Data of the Future: Digital Cities

Digital Twin of a City Utility

Issues, science, implementation, and results

Presented at:

Better Buildings Summit

Arlington, VA

Presented by:

Bill Copeland
Electric Power Board of Chattanooga, TN

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

July 11, 2019

ORNL is managed by UT-Battelle
for the US Department of Energy

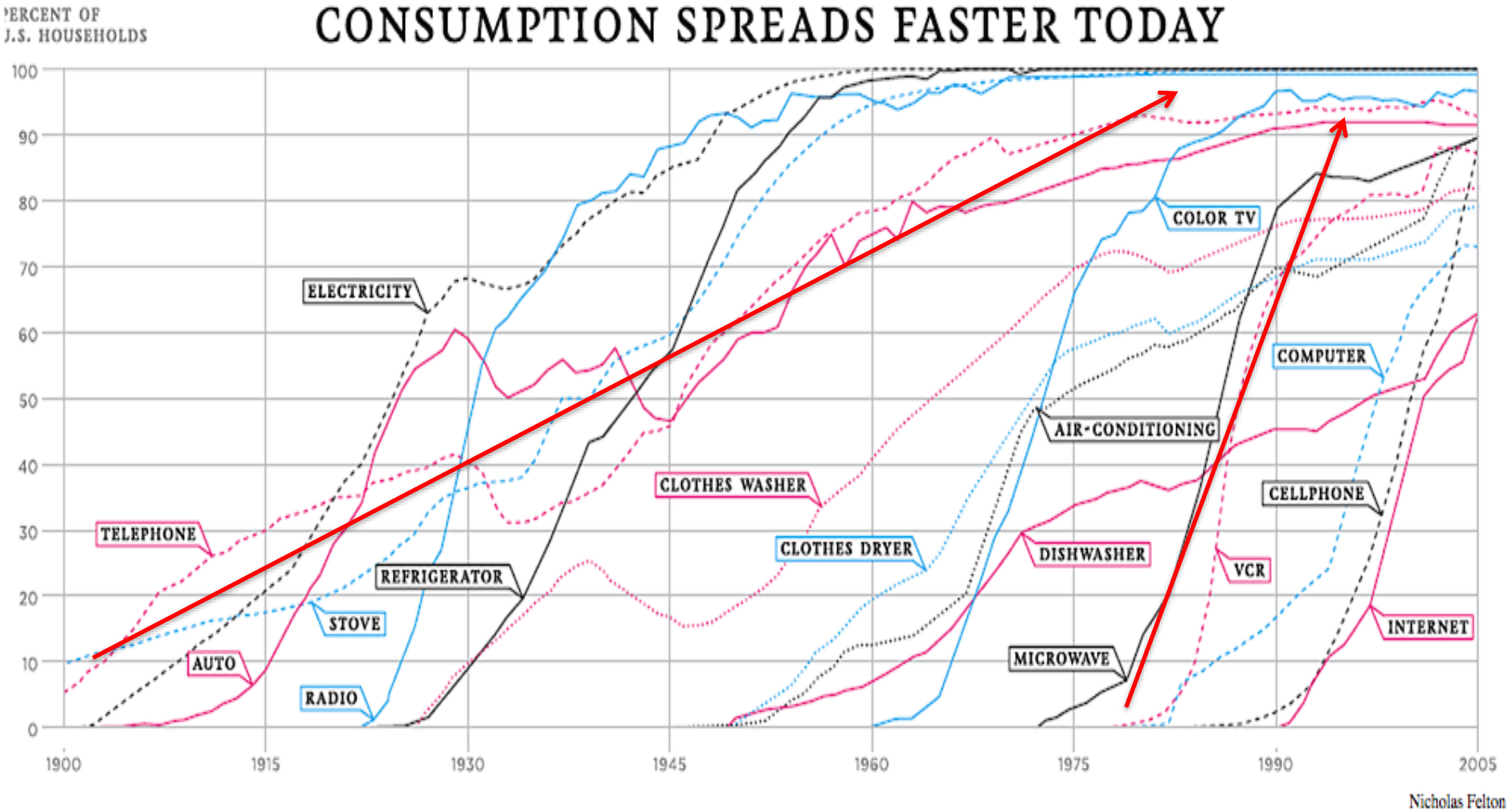
OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Strategic Research

A 21st Century Crossroads

Strategic Research

Technology Adoption Rates Accelerate



Strategic Research

Wireless Broadband IoT Age Is Upon Us

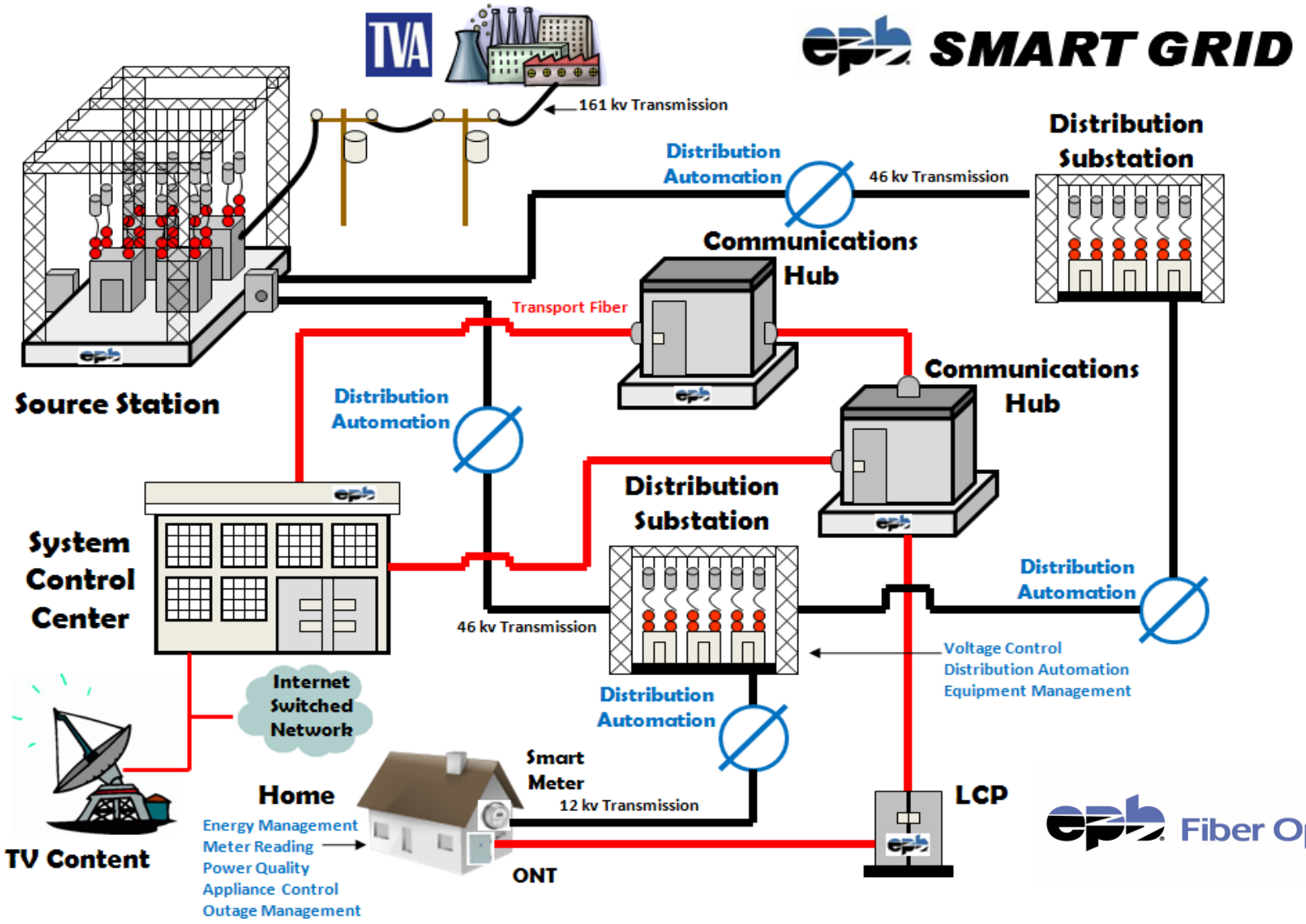
Papal Conclave 2005

Gigabit Speed Wireless Broadband Coming Soon in 2018-2019

Papal Conclave 2013

Strategic Research

ENERGY and INTERNET NETWORKS



Strategic Research

A New Generation of Smart Energy Appliances

2011

$250
Artificial Intelligence

2015

$5000
5KWh

Strategic Research

AUTOBEM Integrated With EPB Appliance Models

TESLA

POWERWALL

CERTIFIED INSTALLER

amazon echo

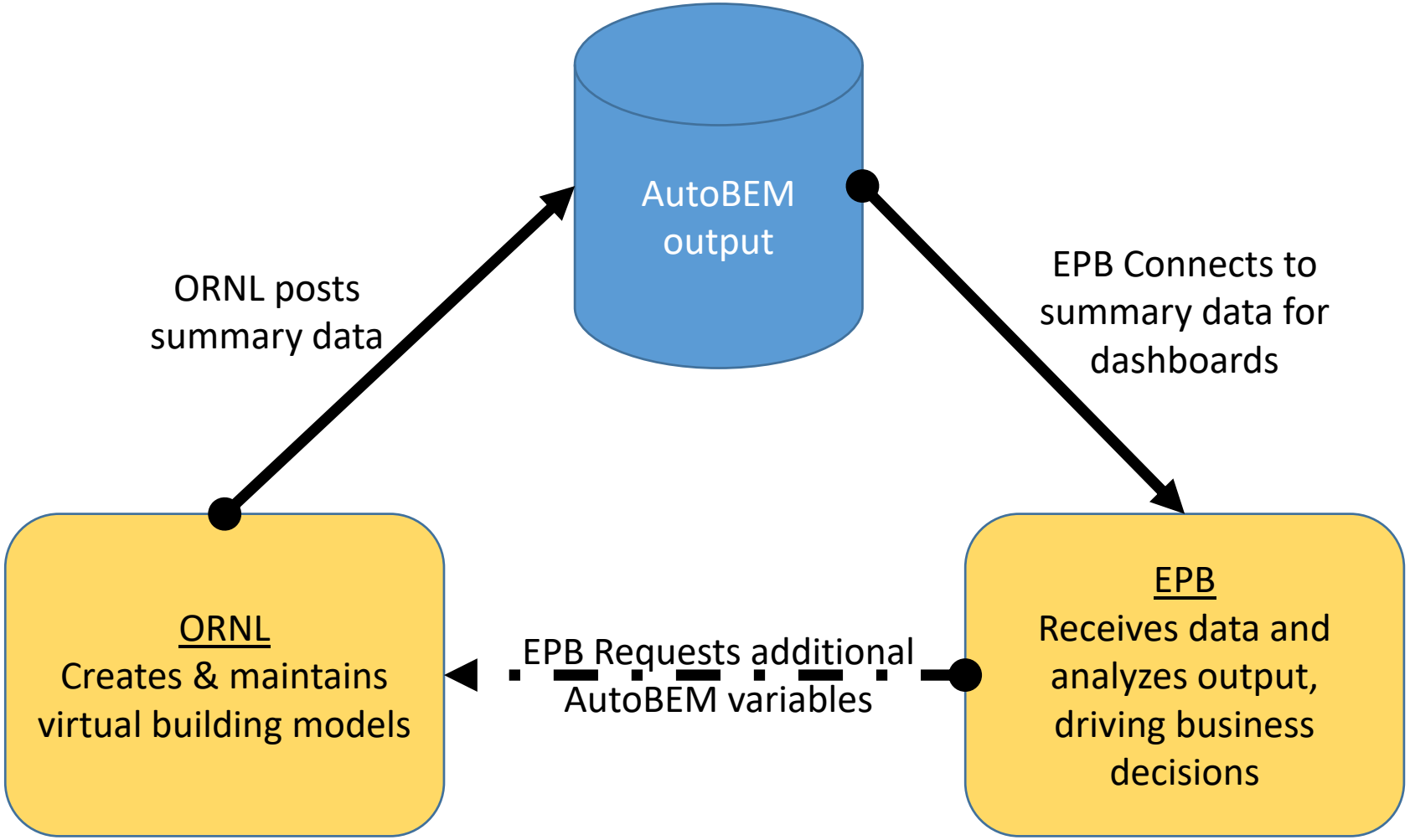
Where do Americans turn for answers we can trust?

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

ORNL/EPB Data Coordination

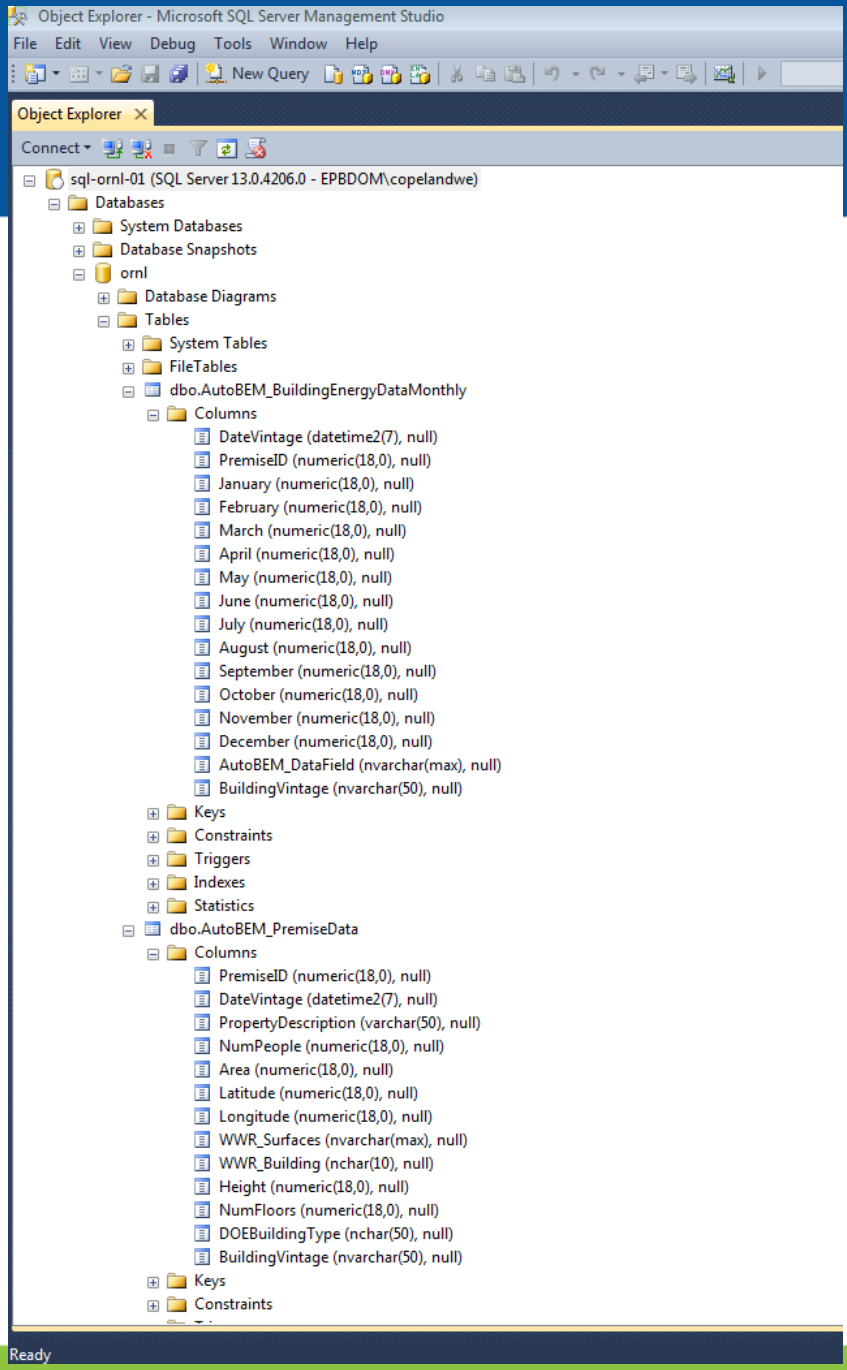


Database status (old):

TableName: AutoBEM_PremiseData	
FieldName	**DataType**
PremiseID	Number
DateVintage	Date
Description	String
NumPeople	Number
Area	Number
Latitude	Number
Longitude	Number
WWR_Surfaces	String
WWR_Building	Number
Height	Number
NumFloors	Number
DOEBuildingType	String

TableName: AutoBEM_BuildingEnergyData	
FieldName	**DataType**
DateVintage	Date
PremiseID	Number
AutoBEMDataField	String
JanuaryDataValue	Number
FebruaryDataValue	Number
MarchDataValue	Number
AprilDataValue	Number
MayDataValue	Number
JuneDataValue	Number
JulyDataValue	Number
AugustDataValue	Number
SeptemberDataValue	Number
OctoberDataValue	Number
NovemberDataValue	Number
DecemberDataValue	Number

Need hourly granularity table, as well as vintage/scenario sensitivity



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 for a theoretical year, all premises**

Join on Premise Number

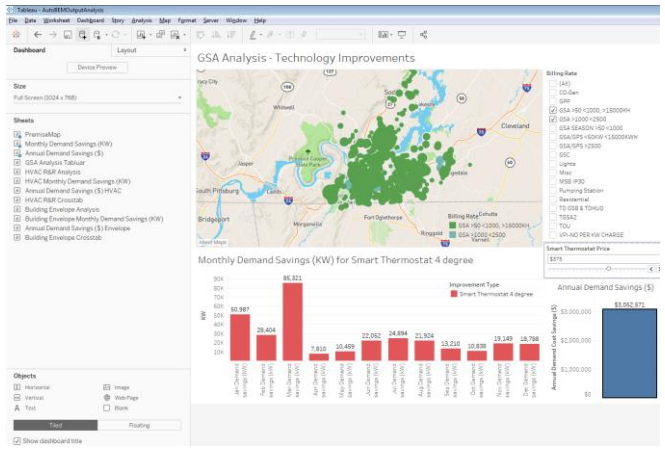
EPB System Attribute Data

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

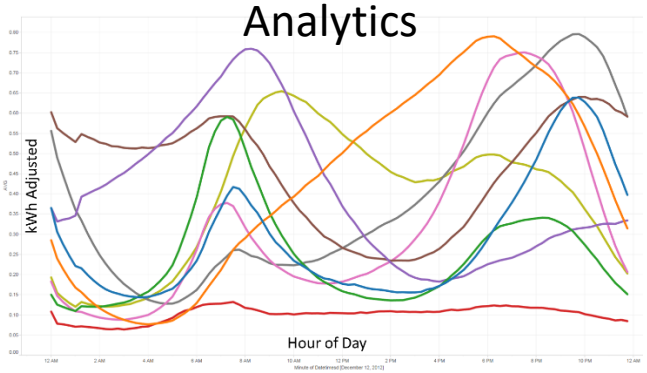
Data feeds to other EPB Systems

Distribution System Capacity Planning

Data Visualization Tools



Customer Clustering & Demand Side Management Analytics



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NumFloors	Number
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MayDataValue	Number
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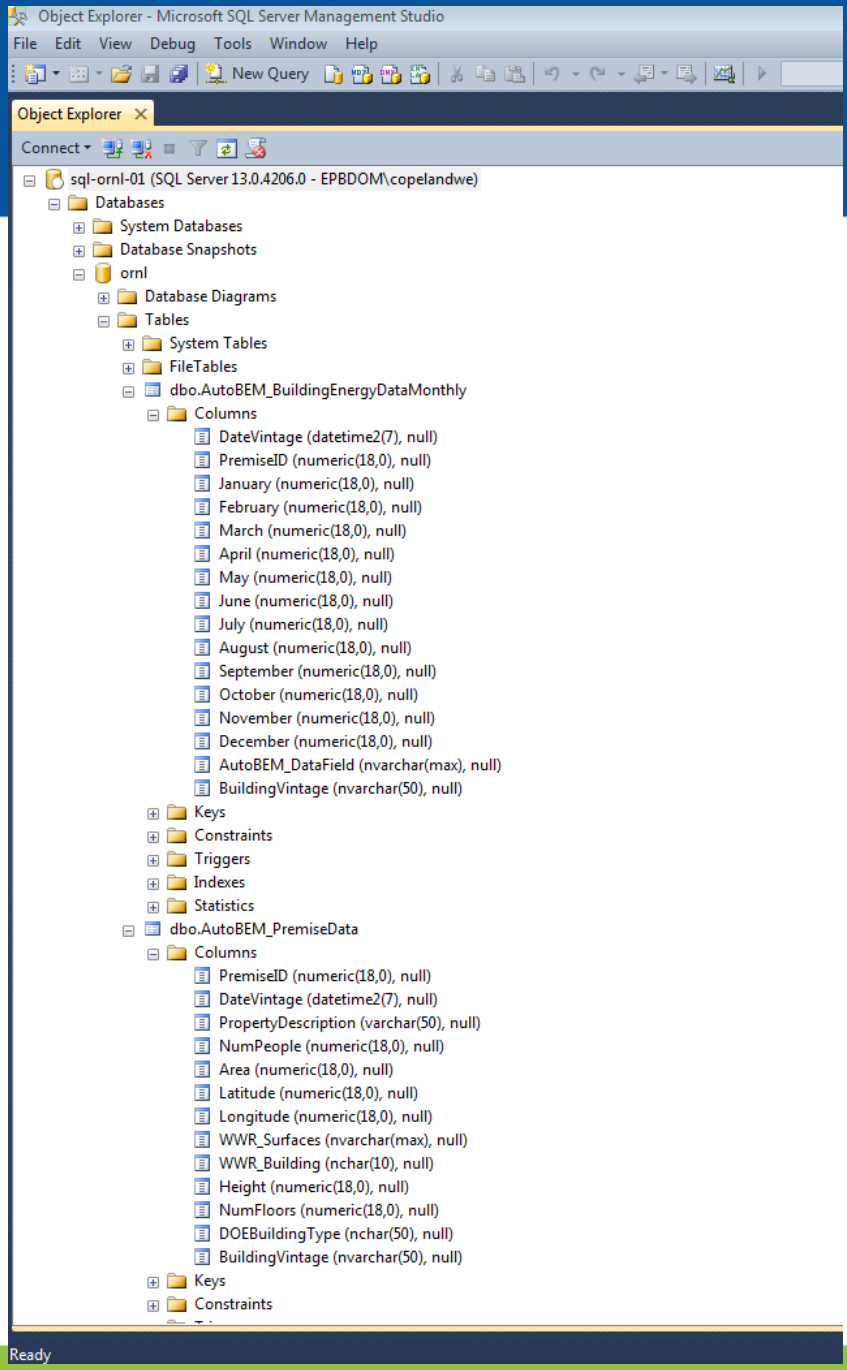
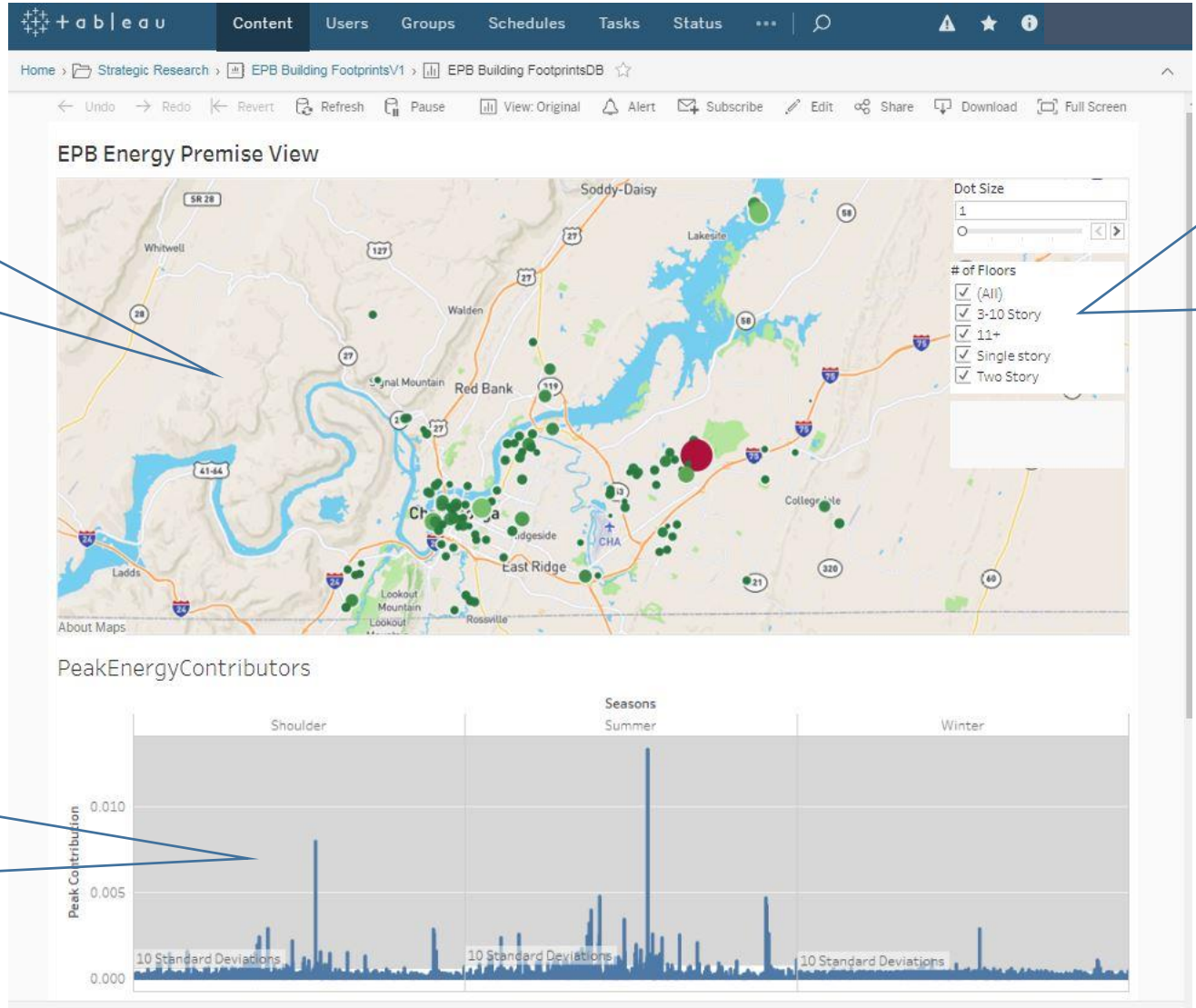


EPB's operational systems (original Dashboard)

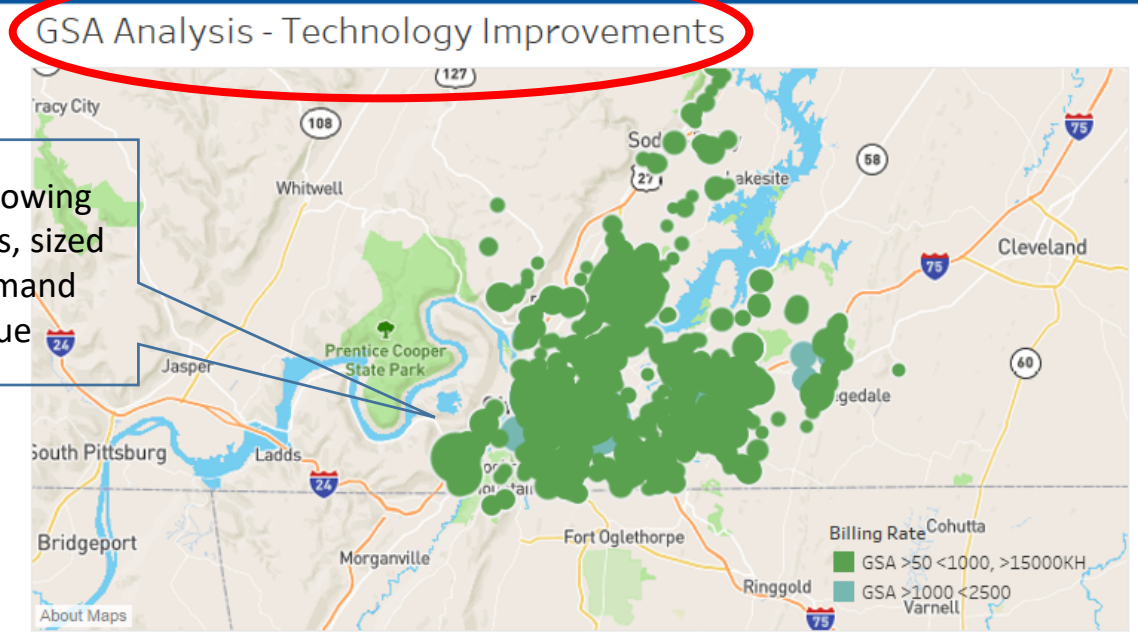
Map showing premises, colored by AutoBEM attribute



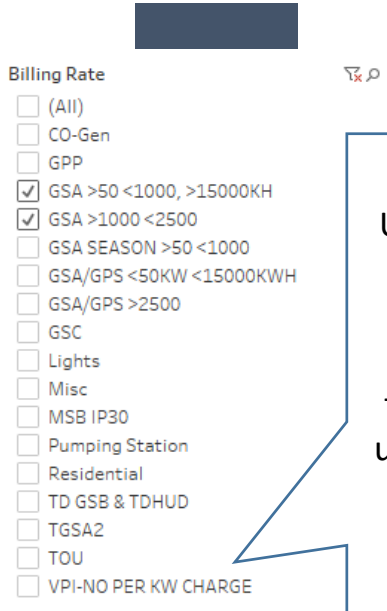
Use of filters create an interactive experience for business users, driving business decisions

Chart showing same data, in time series format

EPB's operational systems (New Dashboards)
Smart Thermostat Value



Map showing premises, sized by Demand Value



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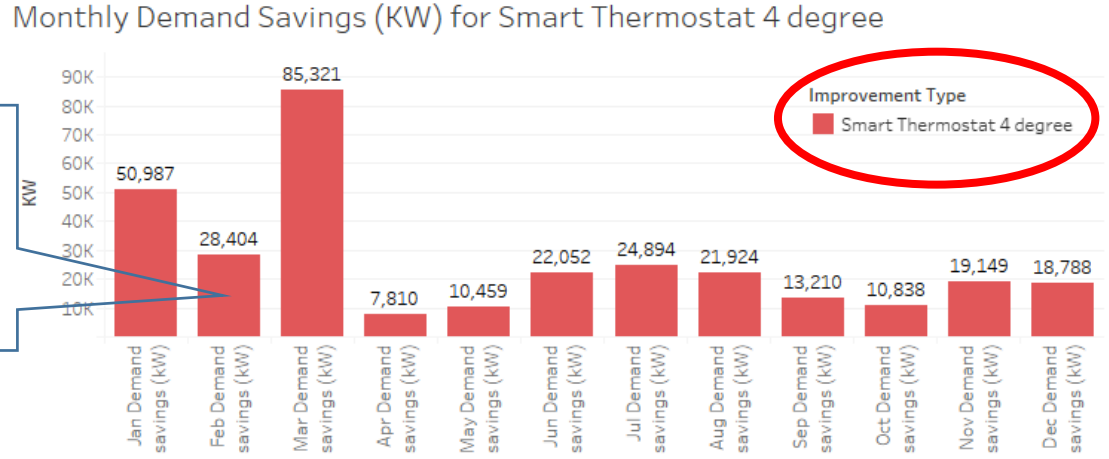
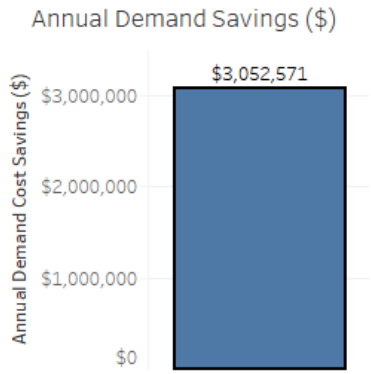
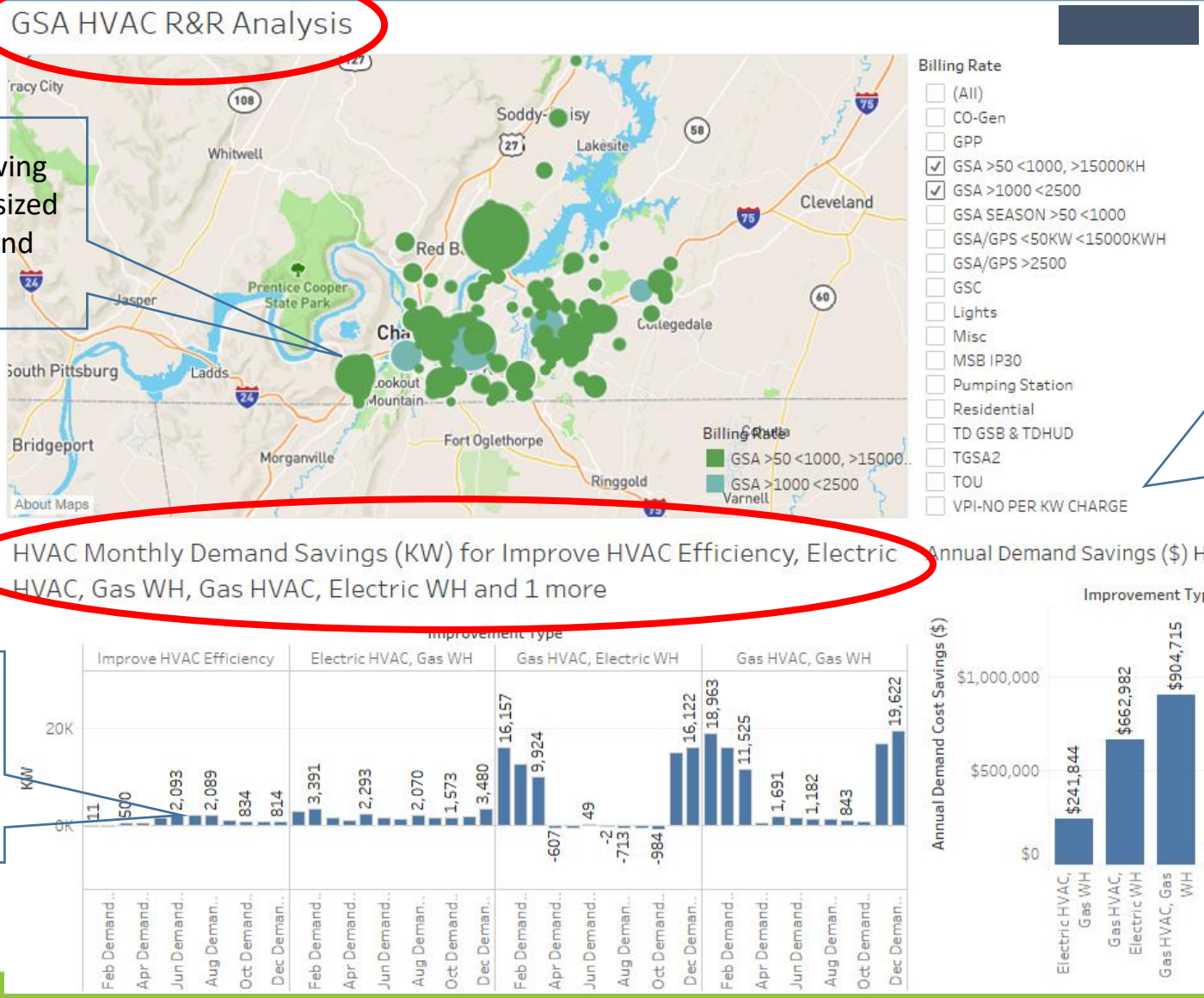


Chart showing monthly demand value



EPB's operational systems (New Dashboards)
HVAC Efficiency improvements



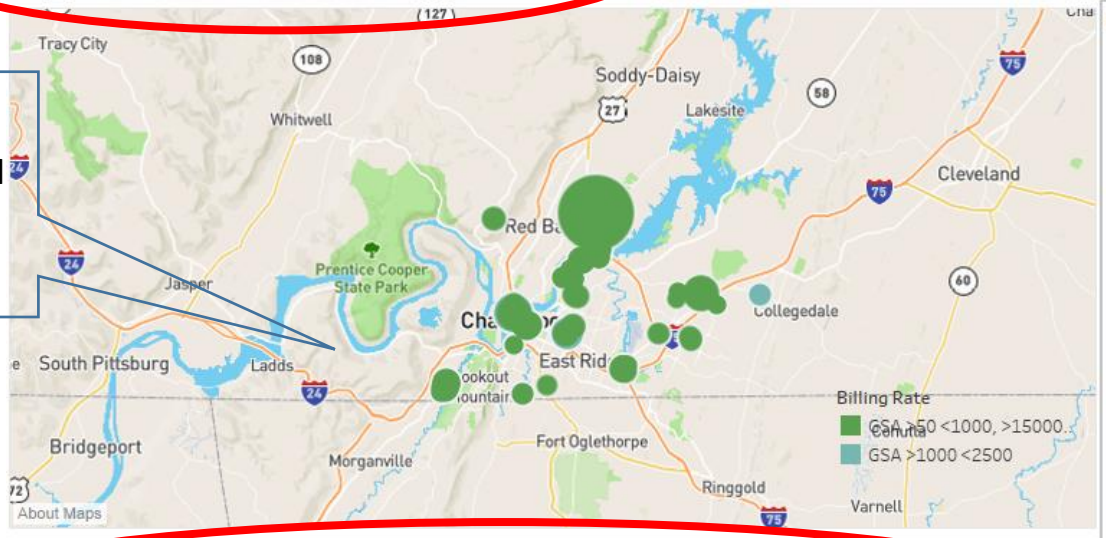
Map showing premises, sized by Demand Value

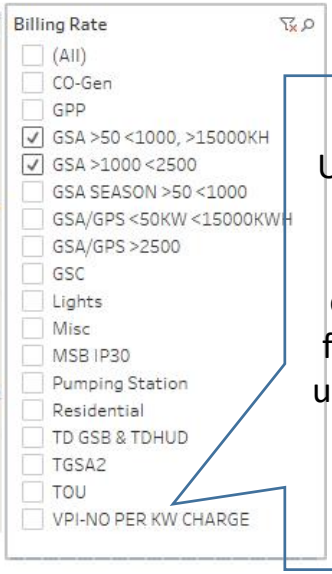
Use of filters create an interactive experience for business users, driving business decisions

Chart showing monthly demand value

EPB's operational systems (New Dashboards)
Structural Building Improvements

Map showing premises, sized by Demand Value

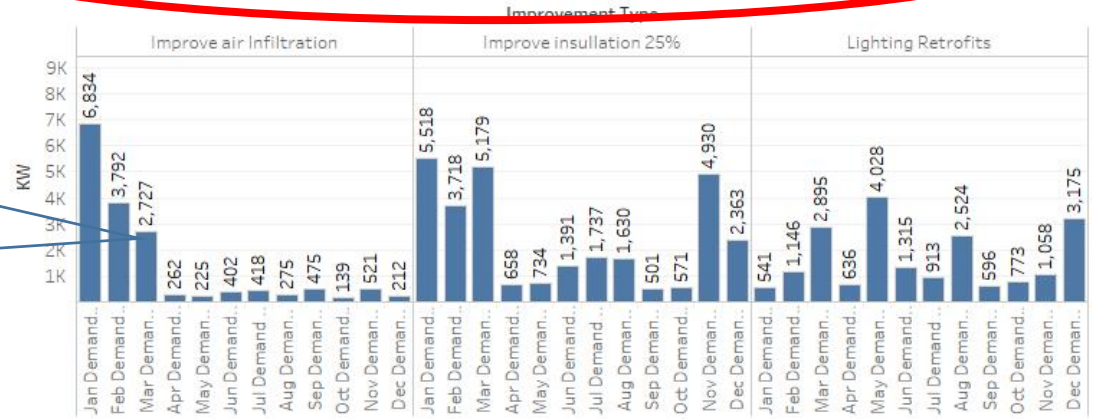




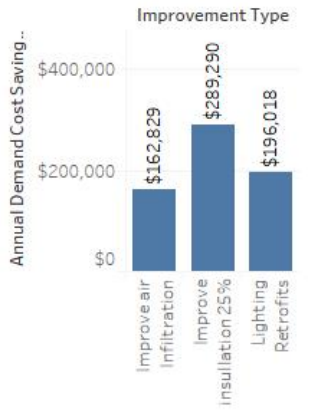
Use of filters create an interactive experience for business users, driving business decisions

Building Envelope Monthly Demand Savings (KW) for Improve air Infiltration
Improve insullation 25%, Lighting Retrofits

Chart showing monthly demand value



Annual Demand Savings ($) Envelope



EPB's operational systems
And of course downloadable crosstabs

GSA Analysis Tabluar for Smart Water Heater & Smart Thermostat 4 degree

Billing Rate	Building Id	Mail Addr Name	Service Address	Annual Demand Cost Savings ($)	SmartThermostat net cost
GSA >50 <1000, >15000KH	3195400000	ULTA	271 NORTHGATE MALL DR	$34,273	33,523
	2659310000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	$17,201	16,451
	1878960000	COVENANT TRANSPORT	400 BIRMINGHAM HWY	$14,271	12,771
	320240000	DIAGNOSTIC CENTER	2205 MCCALLIE AVE	$12,262	11,512
	1969670000	HOSPITAL CORPORATION ..	2205 MCCALLIE AVE	$12,262	11,512
	137290000	ADM MILLING COMPANY	1120 KING ST	$12,086	11,336
	137300000	CHATTANOOGA NEWS FR..	400 E 11TH ST	$12,086	11,336
	1739720000	TOP FLIGHT INC	1300 CENTRAL AVE	$9,328	7,828
	338530000	DOC-725 GLENWOOD DRI..	721 GLENWOOD DR	$9,263	8,513
	2609220000	UNIVERSITY OF TENNESS..	818 UNIVERSITY ST	$9,205	8,455
	2609240000	UNIVERSITY OF TENNESS..	818 UNIVERSITY ST	$9,205	8,455
	3003970000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	$9,118	
	3003980000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	$9,118	
	643650000	TALLAN PROPERTIES CO	100 W MARTIN LUTHER KI..	$8,907	
	50000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	60000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	260000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	620000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	1210000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	1480000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	3600000	TUESDAY MORNING INC	5600 BRAINERD RD	$8,298	
	3740000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	3790000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	3970000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	
	402390000	EAST NOOGA, LLC	5600 BRAINERD RD	$8,298	

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HVAC R&R Crosstab

Building Id	Mail Addr Name	Service Address	Billing Rate	Annual Demand Cost Savin..	SmartThermostat net cost
3195400000	ULTA	271 NORTHGATE MALL DR	GSA >50 <1000, >15000KH	$78,933	77,433
525460000	PARKRIDGE HOSPITAL	2333 MCCALLIE AVE	GSA >1000 <2500	$48,567	47,067
1878960000	COVENANT TRANSPORT	400 BIRMINGHAM HWY	GSA >50 <1000, >15000KH	$29,150	26,150
592780000	U S POST OFFICE	6050 SHALLOWFORD RD	GSA >1000 <2500	$20,417	18,917
338530000	DOC-725 GLENWOOD DRI..	721 GLENWOOD DR	GSA >50 <1000, >15000KH	$18,658	17,158
643650000	TALLAN PROPERTIES CO	100 W MARTIN LUTHER KI..	GSA >50 <1000, >15000KH	$18,508	17,008
794870000	STATE OF TENN	100 MOCCASIN BEND RD	GSA >1000 <2500	$16,150	14,650
1267210000	UNIV OF TN AT CHATT	540 MCCALLIE AVE	GSA >50 <1000, >15000KH	$15,440	13,940
1173520000	STEWARD ADVANCED MA..	1220 E 38TH ST	GSA >50 <1000, >15000KH	$15,384	13,884
2718230000	CHATTANOOGA HOTEL PR..	2321 LIFESTYLE WAY	GSA >50 <1000, >15000KH	$14,881	13,381
1626980000	TENNESSEE AQUARIUM	1 BROAD ST	GSA >50 <1000, >15000KH	$14,645	13,145
1969820000	U S XPRESS ENTERPRISE	4080 JENKINS RD	GSA >50 <1000, >15000KH	$14,057	12,557
40000	EAST NOOGA, LLC	5600 BRAINERD RD	GSA >50 <1000, >15000KH	$13,663	12,163
3800000	EAST NOOGA, LLC	5600 BRAINERD RD	GSA >50 <1000, >15000KH	$13,663	12,163
3810000	CHEROKEE HEALTH SYST..	5600 BRAINERD RD	GSA >50 <1000, >15000KH	$13,663	12,163
2460690000	KOCH FOODS LLC	1835 KERR ST	GSA >50 <1000, >15000KH	$11,644	10,144
643570000	A & D HOLDINGS GP	401 CHESTNUT ST	GSA >50 <1000, >15000KH	$11,599	10,099
2609660000	PUBLIX TENNESSEE LLC	5958 SNOW HILL RD	GSA >50 <1000, >15000KH	$11,474	9,974
1947100000	METALWORKING SOLUTI..	370 LABELING WAY	GSA >50 <1000, >15000KH	$10,842	9,342
2494720000	POWERTEL/MEMPHIS INC	6730 CUSTOMER DELIGH..	GSA >50 <1000, >15000KH	$10,733	9,233
592840000	STANDIFER PLACE LLC	2626 WALKER RD	GSA >50 <1000, >15000KH	$10,699	9,199
592860000	STANDIFER PLACE LLC	2626 WALKER RD	GSA >50 <1000, >15000KH	$10,505	9,005
1604830000	LIFETOUCH NATIONAL	6104 PRESERVATION DR	GSA >50 <1000, >15000KH	$9,233	7,733
2540990000	MILLER IND TOWING EQU..	8503 HILLTOP DR	GSA >1000 <2500	$9,119	7,619
854610000	CHATTANOOGA BAKERY I..	900 MANUFACTURERS RD	GSA >50 <1000, >15000KH	$9,070	6,070
1911010000	PUBLIX TENNESSEE LLC	8644 E BRAINERD RD	GSA >50 <1000, >15000KH	$8,711	7,211
1594890000	WAL-MART STORES EAST ..	2020 GUNBARREL RD	GSA >50 <1000, >15000KH	$8,226	6,726
1054560000	SILVER TREE SENIOR APT..	5465 HIGHWAY 58	GSA >50 <1000, >15000KH	$8,142	6,642
1520850000	FOOD LION, LLC	4338 RINGGOLD RD	GSA >50 <1000, >15000KH	$7,617	6,117
2623260000	JARNIGAN ROAD III LLC	2034 HAMILTON PLACE B	GSA >50 <1000, >15000KH	$7,405	5,905

Building Envelope Crosstab

Building Id	Mail Addr Name	Service Address	Billing Rate		
3195400000	ULTA	271 NORTHGATE MALL DR	GSA >50 <1000, >150		
3003970000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	GSA >50 <1000, >150		
3003980000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	GSA >50 <1000, >150		
2659340000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
2659300000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
2659330000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
2659350000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
2659310000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >50 <1000, >150		
2659280000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
2659320000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500		
525460000	PARKRIDGE HOSPITAL	2333 MCCALLIE AVE	GSA >1000 <2500	$3,257	2,132
137290000	ADM MILLING COMPANY	1120 KING ST	GSA >50 <1000, >15000KH	$2,714	1,589

The devil is in the data details (as usual)
Golden Opportunity for M&V activities

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3800000	EAST NOOGA, LLC	5600 BRAINERD RD	GSA >50 <1000, >15000KH	$13,663	12,163
3810000	CHEROKEE HEALTH SYST..	5600 BRAINERD RD	GSA >50 <1000, >15000KH	$13,663	12,163
2460690000	KOCH FOODS LLC	1835 KERR ST	GSA >50 <1000, >15000KH	$11,644	10,144
643570000	A & D HOLDINGS GP	401 CHESTNUT ST	GSA >50 <1000, >15000KH	$11,599	10,099
2609660000	PUBLIX TENNESSEE LLC	5958 SNOW HILL RD	GSA >50 <1000, >15000KH	$11,474	9,974
1947100000	METALWORKING SOLUTI..	370 LABELING WAY	GSA >50 <1000, >15000KH	$10,842	9,342
2494720000	POWERTEL/MEMPHIS INC	6730 CUSTOMER DELIGH..	GSA >50 <1000, >15000KH	$10,733	9,233
592840000	STANDIFER PLACE LLC	2626 WALKER RD	GSA >50 <1000, >15000KH	$10,699	9,199
592860000	STANDIFER PLACE LLC	2626 WALKER RD	GSA >50 <1000, >15000KH	$10,505	9,005
1604830000	LIFETOUCH NATIONAL	6104 PRESERVATION DR	GSA >50 <1000, >15000KH	$9,233	7,733
2540990000	MILLER IND TOWING EQU..	8503 HILLTOP DR	GSA >1000 <2500	$9,119	7,619
854610000	CHATTANOOGA BAKERY I..	900 MANUFACTURERS RD	GSA >50 <1000, >15000KH	$9,070	6,070
1911010000	PUBLIX TENNESSEE LLC	8644 E BRAINERD RD	GSA >50 <1000, >15000KH	$8,711	7,211
1594890000	WAL-MART STORES EAST ..	2020 GUNBARREL RD	GSA >50 <1000, >15000KH	$8,226	6,726
1054560000	SILVER TREE SENIOR APT..	5465 HIGHWAY 58	GSA >50 <1000, >15000KH	$8,142	6,642
1520850000	FOOD LION, LLC	4338 RINGGOLD RD	GSA >50 <1000, >15000KH	$7,617	6,117
2623260000	JARNIGAN ROAD III LLC	2034 HAMILTON PLACE B	GSA >50 <1000, >15000KH	$7,405	5,905

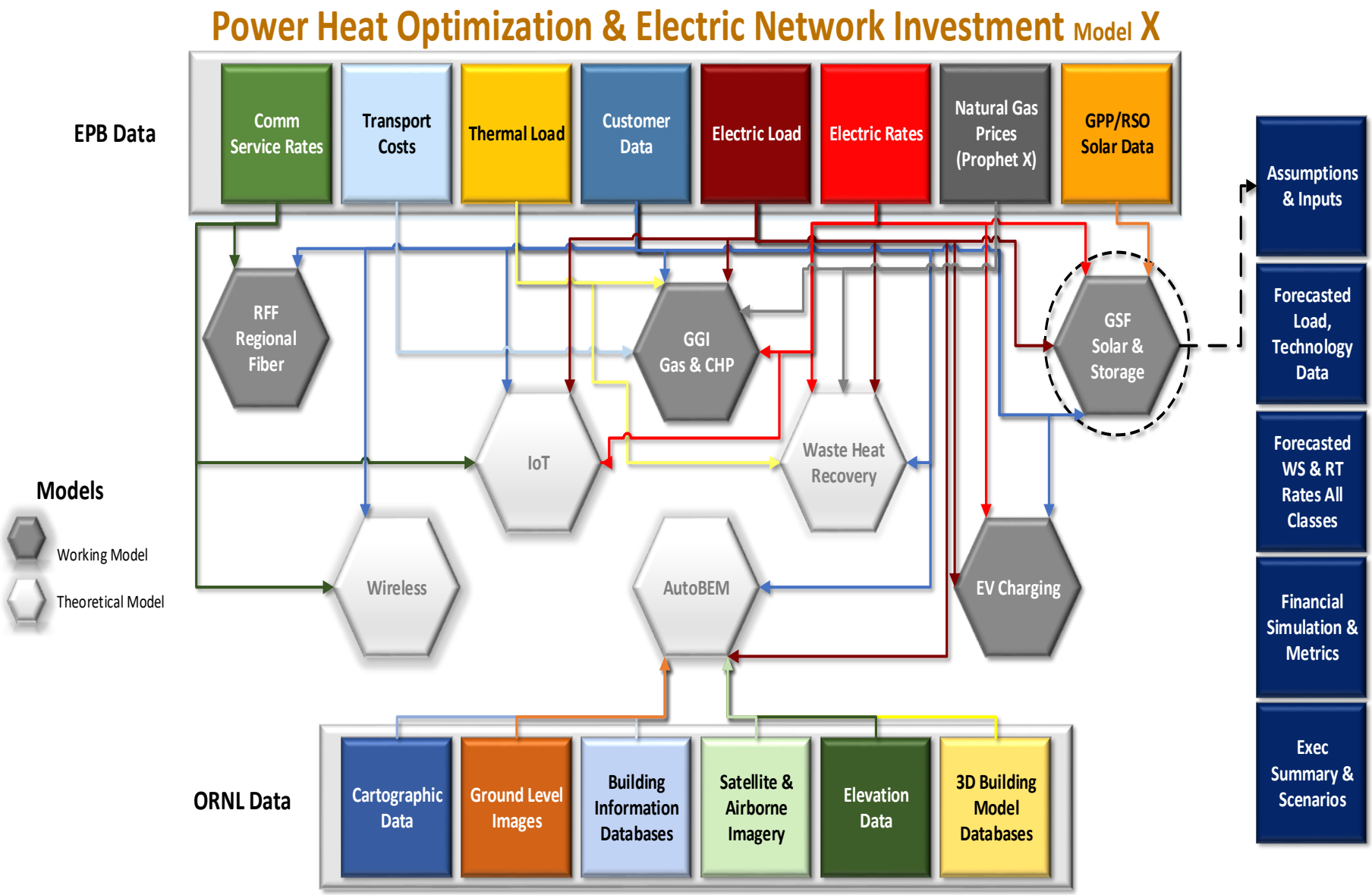
Building Envelope Crosstab

Building Id	Mail Addr Name	Service Address	Billing Rate
3195400000	ULTA	271 NORTHGATE MALL DR	GSA >50 <1000, >150
3003970000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	GSA >50 <1000, >150
3003980000	AMAZON.COM SERVICES I..	7200 VOLKSWAGEN DR	GSA >50 <1000, >150
2659340000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
2659300000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
2659330000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
2659350000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
2659310000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >50 <1000, >150
2659280000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
2659320000	BLUE CROSS BLUE SHIELD..	1 CAMERON HILL CIR	GSA >1000 <2500
525460000	PARKRIDGE HOSPITAL	2333 MCCALLIE AVE	GSA >1000 <2500
137290000	ADM MILLING COMPANY	1120 KING ST	GSA >50 <1000, >15000KH

$3,257	2,132
$2,714	1,589

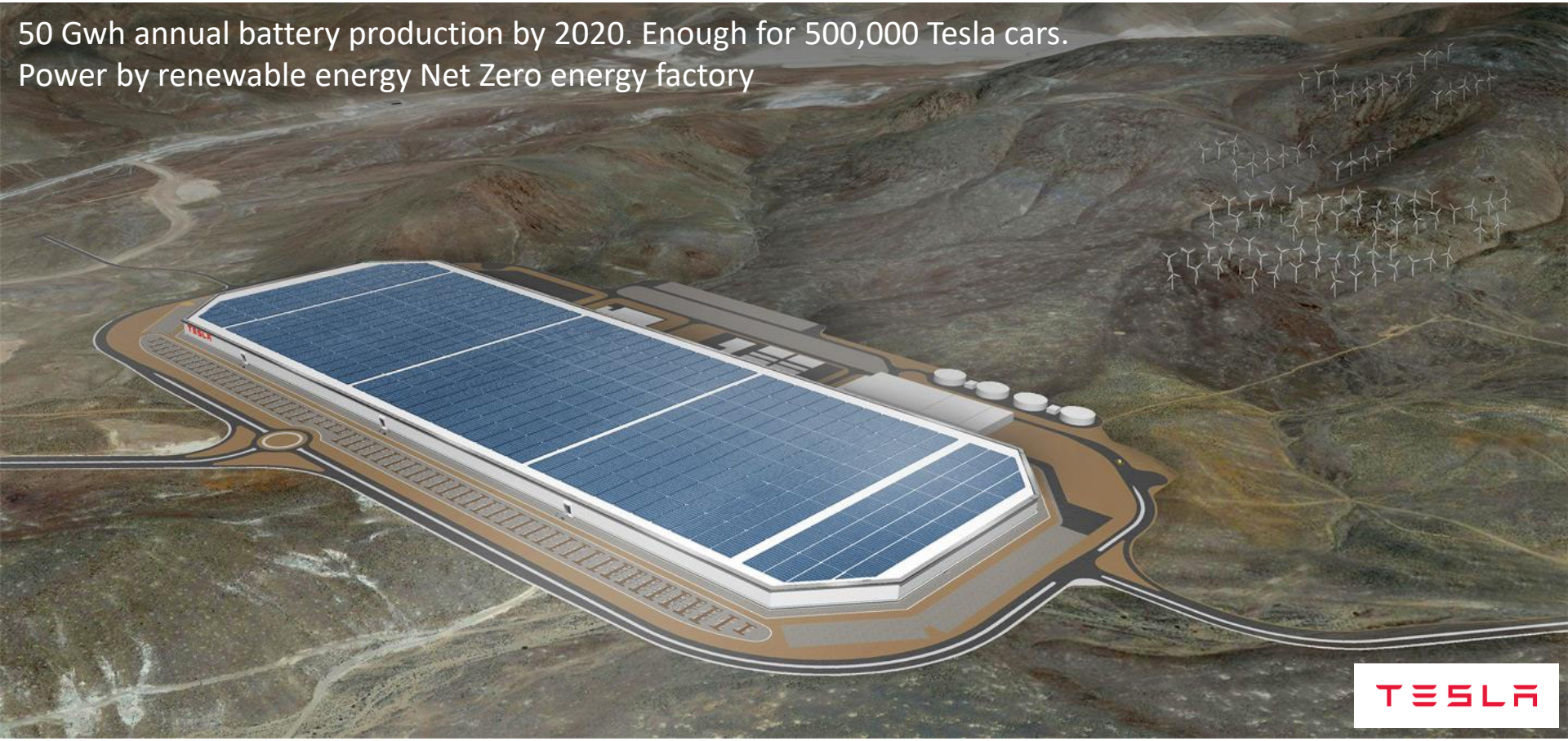
Strategic Research

AUTOBEM Integrated With EPB Appliance Models



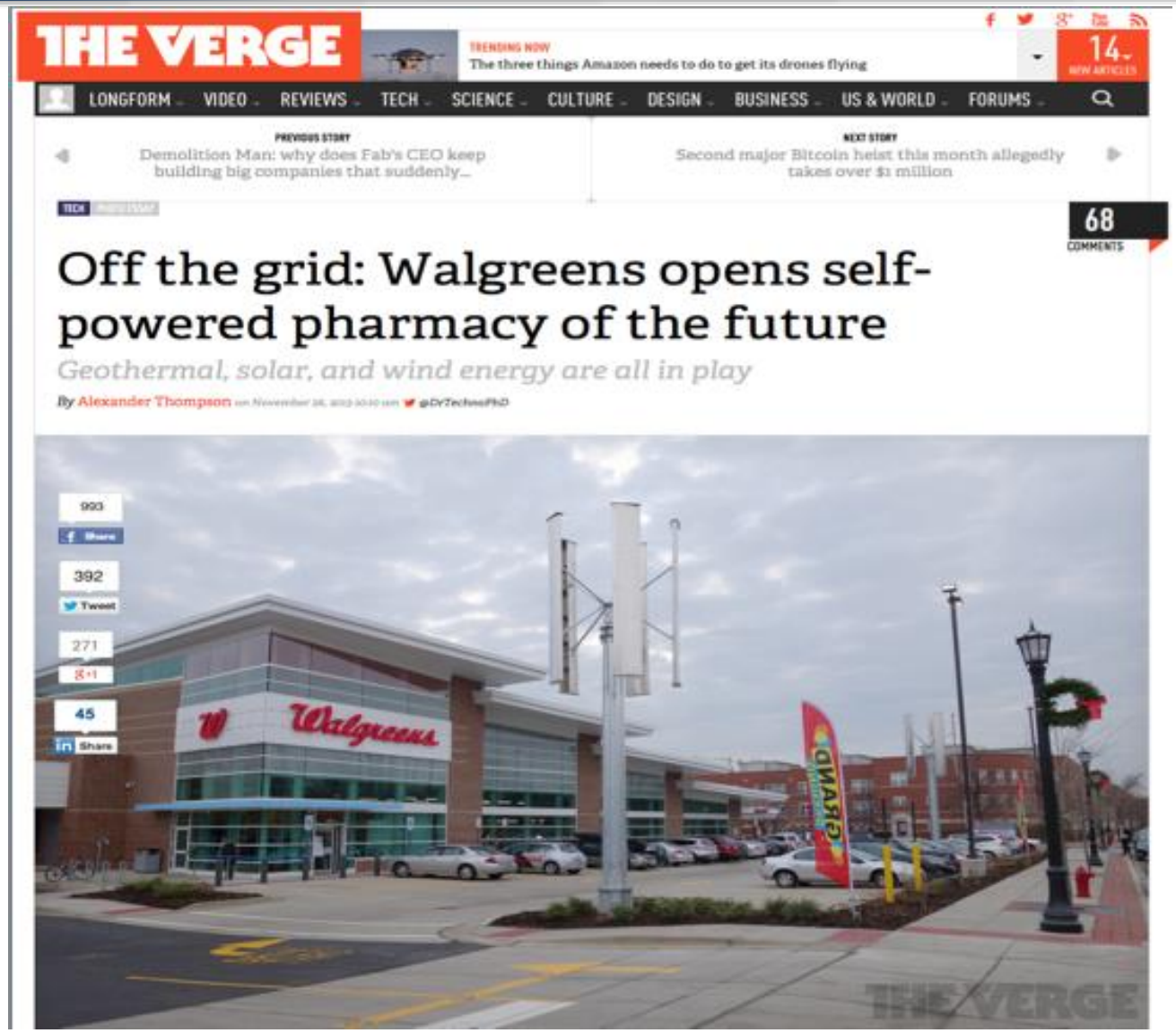
Strategic Research

The New Industrial Customer



Strategic Research

New Business Models Emerging



New Commercial Customers Rising

Open 2013
Awards 2014
No FB Post 2015

Commercial Customer Net-Zero That Works

OATI Microgrid Technology Center

Strategic Research

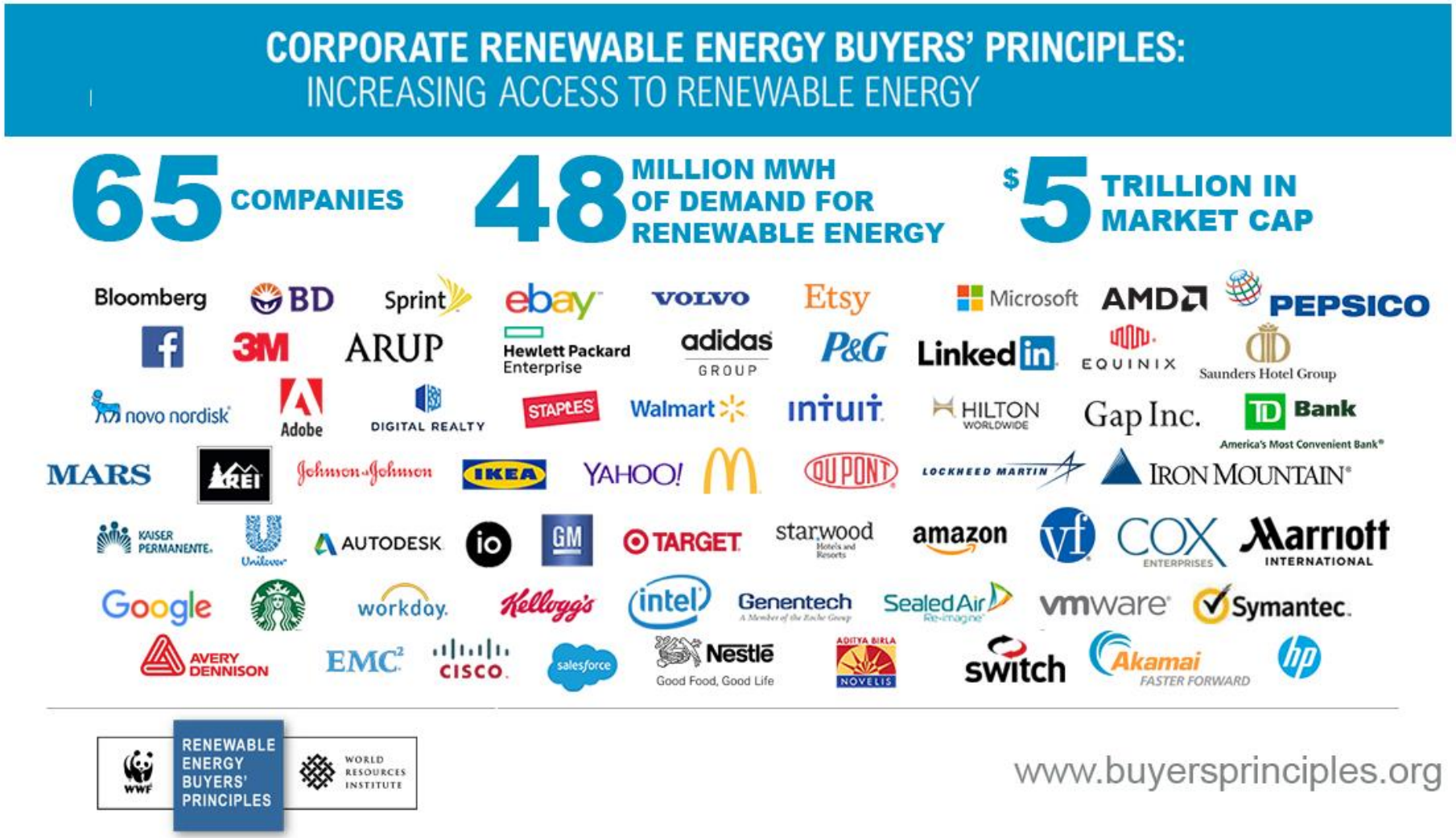
Residential Customer November 2016 Surprise

Why Tesla's new solar roof tiles and home battery are such a big deal

New Residential Customers Rising

Strategic Research

The The Fortune 500 Is All In - Customer Demand



epb
Strategic Research

Some Partner With The Electric Company

amazon

Dominion Energy℠

Strategic Research

Some Do It On Their Own

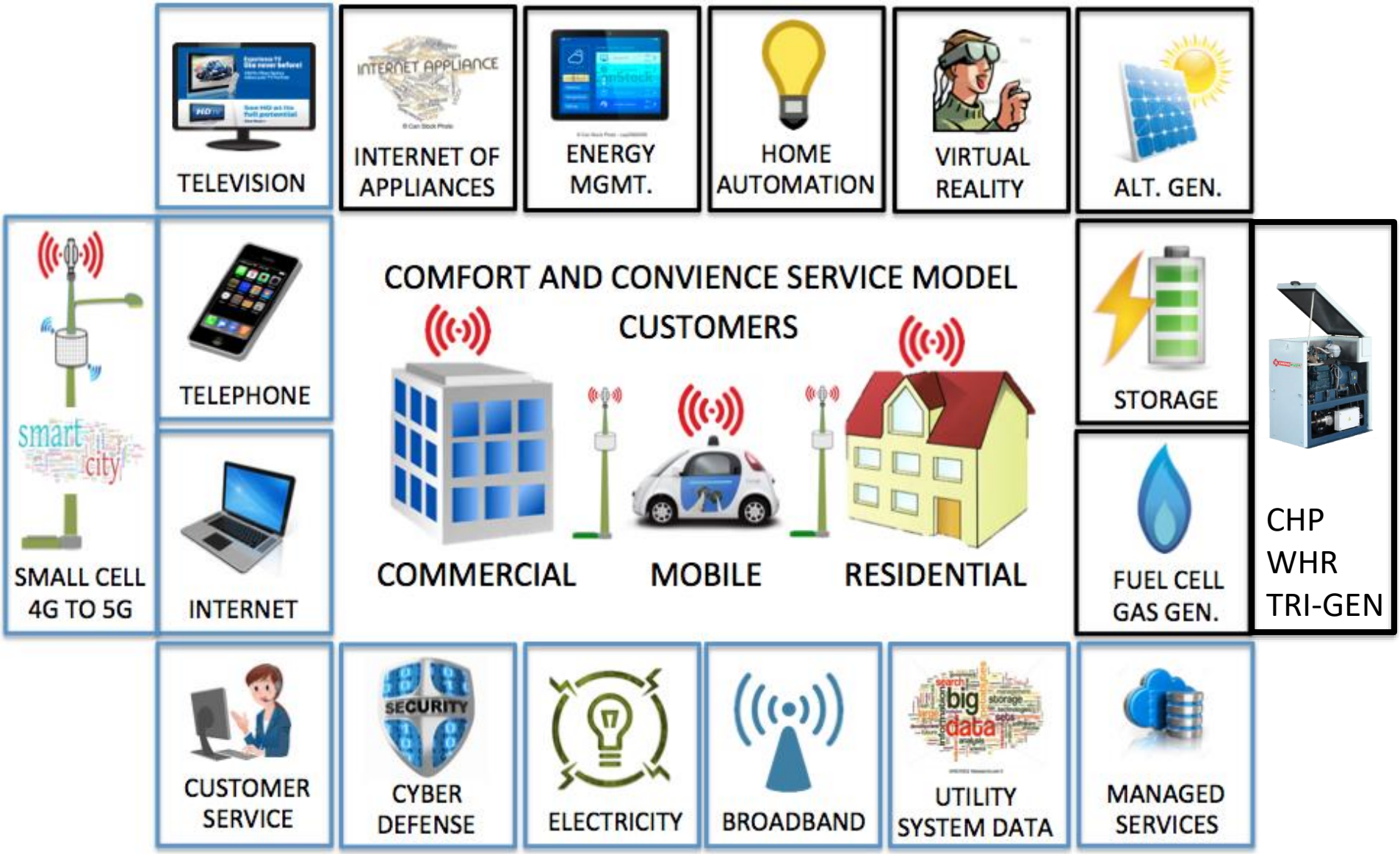
SIGNAL ENERGY®
CONSTRUCTORS

WE HARNESS CREATIVE ENERGY

epb Strategic Research

Or Hire An Energy Service Company

THE UTILITY OF THE FUTURE AT THE CUSTOMER PREMISE

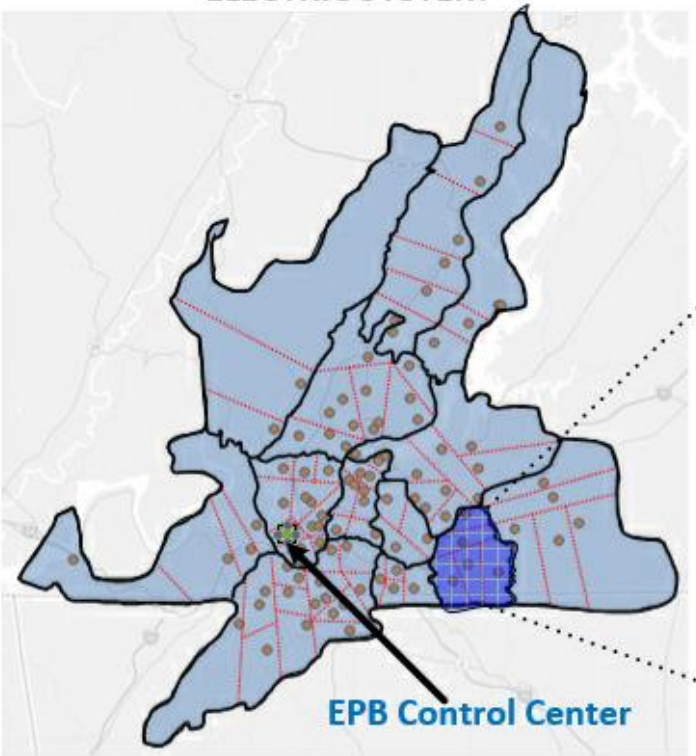


Strategic Research

Control and Manage Load Factor Is The Key

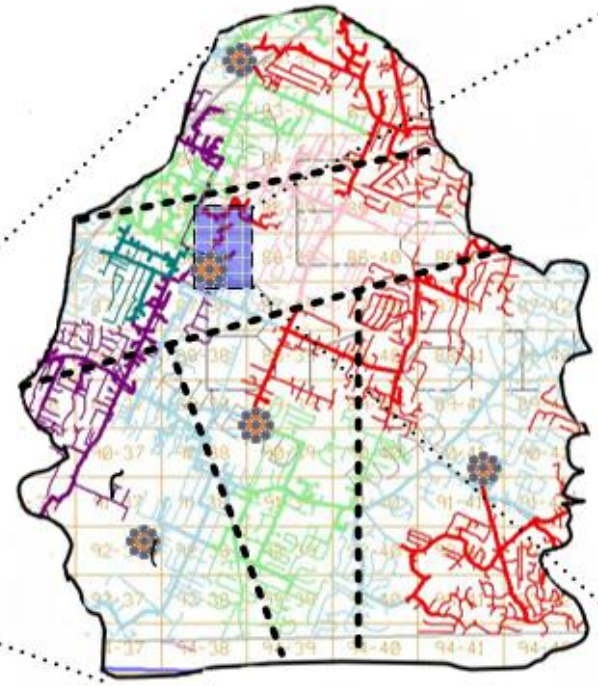
AUTOBEM = MANAGE LOAD FACTOR

ELECTRIC SYSTEM



111 SUBSTATIONS
336 FEEDERS
166,000 BUILDINGS

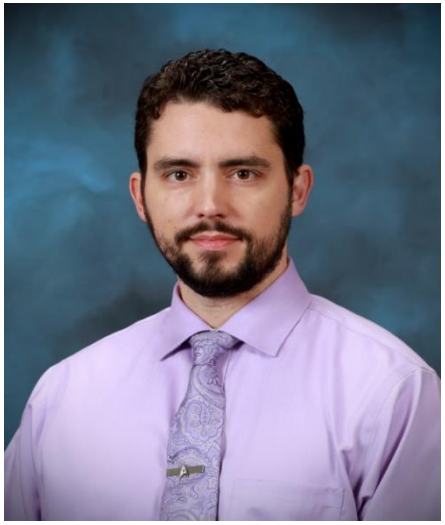
CIRCUITS



MICROGRID
UTILITY SCALE
GENERATION/STORAGE/
ENERGY EFFICIENCY

CUSTOMER

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 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.
  - 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

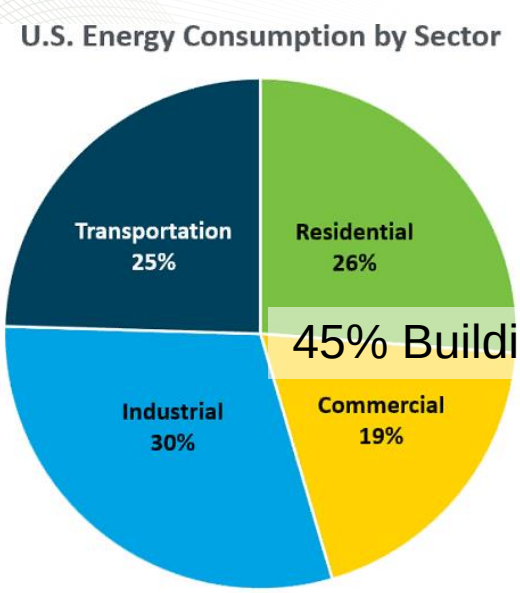
Certifications

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

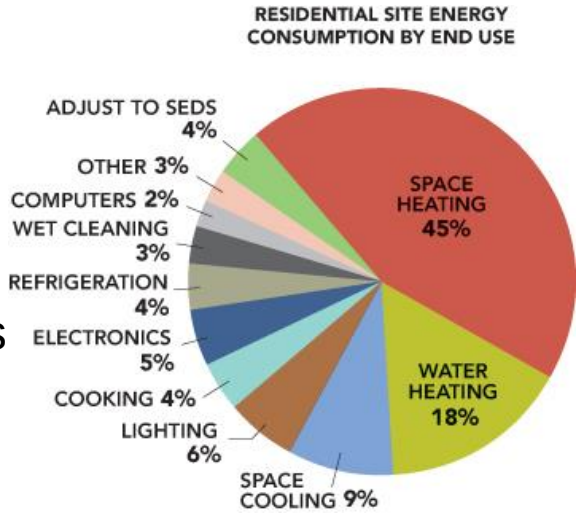
Artificial Intelligence

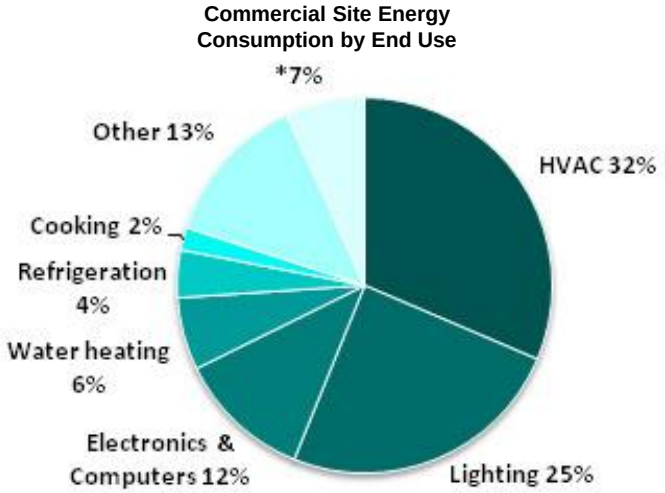
- President's National S&T Council's Machine Learning and Artificial Intelligence Subcommittee's Artificial Intelligence Consortium

Energy Consumption and Production



45% Buildings





Buildings consume 73% of the nation's electricity

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

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

ASHRAE Climate Zones

- Based on weather stations, most w/ 18+ yrs of quality data (1961-1990)

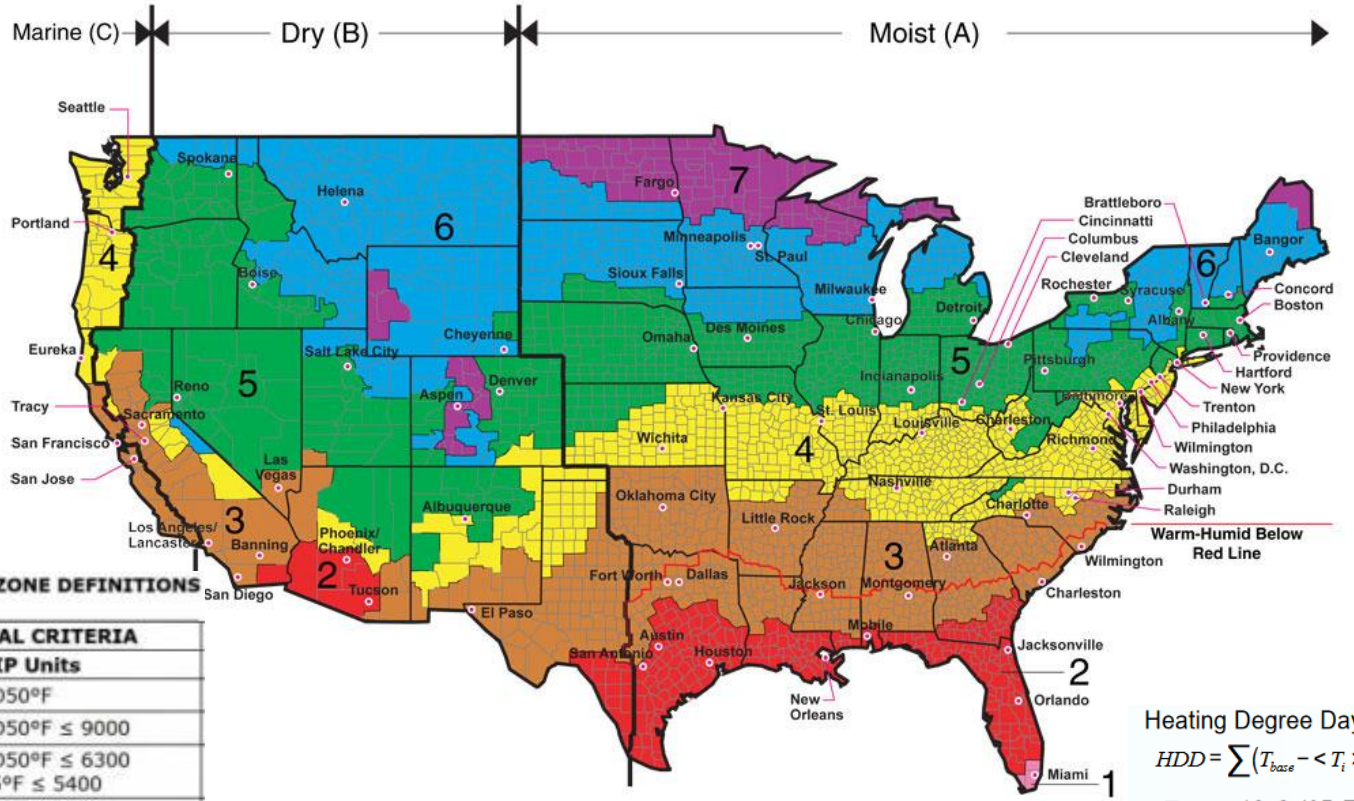


TABLE 301.3(2) INTERNATIONAL CLIMATE ZONE DEFINITIONS

ZONE NUMBER	THERMAL CRITERIA IP Units
1	9000 < CDD50°F
2	6300 < CDD50°F ≤ 9000
3A and 3B	4500 < CDD50°F ≤ 6300 AND HDD65°F ≤ 5400
4A and 4B	CDD50°F ≤ 4500 AND HDD65°F ≤ 5400
3C	HDD65°F ≤ 3600
4C	3600 < HDD65°F ≤ 5400
5	5400 < HDD65°F ≤ 7200
6	7200 < HDD65°F ≤ 9000
7	9000 < HDD65°F ≤ 12600
8	12600 < HDD65°F

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

Heating Degree Days:

$$HDD = \sum (T_{base} - < T_i >)^+$$

T_{base} = 18°C (65°F)

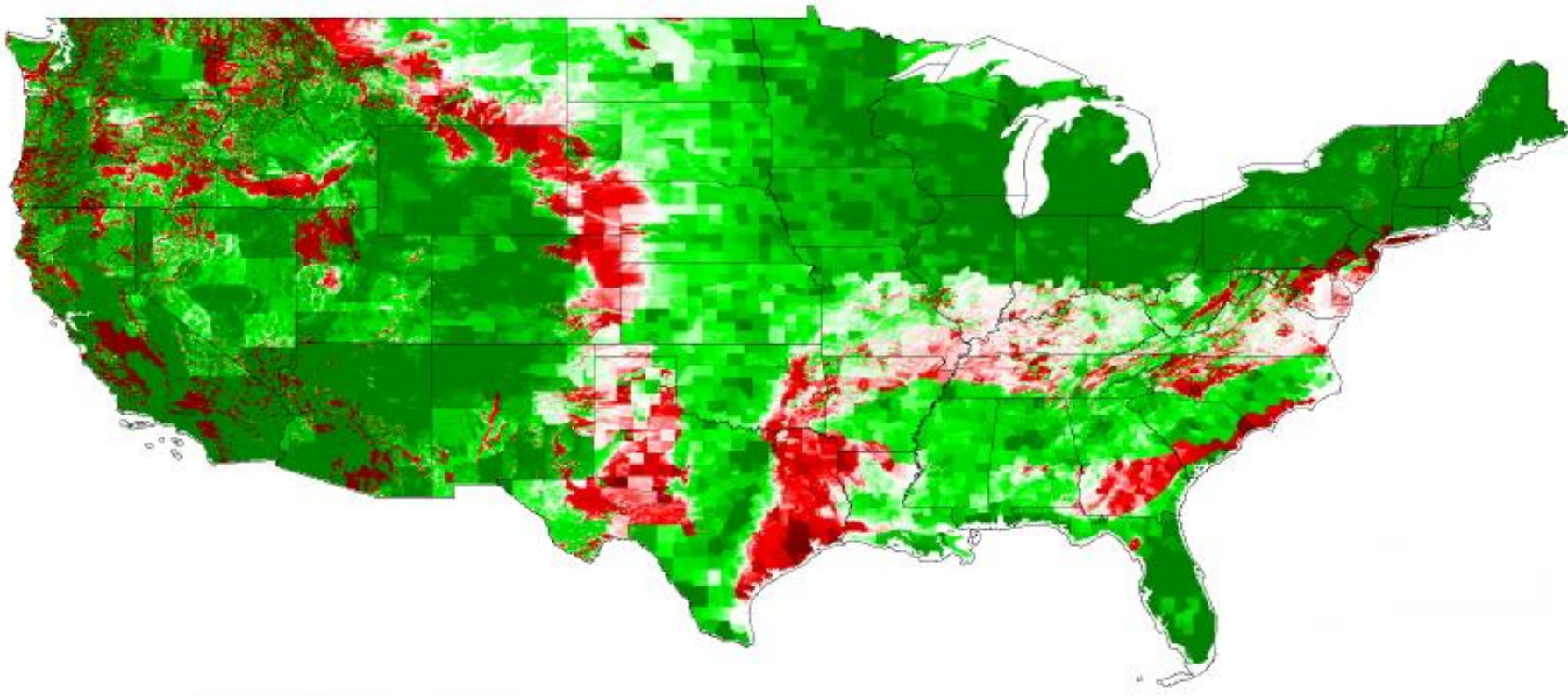
Cooling Degree Days:

$$CDD = \sum (< T_i > - T_{base})^+$$

T_{base} = 10°C (50°F)

Building-adjusted CZ improvement

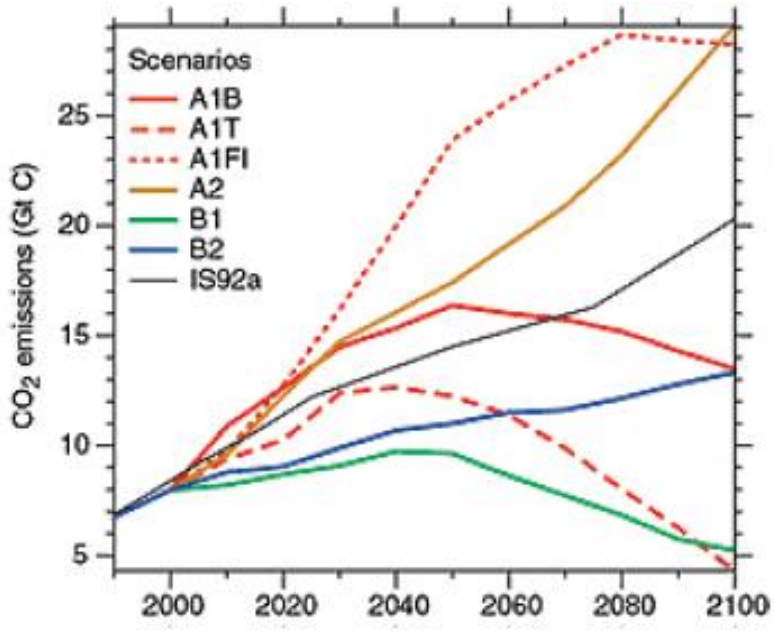
- What other (e.g. political) variables should be included?
- How could the nation's energy security and critical infrastructure resiliency be improved by incorporating future scenarios into the built environment?
- **How much energy and $ could be saved by having a forward-looking climate-aware building code?**

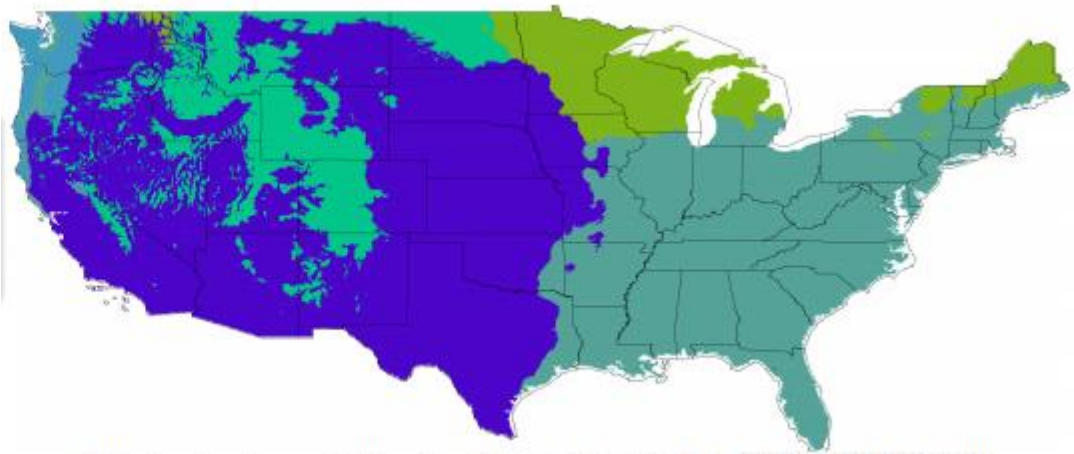


Climate Change Impacts

Contemporary Period

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





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

Building Energy Modeling

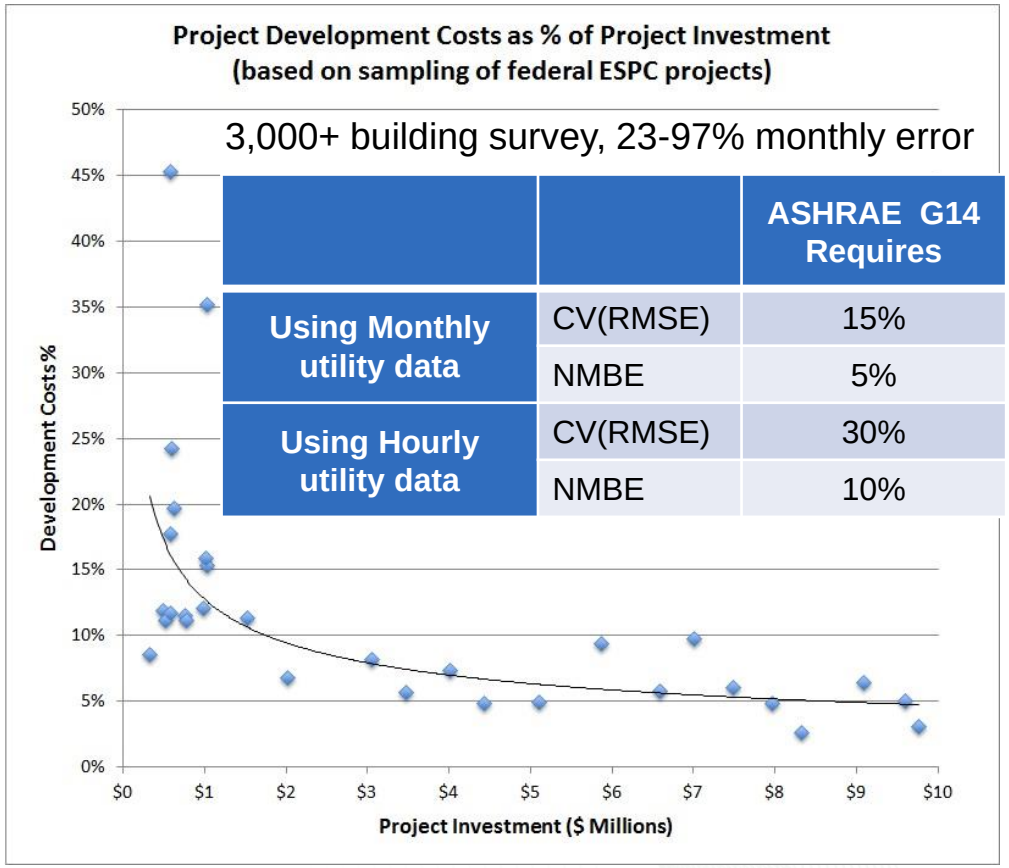
Optimal Return on Investment (for building energy savings)

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

EnergyPlus

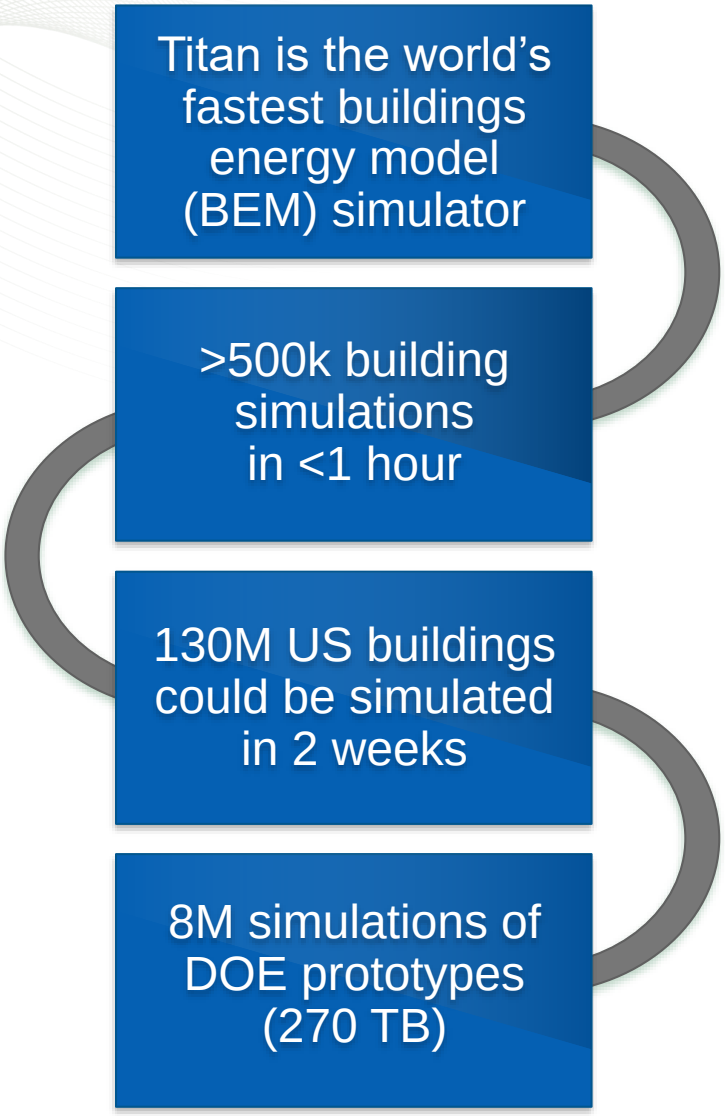
OpenStudio

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



		ASHRAE G14 Requires
Using Monthly utility data	CV(RMSE)	15%
	NMBE	5%
Using Hourly utility data	CV(RMSE)	30%
	NMBE	10%

HPC scalability for desktop software



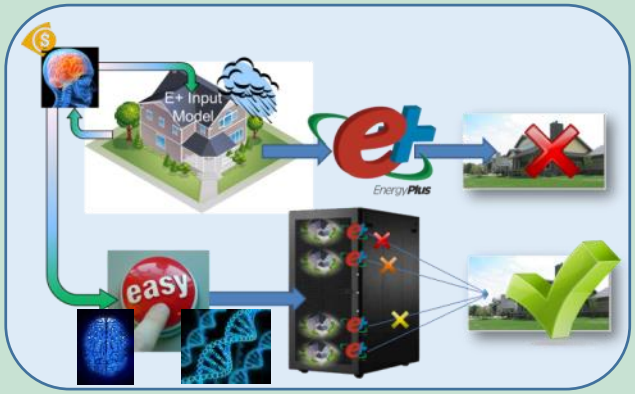
CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
16	18:14	5 GB	64
32	18:19	11 GB	128
64	18:34	22 GB	256
128	18:22	44 GB	512
256	20:30	88 GB	1,024
512	20:43	176 GB	2,048
1,024	21:03	351 GB	4,096
2,048	21:11	703 GB	8,192
4,096	20:00	1.4 TB	16,384
8,192	26:14	2.8 TB	32,768
16,384	26:11	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

Calibration Performance – automated M&V

National HPC Resources → **Applied Research** → **Industry and building owners**

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:
  `http://bit.ly/autotune_science`
- Open source (GitHub):
  `http://bit.ly/autotune_code`

Results

		ASHRAE G14 Requires	Autotune Results
Monthly utility data	CVR	15%	1.20%
	NMBE	5%	0.35%
Hourly utility data	CVR	30%	3.65%
	NMBE	10%	0.35%

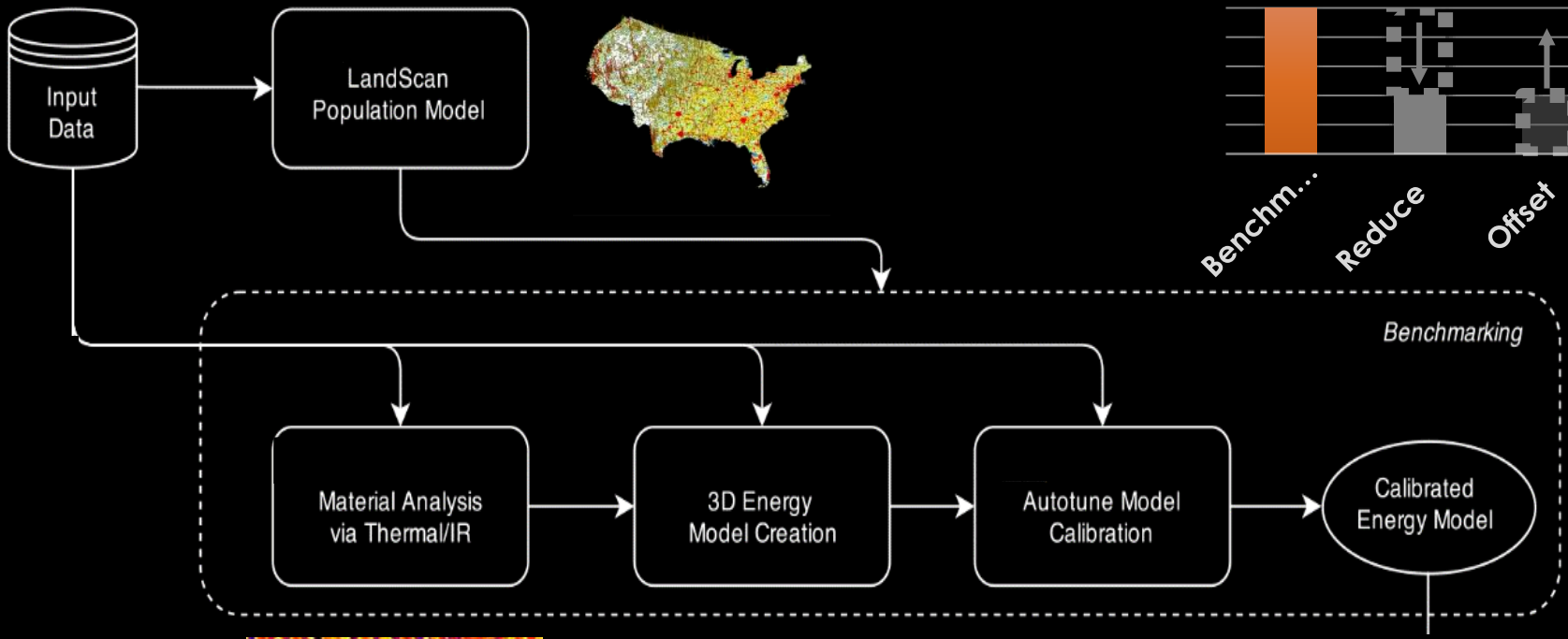
Results of 20,000+ Autotune calibrations
(15 types, 47-282 tuned inputs each)

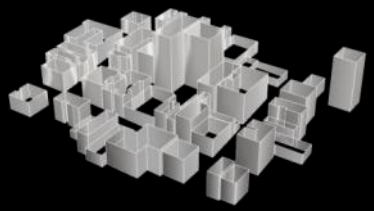
Other error metrics

Residential home	Tuned input avg. error
Within 30¢/day (actual use $4.97/day)	Hourly – 8% Monthly – 15% 3 bldgs, 8-79 inputs

Leveraging HPC resources to calibrate models for optimized building efficiency decisions

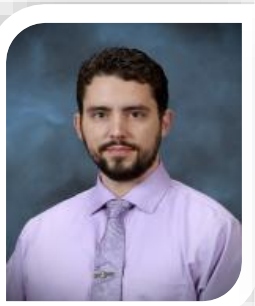
Model America 2020 – BEM for every U.S. building





Acknowledgements

- U.S. Department of Energy
- National Nuclear Security Administration
- Oak Ridge National Laboratory
- Building Technologies Office
- Office of Electricity

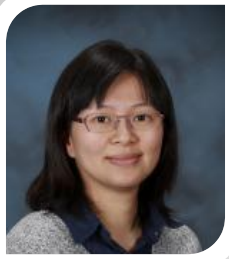










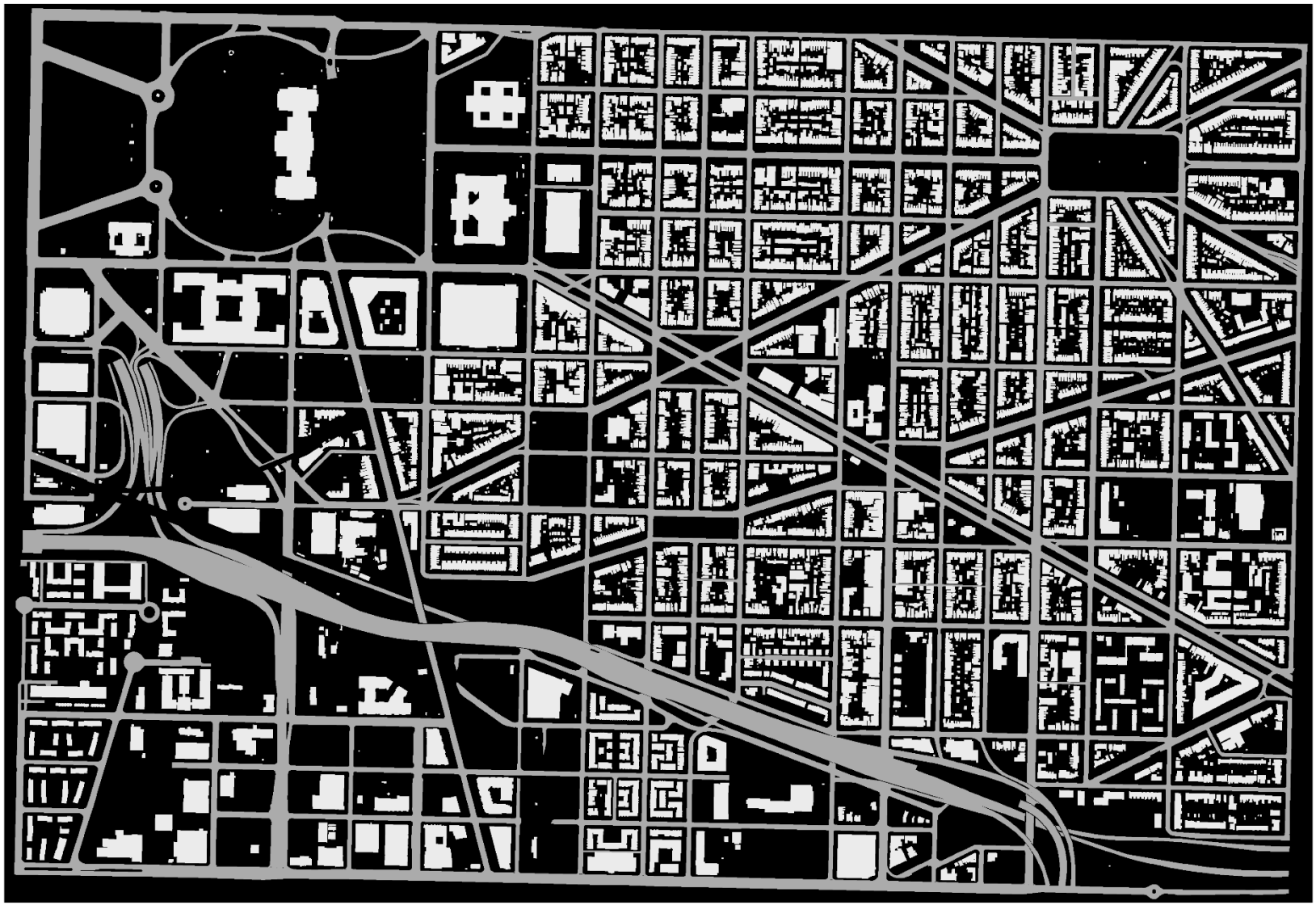



Data Sources

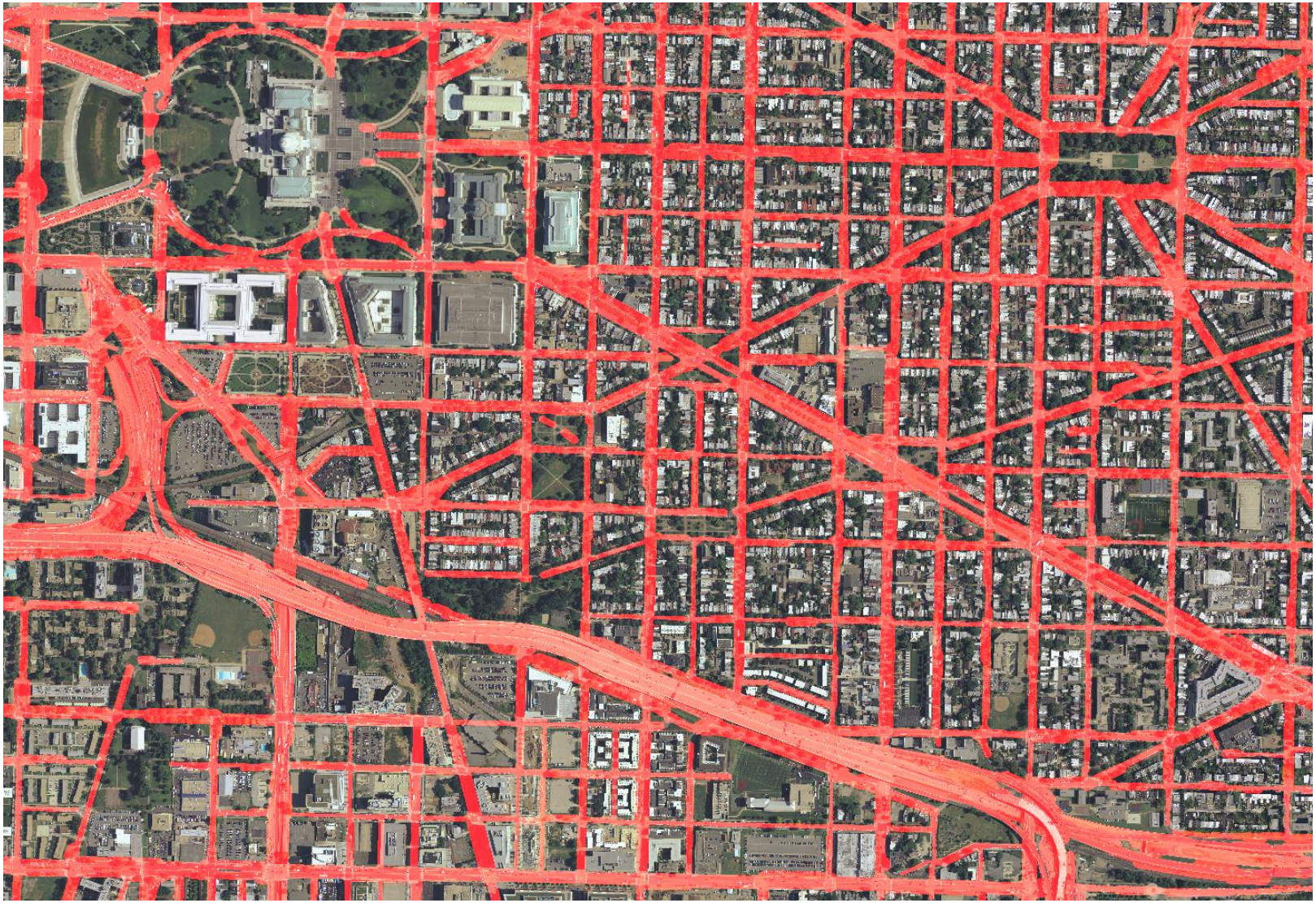
- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

	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

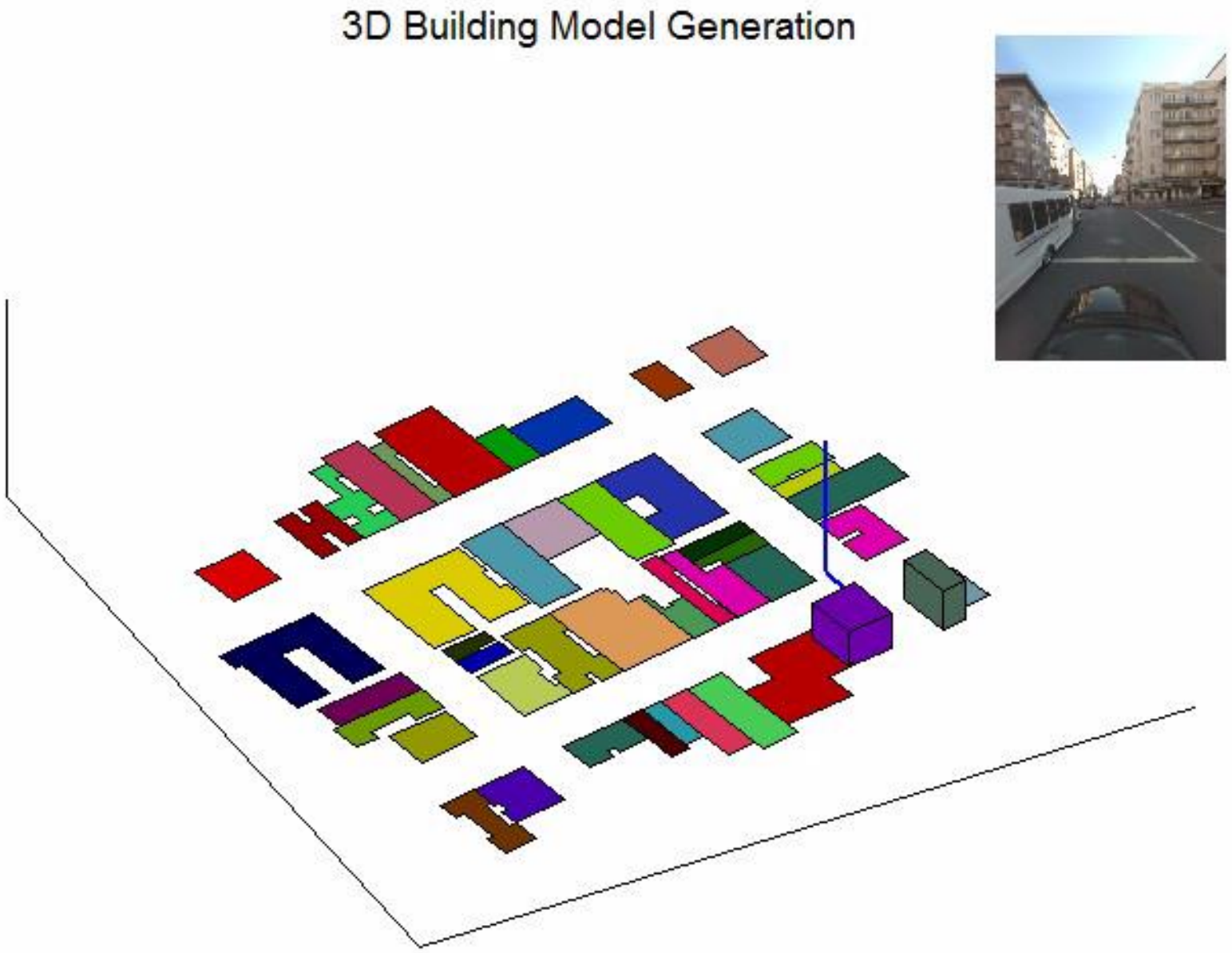


Automatic Building Footprint Extraction

Algorithm: Deep Learning extended and using GPUs for fast building footprint and area extraction over large geographical areas.

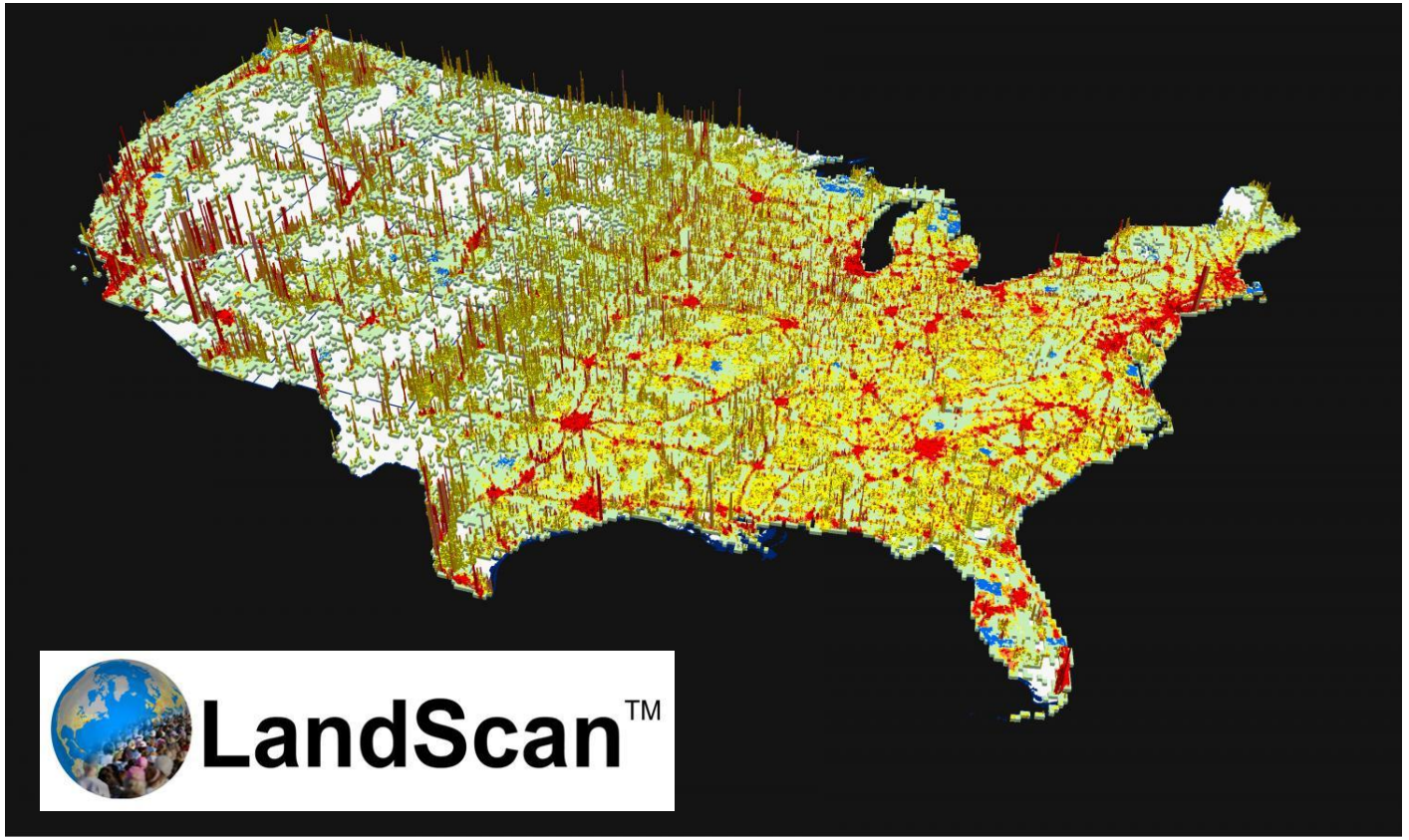
Multi-company Competition Precision/Recall – 30/35; Current Precision/Recall – 60+/60+

Processing Street-Level Imagery – Jiangye Yuan



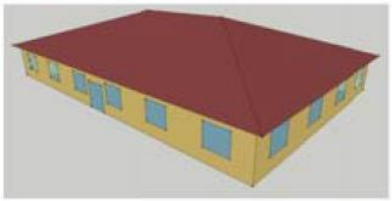
LandScan USA – Amy Rose

- 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

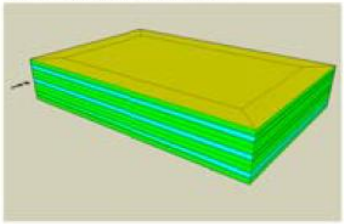


Prototype Buildings

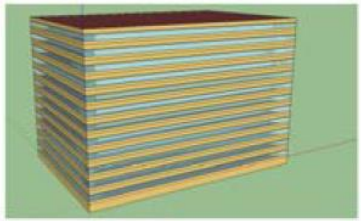
Small Office



Medium Office

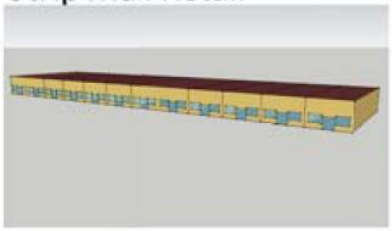


Large Office

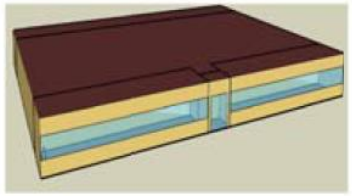


Warehouse

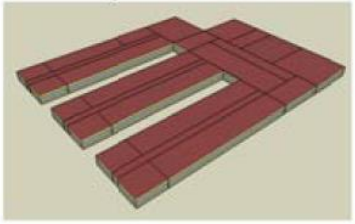
Strip Mall Retail



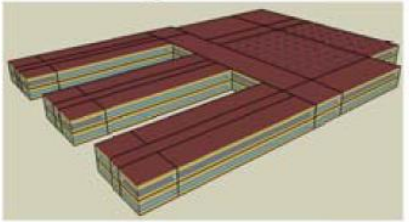
Standalone Retail



Primary School

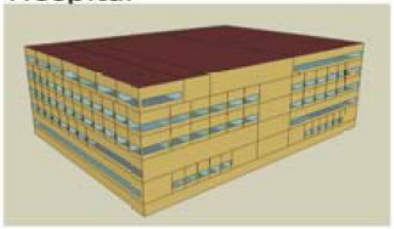


Secondary School



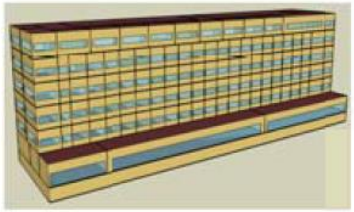
Outpatient Healthcare

Hospital

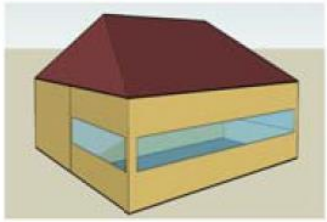


Small Hotel

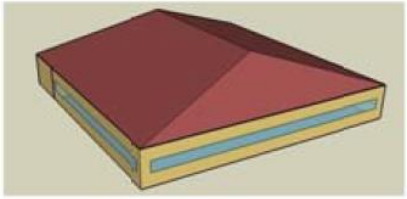
Large Hotel



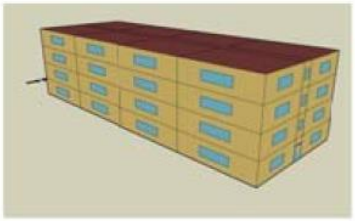
Quick-service Restaurant



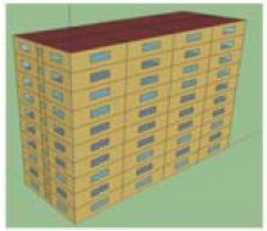
Full-service Restaurant



Mid-rise Apartment



High-rise Apartment



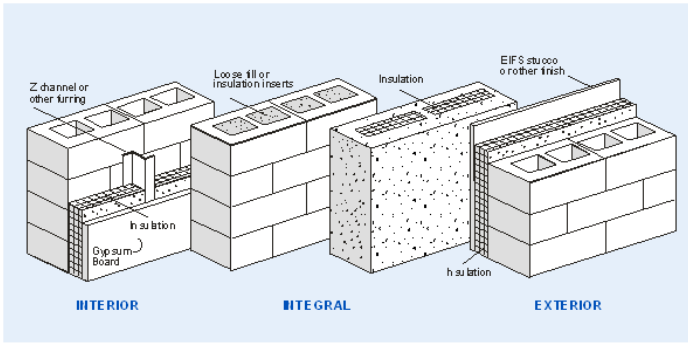
Prototype and Reference Building Updates

- 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 33.3

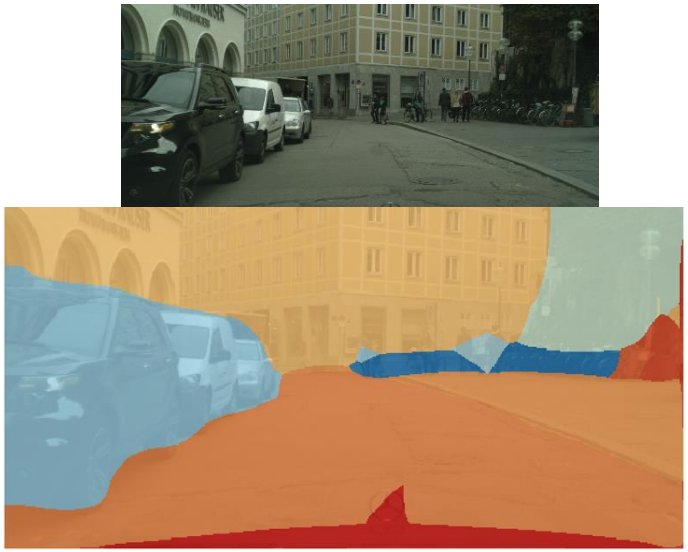
Table 3 Properties of Solids

Material Description	Specific Heat, Btu/lb·°F	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F	Emissivity Ratio	Emissivity Surface Condition
Aluminum (alloy 1100)	0.214[b]	171[u]	128[u]	0.09[u]	Commercial sheet
				0.20[u]	Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	0.09[u]	517[u]	58[u]		
Asbestos: Fiber	0.25[b]	150[u]	0.097[u]		
Insulation	0.20[t]	36[b]	0.092[b]	0.93[b]	"Paper"
Ashes, wood	0.20[t]	40[b]	0.041[b] (122)		
Asphalt	0.22[b]	132[b]	0.43[b]		
Bakelite	0.35[b]	81[u]	9.7[u]		
Bell metal	0.086[7] (122)				
Bismuth tin	0.040*		37.6*		
Brick, building	0.2[b]	123[u]	0.4[b]	0.93*	

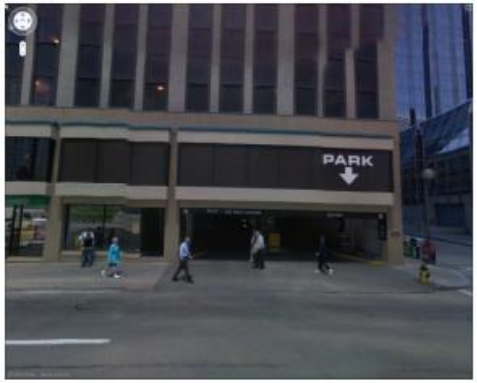


Street-level imagery (Lexie Yang)

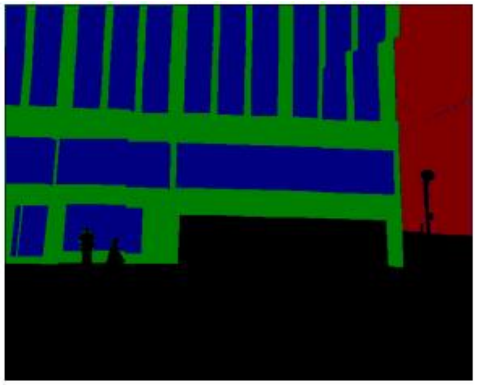
Façade Type



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

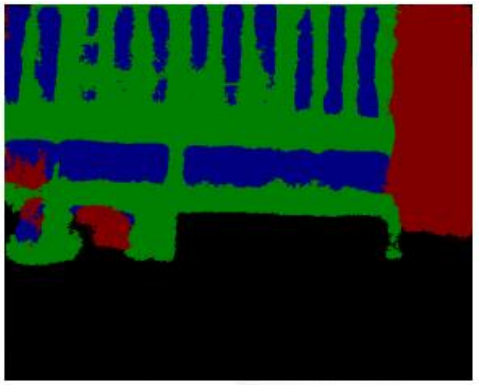


Input image



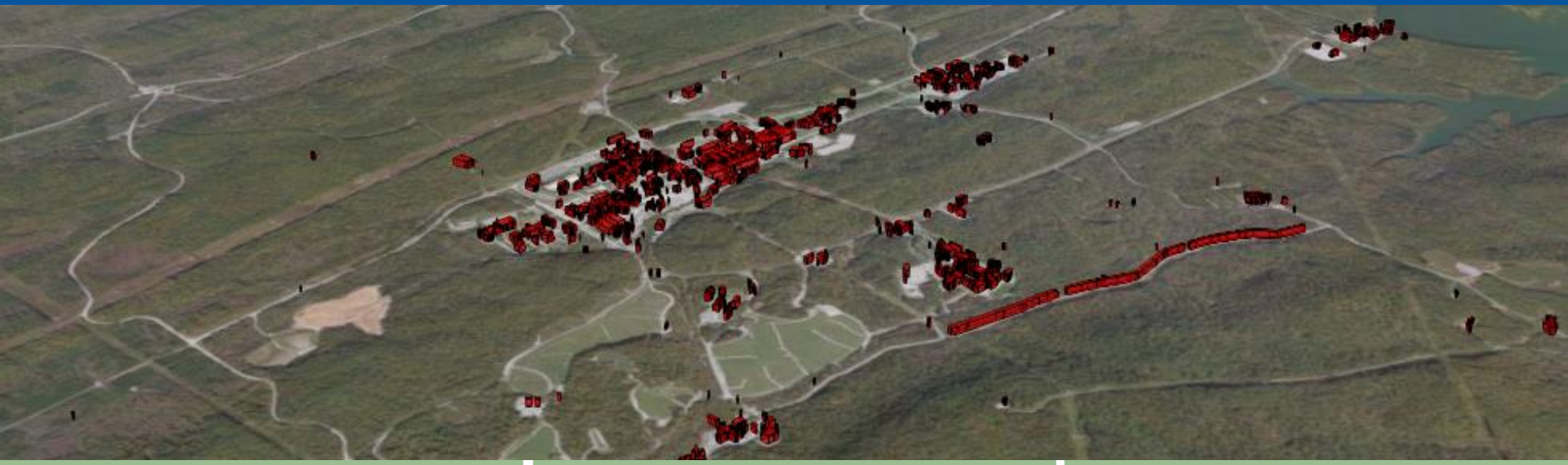
Window-to-wall ratio

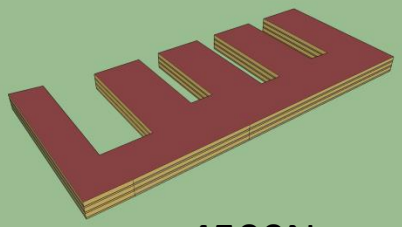
Ground truth



Model output

Oak Ridge National Laboratory





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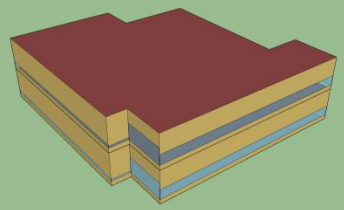

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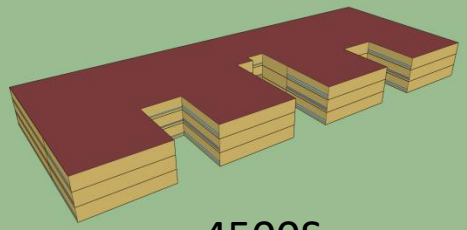

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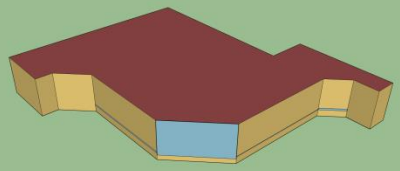

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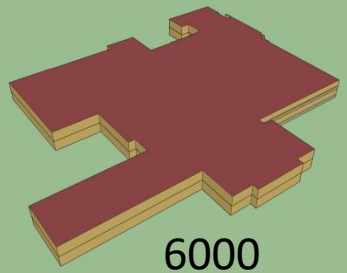

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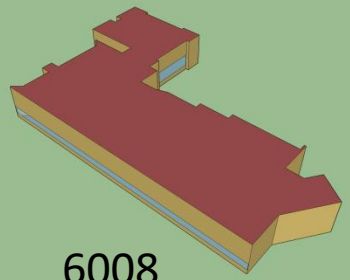
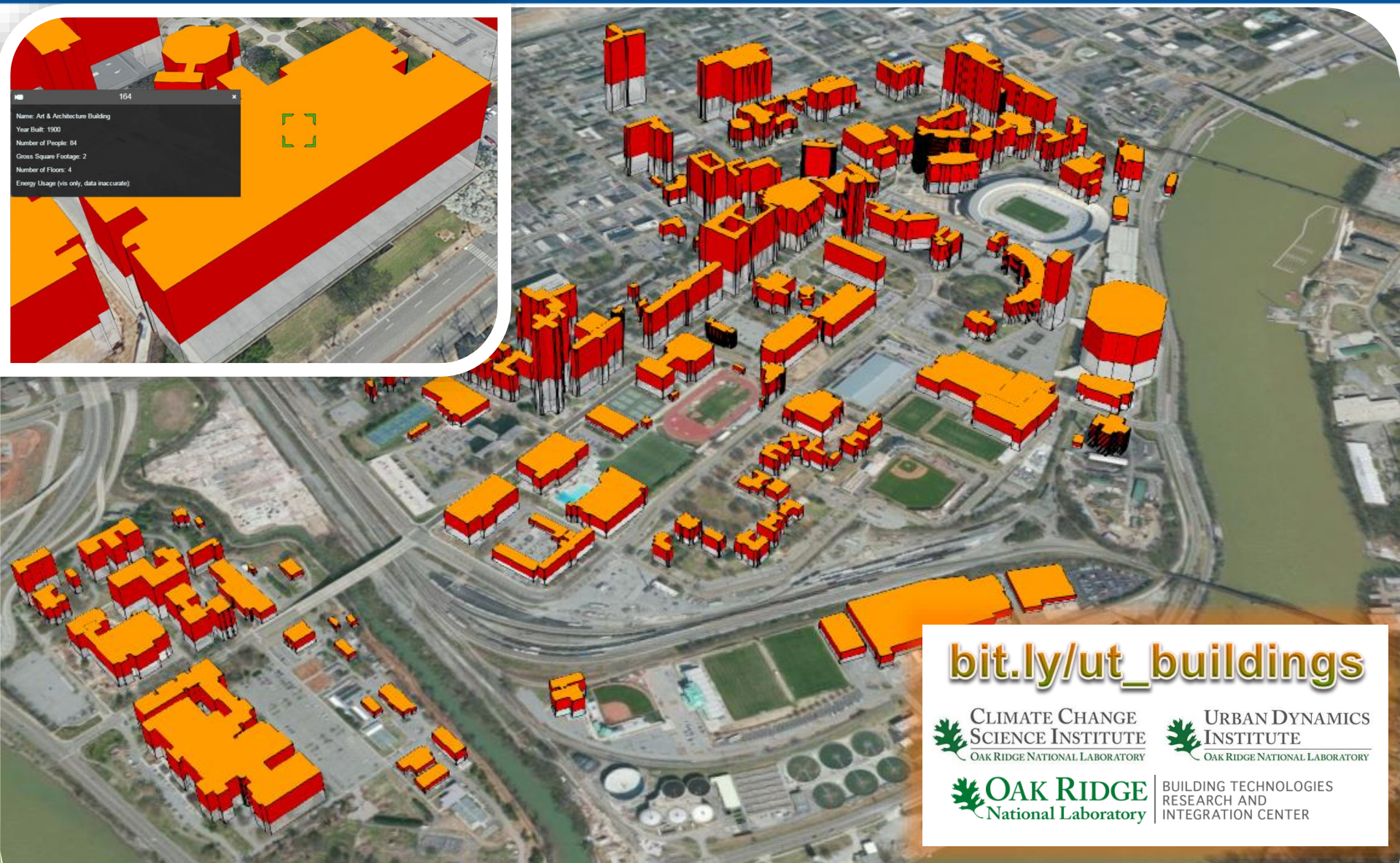


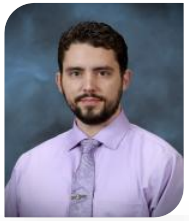
6008

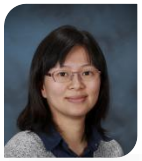
Oak Ridge National Laboratory (interactive)

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)
    - 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

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

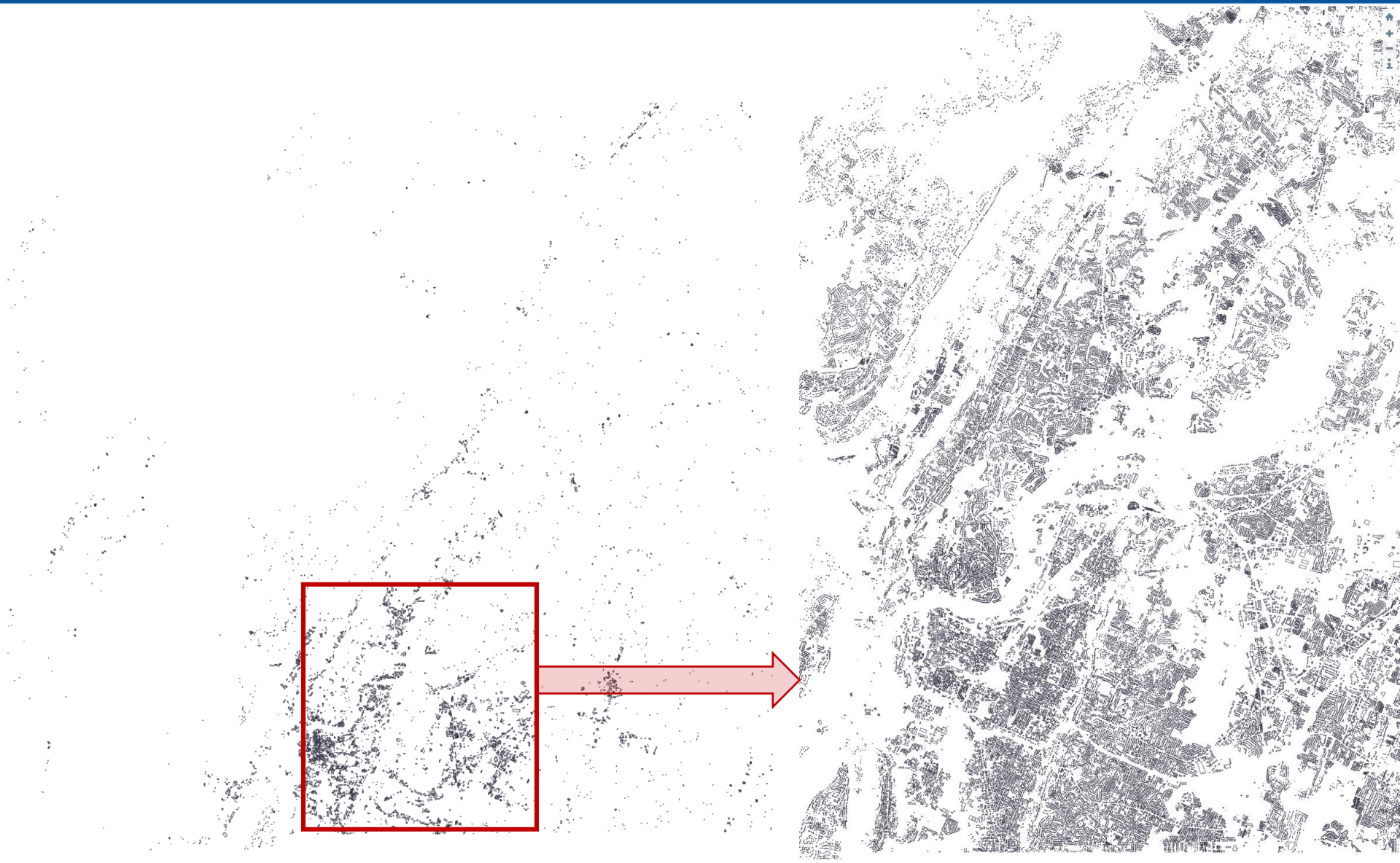
  - 2 projects, funded and tracked separately
  - Total - $700k (OE-$450k, 41 tasks; BTO-$250k, 15 tasks + BTO: $400k FY19)
  - 56 tasks, 12 milestones, 1 Go/No-Go (passed)
  - On-schedule except for 1 technical input (High-res bldgs) and 1 task (QA/QC)
  - 3.5% over-budget

Utility Use Cases for Virtual EPB

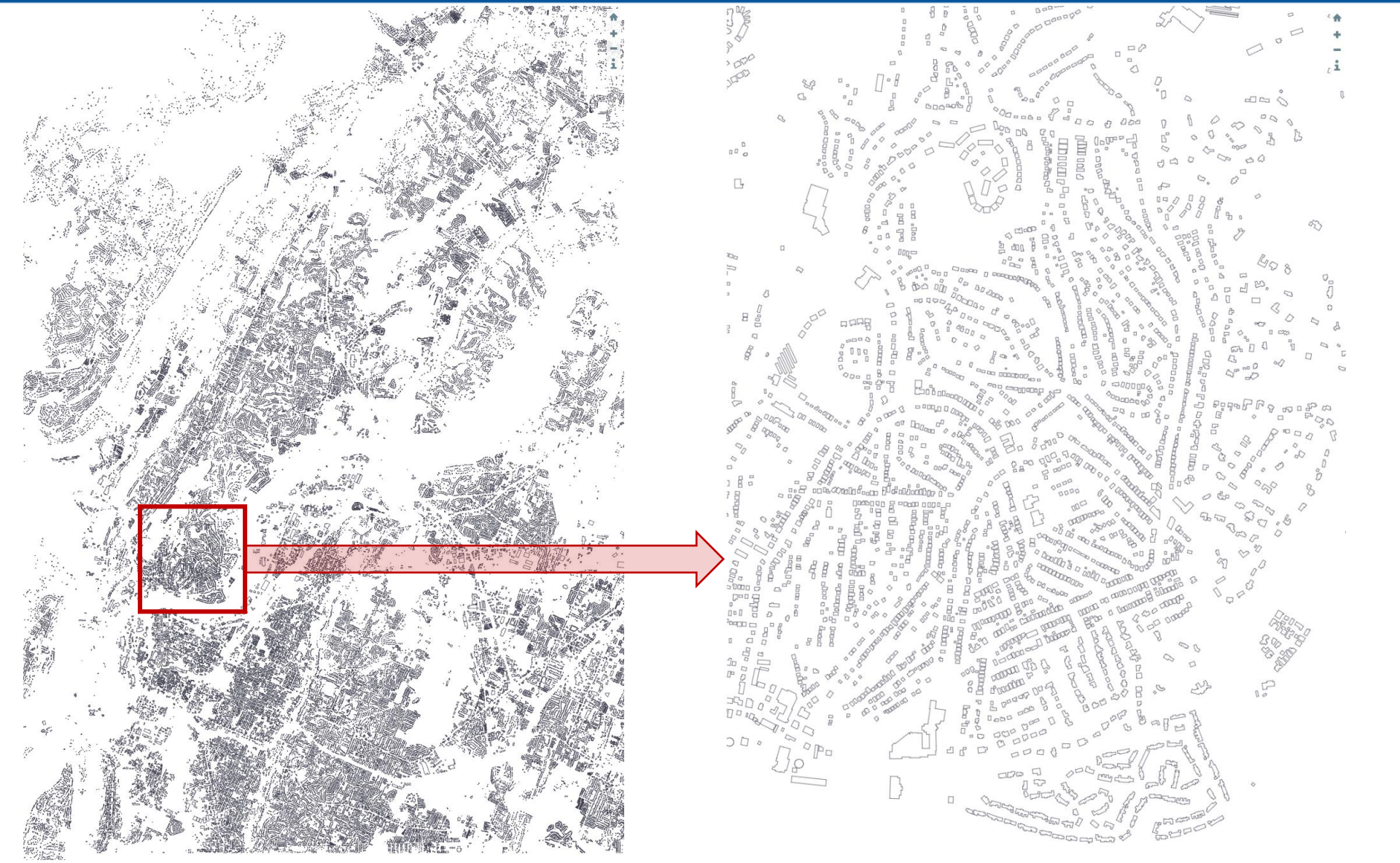
- **Peak Rate Structure** - model peak segment customers in aggregate as disproportionate contributors to electric utilities' wholesale demand charges for more equitable rate structures.
- **Demand Side Management** – identify DSM products and grid services for better distribution grid management that 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)

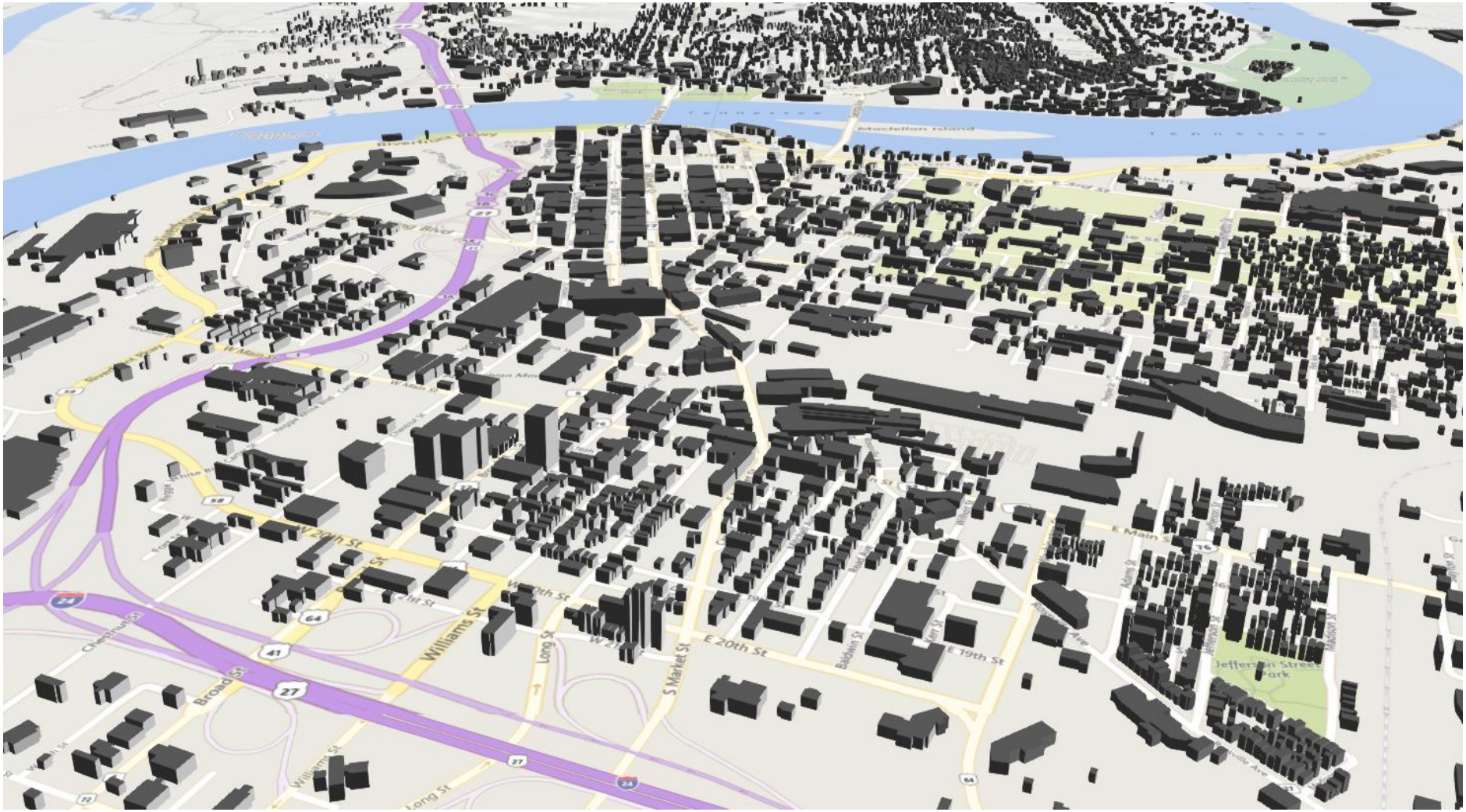


EPB buildings in Tennessee (166,944)



EPB buildings in Tennessee (166,944)

Chattanooga, TN (100,000+ buildings)



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

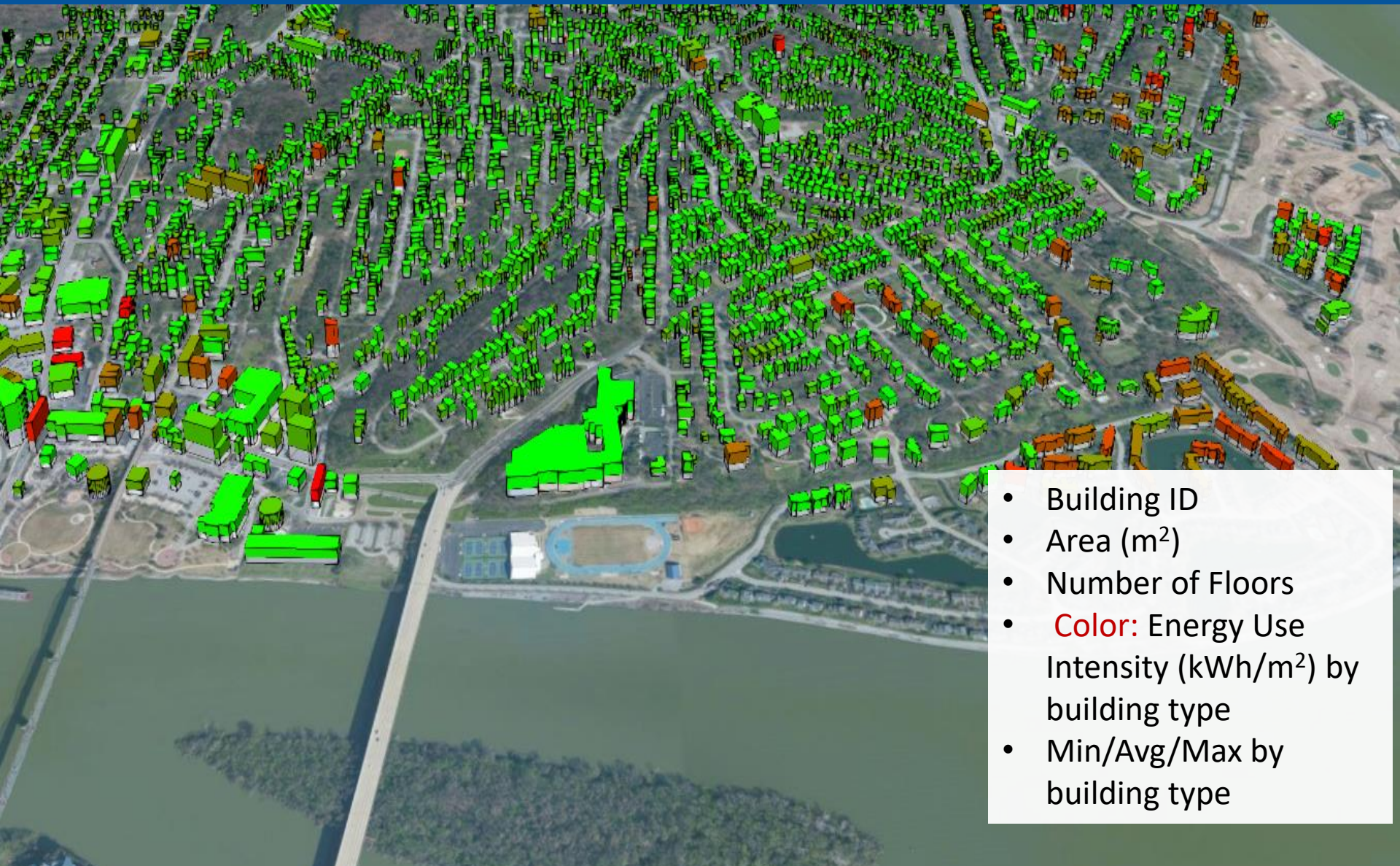
Time for creation, annual simulation, and analyzing "all" EPB buildings
6.5 hours (6.1h –36.5h)

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.

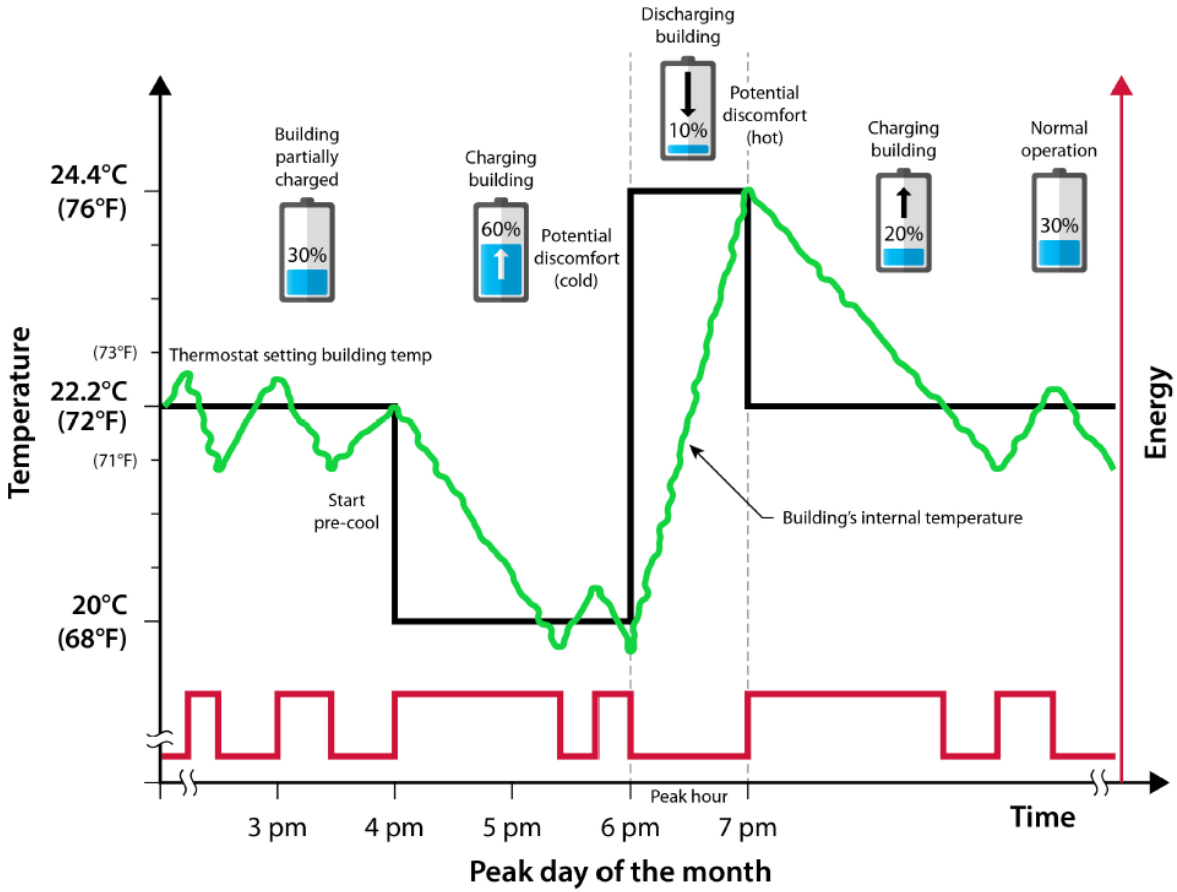
1a – Peak contribution percentile by type



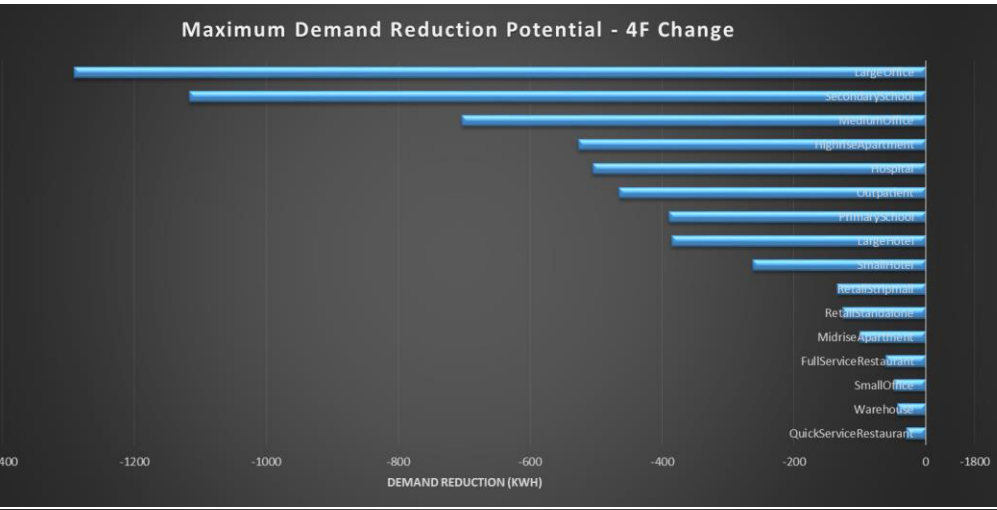
- Building ID
- Area (m^2)
- Number of Floors
- Color: Energy Use Intensity (kWh/m^2) by building type
- Min/Avg/Max by building type

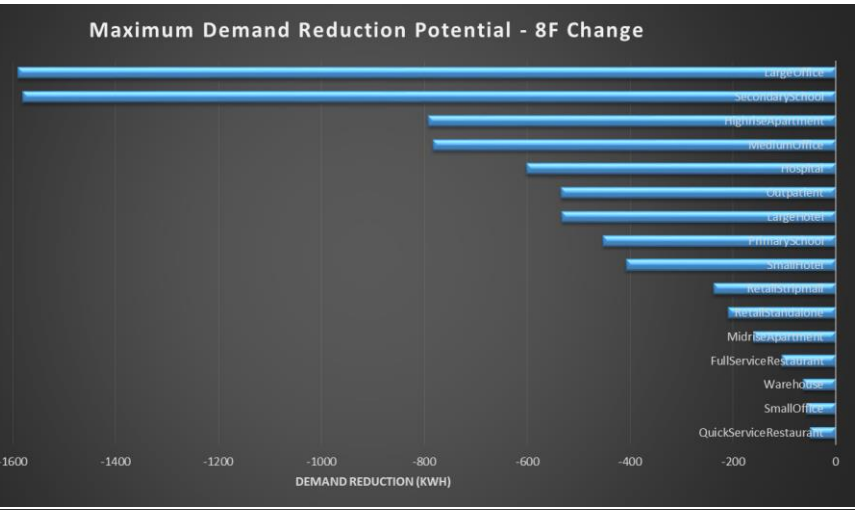
Demand and emissions

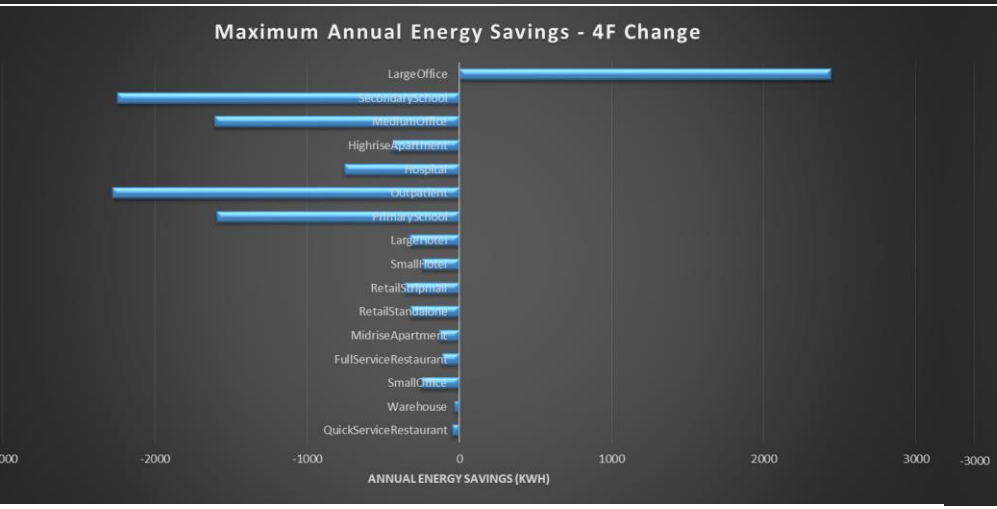
- Pre-heat/pre-cool 2 or 4 hours prior to peak demand hour each month
  - Single Heating or Single Cooling thermostat – up or down 4°F and 8°F
  - Dual Setpoint Thermostat – Average of baseline cooling and heating setpoints with a 0.5°C deadband
  - Altered thermostat values affects 38 (1-4 per building type) thermostat schedules in 518 (3-118 per building type) thermal zones for 16 different building types
- 3a: Emission Footprint for each building
  - Carbon footprint (CO_2)
  - Nitrogen oxides (NOx)
  - Sulfur Dioxide (SO_2)
  - *Methane (CH4)*
  - *Nitrous Oxide (N2O)*

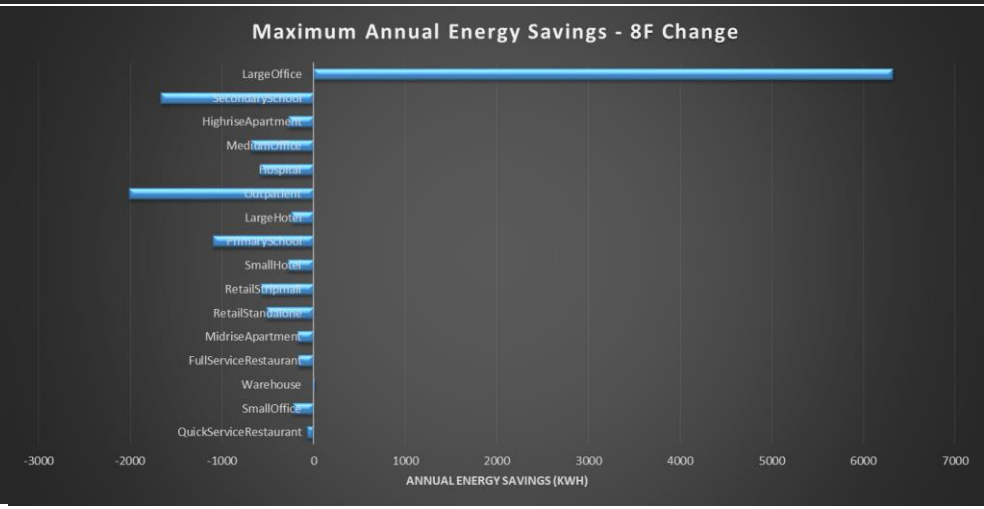


2a - Smart Thermostat: Maximum Demand and Energy Reduction Potential

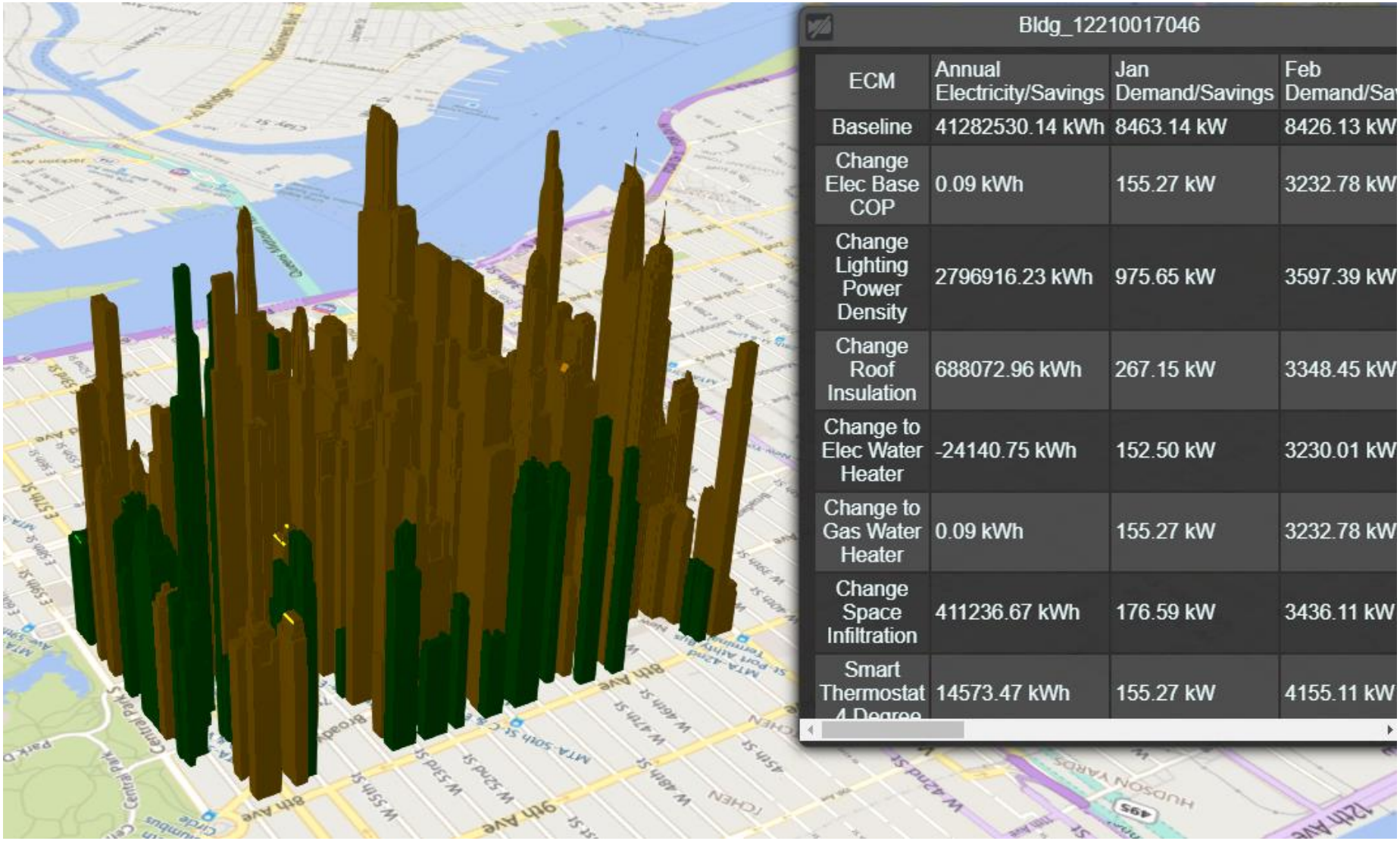








Virtual NYC – interactive results



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	14573.47 kWh	155.27 kW	4155.11 kW
4 Degree			

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

LiDAR vs. Microsoft Footprints (preliminary)

Microsoft releases 125 million building footprints June 28, 2018. (https://github.com/Microsoft/USBuildingFootprints)

- Goal to improve OpenStreetMap which had 30,567,953 US building footprints
- Stage 1 – Semantic segmentation (Open Source CNTK Unified Tolkkit, Deep Neural Networks, ResNet34 with RefineNet up-sampling layers, Bing overhead imagery)
- Stage 2 – Polygonization (creates walls from pixel-based classification)

Discussion with Jubal Harpster afterward

Value of MS footprints as a building data layer
116,506 unique buildings

- Largest LiDAR-derived GPS distance is ~0.1 (GPS bldg centroid and electrical meter)
- Largest MS-derived GPS distance is 0.0149 (maximum distance is ~6x smaller)

- Each building 1,024 ft^2 smaller than LiDAR (better aligns with energy use data)

	ID	AreaOld	AreaM	diff
count	1.783550e+05	1.783550e+05	1.783550e+05	1.783550e+05
mean	1.283970e+09	1.353843e+04	1.251411e+04	-1.024317e+03
std	8.634363e+08	5.693321e+04	5.332367e+04	3.197508e+04
min	1.000000e+04	1.600000e+02	9.765405e+01	-2.058451e+06
25%	5.764950e+08	2.277000e+03	2.169542e+03	-5.954823e+02
50%	1.126530e+09	3.896000e+03	3.781828e+03	-1.250858e+02
75%	1.881395e+09	7.596000e+03	7.196649e+03	3.512558e+02
max	3.230080e+09	3.451038e+06	3.251502e+06	3.008718e+06

Discussion

HPC Tools for Modeling and Simulation
Capturing building energy consumption

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