Nailing the Peak: City-Scale, Building-Specific Load Factor and Contribution to a Utility's Hour of Critical Generation

Presented at:

IBPSA Building Simulation Conference

Rome, Italy

Presented by:

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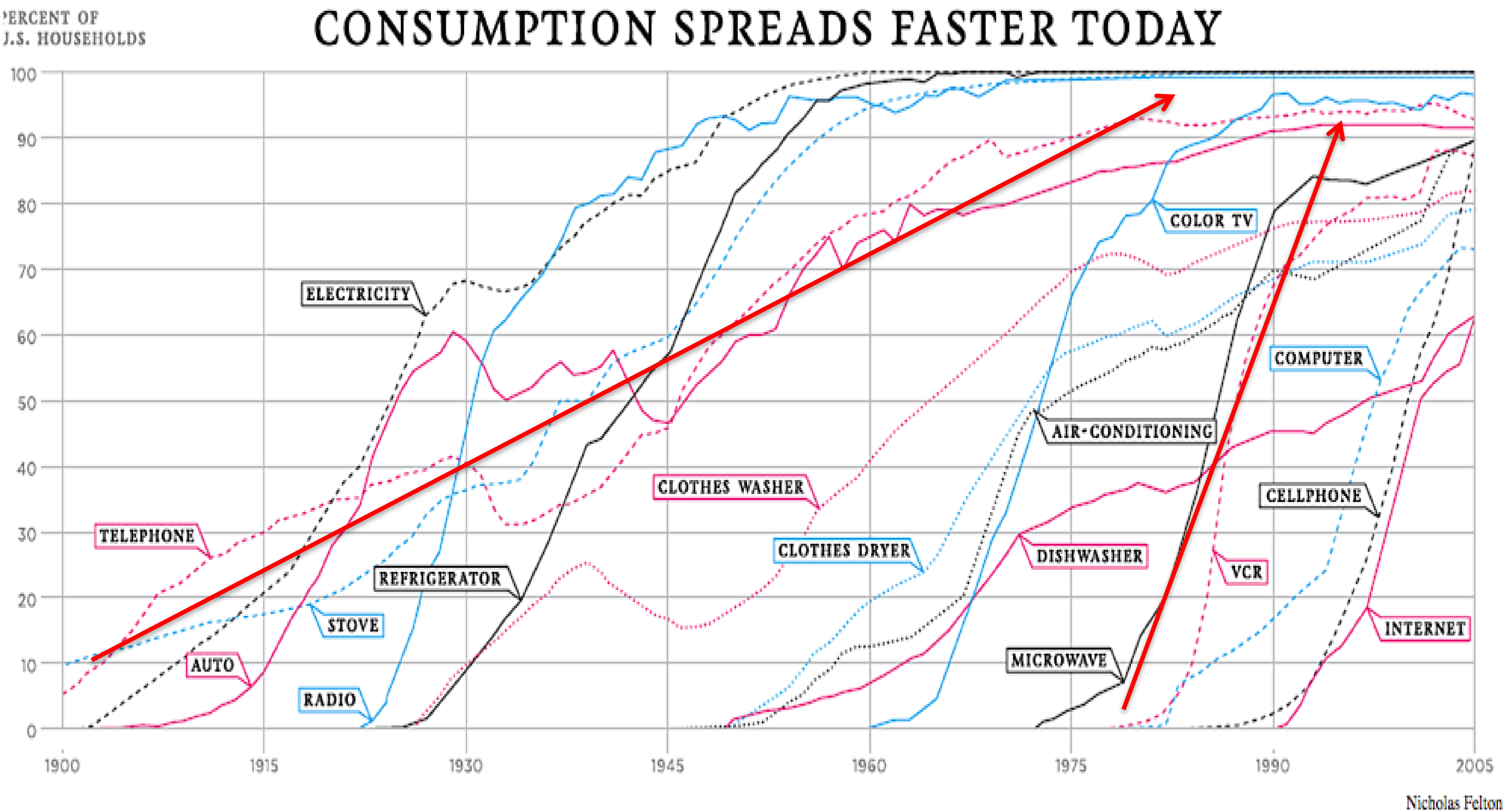
September 2, 2019

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Strategic Research

Technology Adoption Rates Accelerate



Wireless Broadband IoT Age Is Upon Us

Strategic Research

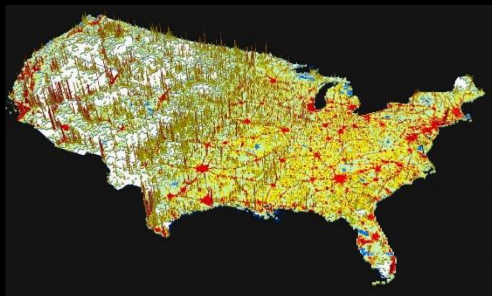
Papal Conclave 2005

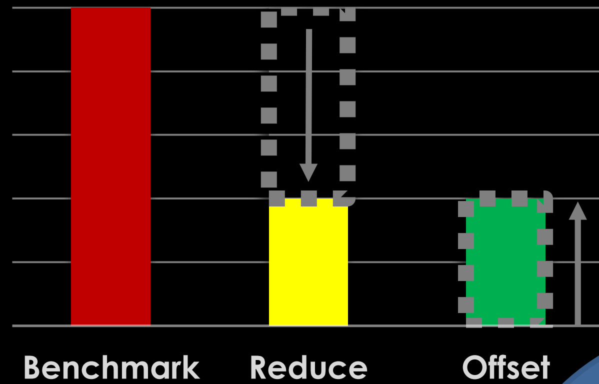
Gigabit Speed Wireless Broadband Coming Soon in 2018-2019

Strategic Research

Papal Conclave 2013

Model America 2020 – BEM for every U.S. Building

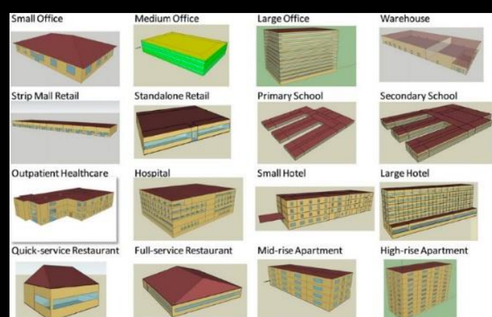




Goal: Stimulate private sector activity for efficient buildings

1. Extract important inputs from available data

2. Create initial building energy model(s)



DOE Prototype Buildings

3. Make models available online

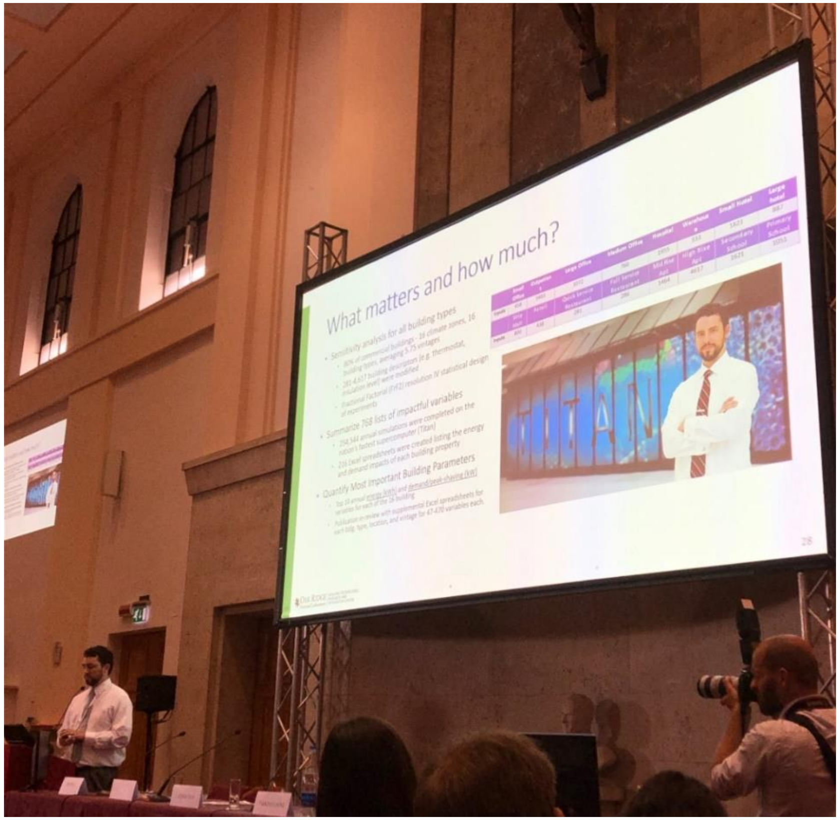
Download BEM via street address

IGA
- Walkthrough Audit
- Calibration to measured data

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.

	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
Inputs	800	438	281	286	1464	4617	1621	1051

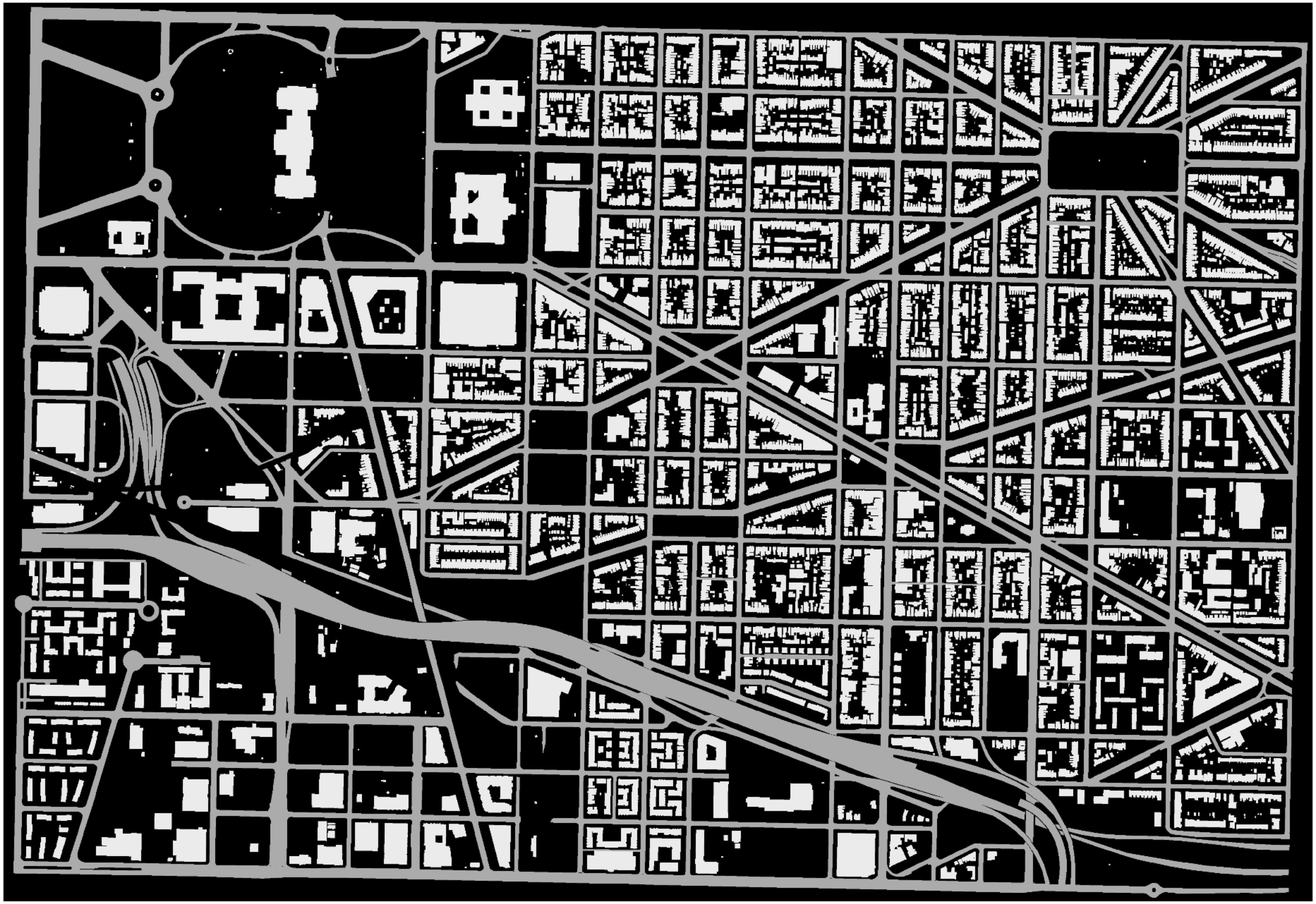


Data Sources

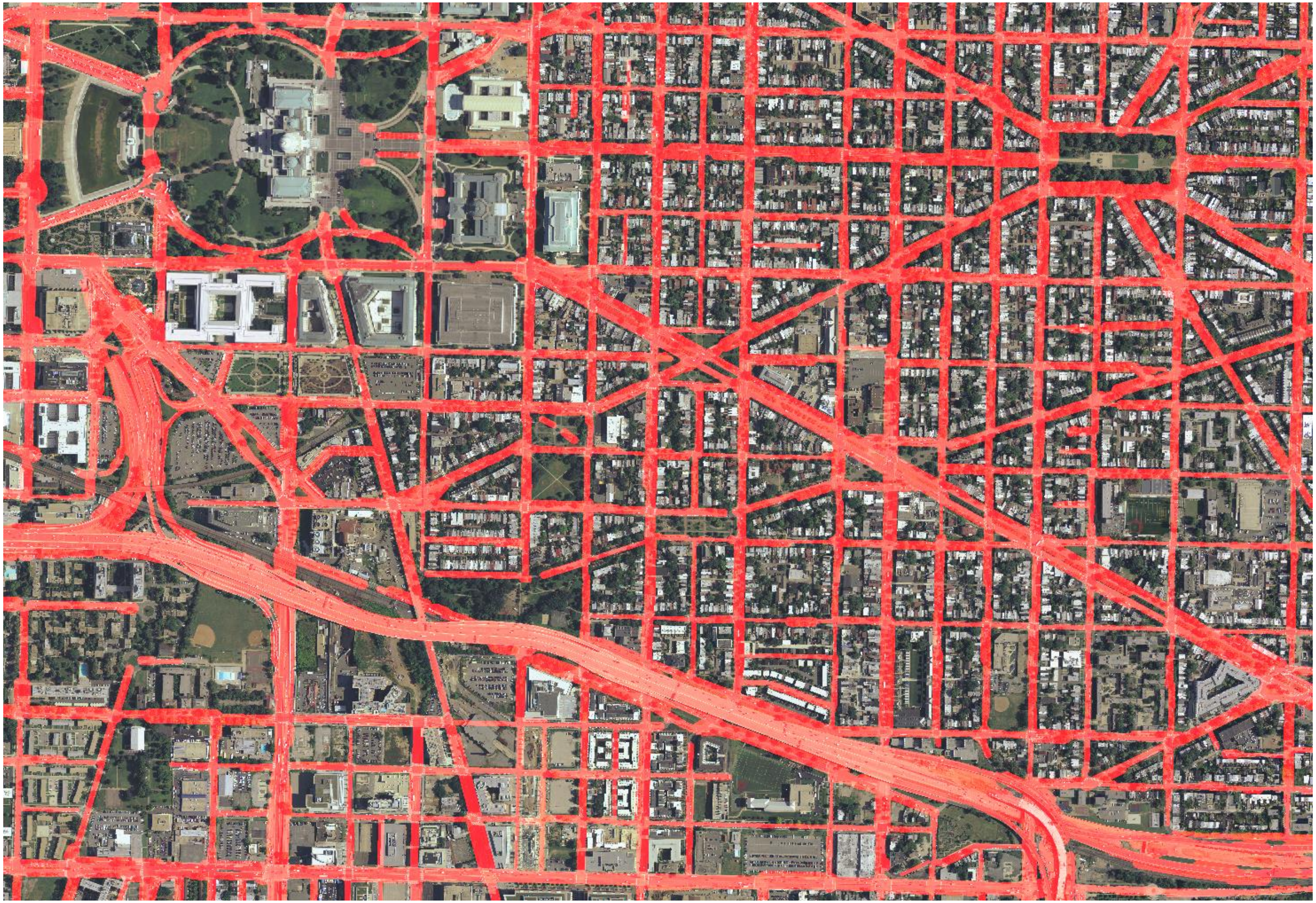
- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

	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	

Manual Segmentation of DC



Automatic Road Extraction



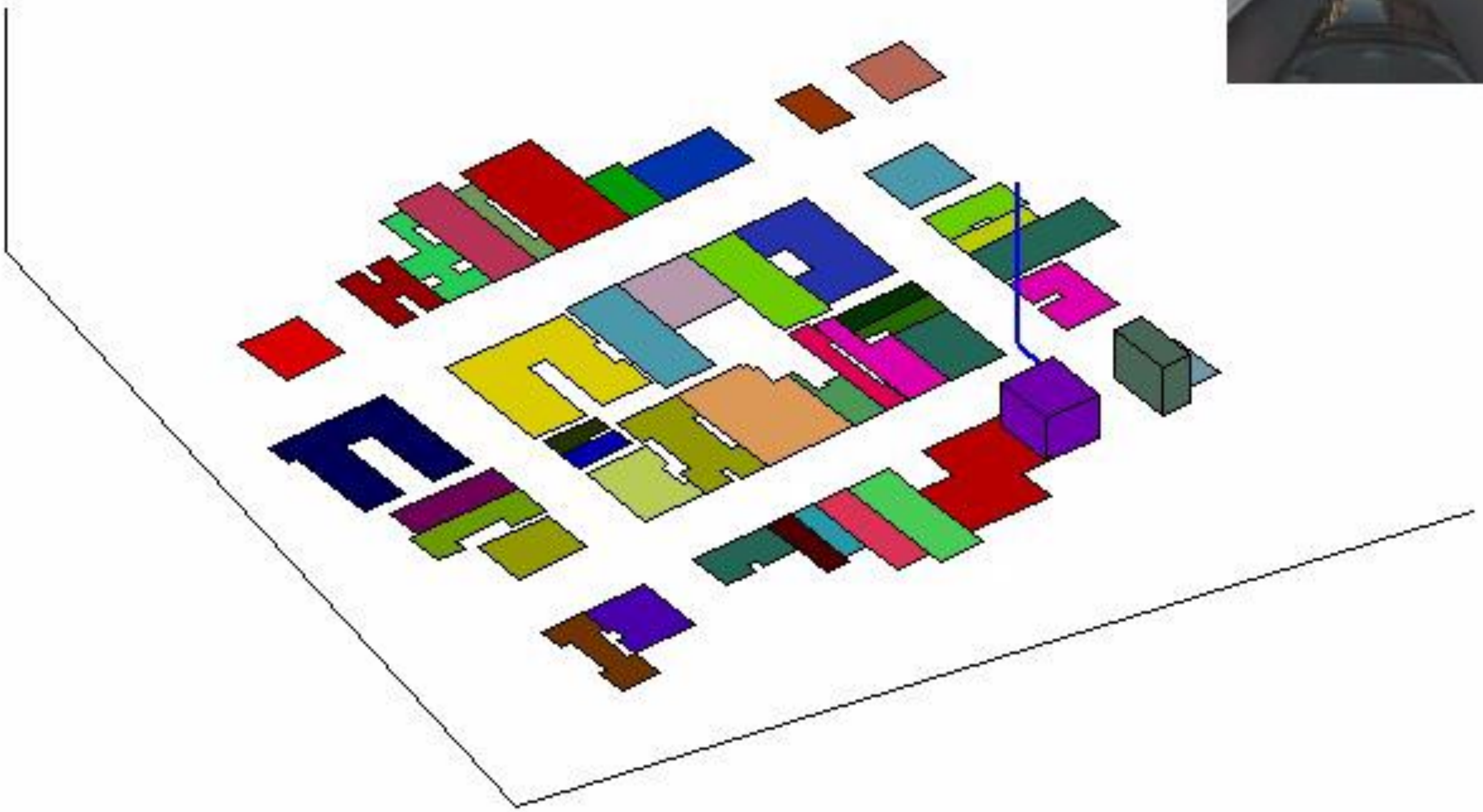
Automatic Building Footprint Extraction

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+

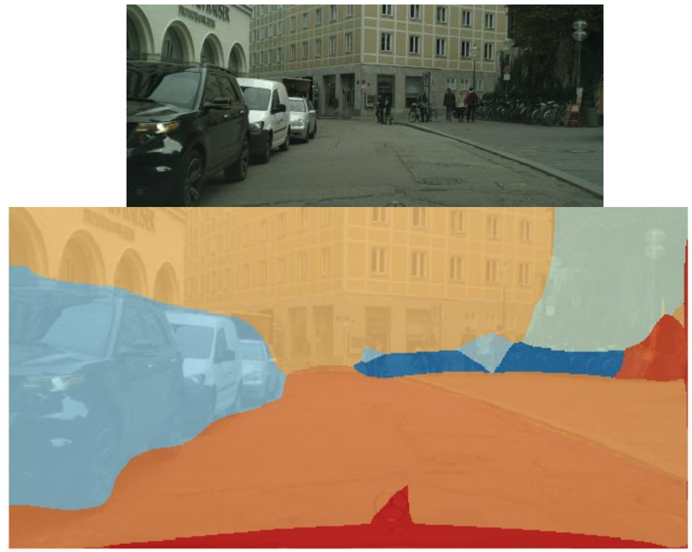
Processing Street-Level Imagery (Jiangye Yuan)

3D Building Model Generation

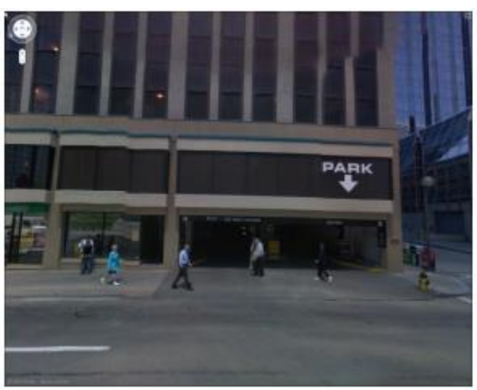


Street-level imagery (Lexie Yang)

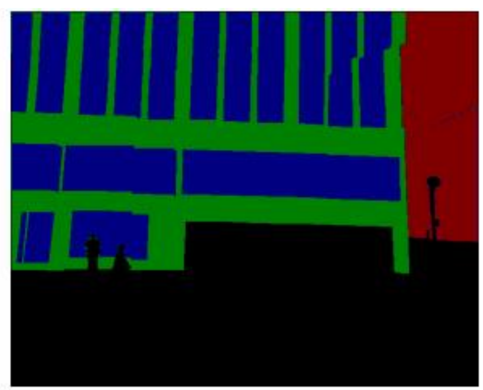
Façade Type



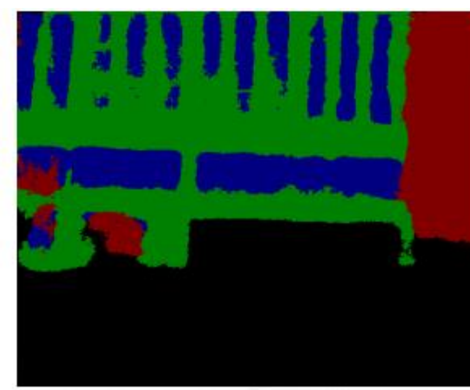
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)



Input image



Ground truth

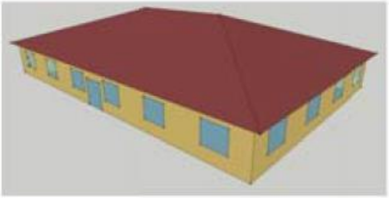


Model output

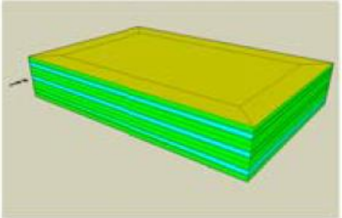
Window-to-wall ratio

Prototype Buildings

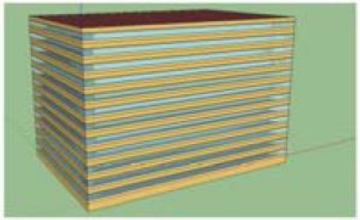
Small Office



Medium Office

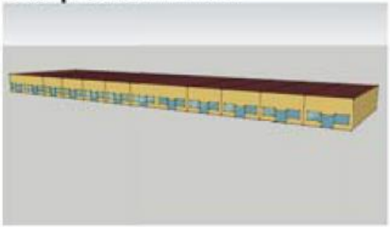


Large Office

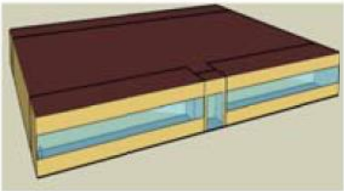


Warehouse

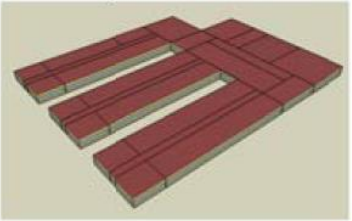
Strip Mall Retail



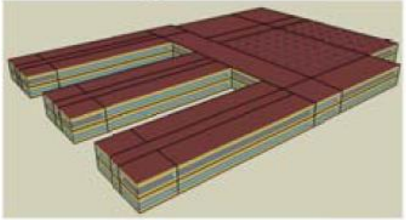
Standalone Retail



Primary School

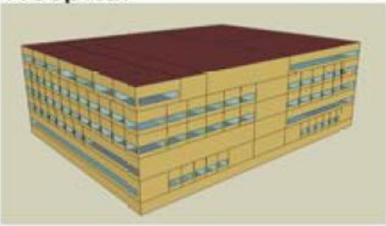


Secondary School

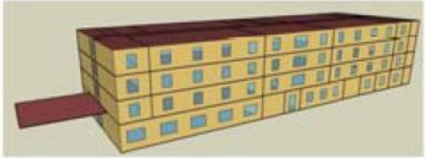


Outpatient Healthcare

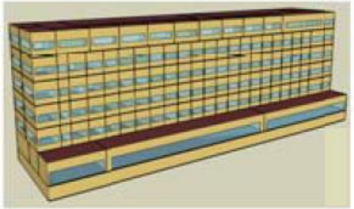
Hospital



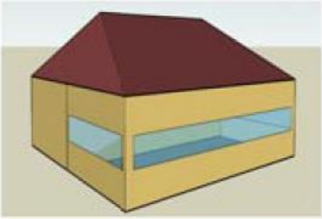
Small Hotel



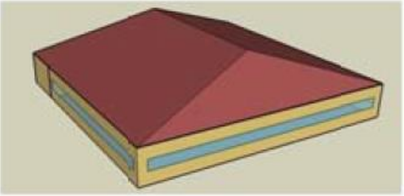
Large Hotel



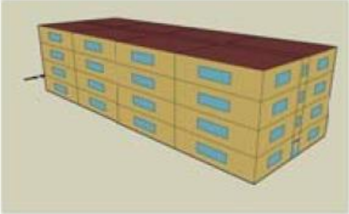
Quick-service Restaurant



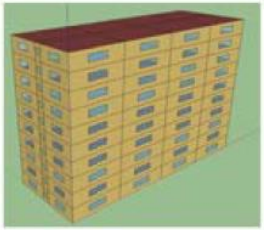
Full-service Restaurant



Mid-rise Apartment



High-rise Apartment



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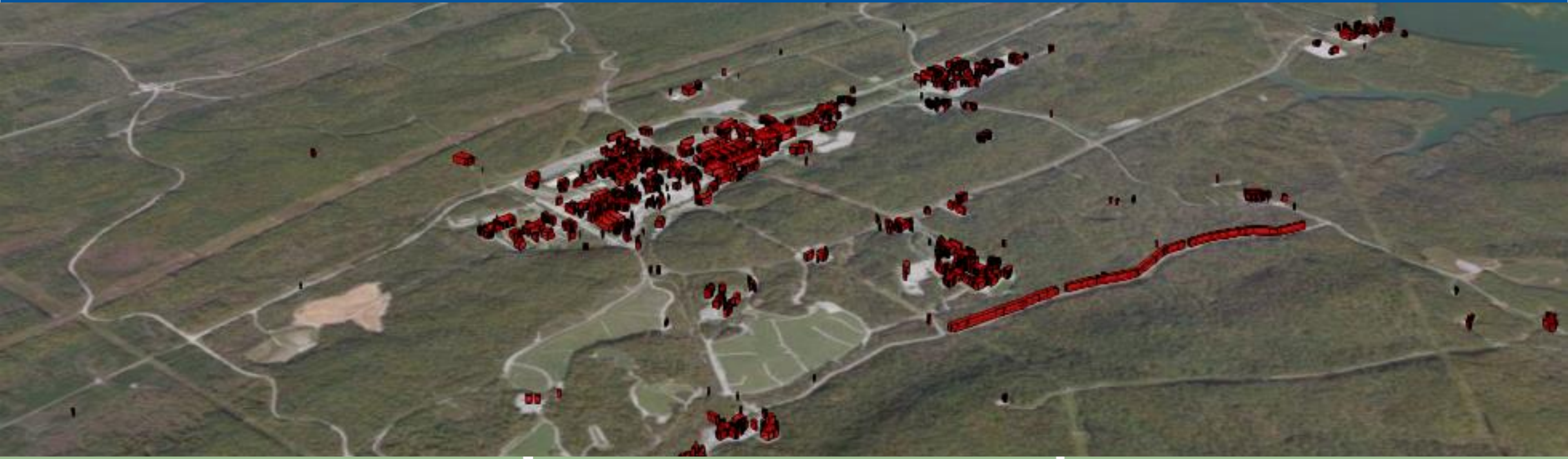
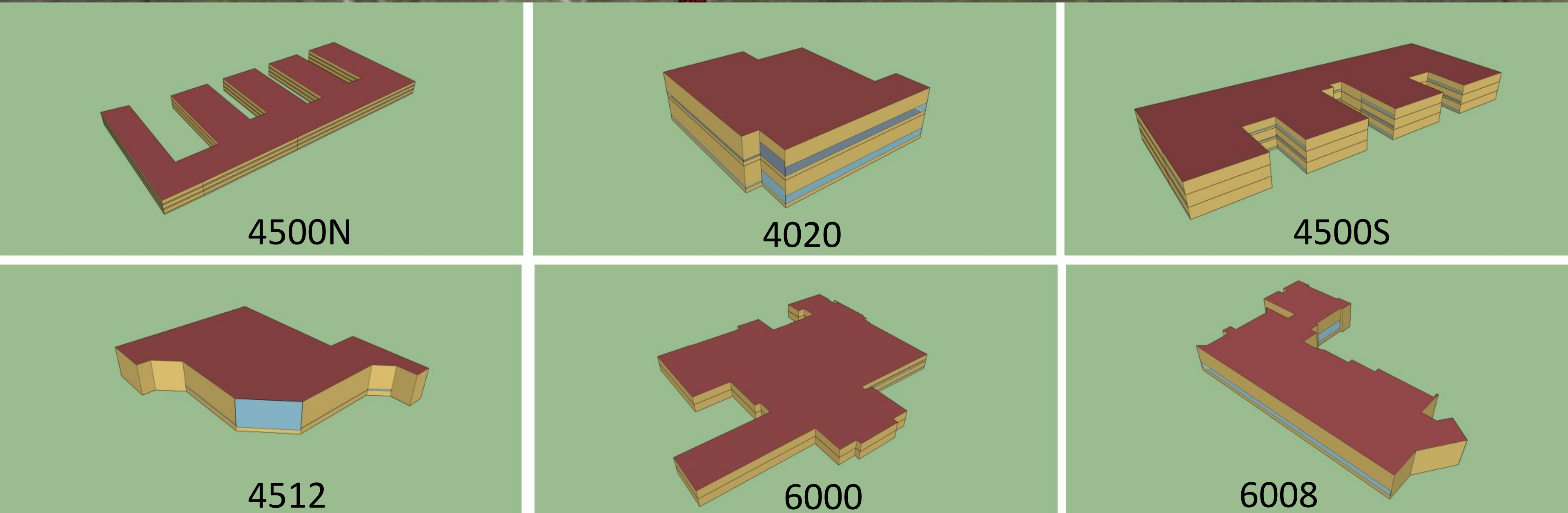
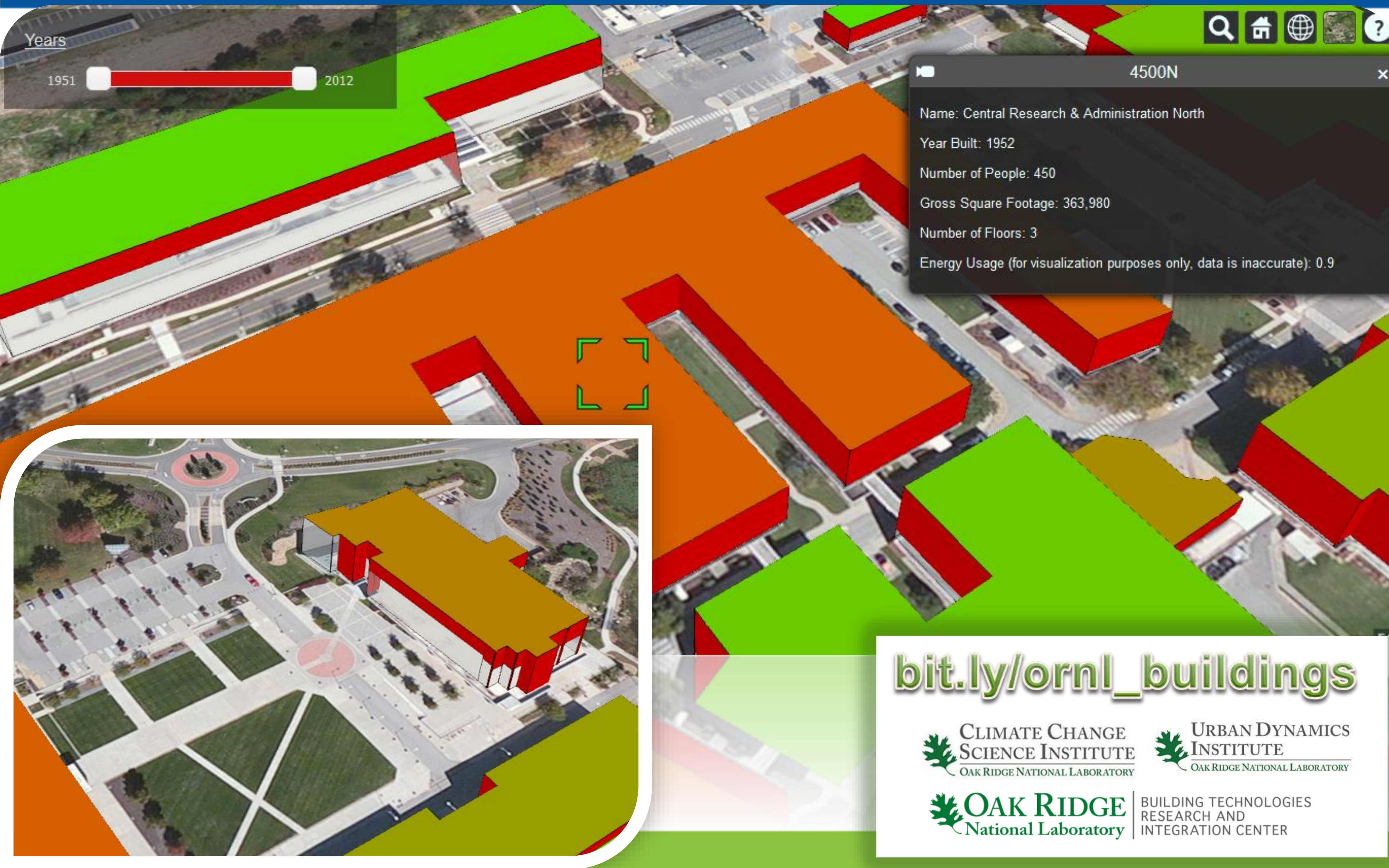




Oak Ridge National Laboratory (interactive)



bit.ly/ornl_buildings

Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

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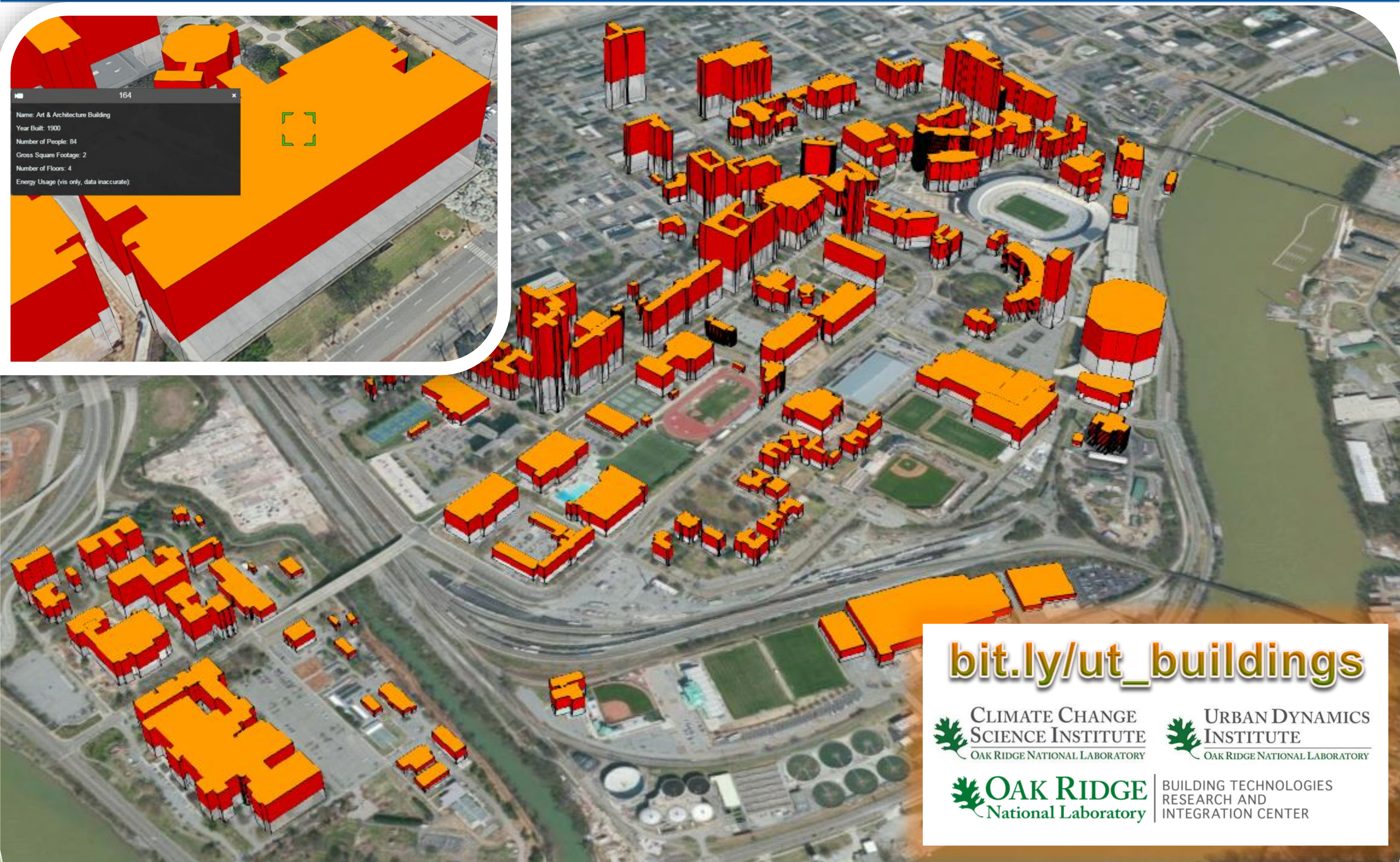
The University of Tennessee (2 days)



bit.ly/ut_buildings

Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

Oak Ridge National Laboratory

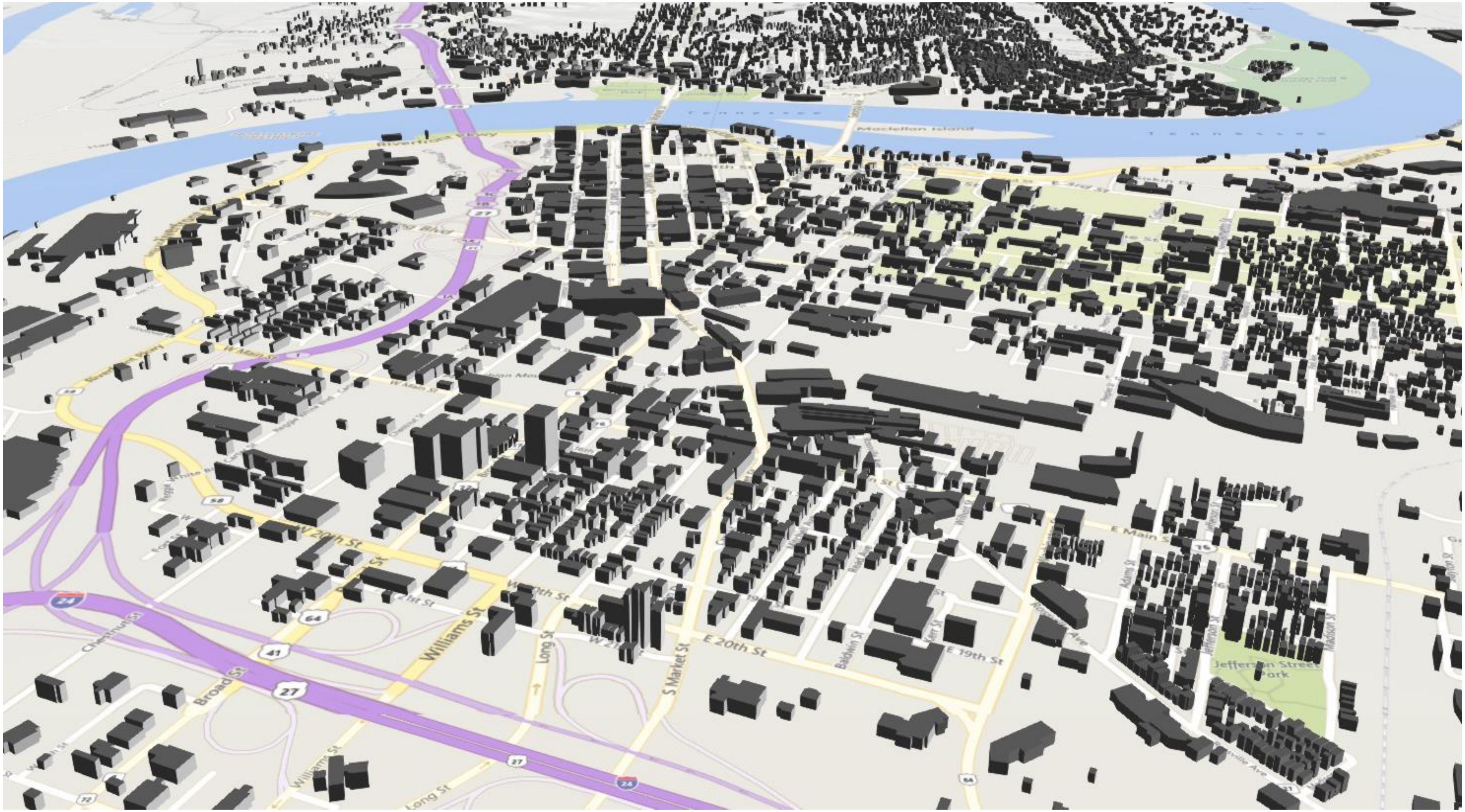
Building Technologies Research and Integration Center

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.

Chattanooga, TN (100,000+ buildings)



The AutoBEM technology "axe"

135,481 building models have been created and matched to EPB's PremiseID

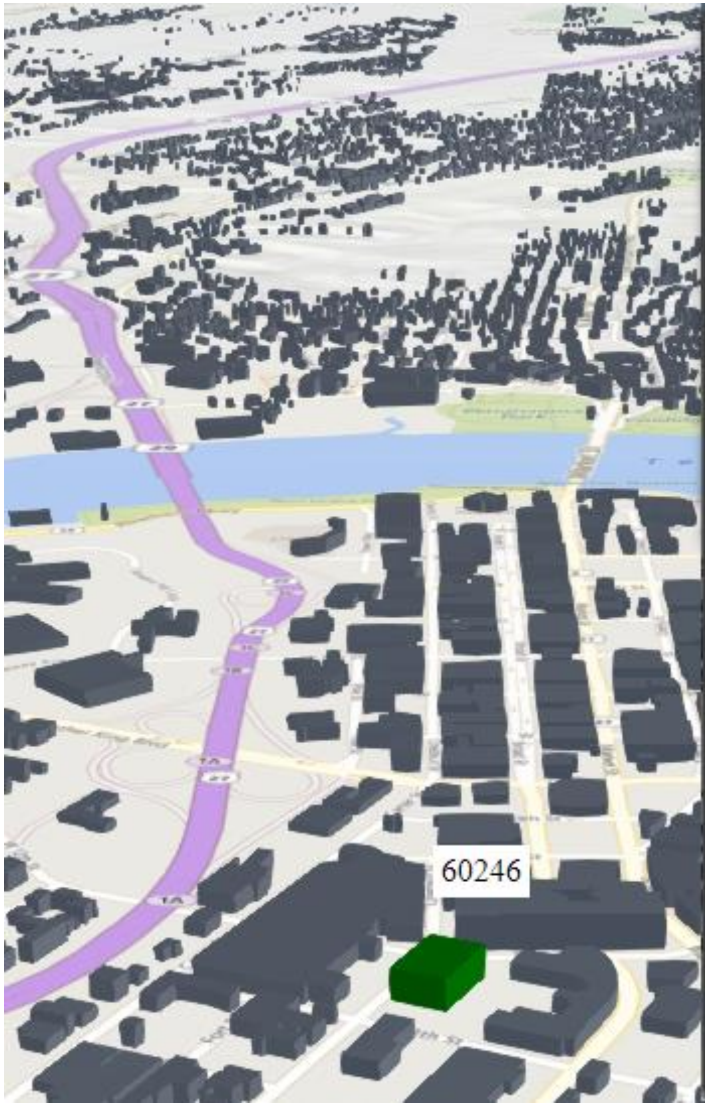
Limitations: limited building types, not calibrated, will improve quarterly
QA/QC: will show how close our simulations are to 15-min data

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 EPB (provided by ORNL) shows the value of technology with interactive dynamic results

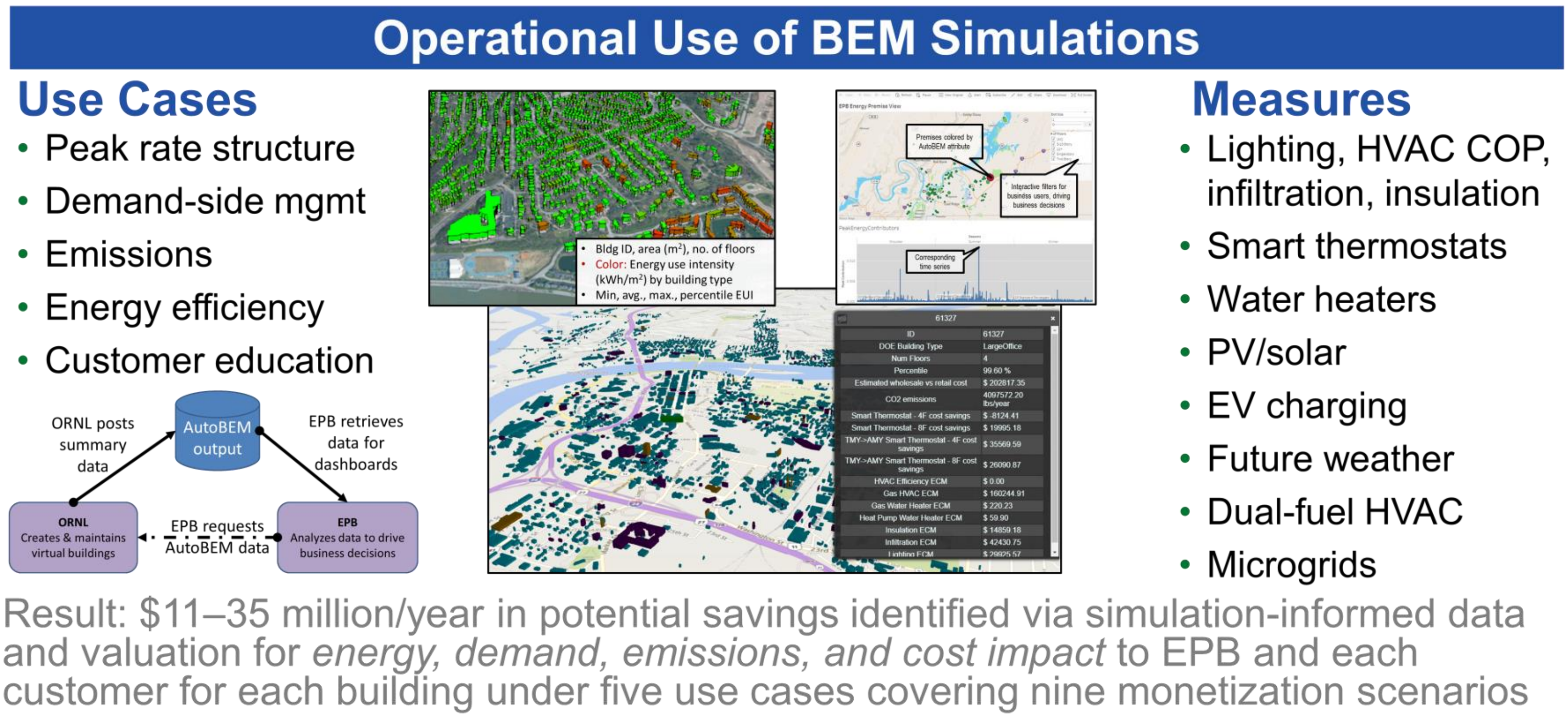


60246

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

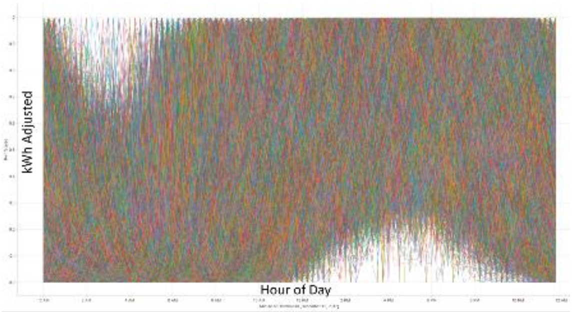
Comparison to real data

- Empirical Validation
  - 15-minute whole-building electrical for 178,368 buildings
  - More accurate than BEM created by a human[1]

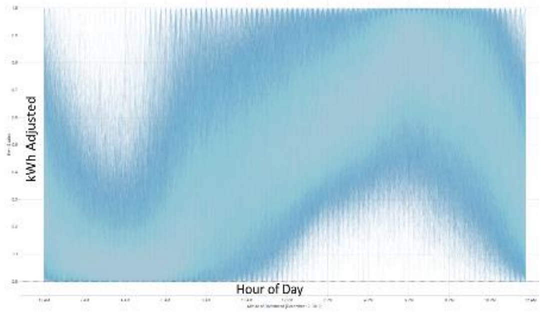


[1]Garrison, Eric, New, Joshua R., and Adams, Mark (2019). "Accuracy of a Crude Approach to Urban Multi-Scale Building Energy Models Compared to 15-min Electricity Use." Best PhD Student Paper award. In *Proceedings of the ASHRAE Winter Conference*, Atlanta, GA, Jan. 12-16, 2019. [PDF] [PPT]

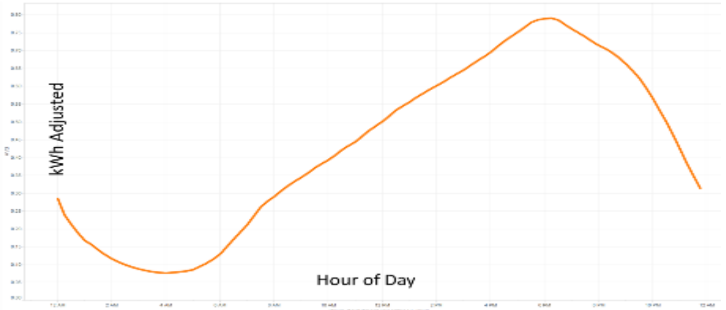
Clustering of (real) 15-min electrical data



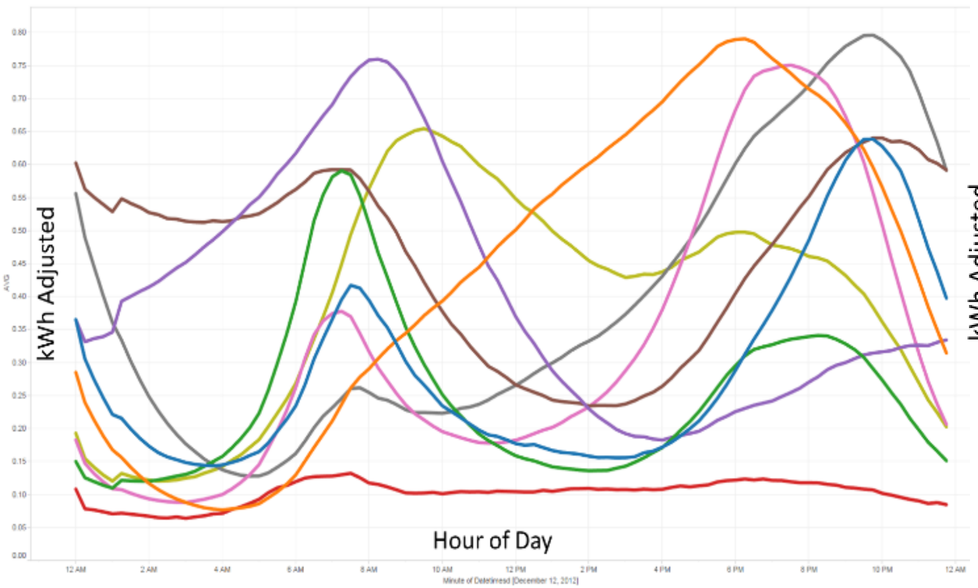
180,000 buildings measured
Whole-building electricity



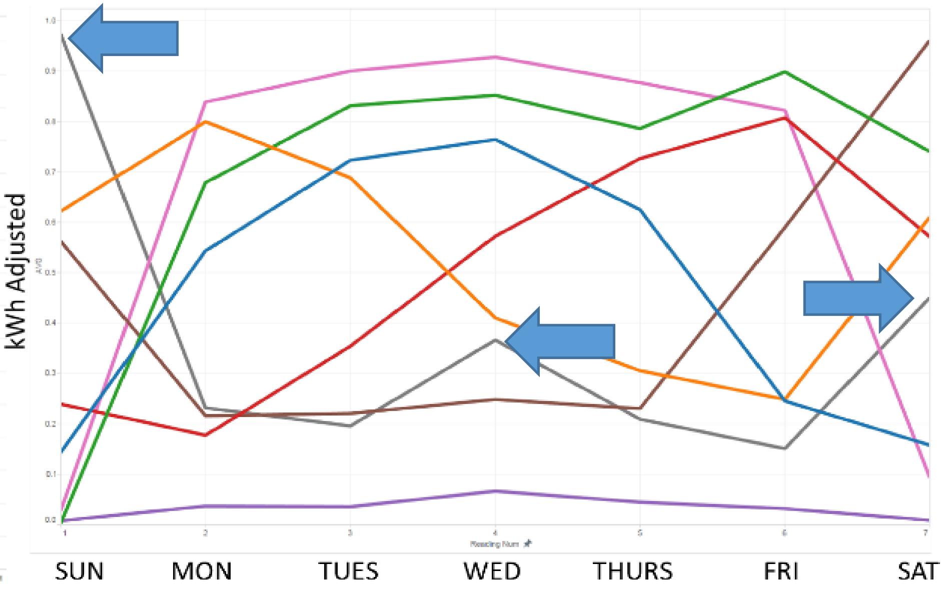
96d clustering (24h)



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



9 residential clusters



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

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

Database status (new):
AutoBEM Monthly Data joined with EPB System Data

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

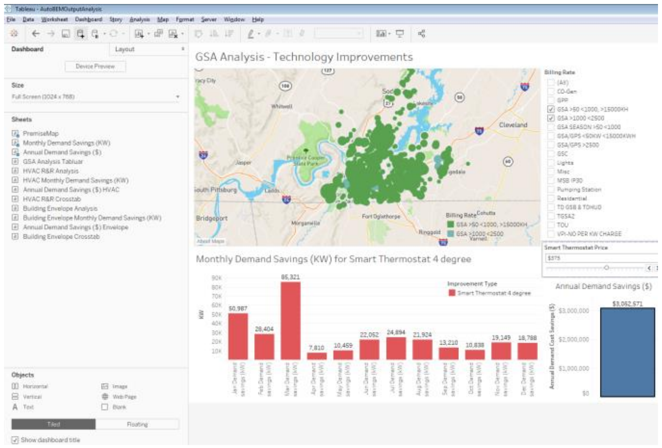
EPB System Attribute Data

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

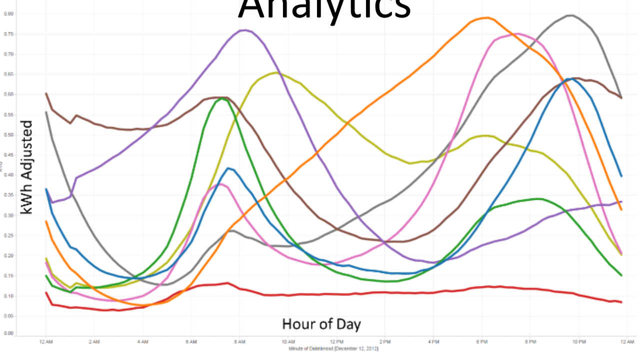
Data feeds to other EPB Systems

Distribution System Capacity Planning

Data Visualization Tools



Customer Clustering & Demand Side Management Analytics

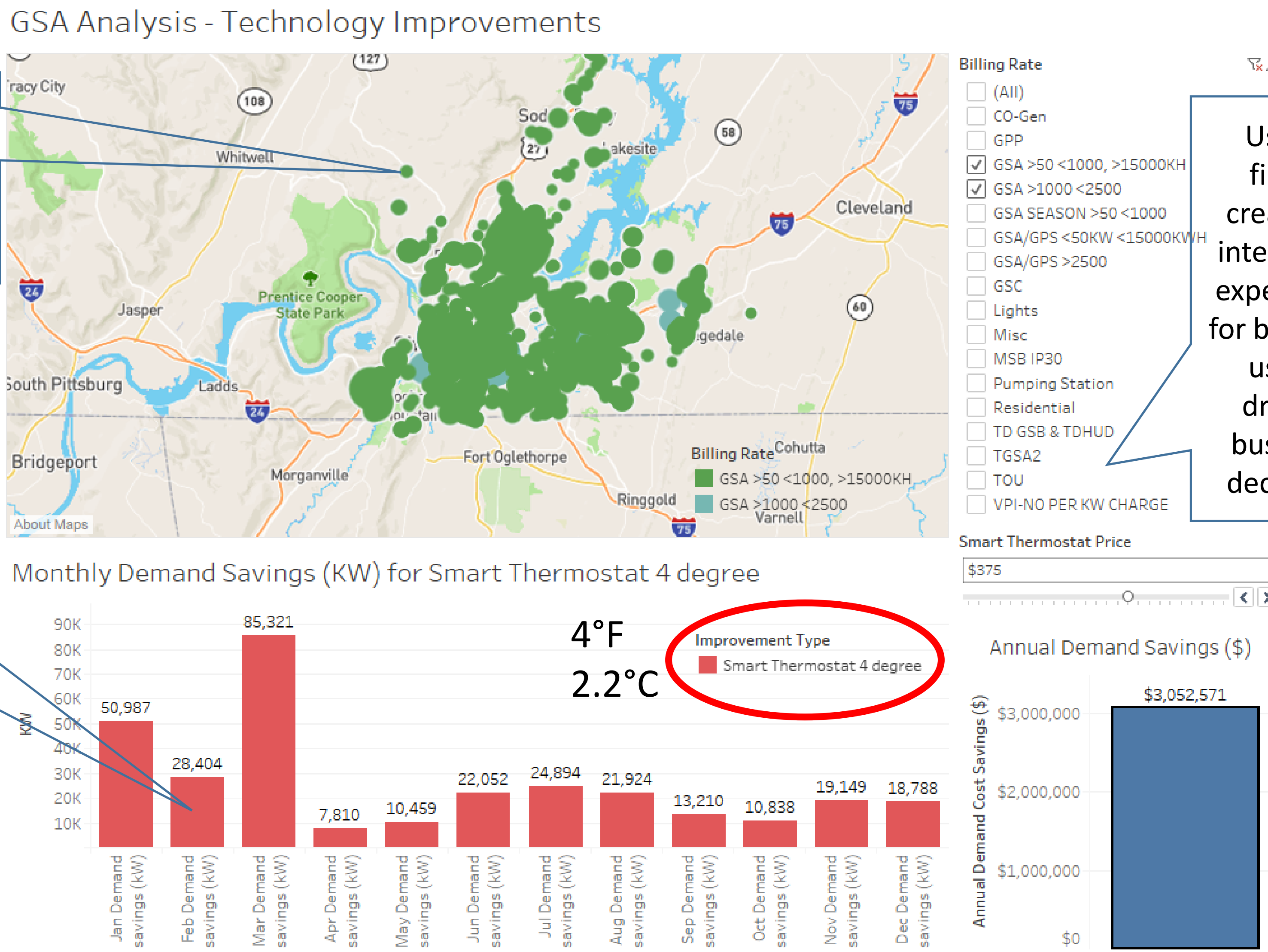


EPB’s operational Business Intel. Dashboard

Map showing premises, sized by Demand Value

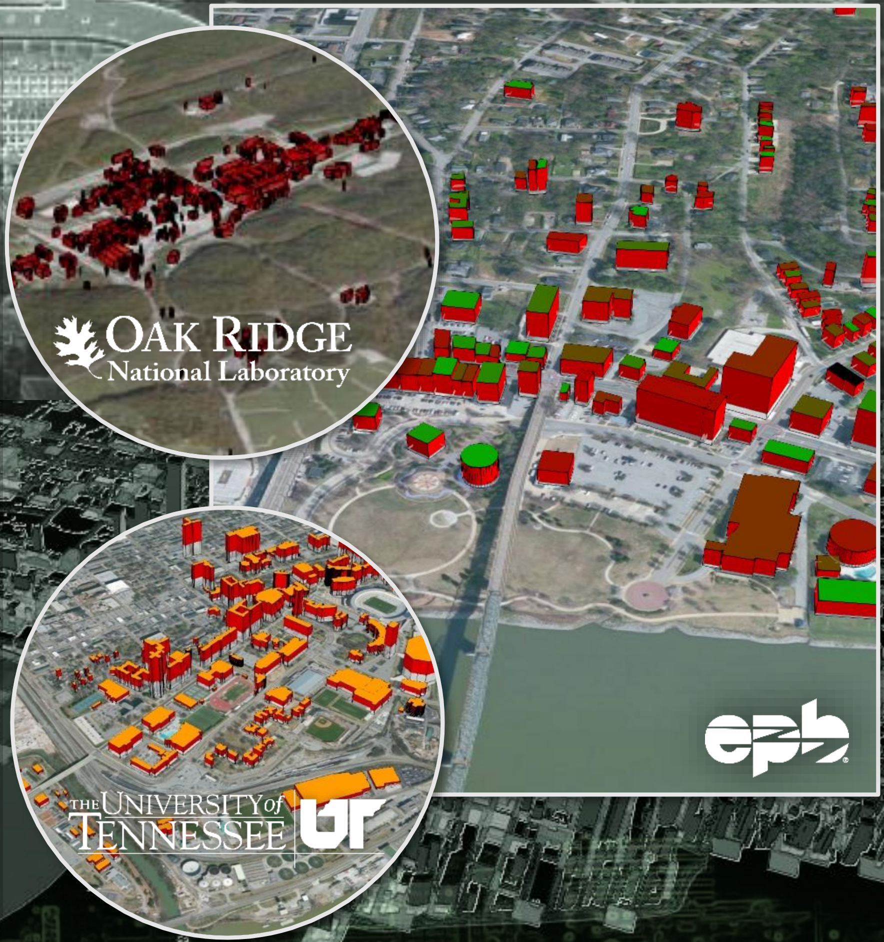
Chart showing monthly demand value

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



Discussion

HPC Tools for Modeling and Simulation
Capturing building energy consumption



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Data source and software overview

Automatic Detection and Building Energy Model Creation (AutoBEM)

Data Sources

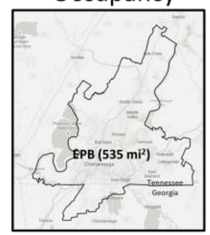
- Imagery (satellite, aerial)
- Street-level imagery
- Cartographic layers
  - Elevation, GIS
- Tax assessors
- Ranking of descriptors
  EE and Demand impacts
  (281–4,617 per building type)

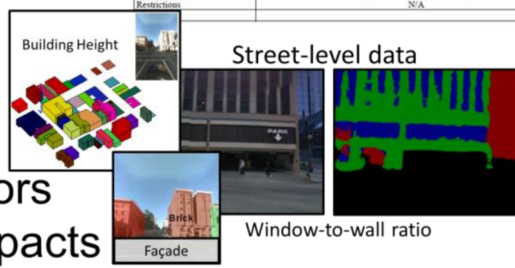
Class	Object	Field	Default	Minimum	Maximum	Distribution	Type	Group	Constraint
Sizing:Parameters		Heating Sizing Factor	1.33	0.931	1.729	uniform	float		
Sizing:Parameters		Cooling Sizing Factor	1.33	0.931	1.729	uniform	float		
Lights	Core_bottom_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform	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	

Data comparison matrix

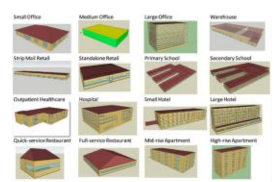
	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
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





Building footprints

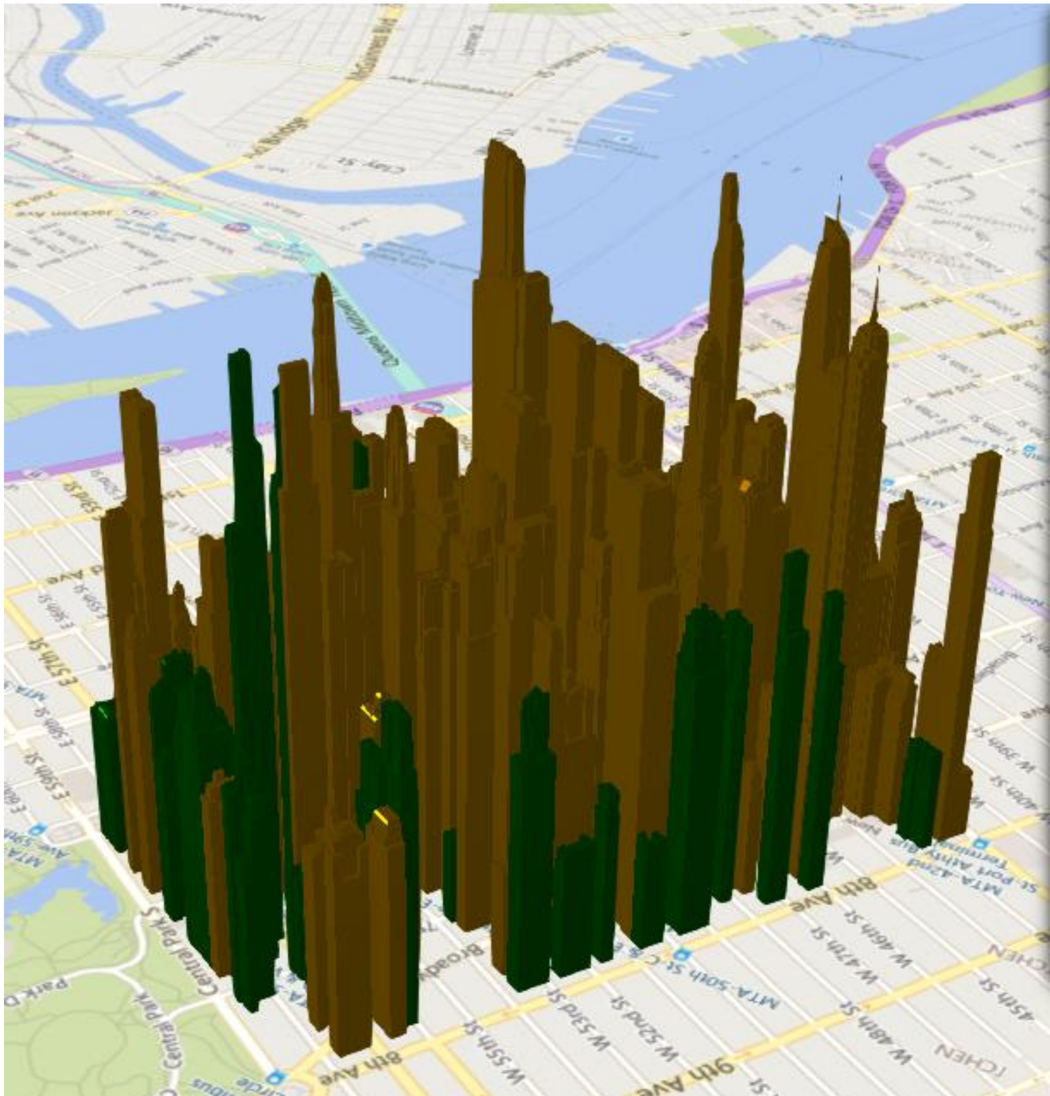


Software Tools

- 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

Virtual NYC – interactive results



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

Virtual NYC – interactive results

Savings across 152 buildings

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

1. **Smart thermostat 2.2C (4F) pre-condition**
   E=[-72, 1.4, 525] D=[-938, 918, 13907]
2. **Natural gas water heater (80% efficient)**
   E=[0, 0, 0] D=[0, 772, 13907]
3. **Heat pump water heater (COP 2.2)**
   E=[-184, -16.4, -2] D=[-30, 768, 13853]
4. **HVAC Efficiency (COP_H 3.55 and COP_C 3.3)**
   E=[0, 0,0] D=[0, 772, 13908]
5. **Lighting Efficiency (0.85 W/ft^2)**
   E=[77, 784, 6757] D=[23, 999, 14410]
6. **Infiltration (reduce 25%)**
   E=[40, 774, 4648] D=[-0.8, 840, 14020]
7. **Insulation (R16.12 to R28.57)**
   E=[12, 204, 1600] D=[1.9, 817, 13928]

building_id	Elec_savings (kWh)	Jan (kW)	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12210000247	-25559.37	5852.94	4309.38	5366.97	6592.65	4262.77	870.72	457.84	431.46	2406.69	6587.84	6630.63	6242.57
12210000469	-721.30	25.08	89.07	156.48	6.73	26.60	168.46	150.48	4.51	7.44	6.22	6.39	12.52
12210000518	-2701.65	7.76	1762.35	3394.86	22.85	550.36	2560.03	2263.61	2697.12	709.85	75.10	74.33	0.00
12210000994	-8481.05	1055.41	905.72	990.42	1474.41	848.47	196.65	194.14	3.66	548.06	1276.96	1252.69	887.56
12210001156	-5736.16	1196.35	1000.11	1101.04	1673.10	954.47	222.70	215.54	216.98	671.15	1469.96	1418.45	973.81
12210001197	546.94	77.19	407.63	1004.80	8.67	143.51	888.66	830.73	901.23	227.86	8.38	69.38	0.00
12210001252	-42452.78	7440.43	5315.70	6722.96	8265.02	6113.35	511.76	625.95	1.15	4142.70	8232.69	7282.54	6572.38
12210001490	-905.68	8.48	39.99	177.69	8.06	30.01	16.00	155.19	158.46	81.12	3.35	0.64	3.88
12210002001	-16751.35	2353.22	1774.32	2166.91	3481.47	2139.86	229.42	419.27	3.45	1610.13	3238.90	2776.87	1857.80
12210002031	-1226.89	1.96	145.84	444.87	-0.66	9.45	-496.24	63.75	116.22	-111.25	10.52	49.65	0.00
12210002047	-692.42	22.52	99.76	370.75	9.39	64.11	347.40	349.46	382.89	179.84	11.41	3.25	0.00
12210002150	30.35	60.50	255.99	806.49	3.48	66.73	812.78	689.28	5.88	147.68	3.96	77.14	0.00
12210002629	-3701.09	882.04	839.96	797.77	1059.83	717.52	153.35	140.93	1.94	482.84	970.80	1050.46	741.97
12210003200	-28557.61	2563.00	2406.68	2510.02	2962.48	2202.89	357.32	419.56	410.43	1519.44	2886.95	3028.13	2298.47
12210003292	-1583.51	4.30	1311.22	2826.54	9.47	448.83	2200.25	1916.39	2278.23	611.96	56.75	85.90	0.00
12210003302	-5519.82	119.63	2140.16	4235.07	33.48	608.39	2922.95	2597.64	2876.36	866.10	103.19	9.61	0.00
12210003314	-5708.34	4.91	2444.18	3982.02	0.71	264.42	1733.69	315.91	49.63	393.20	12.85	158.36	0.00
12210003317	-3372.72	111.52	510.91	1173.94	9.19	255.62	1086.71	950.19	1091.03	408.28	31.76	9.90	0.00
12210003333	-1604.88	1.96	84.76	221.98	5.28	6.44	21.88	212.90	20.55	82.06	2.34	5.21	0.15
12210003346	-2131.77	5.41	1474.50	3019.75	11.03	474.57	2247.52	1996.23	2414.45	577.55	42.52	74.95	0.00
12210003350	-891.15	54.48	119.26	163.76	6.54	16.33	187.35	170.99	3.96	9.51	5.52	7.50	9.59
12210003354	-17125.51	4898.93	4556.63	4387.42	5461.75	3512.42	38.73	682.57	661.52	2552.29	5508.01	5809.67	4086.09
12210003361	-1214.74	9.77	58.91	210.65	0.63	6.87	-5.49	191.78	204.65	97.66	2.19	1.29	0.45
12210003379	759.09	63.94	308.85	797.63	4.71	97.05	791.79	701.29	669.47	6.47	4.73	63.31	0.00
12210003383	2626.09	118.49	681.87	1367.29	25.09	224.15	1207.86	1043.81	2.29	341.70	64.43	95.22	0.00
12210003661	-42.89	7.47	88.91	223.08	6.93	15.57	232.71	212.10	5.81	1.05	10.39	4.12	0.09
12210003791	-676.58	1.83	108.79	273.89	4.62	-0.71	266.11	11.88	10.69	51.54	12.46	30.17	0.21
12210004115	2116.15	22.16	265.01	744.60	3.08	96.42	759.76	510.54	57.95	57.73	6.83	49.82	0.00
12210004205	1070.38	82.79	545.31	1222.73	3.25	160.14	1072.99	873.94	14.49	48.06	8.56	99.29	0.00
12210004223	380.10	38.15	95.93	354.41	15.05	76.17	337.95	319.08	361.81	192.99	36.14	1.04	0.00
12210004406	-2142.06	123.81	557.33	1385.46	15.95	278.12	1199.00	1104.96	1282.00	403.57	12.01	11.16	0.00