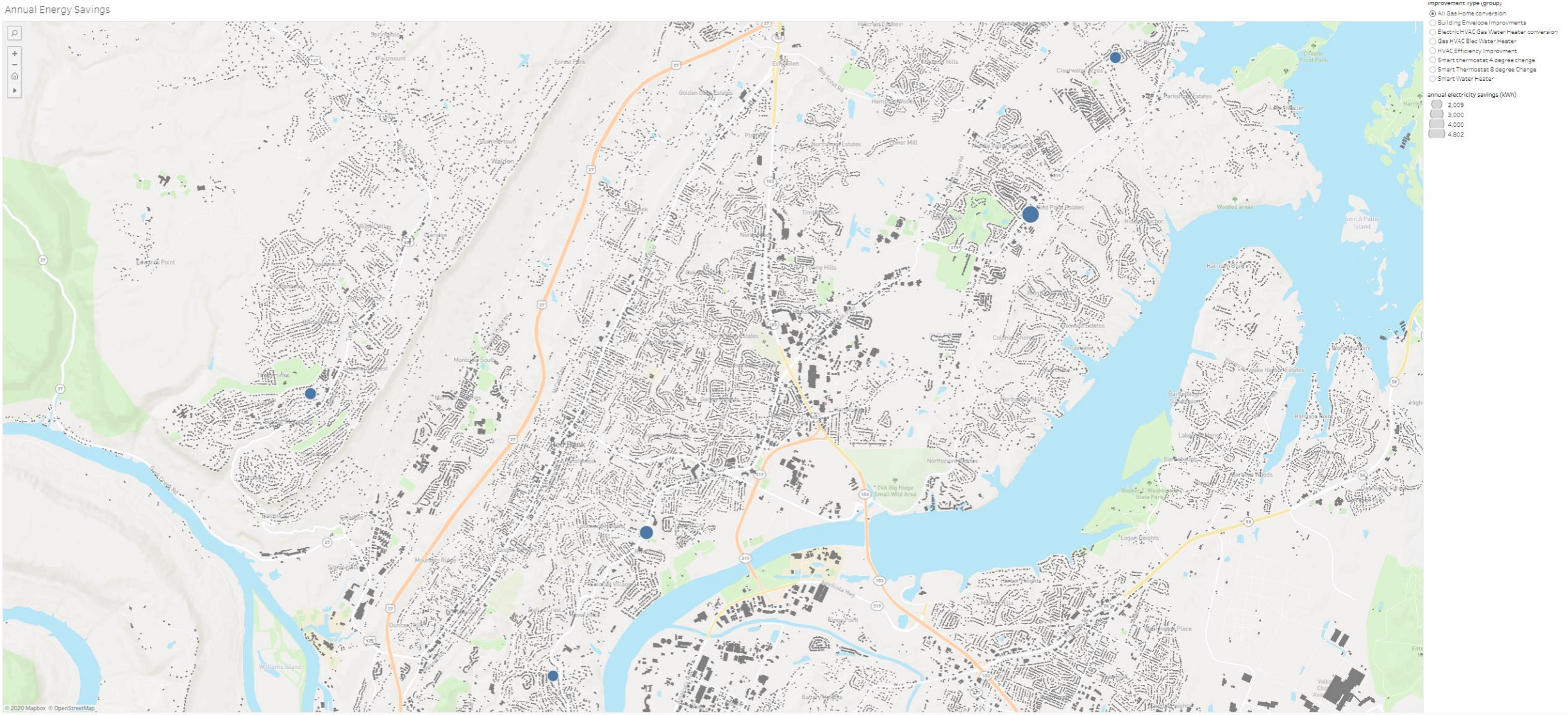
Data Visualization Tools



Customer Clustering & Demand Side Management Analytics



AutoBEM data in action



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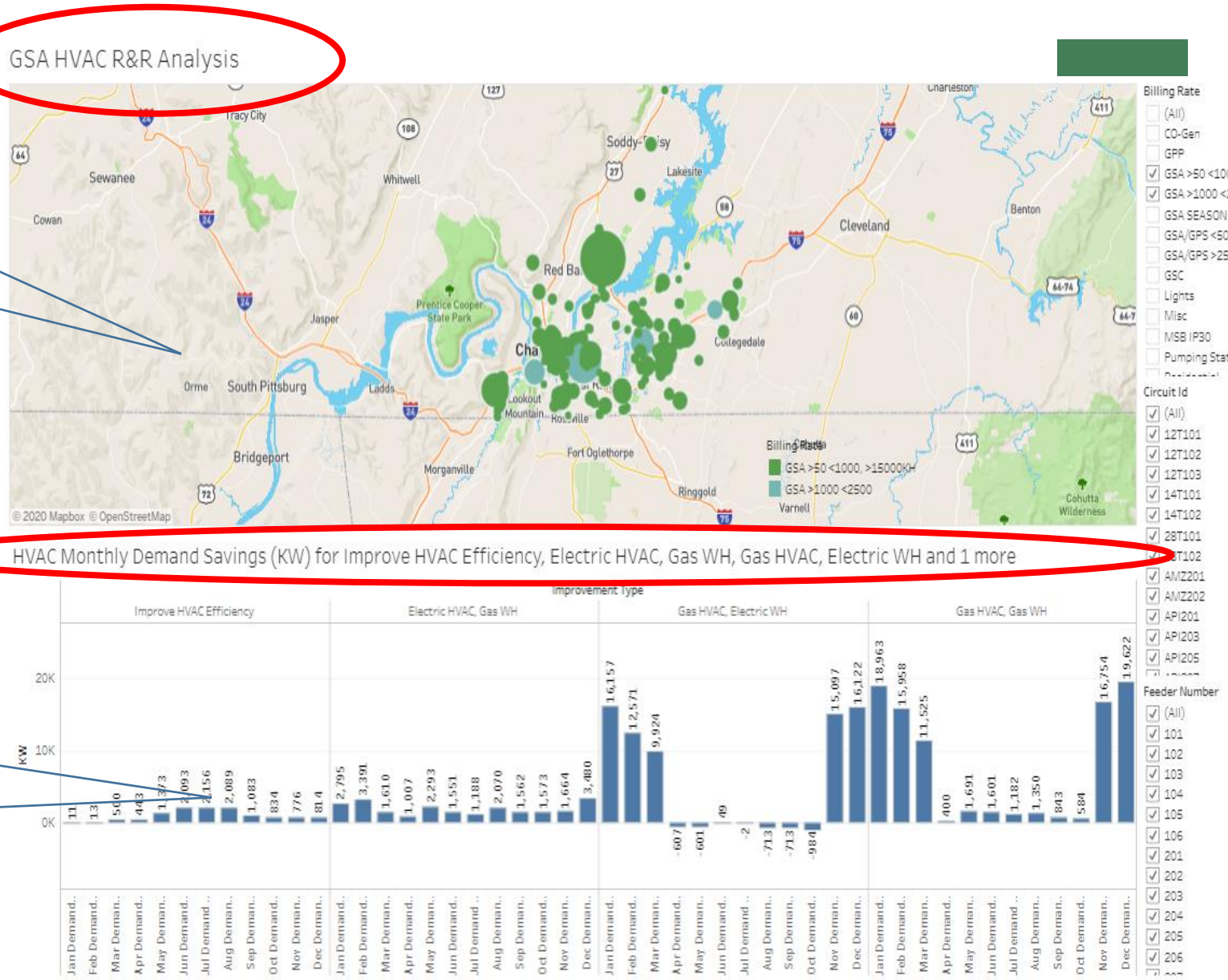
AutoBEM data in action – EPB Dashboards

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



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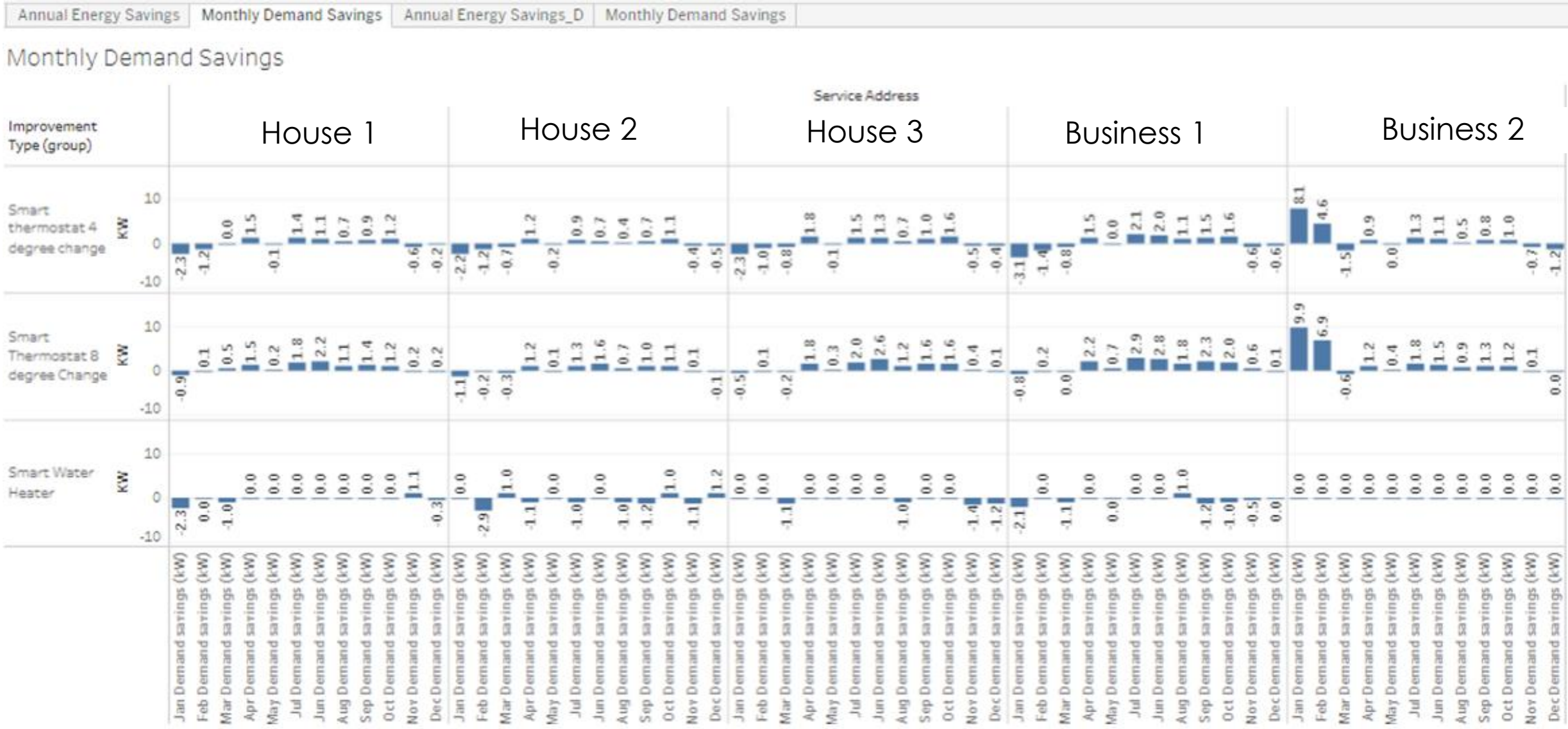
AutoBEM data in action



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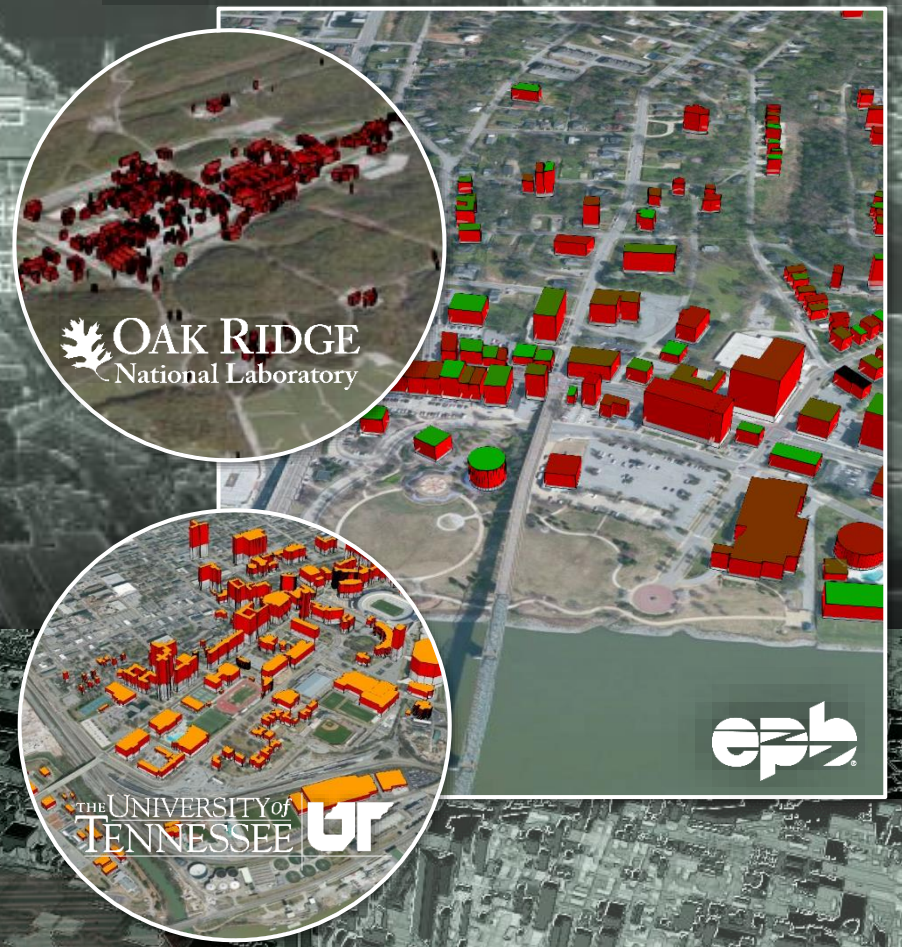
Discussion

HPC Tools for Modeling and Simulation
Capturing building energy consumption



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