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January 28-30, 2020 • #DTECH2020

Title

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

Presenter

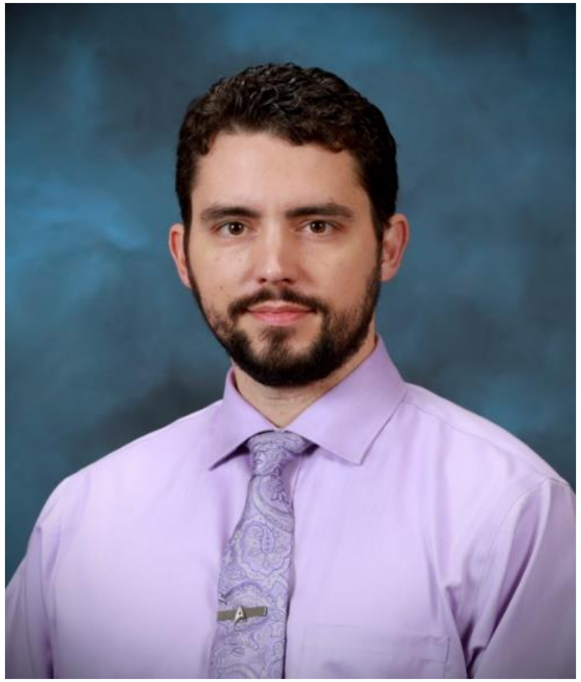
Joshua New, Ph.D., C.E.M., PMP, CMVP, CSM
Senior R&D Staff, Oak Ridge National Laboratory
Oak Ridge, TN

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**
  - The University of TN, (2004-2009), Knoxville; Ph.D. Comp. Sci.
  - Jacksonville State University, AL (1997-2001, 2001-2004)
    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



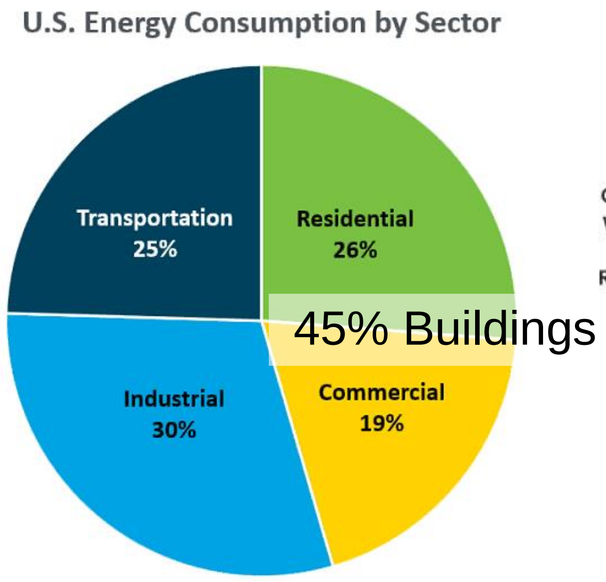
Certifications

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

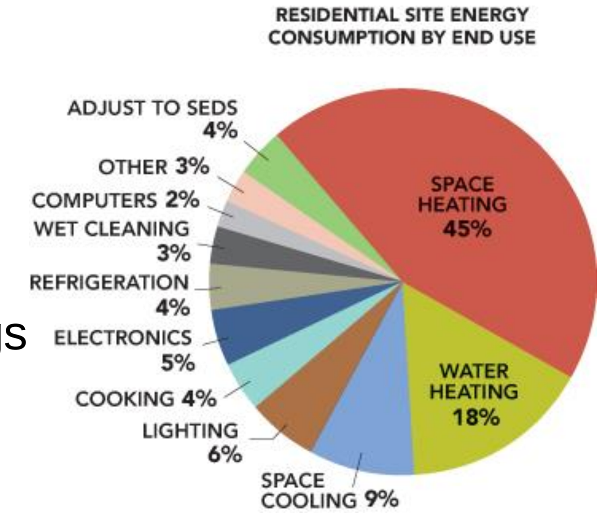
Artificial Intelligence

- President's National S&T Council's Machine Learning and Artificial Intelligence Subcommittee's Artificial Intelligence Consortium

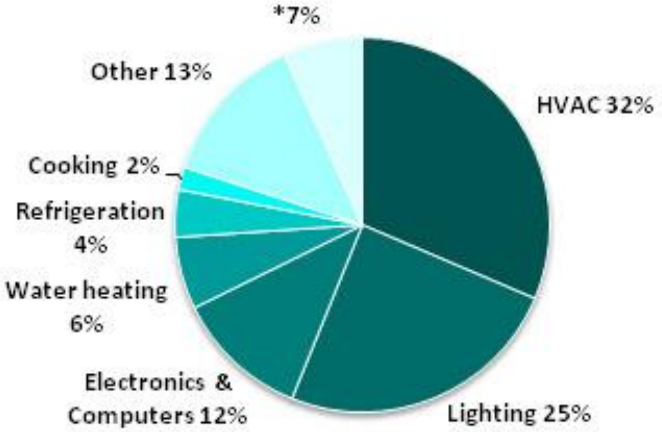
Energy and Buildings Overview



Source: U.S. Energy Information Administration, January 2016 to January 2017, *Monthly Energy Review – Table 2.1*.



Commercial Site Energy Consumption by End Use



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

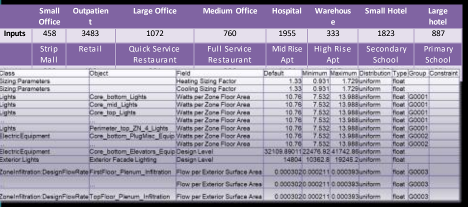
Building Energy Modeling – building descriptions + weather = estimated building energy consumption

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

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

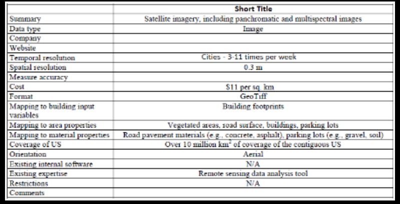


	Small Office	Outpatient	Large Office	Medium Office	Hospital	Warehouse	Small Hotel	Large hotel
Inputs	458	3483	1072	760	1955	333	1823	887
	Strip Mall	Retail	Quick Service Restaurant	Full Service Restaurant	Mid Rise Apt	High Rise Apt	Secondary School	Primary School

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	

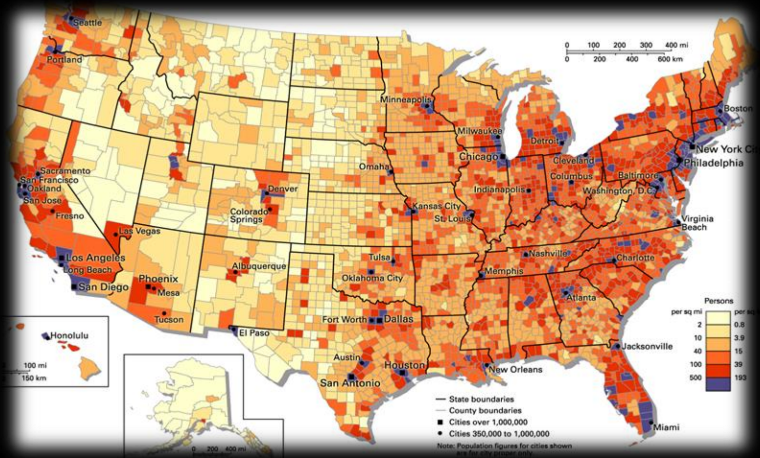
Sensitivity Analysis

3. Identify and compare data sources for important inputs



	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
Comments	

Comparison Matrix

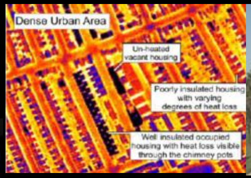


Goal: Stimulate private sector activity and academic research for a sustainable built environment

2. Time on world's #1 fastest HPC resources

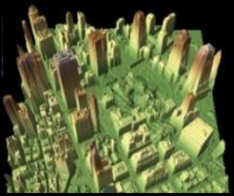
Supercomputers

4. Establish partnerships and APIs for scalable data retrieval



Satellite/Aerial

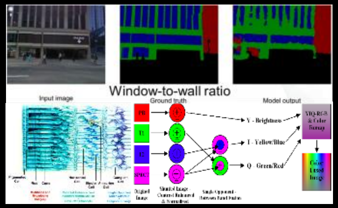
StreetView



LIDAR

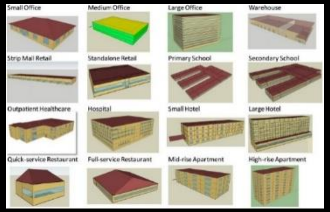
Databases

5. Algorithms to extract bldg properties



Computer Vision

6. Create OpenStudio, EnergyPlus models



DOE Prototype Buildings

7. Make models freely available

Download BEM via street address

Potential use cases:

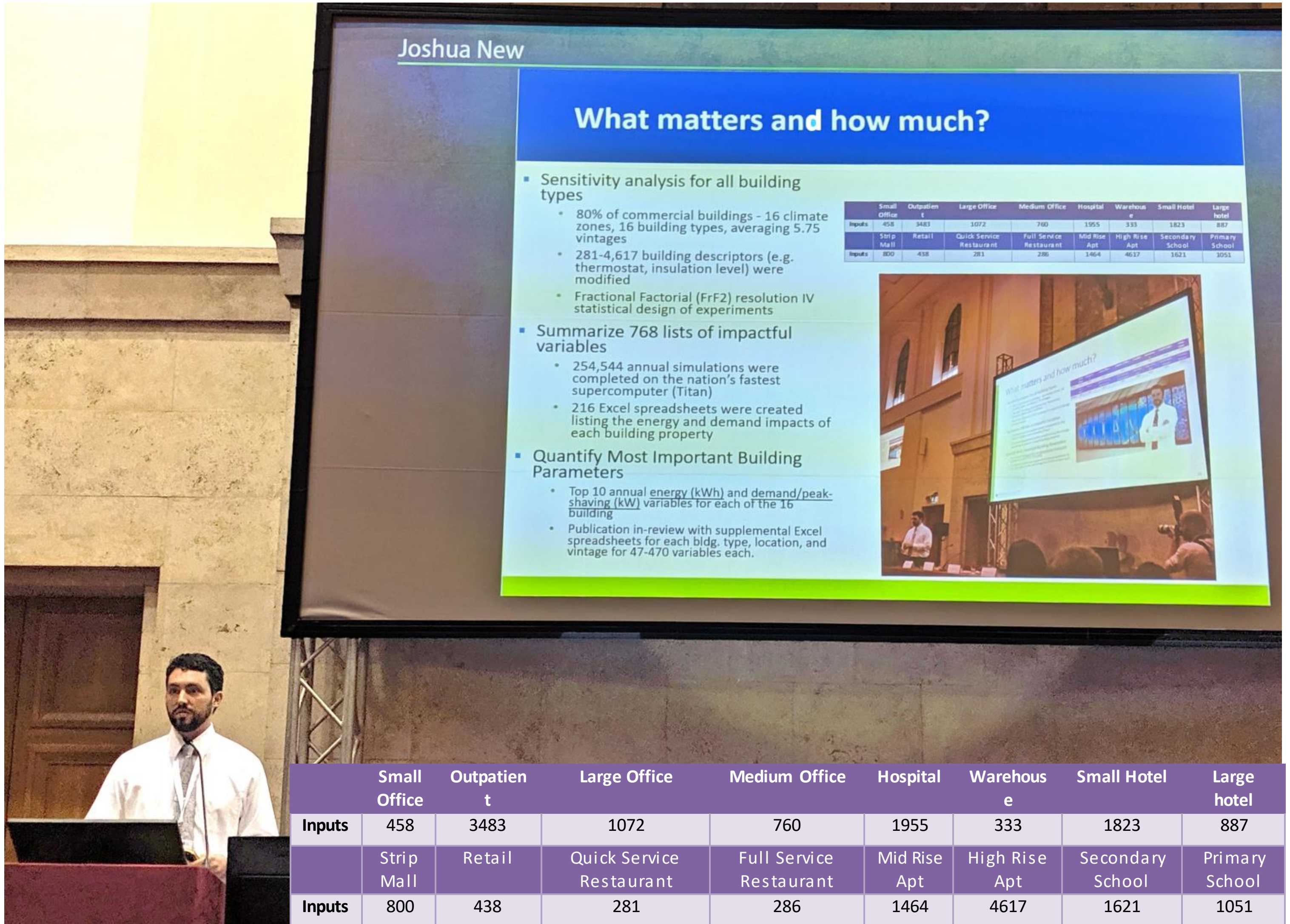
- Load management
- Utility program formulation
- Sales/market leads
- Incentive structure
- EaaS business model
- IGA walkthroughs
- Automated financing
- Simulation-informed analysis

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 <u>energy (kWh)</u> and <u>demand/peak-shaving (kW)</u> variables for each of the 16 building
  - Publication in-review with supplemental Excel spreadsheets for each bldg. type, location, and vintage for 47-470 variables each.



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Inputs	800	438	281	286	1464	4617	1621	1051

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)

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
512	20:43	176 GB	2,048
1,024	21:03	351 GB	4,096
2,048	21:11	703 GB	8,192
4,096	20:00	1.4 TB	16,384
8,192	26:14	2.8 TB	32,768
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

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

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Restrictions	N/A
Comments	

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)

Class	Object	Field	Default	Minimum	Maximum	Distribution	Type	Group	Constraint
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Data comparison matrix

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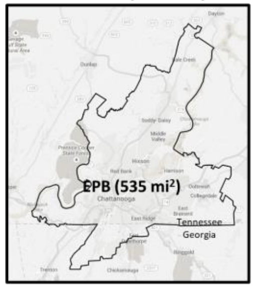
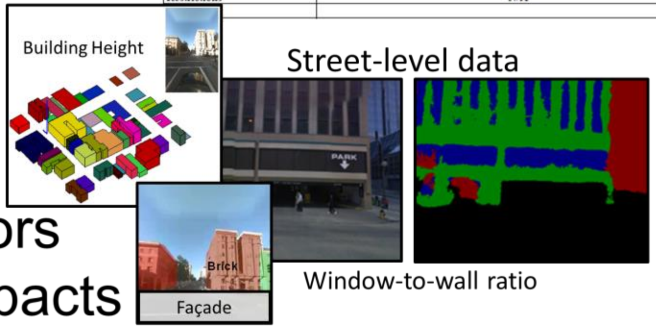
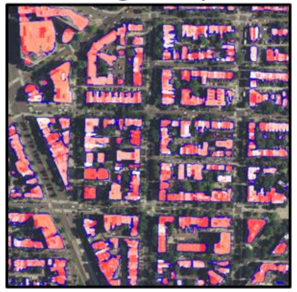
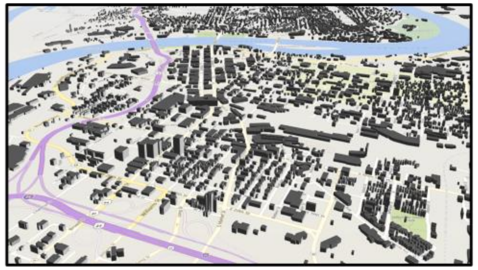
Occupancy

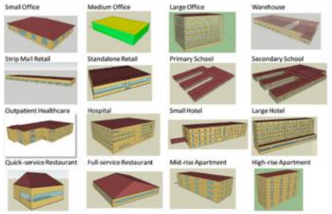




Building footprints





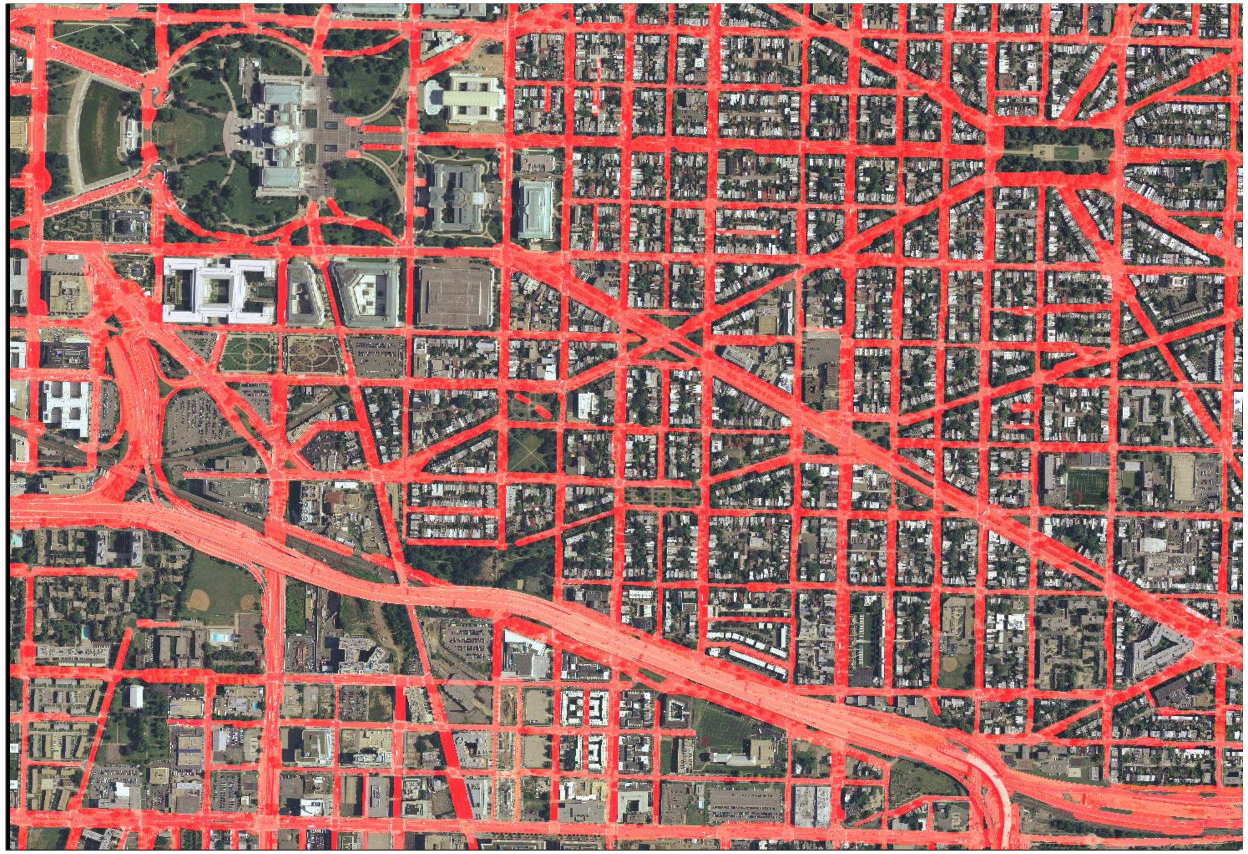


Software Tools

- 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

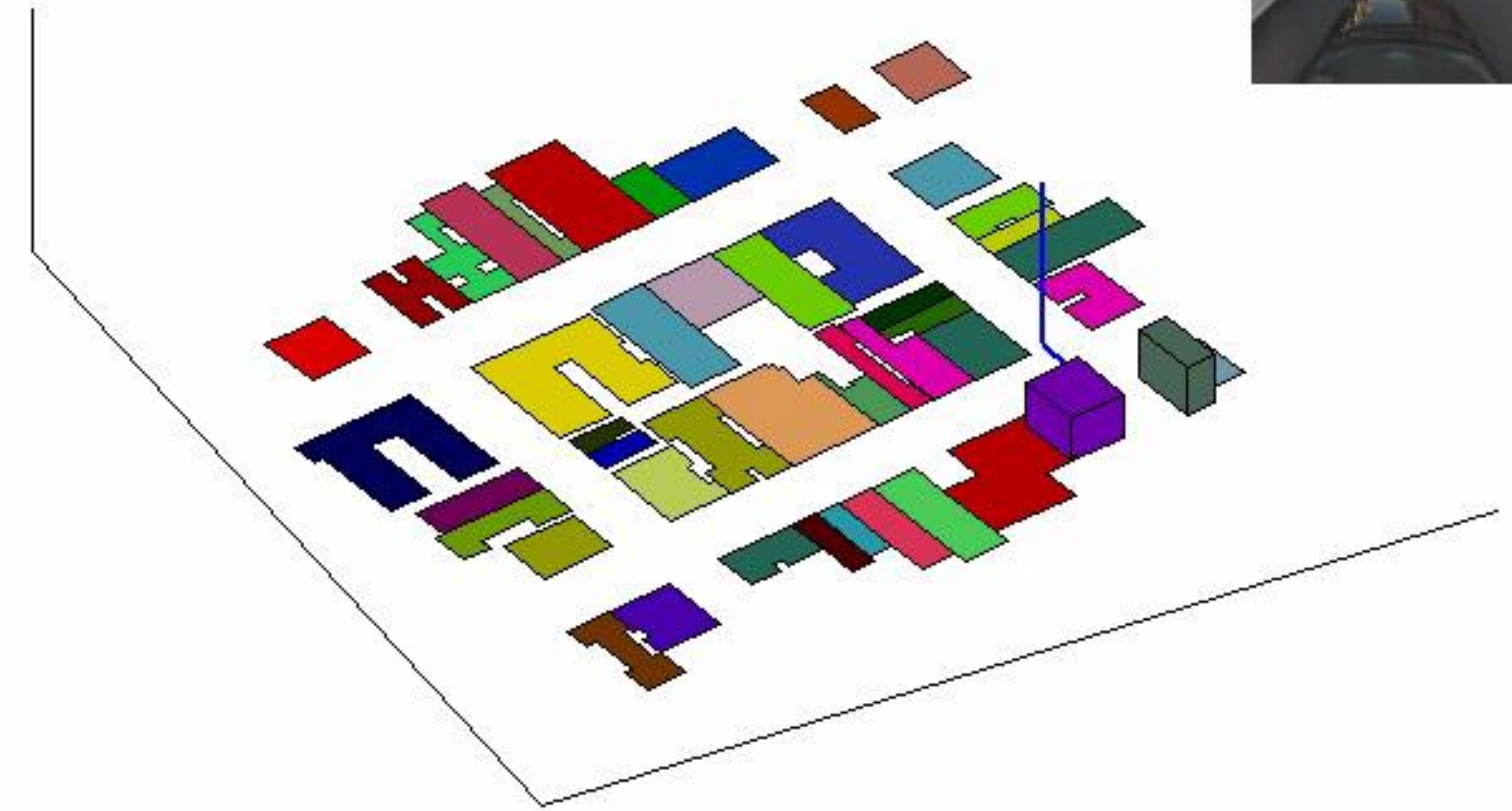
Building Footprints from Satellite Imagery



Open Competition Precision/Recall – 30/35
ORNL Current Precision/Recall – 60+/60+

Processing Street-Level Imagery (Jiangye Yuan)

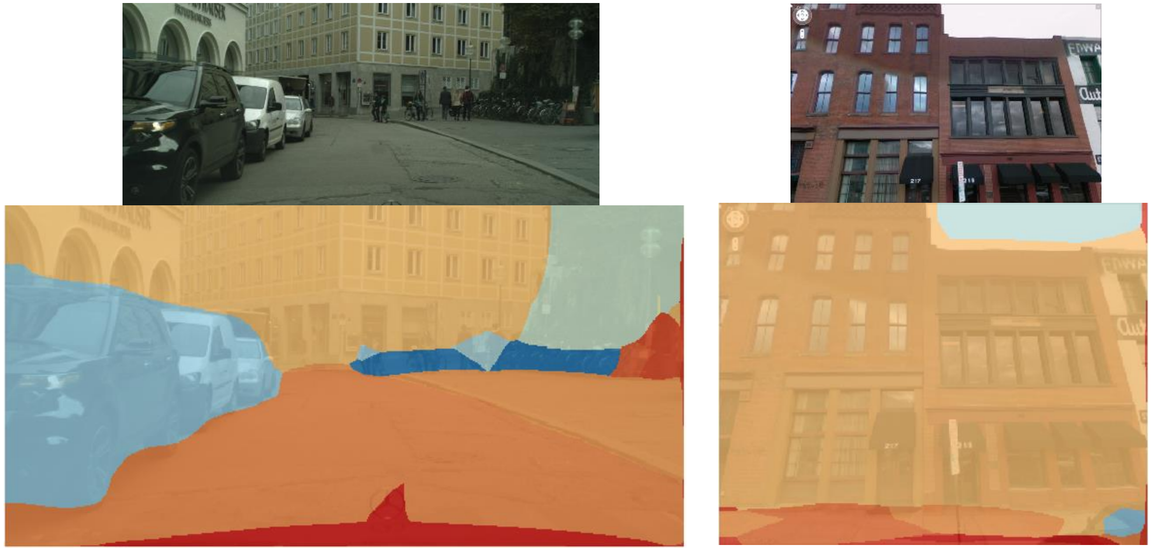
3D Building Model Generation



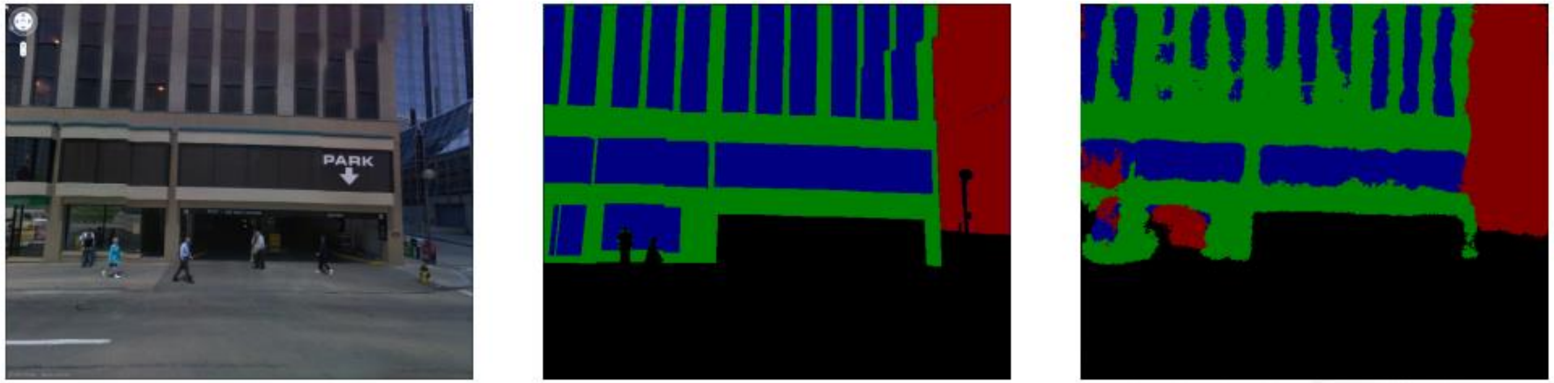
Oak Ridge National Laboratory

Street-level imagery (Lexie Yang)

Façade Type



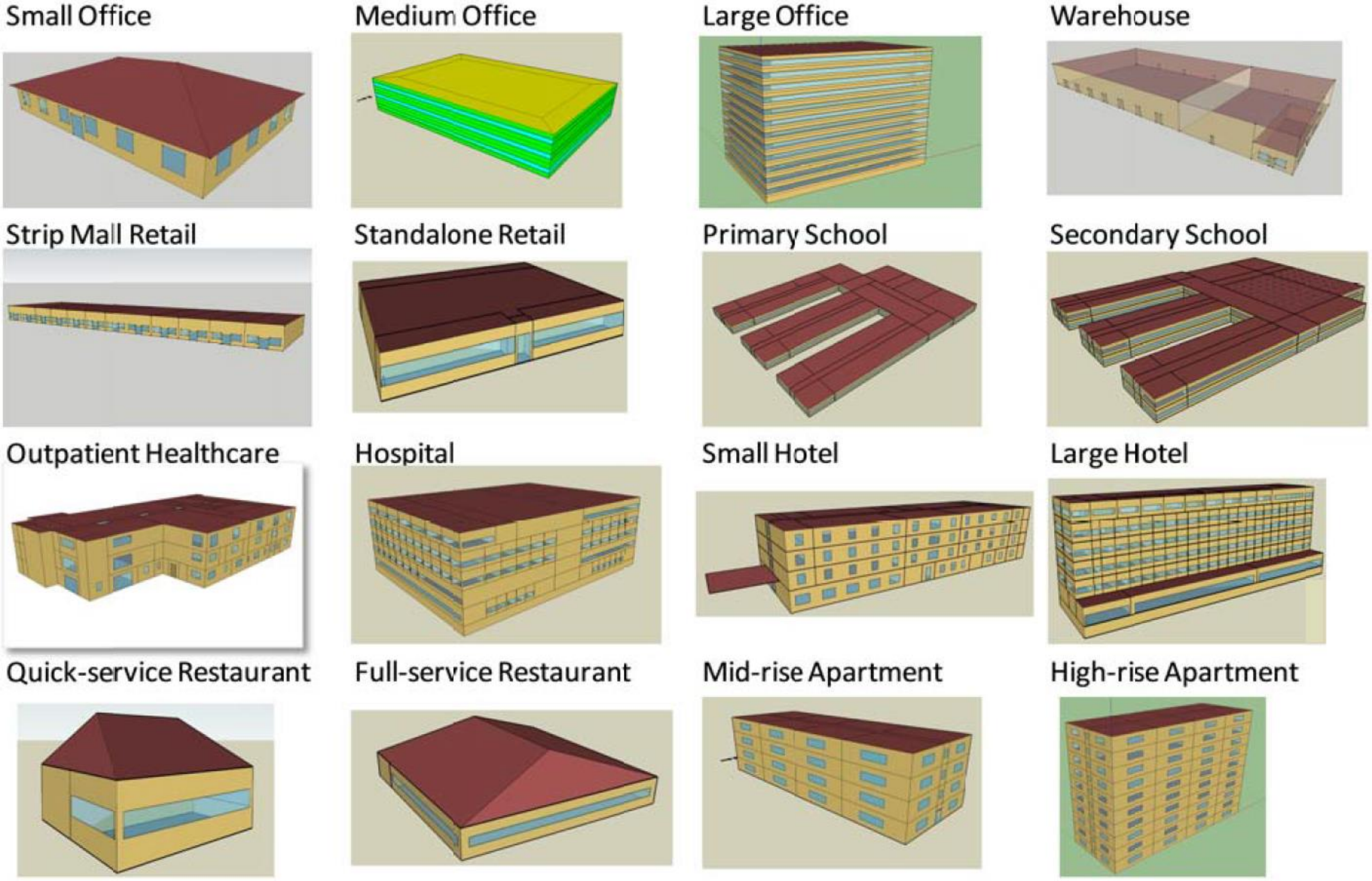
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)



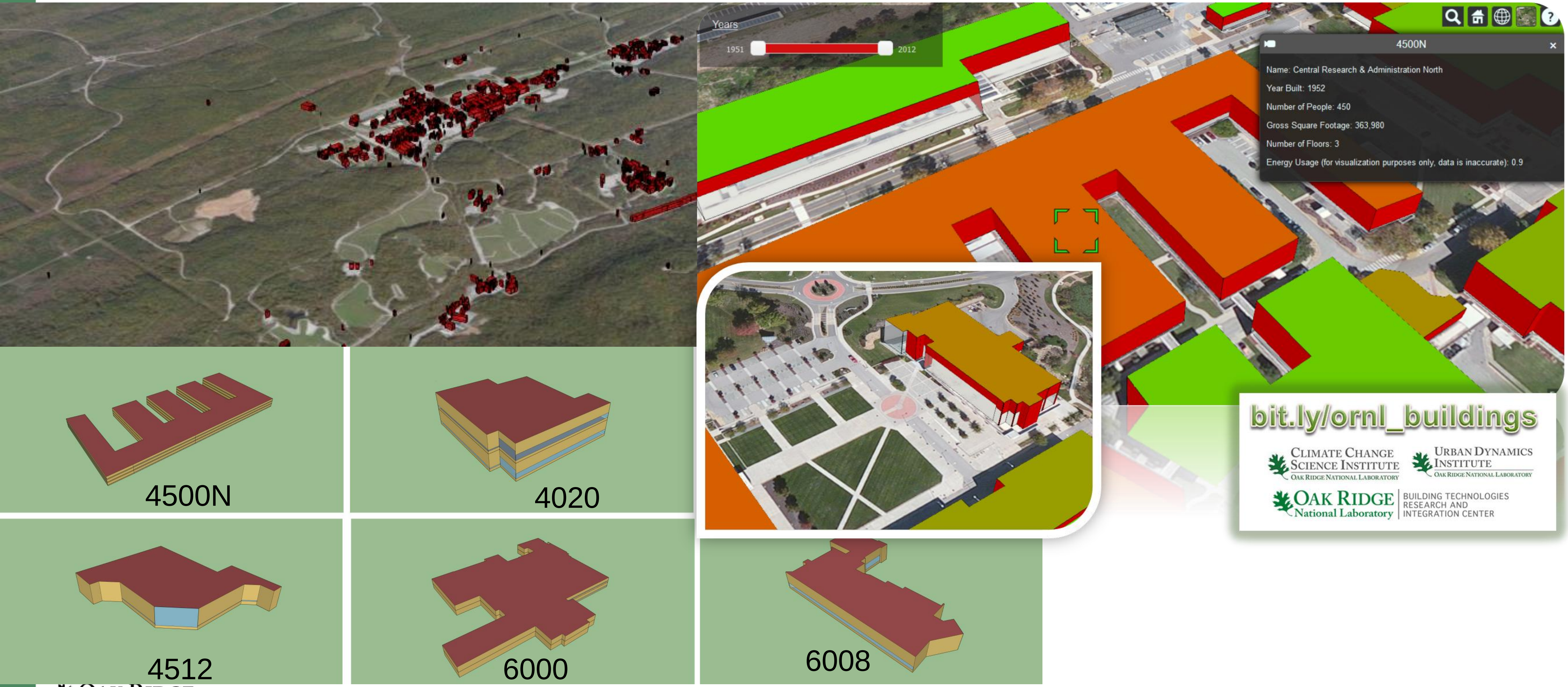
Window-to-wall ratio

Input image | Ground truth | Model output

Prototype Buildings



Oak Ridge National Laboratory



The University of Tennessee (2 days)

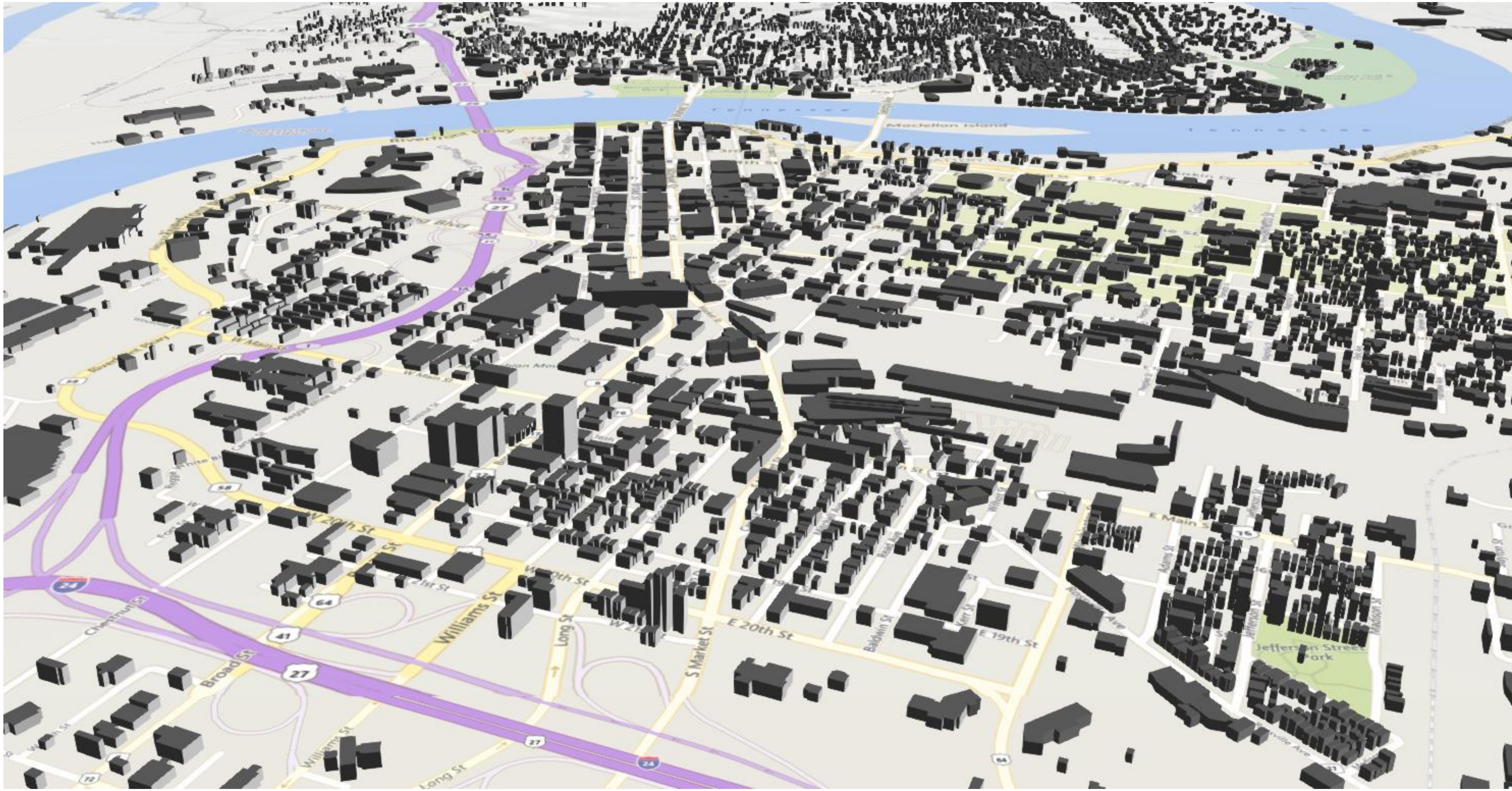
bit.ly/ut_buildings

Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

Oak Ridge National Laboratory
Building Technologies Research and Integration Center

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)

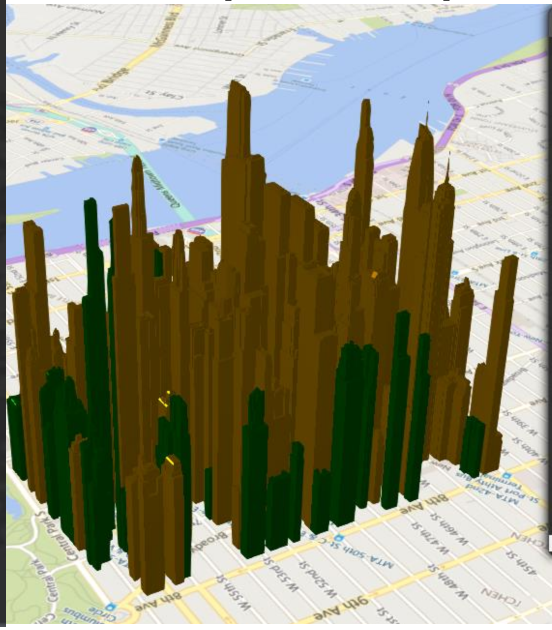
Virtual Utility – interactive results

60246

ID	60246
DOE Building Type	SmallOffice
Num Floors	3
Percentile	87.70 %
Estimated wholesale vs retail cost	$ 9797.07
CO2 emissions	222052.32 lbs/year
Smart Thermostat - 4F cost savings	$ 1316.61
Smart Thermostat - 8F cost savings	$ 2325.84
TMY->AMY Smart Thermostat - 4F cost savings	$ 204.99
TMY->AMY Smart Thermostat - 8F cost savings	$ 103.41
HVAC Efficiency ECM	$ 1291.79
Gas HVAC ECM	$ 4276.69
Gas Water Heater ECM	$ 725.58
Heat Pump Water Heater ECM	$ 476.95
Insulation ECM	$ 736.27
Infiltration ECM	$ 1577.50
Lighting ECM	$ 2898.95

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

1. **Lighting Efficiency (0.85 W/ft²)**
   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]

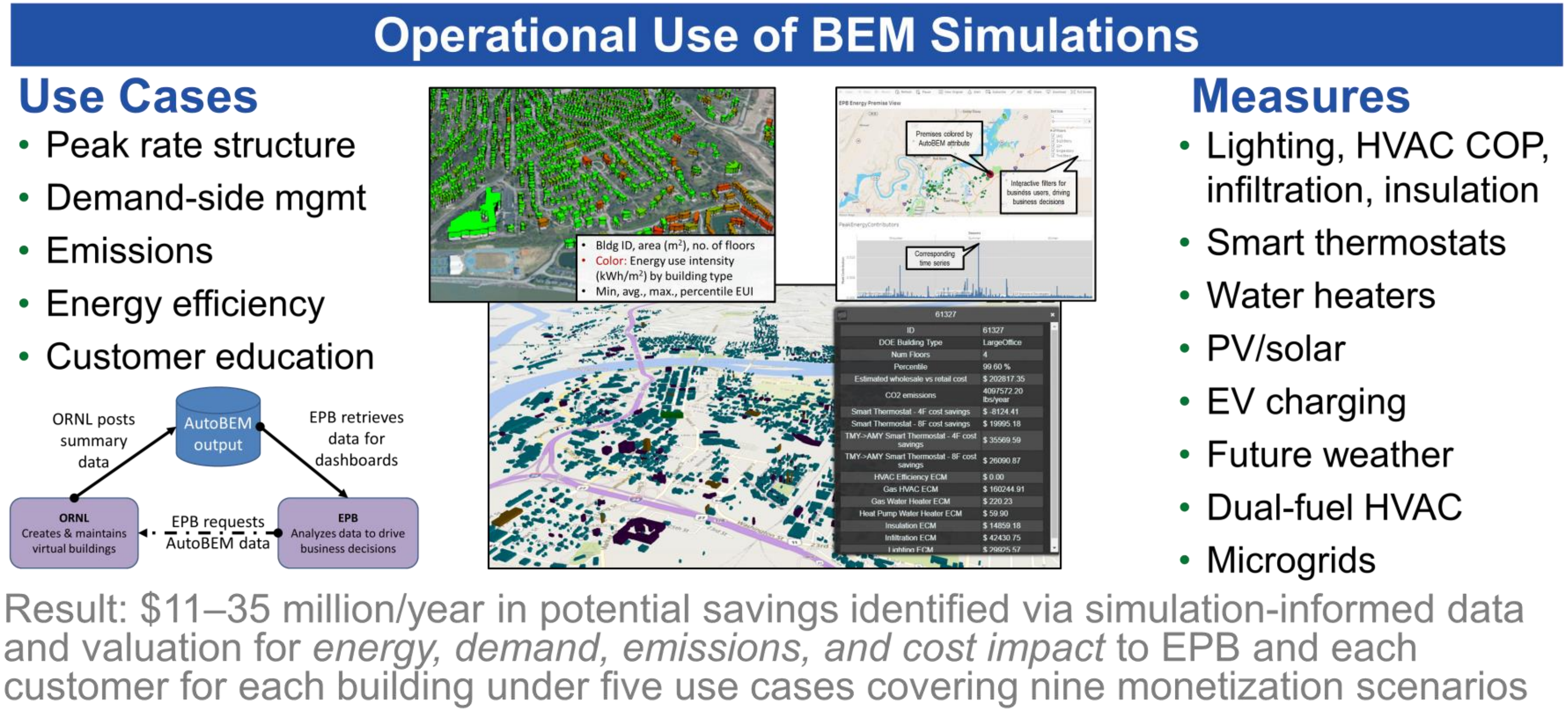


Bldg_12210017046

ECM	Annual Electricity/Savings	Jan Demand/Savings	Feb Demand/Sa
Baseline	41282530.14 kWh	8463.14 kW	8426.13 kW
Change Elec Base COP	0.09 kWh	155.27 kW	3232.78 kW
Change Lighting Power Density	2796916.23 kWh	975.65 kW	3597.39 kW
Change Roof Insulation	688072.96 kWh	267.15 kW	3348.45 kW
Change to Elec Water Heater	-24140.75 kWh	152.50 kW	3230.01 kW
Change to Gas Water Heater	0.09 kWh	155.27 kW	3232.78 kW
Change Space Infiltration	411236.67 kWh	176.59 kW	3436.11 kW
Smart Thermostat 4 Degree	14573.47 kWh	155.27 kW	4155.11 kW

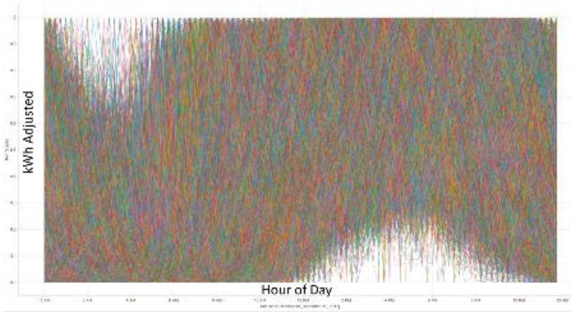
Accuracy compared to real 15-minute data for each building

- 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

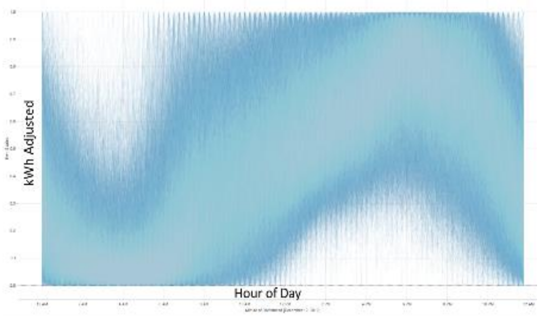


[1]Garrison, Eric, New, Joshua R., and Adams, Mark (2019). "Accuracy of a Crude Approach to Urban Multi-Scale Building Energy Models Compared to 15-min Electricity Use." Best PhD Student Paper award. In *Proceedings of the ASHRAE Winter Conference*, Atlanta, GA, Jan. 12-16, 2019. [PDF] [PPT]

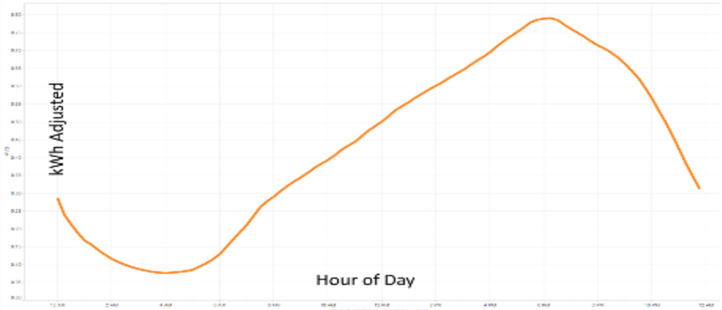
Clustering of (real) 15-min electrical data



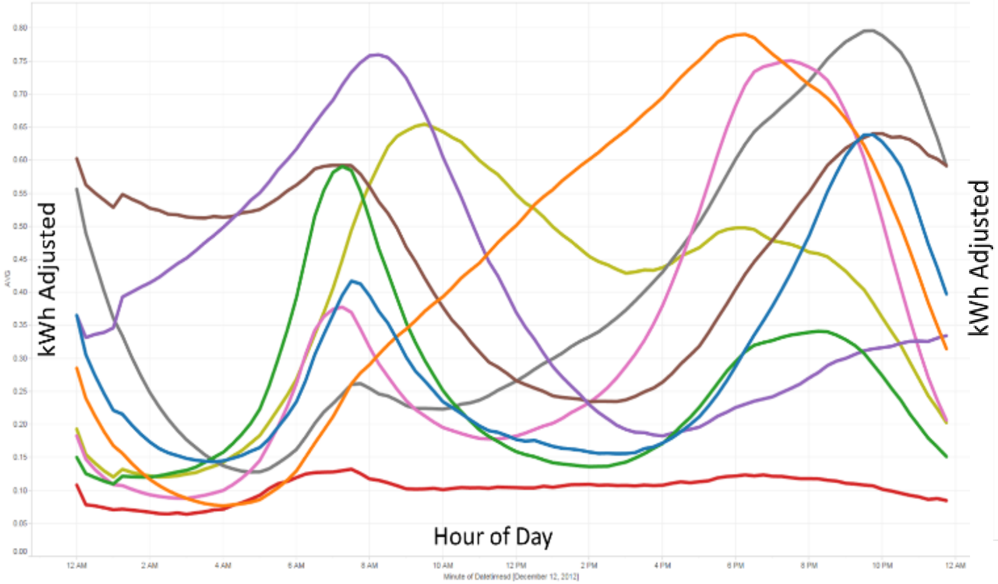
180,000 buildings measured
Whole-building electricity



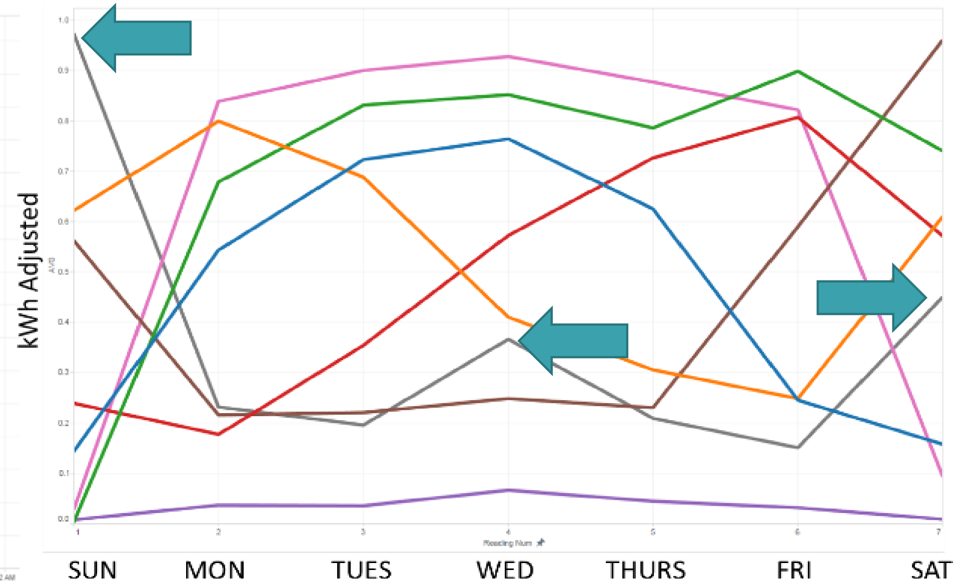
96d clustering (24h)



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



9 residential clusters



8 commercial clusters (GSA1-3, 8am-5pm)

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Load Factor summary

- Utility load factor $LoadFactor = Total(kWh)\ /\ (kWpeak * numHours)$
  - Close to 0, more opportunity for energy storage

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

Building Type	Num Bldgs	% of all Bldgs	Avg. Load Factor
IECC Residential	171821	96.35%	0.164
Warehouse	799	0.45%	0.166
MidriseApartment	851	0.48%	0.261
SmallHotel	1557	0.87%	0.261
HighriseApartment	2068	1.16%	0.263
LargeHotel	408	0.23%	0.365
QuickServiceRest.	318	0.18%	0.380
Hospital	319	0.18%	0.399
Outpatient	59	0.03%	0.501

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

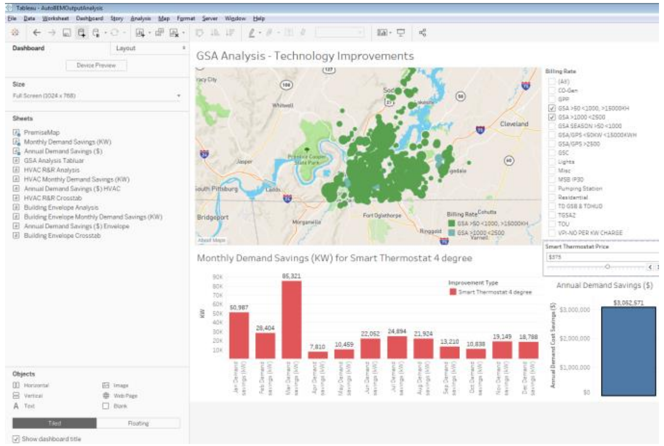
EPB System Attribute Data

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

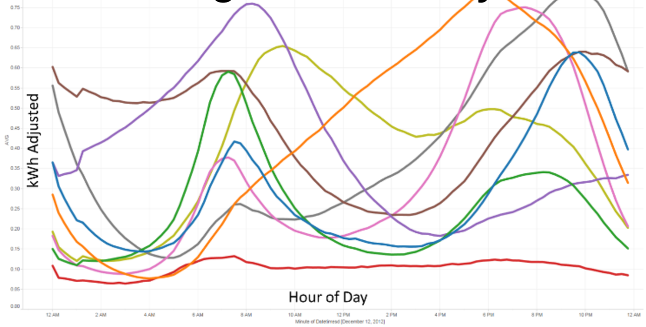
Data feeds to other EPB Systems

Distribution System Capacity Planning

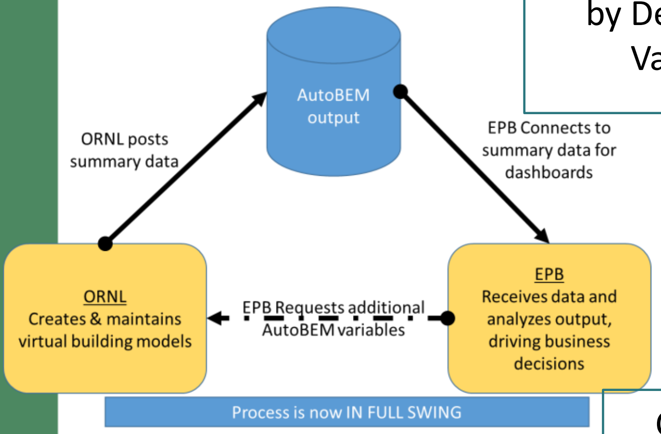
Data Visualization Tools



Customer Clustering & Demand Side Management Analytics



Virtual Utility integration



Map showing premises, sized by Demand Value

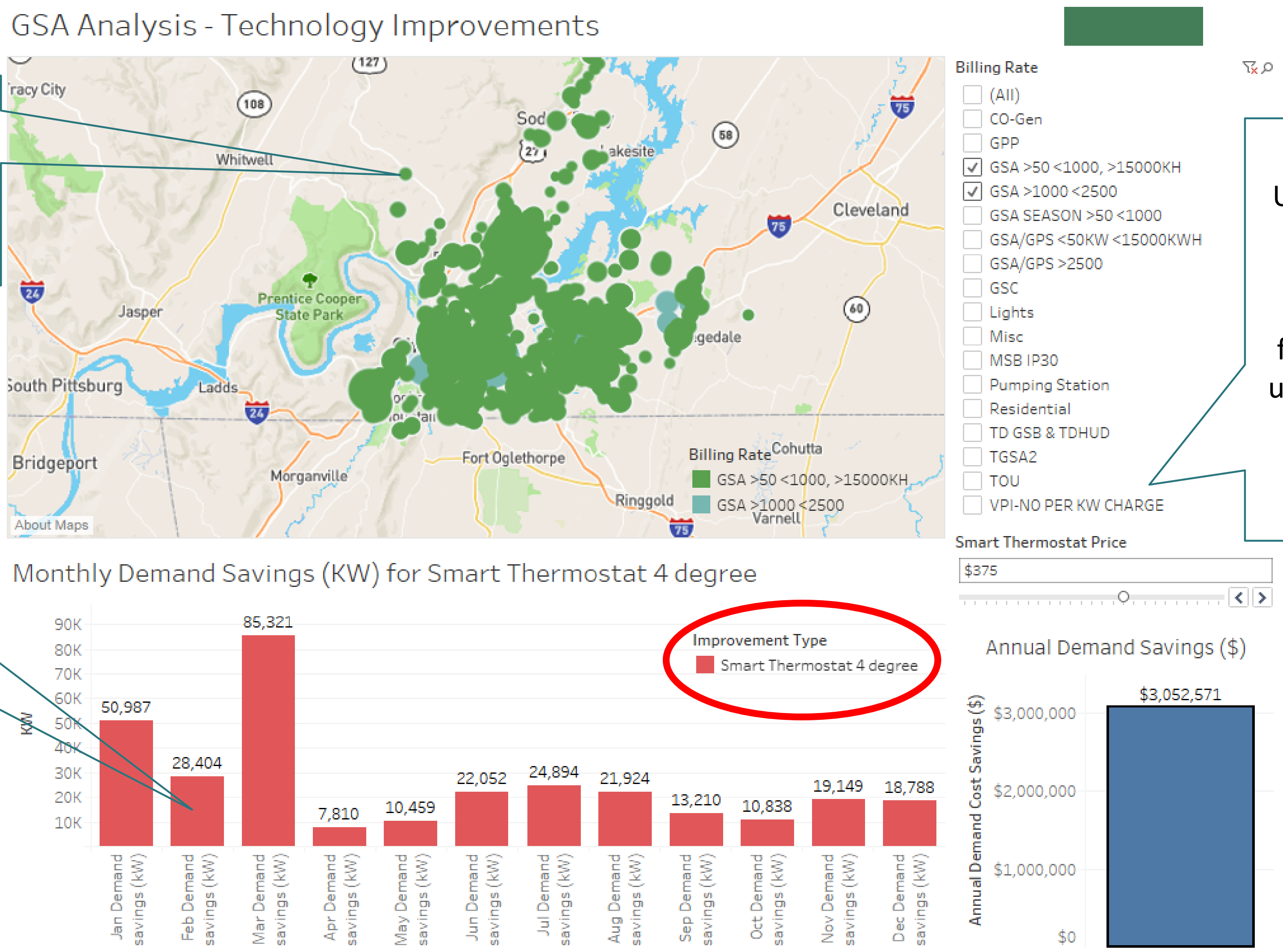


Chart showing monthly demand value

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

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Virtual Utility via AutoBEM Modeling and Simulation
Capturing building energy consumption