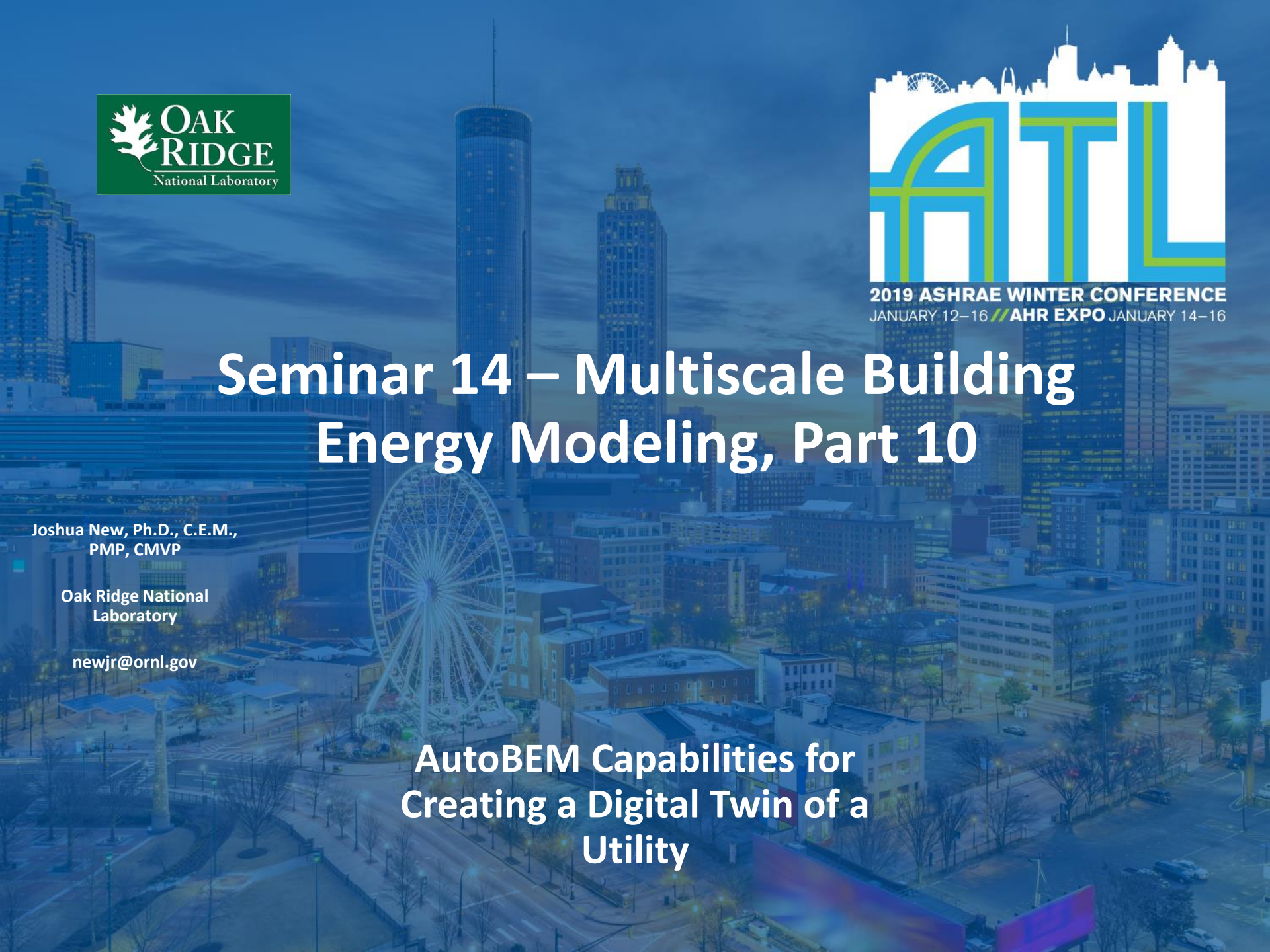

Seminar 14 – Multiscale Building Energy Modeling, Part 10

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AutoBEM Capabilities for Creating a Digital Twin of a Utility

Learning Objectives

- Introduce the EnergyPlus features to enable building energy models to explicitly consider thermal interactions between building and among buildings and the urban atmosphere
- Describe the different Zero Energy Community definitions
- Understand design principles for Zero Energy Communities
- Understand the scalability and accuracy of an urban/multi-scale approach

Acknowledgements

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- Amy Rose
- Hsiuhan (Lexie) Yang

…and many more

The Univ. of Tennessee:

- Eric Garrison
- Brett Bass

Outline/Agenda

- Utility Context
- Overarching Goal
- Multiscale modeling
  - Automatic Building detection and Energy Model creation (AutoBEM) – aka “Platform”
- Platform for a Virtual Utility (Virtual EPB)
  - Utility-prioritized use cases
  - Developed capabilities
  - Challenges
  - Preliminary results

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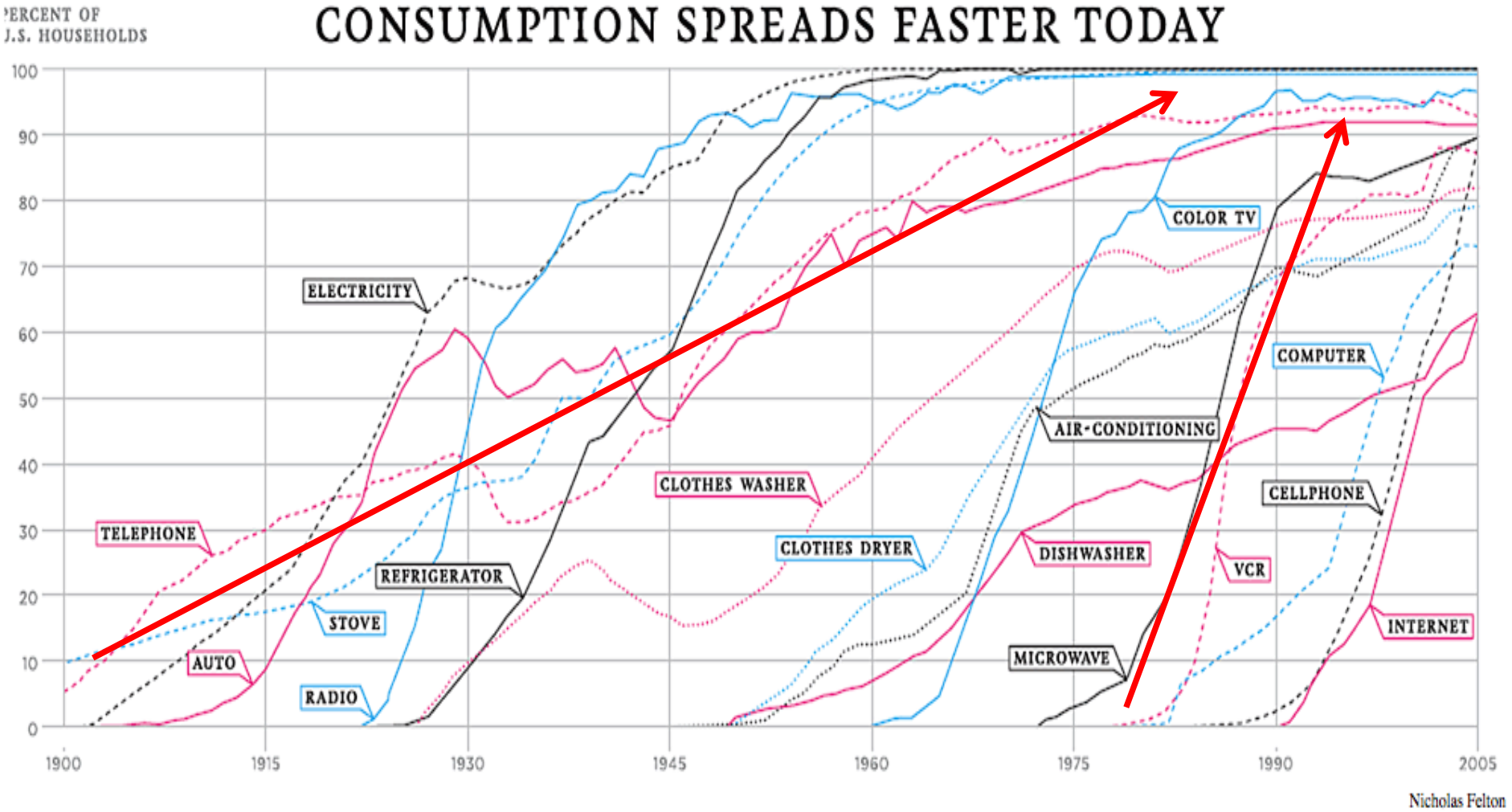


Utility Context

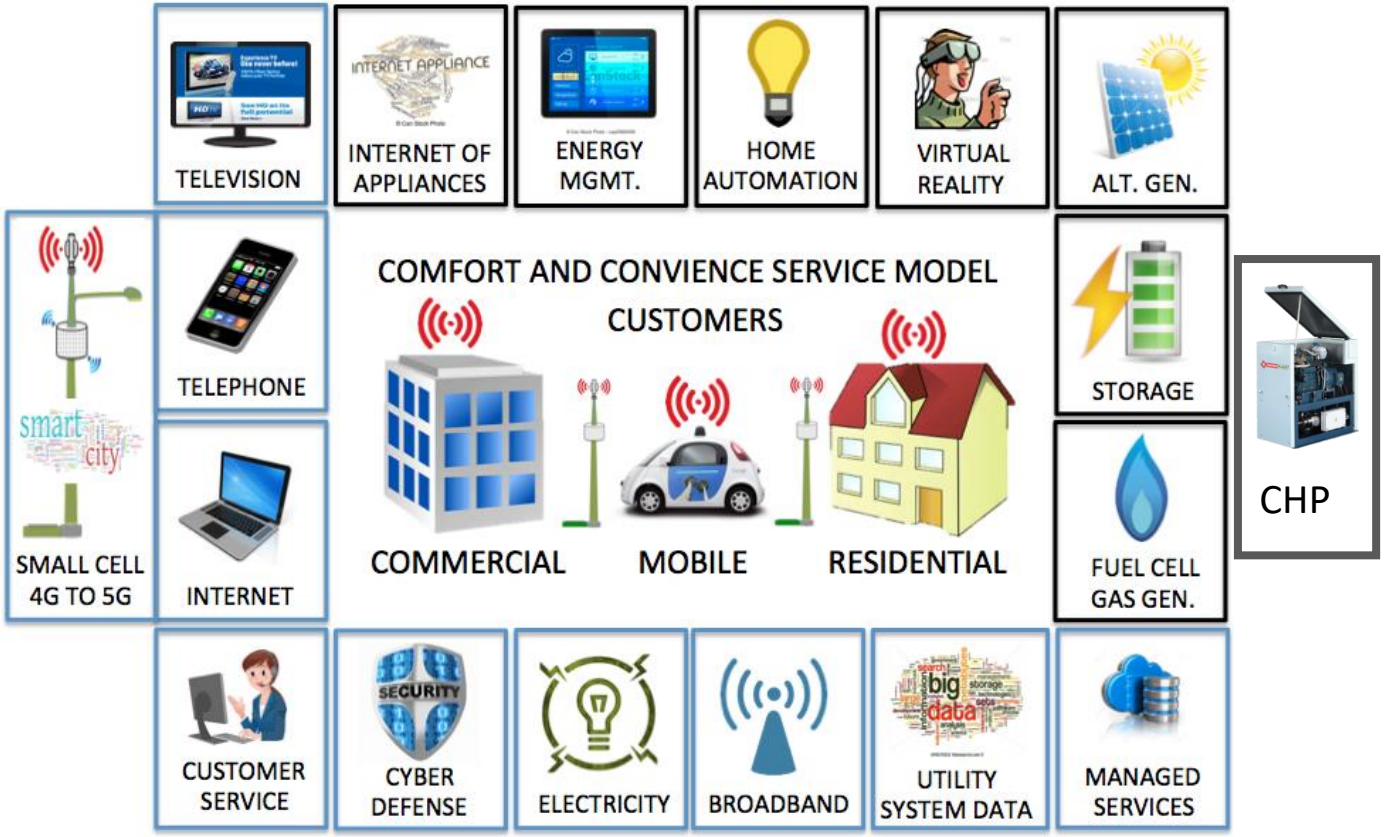
2005

Utility Context

2013

Utility Context

- Building Energy Efficiency and Renewable Energy is eroding revenue/customer
- Cost-effective communication and controls is shifting the utility business model toward Grid-interactive Efficient Buildings



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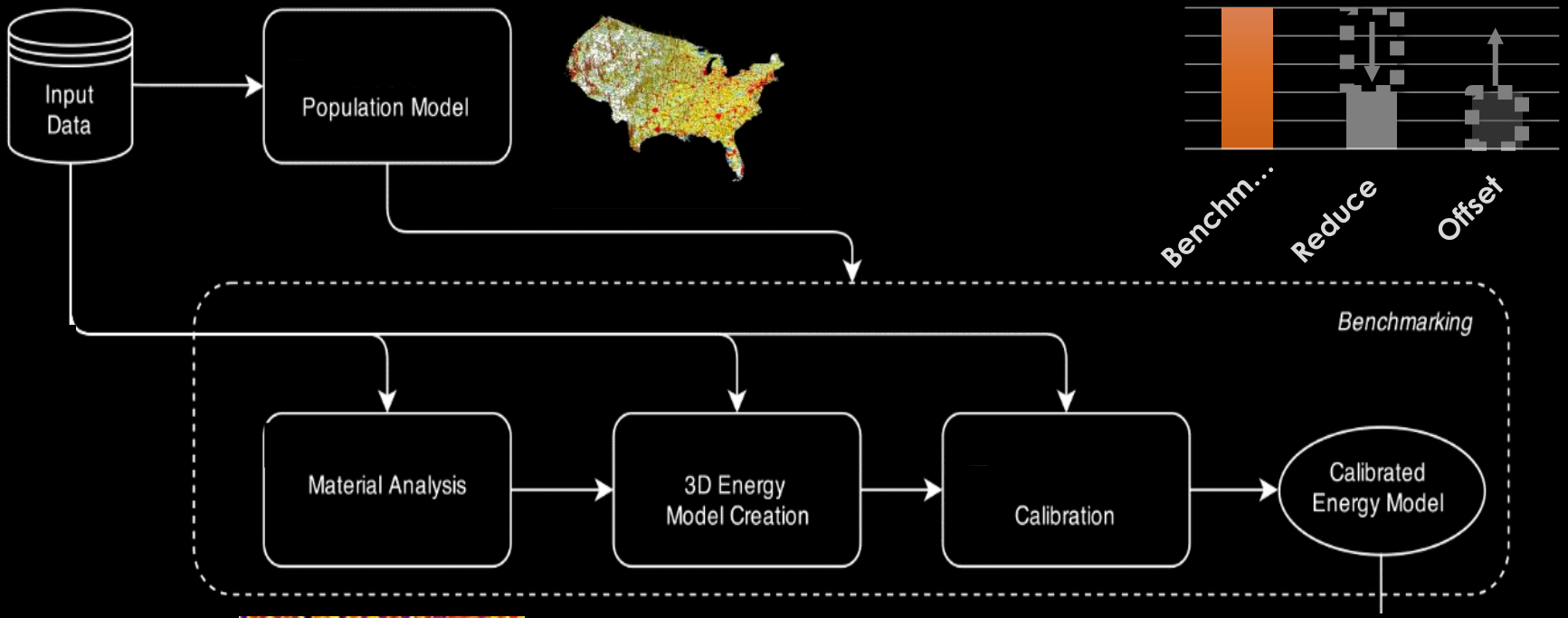
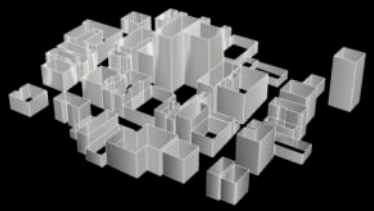
Model America 2020 – BEM info for every U.S. building





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Multiscale Modeling – previous work

- Project Goal: create a digital twin of every building in the utility'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 scenarios

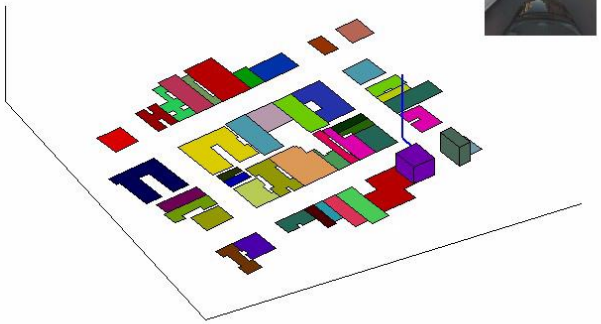
Data Sources

	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

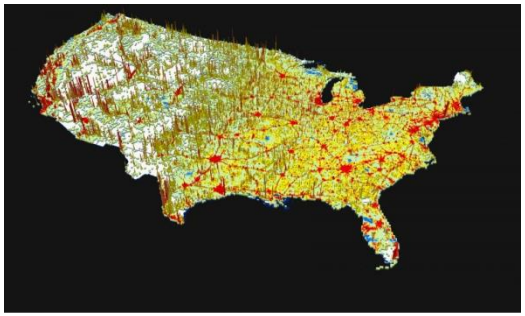
Road Extraction

Bldg Footprints

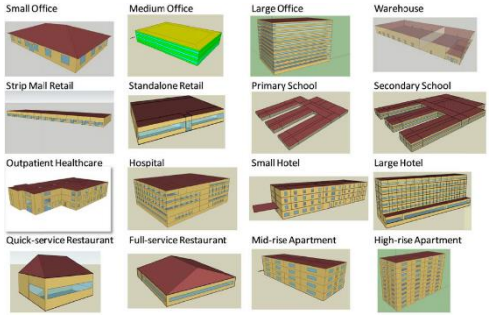
3D Building Model Generation



Street-level properties



Occupancy Data



Prototype Buildings

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Utility-prioritized Use Cases

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.

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Platform capabilities – what matters and how much?

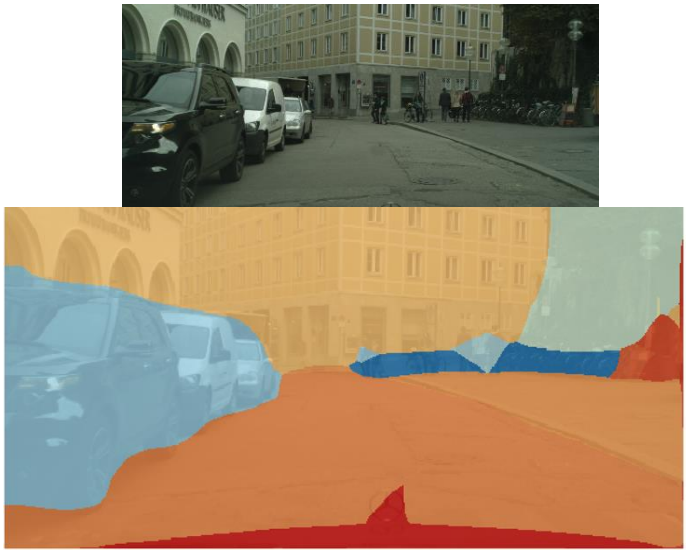
- Sensitivity analysis for all commercial building types
  - 80% of commercial buildings - 16 climate zones, 16 building types, averaging 5.75 vintages
  - 281-4,617 building descriptors (e.g. thermostat, insulation level) were modified
  - Fractional Factorial (FrF2) resolution IV statistical design of experiments

	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

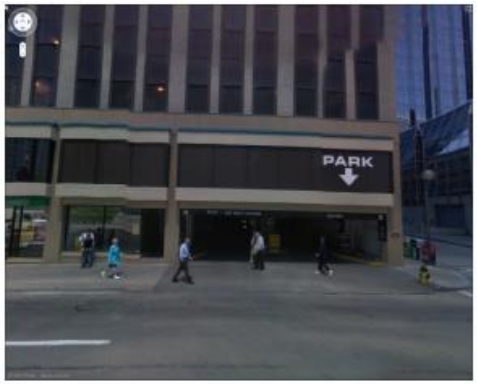
Class	Object	Field	Default	Minimum	Maximum	Distribution	Type	Group	Constraint
Sizing:Parameters		Heating Sizing Factor	1.33	0.931	1.729	uniform	float		
Sizing:Parameters		Cooling Sizing Factor	1.33	0.931	1.729	uniform	float		
Lights	Core_bottom_Lights	Watts per Zone Floor Area	10.76	7.532	13.988	uniform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

- Quantify Most Important Building Parameters
  - 216 Excel spreadsheets for energy and demand impacts of each building type
  - Top 10 annual energy (kWh) and demand/peak-shaving (kW) variables for each of the 16 building types

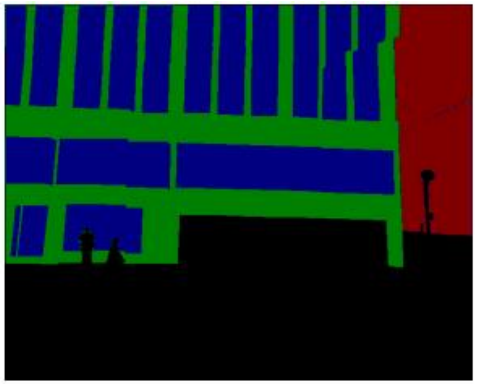
Platform capabilities – street-level updates



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

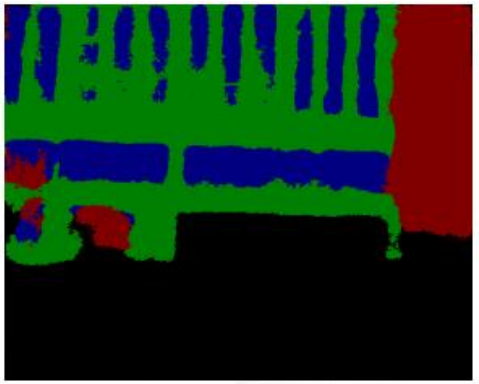


Input image



Ground truth

Window-to-wall ratio



Model output

Platform capabilities – imagery updates

- StreetView processing for high-resolution details of Window-to-wall ratio and HVAC detection not currently feasible without higher-resolution data (aerial instead of highest-resolution satellite)

Window-to-Wall Ratio

2 views of the same building

view_01_00	
Facade pixels:	54073
Window pixels:	21120
Ratio:	0.28087721
view_01_01	
Facade pixels:	63356
Window pixels:	27212
Ratio:	0.30045932

Worst cases

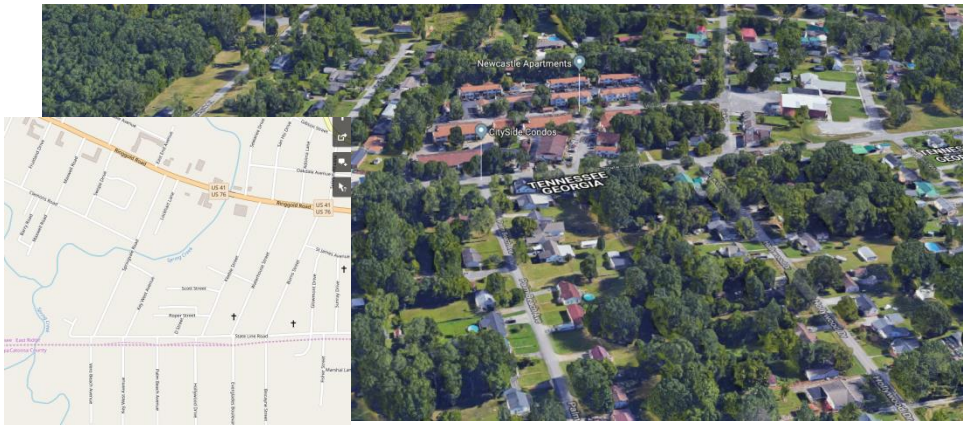
Building Footprints

Satellite-derived building footprints are irregular often must be simplified for modeling.

Platform capabilities – imagery and population updates, challenges

Building Footprints

LiDAR acquisition date can lead to discrepancies



HVAC Detection

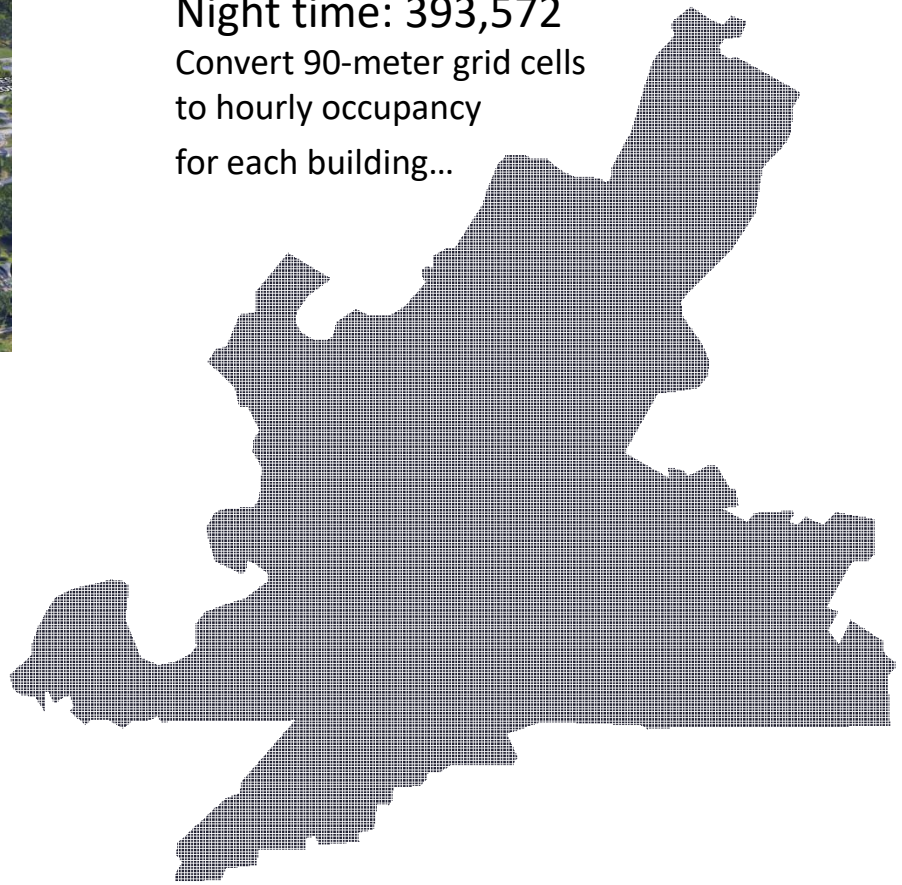
Aerial HVAC classification requires higher-resolution imagery (~10cm/pixel)

Population in Utility's Area

Day time: 434,725

Night time: 393,572

Convert 90-meter grid cells to hourly occupancy for each building…



Platform capabilities – data synthesis, challenges

N/A	Res labeled Com	Comm labeled Res
20828	3086	18003
11.7%	1.7%	10.1%

RateClass	Number	%
Residential	109,475	80.8
N/A	14,774	10.9
GSA1	8,477	6.3
GSA2	2,257	1.7
Other1	224	<0.1
100	80	<0.1
GSA3	75	<0.1
38	59	<0.1
30	23	<0.1
130	22	<0.1
Industrial	13	<0.1
19	1	<0.1
345	1	<0.1
TOTAL	135,481	100

Preliminary BuildingType		
IECC-Residential	171821	96.35%
HighriseApartment	2068	1.16%
SmallHotel	1557	0.87%
MidriseApartment	851	0.48%
Warehouse	799	0.45%
LargeHotel	408	0.23%
Hospital	319	0.18%
QuickServiceRestaurant	318	0.18%
Outpatient	59	0.03%
FullServiceRestaurant	42	0.02%
LargeOffice	41	0.02%
RetailStripmall	26	0.01%
MediumOffice	4	0.00%
RetailStandalone	3	0.00%
SmallOffice	3	0.00%
PrimarySchool	2	0.00%
SecondarySchool	2	0.00%
TOTAL	178323	

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Preliminary results – accuracy

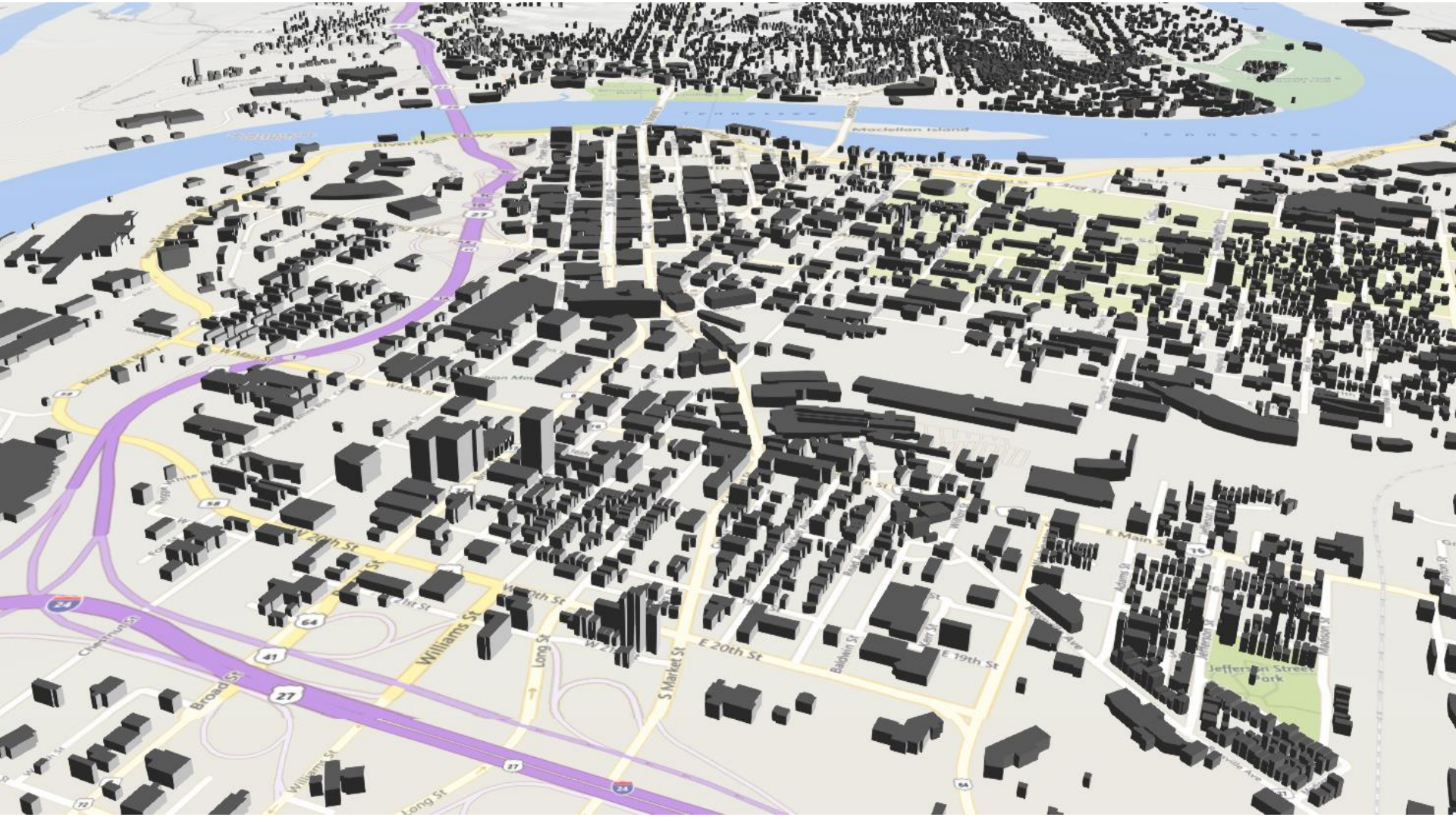
- Utility provided 15-min data for every building!
- Walk-through audits – CV(RMSE) 23-97% *monthly* data
  - Based on data from 3,000+ audits
- Error information
  - Report % error for every building in CV(RMSE) and NMBE
  - Show improvement every quarter as BEM data layers improve

$$\mathrm{CV(RMSE)} = \frac{\sqrt{\sum_{i=1}^{N_i}\left[\frac{[(M_i - S_i)]^2}{N_i}\right]}}{\frac{1}{N_i}\sum_{i=1}^{N_i} M_i} \qquad \mathrm{MBE} = \frac{\sum_{i=1}^{N_i}(M_i - S_i)}{\sum_{i=1}^{N_i} M_i}$$

	Manual	3 Office Types, 3 vintages
$CVRMSE_M$	24-97%	
$CVRMSE_H$	48-194%	
$CVRMSE_{15*}$	96-388%?	
$NMBE_M$		
$NMBE_H$		
$NMBE_{15*}$		
LoadFactor		

Proper GPS registration of buildings to meters may improve.

Preliminary Results – model for every building



Preliminary Results – analysis pipeline

135,481 building models have been created and matched to EPB's PremiseID
Limitations: not yet calibrated, will improve quarterly with new data

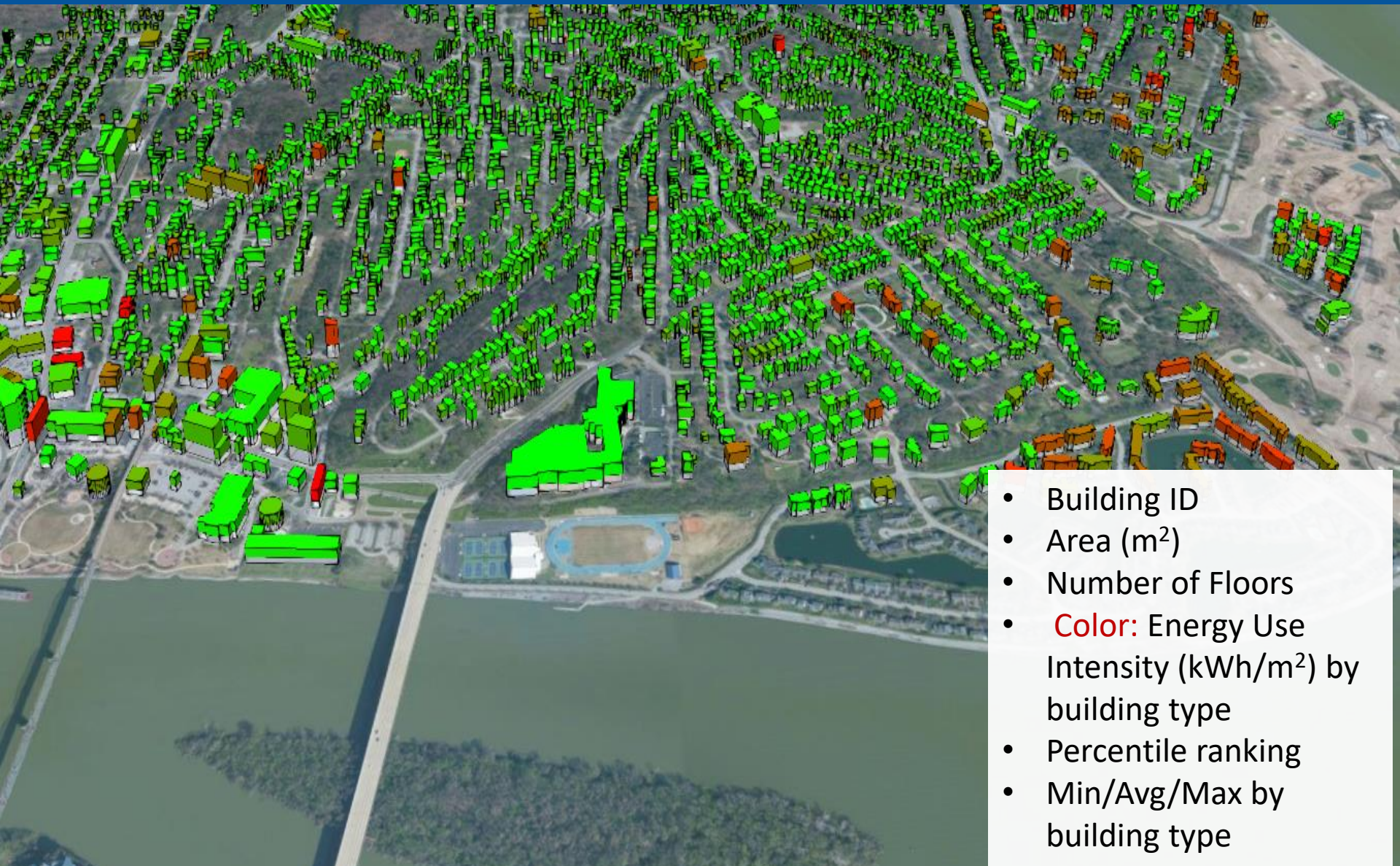
3.2 million building energy model simulations using our Multiscale Modeling Platform, Titan, cloud, and local servers to produce and analyze 18 TB of simulation data.

1. Generate baseline building – OS measures (1.5-3h cloud, 30h internal)
2. Run ECM measures – OS measure (30 mins cloud, 2h internal), Custom (1m cloud, 5m intl.)
3. Copy data to Titan – 1 min (1.2GB tar.gz)
4. Submit to Titan – 0-2 hours in queue
5. EP simulation time – 30-45 mins
   (5mins/sim = 1.4 years to simulate utility area 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

CPU Cores	Wall-clock Time (mm:ss)	Data Size	Annual Bldg 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

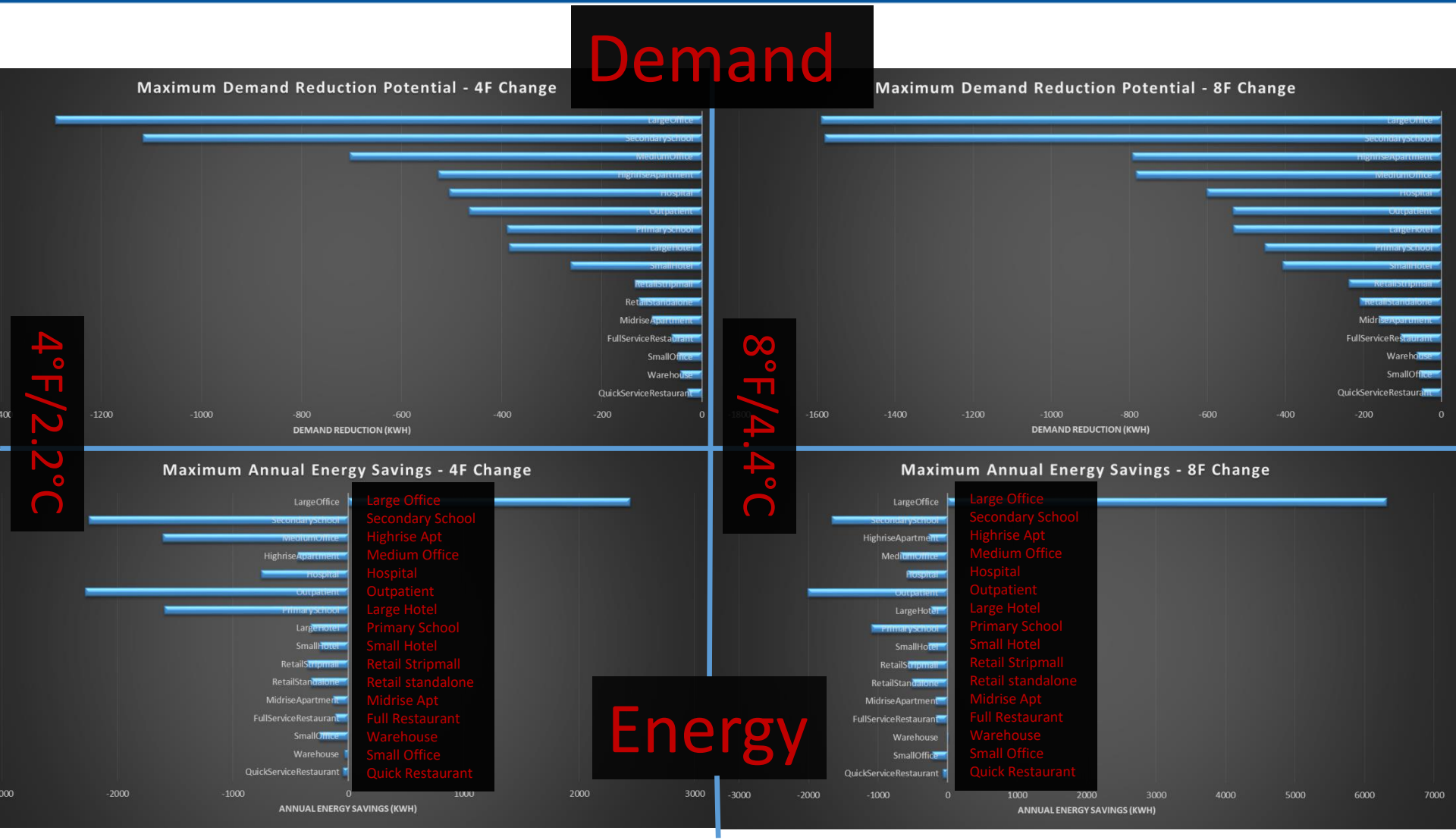
Time for creation, annual simulation, and analyzing "all" EPB buildings
6.5 hours (6.1h –36.5h)

Preliminary Results – energy use intensity



- Building ID
- Area (m^2)
- Number of Floors
- Color: Energy Use Intensity (kWh/m^2) by building type
- Percentile ranking
- Min/Avg/Max by building type

Preliminary Results – smart thermostats for buildings as batteries



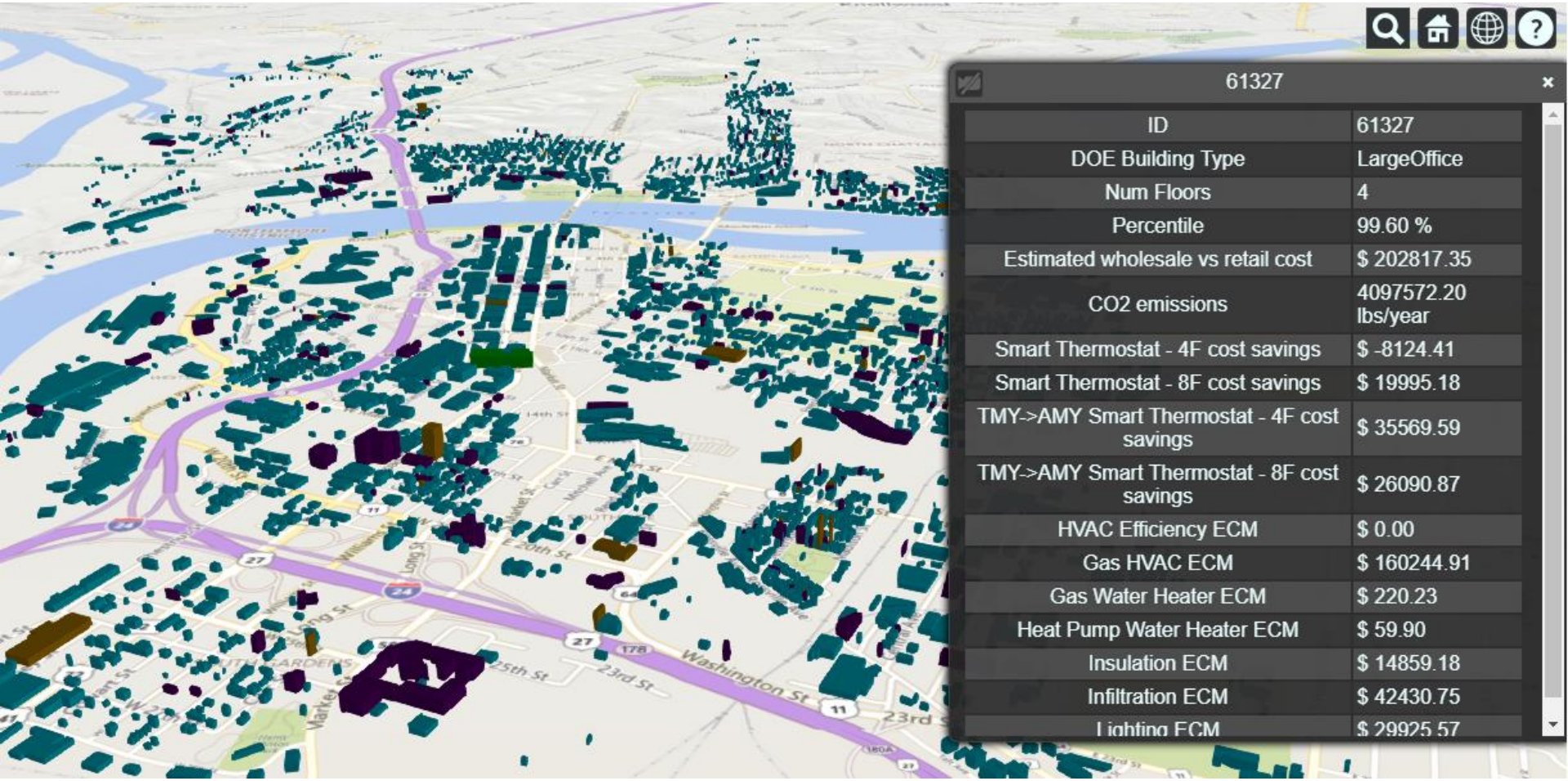
Preliminary Results

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

ECMs	Different Fields Calculated for Each ECM							
HVAC	1.Total	2.Annual	3.Energy	4.Annual	5.Annual	6.Annual	7.Annual	8.Total
Lighting	Cost	Electric	Cost	Electric	Demand	Demand	Demand	Cost
Infiltration	Savings	Savings	Savings		Savings	Cost		Savings
8F setback						Savings		
HVAC Efficiency	$	kWh	$	kWh	kW	$	kW	$
4F setback								
Insulation	9.Annual	10.Energy	11.Annual	12.Percent	13.Annual	14.Annual		
Water heater	Electric	Cost	Electric	Savings	Demand	Demand		
Heat pump	Savings	Savings			Cost Savings			
Smart WH	kWh	$	kWh	$	$	kW		

- ***Preliminary*** building-specific estimates show cost savings totaling **$11-$35 million per year.**

Preliminary Results



Questions?

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