Energy Exchange℠

Be Efficient And Resilient

U.S. Department of Energy

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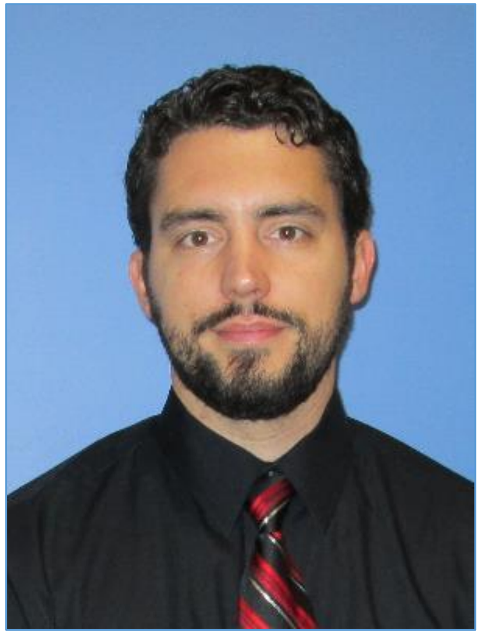
Senior R&D Staff, Oak Ridge National Laboratory



Energy and Water Assessments: Virtual and Conventional

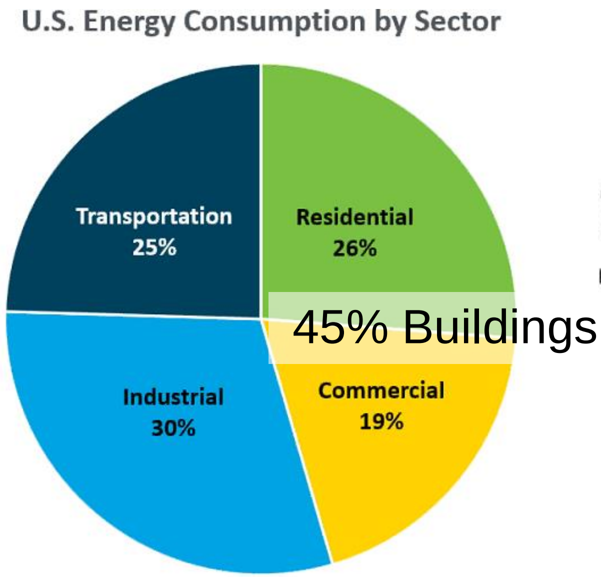
Automatic Building detection and Energy Model creation (AutoBEM) technologies for remote audit of individual buildings at urban scales

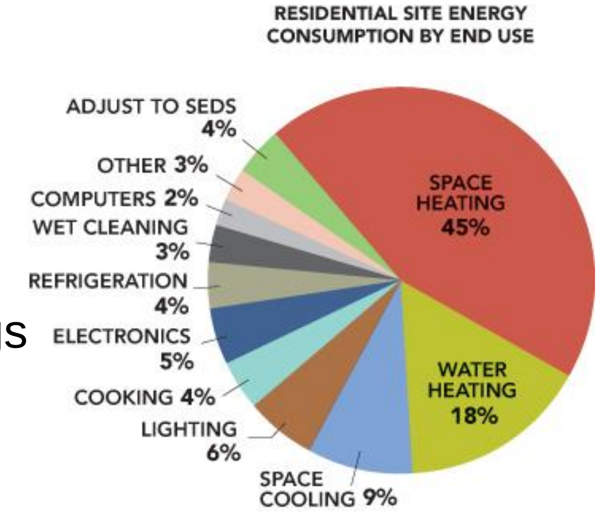
Joshua New, Ph.D., C.E.M., PMP, CMVP, CSM

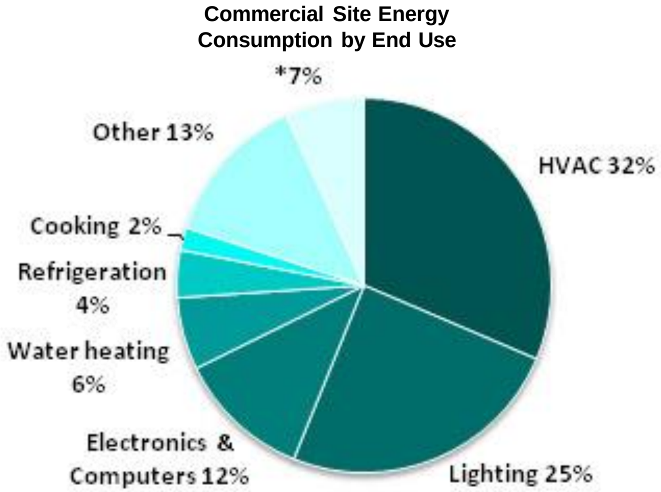
- **Career**
  - 2009+ Oak Ridge National Laboratory, R&D staff
    - ETSD, Building Technology Research & Integration Center (BTRIC), Building Envelope & Urban Systems Research Group (BEUSR)
    - Urban Dynamics Institute, Resiliency Team member
  - 2012+ The University of Tennessee, Joint Faculty
- **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







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:
30% energy reduction per sq. ft.
by 2030 compared to 2010 baseline

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

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

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Energy Audit

- Typical audit criteria
  - Location, fuel types, building type
  - Form – area, shape, number floors, WWR, thermal zones
  - Architecture – walls, roof, window, skylight, foundation
  - HVAC – System type, efficiency, control, fan, pump, water heating
  - Internal loads – lighting, plug, occupancy

	Item	Descriptions (Example)
	Location	City, State, Country
	Available fuel types	Gas, electricity
	Building Type (Principal Building Function)	**Office**
Form		
	Total Floor Area (sq feet),(Width & Depth)	
	Building shape	
	Number of Floors	
	Window Fraction	
	Window Locations	
	Shading Geometry	
	Azimuth	
	Thermal Zoning	
	Floor to floor height (feet)	
	Floor to ceiling height (feet)	
	Glazing sill height (feet)	

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

Int'l Performance Measurement & Verification Protocol (IPMVP)

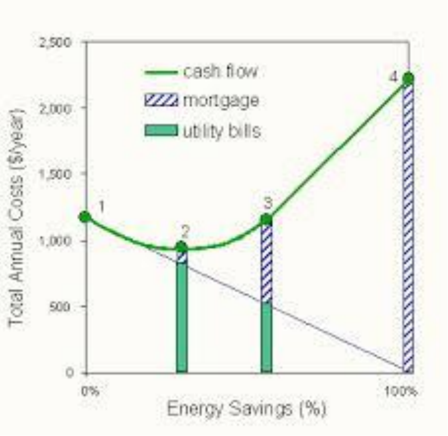
IPMVP Option	How Savings Calculated	Typical Application
A. Retrofit Isolation: Key Parameter Measurement Savings estimated in the field by measurement of key performance parameters	Engineering calculation of baseline and reporting period from measurements, estimated values. Estimated Value x (Baseline-Period, measured parameter – Reporting-period, measured parameter)	Lighting retrofit (power draw measured periodically and hours estimated from schedule)
B. Retrofit Isolation: All Parameter Measurement Field measurement of energy use of ECM affected system.	Measurements of baseline and reporting period energy using measurements of proxies of energy use Baseline Energy - Reporting-Period Energy	Variable speed drive and controls to a motor to adjust pump flow. Measure electric power with a kW meter every minute for a week.
C. Whole Facility Savings based on whole facility or sub-facility	Analysis of utility meter data Baseline Energy - Reporting-Period Energy (usually from revenue-grade meter)	Multiple ECMs affecting many systems. Requires 12 month baseline of elec. and gas.
D. Calibrated Simulation Simulation of whole facility or sub-facility. Usually requires considerable skill.	Energy use simulation, calibrated with hourly or monthly utility bills. Baseline energy from the calibrated model [hypothetical or without ECMs] – Reporting-period energy from the calibrated model [with ECMs]	Multiple ECMs affecting many systems. Useful when no meter available in baseline period.

Building Energy Modeling

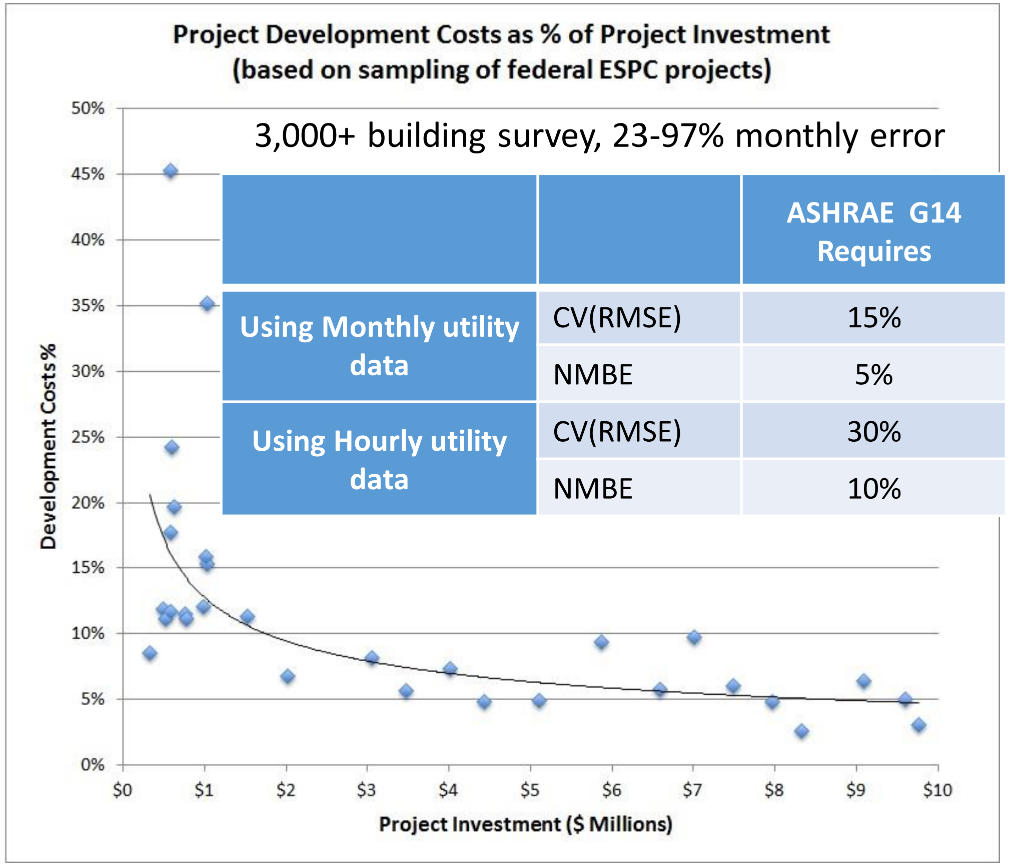
Simulation Engine and Analysis Platform
U.S. Dept. of Energy
$93M, 1995–?

EnergyPlus **OpenStudio**

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



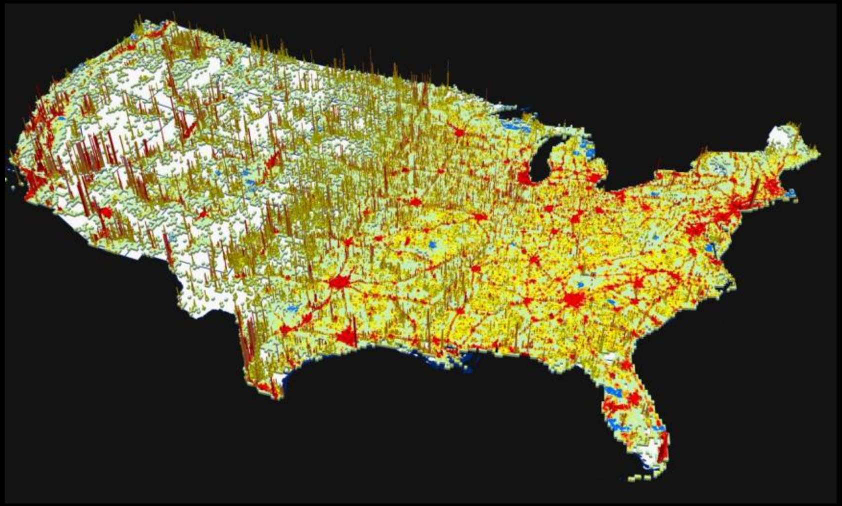
Optimal Return on Investment
(for building energy savings)

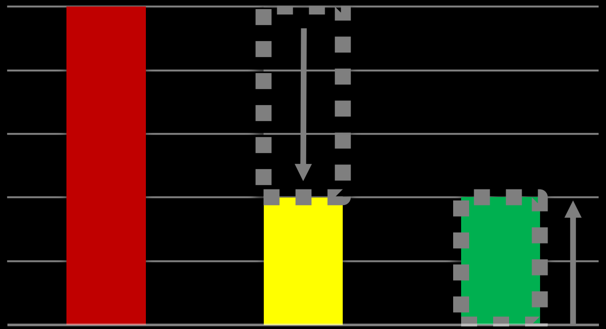


3,000+ building survey, 23-97% monthly error

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

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

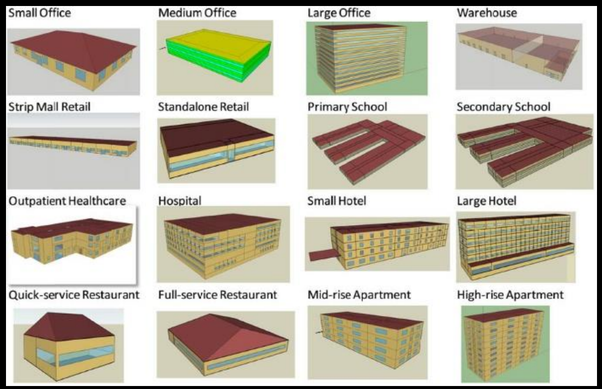




Goal: Stimulate private sector activity for efficient buildings

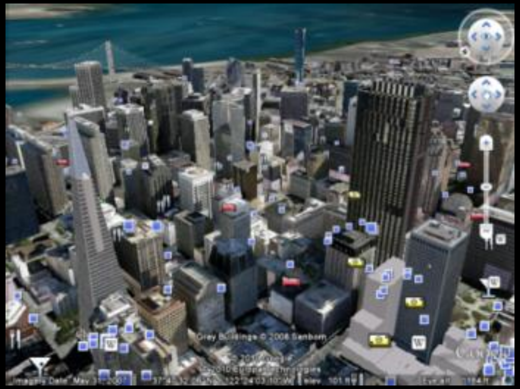
1. Extract important inputs from available data

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

Acknowledgements

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

Model America 2020 plans

- 124 million BEM by 12/31/20
- Analysis of energy and demand measures
- Freely available in 2021

Automatic Detection and Building Energy Model Creation (AutoBEM)

Data Sources

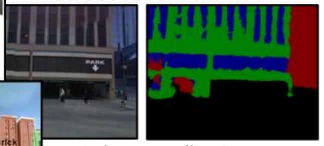
- Imagery (satellite, aerial)
- Street-level imagery
- Cartographic layers
  - Elevation, GIS
- Tax assessors
- Ranking of descriptors EE and Demand impacts (281–4,617 per building type)

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

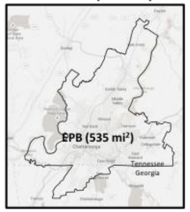
	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints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

Street-level data

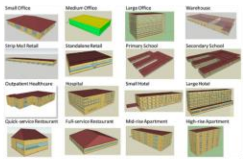


Window-to-wall ratio

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

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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
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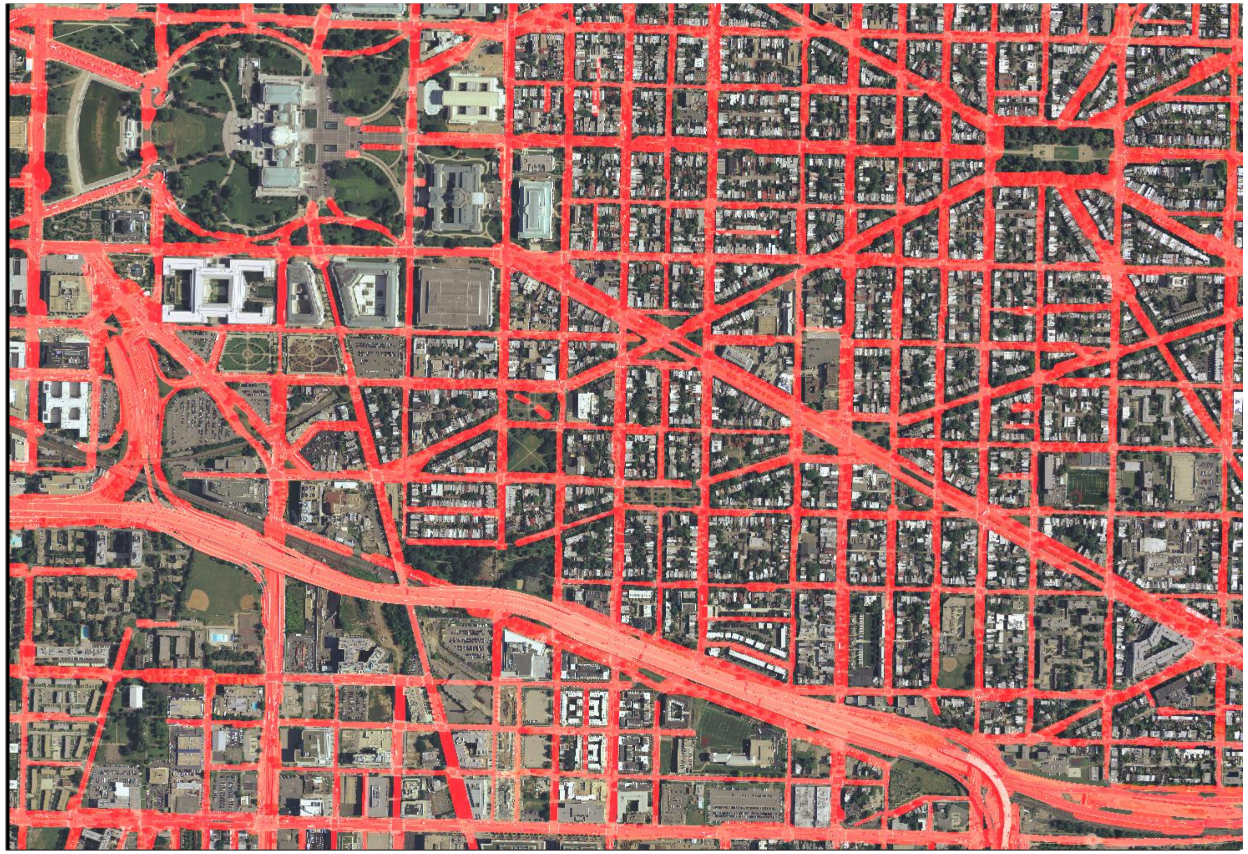
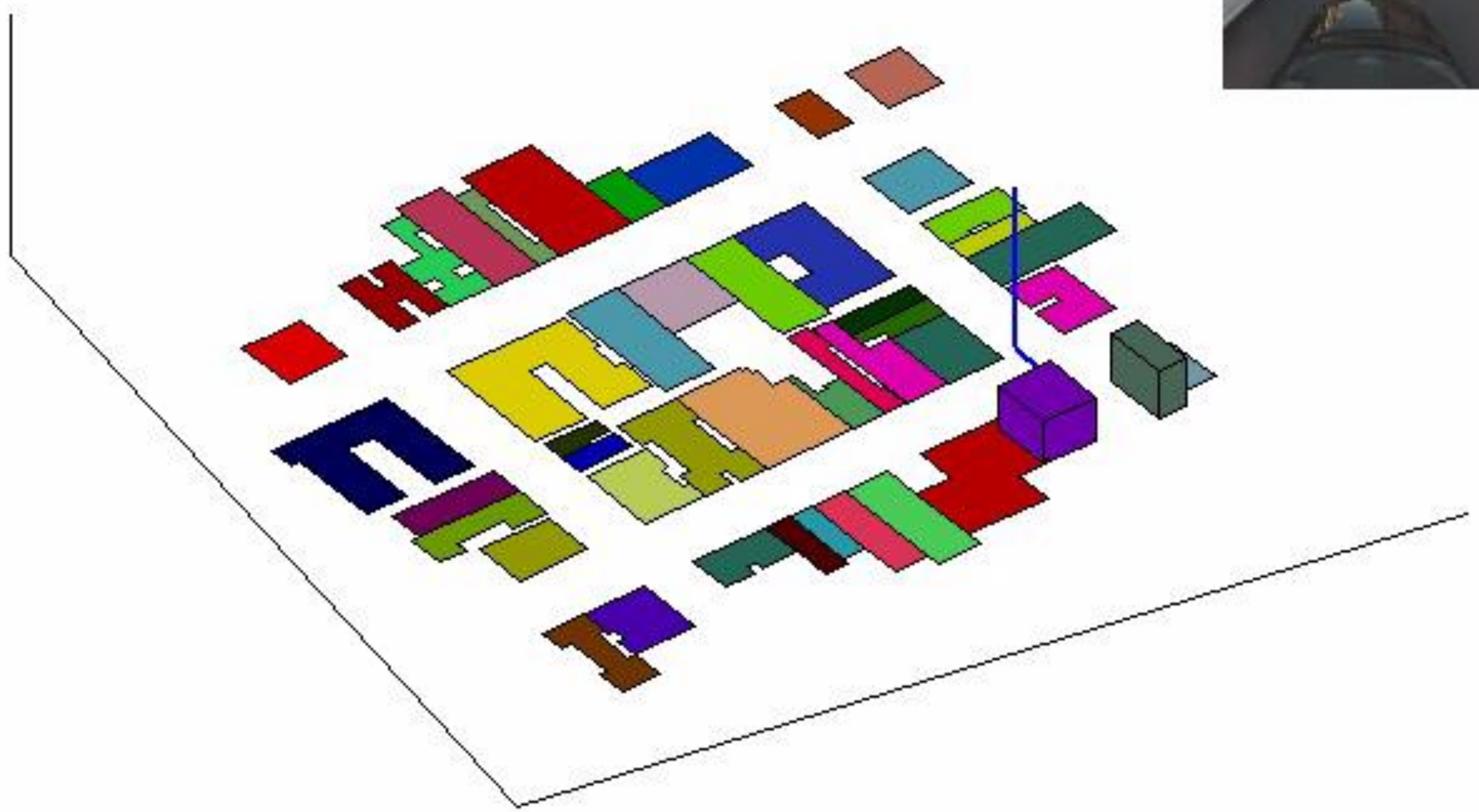
Comments	

Computer Vision for DC

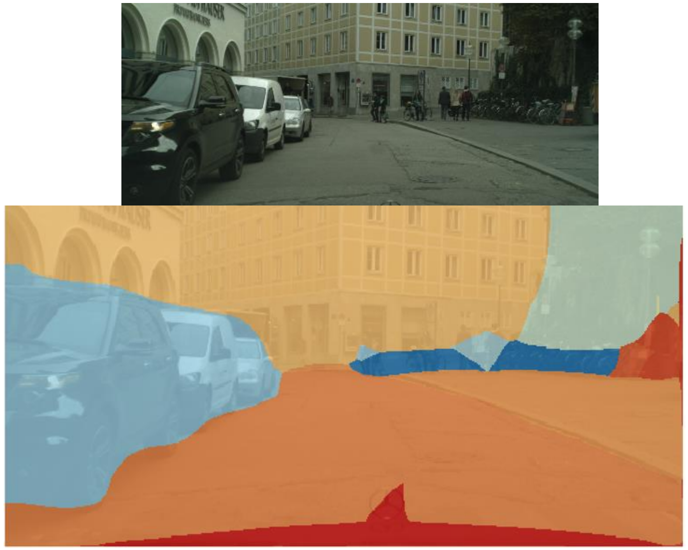


Open Competition Precision/Recall – 30/35
ORNL Current Precision/Recall – 60+/60+

Street-level Image Processing (height)

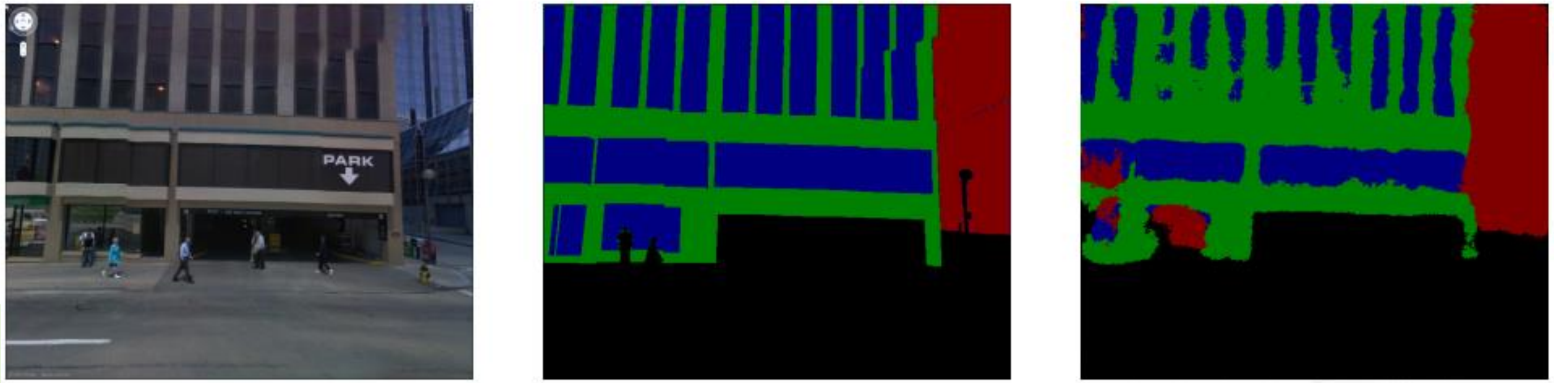


Street-level details



Façade Type

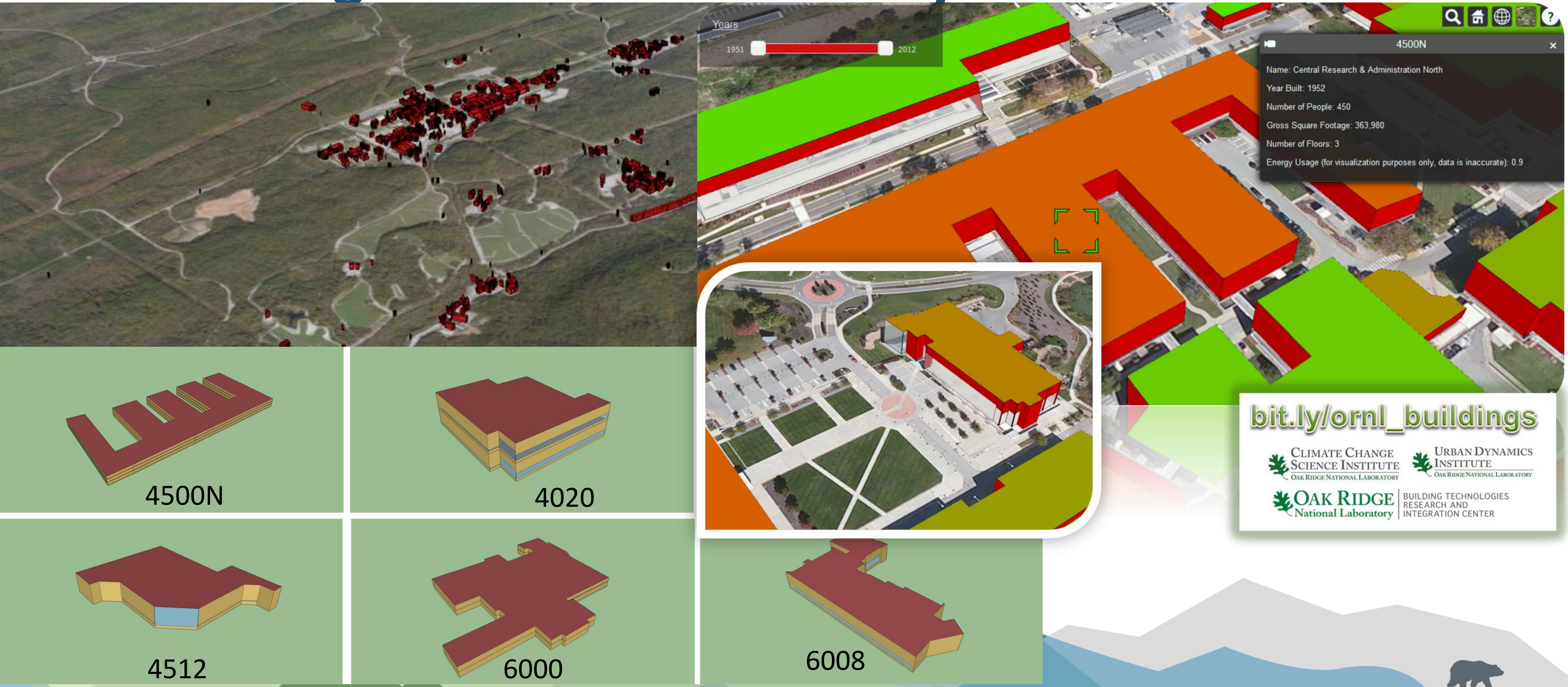
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)



Input image Ground truth Model output

Window-to-wall ratio

Oak Ridge National Laboratory



The University of Tennessee (2 days)

bit.ly/ut_buildings

CLIMATE CHANGE SCIENCE INSTITUTE
OAK RIDGE NATIONAL LABORATORY

URBAN DYNAMICS INSTITUTE
OAK RIDGE NATIONAL LABORATORY

OAK RIDGE National Laboratory

BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

Digital Twin of a Utility

Energy Exchange

The AutoBEM Technology “axe”

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

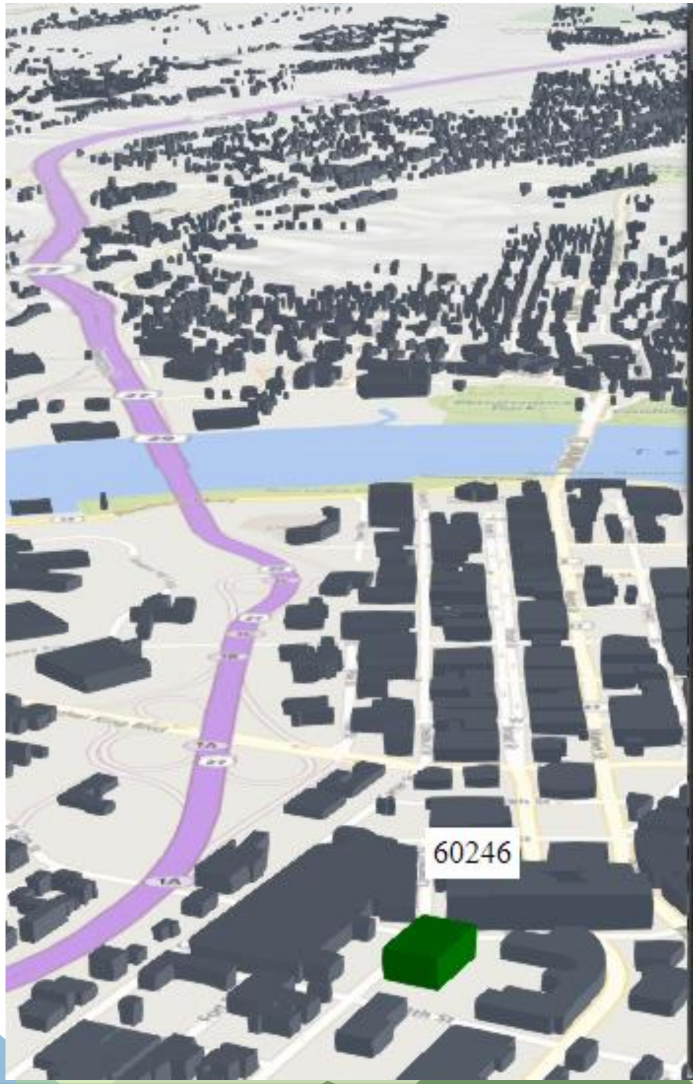
Limitations: limited building types, not calibrated, will improve quarterly
QA/QC: will show how close our simulations are to 15-min data

3.5+ million EnergyPlus building energy models using AutoBEM technology, Titan, cloud, and local servers to produce and analyze 13 TB of simulation data.

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

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

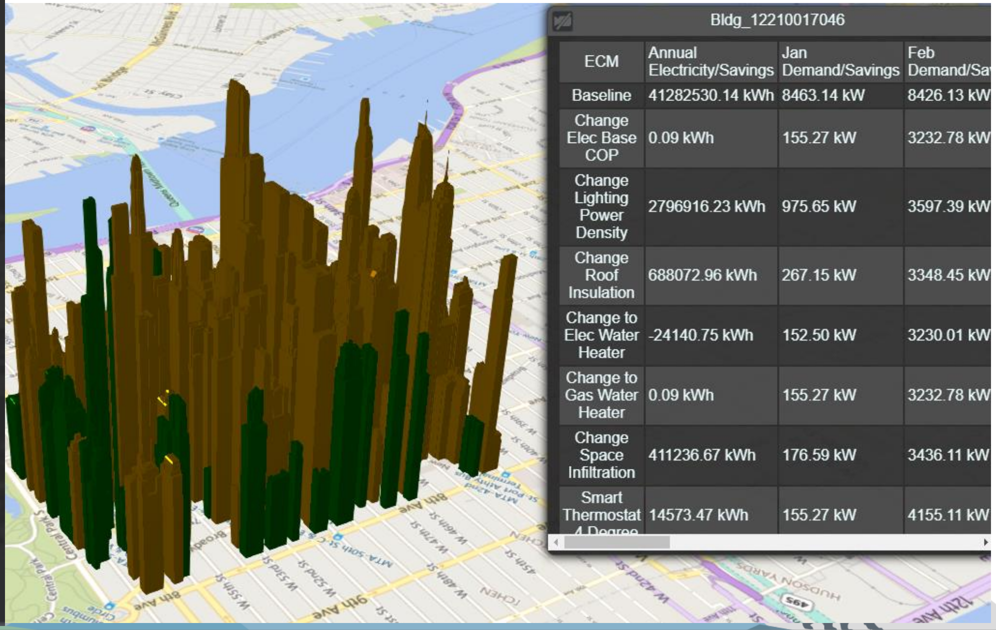
Virtual Utility – interactive results



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

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

1. **Lighting Efficiency (0.85 W/ft^2)**
   E=[77, 784, 6757] D=[23, 999, 14410]
2. **Infiltration (reduce 25%)**
   E=[40, 774, 4648] D=[-0.8, 840, 14020]
3. **Insulation (R16.12 to R28.57)**
   E=[12, 204, 1600] D=[1.9, 817, 13928]
4. **Smart thermostat 2.2C (4F) pre-condition**
   E=[-72, 1.4, 525] D=[-938, 918, 13907]



Bldg_12210017046

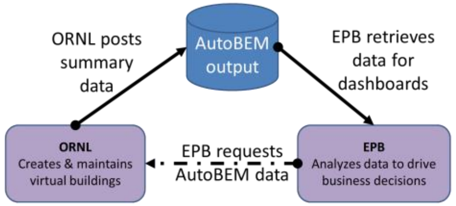
ECM	Annual Electricity/Savings	Jan Demand/Savings	Feb Demand/Sa
Baseline	41282530.14 kWh	8463.14 kW	8426.13 kW
Change Elec Base COP	0.09 kWh	155.27 kW	3232.78 kW
Change Lighting Power Density	2796916.23 kWh	975.65 kW	3597.39 kW
Change Roof Insulation	688072.96 kWh	267.15 kW	3348.45 kW
Change to Elec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

Accuracy compared to 15-minute data

- Empirical Validation
  - 15-minute whole-building electrical for 178,368 bldgs
  - More accurate than BEM created by a human[1]
    - ½ error of the average manually-created BEM when compared to measured data

Operational Use of BEM Simulations

Use Cases
- Peak rate structure
- Demand-side mgmt
- Emissions
- Energy efficiency
- Customer education

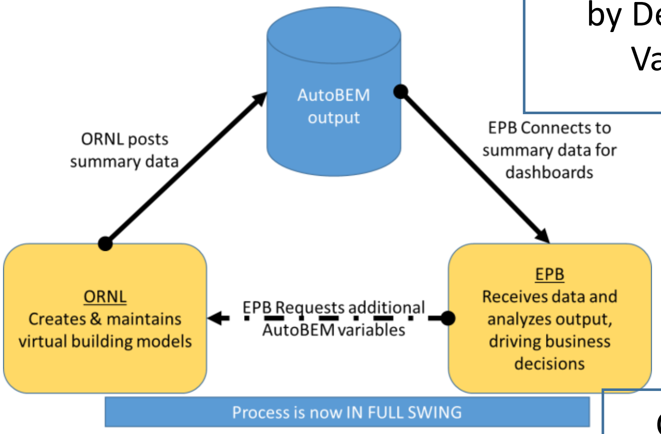


Measures
- Lighting, HVAC COP, infiltration, insulation
- Smart thermostats
- Water heaters
- PV/solar
- EV charging
- Future weather
- Dual-fuel HVAC
- Microgrids

Result: $11–35 million/year in potential savings identified via simulation-informed data and valuation for *energy, demand, emissions, and cost impact* to EPB and each customer for each building under five use cases covering nine monetization scenarios

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

Virtual Utility Integration



Map showing premises, sized by Demand Value

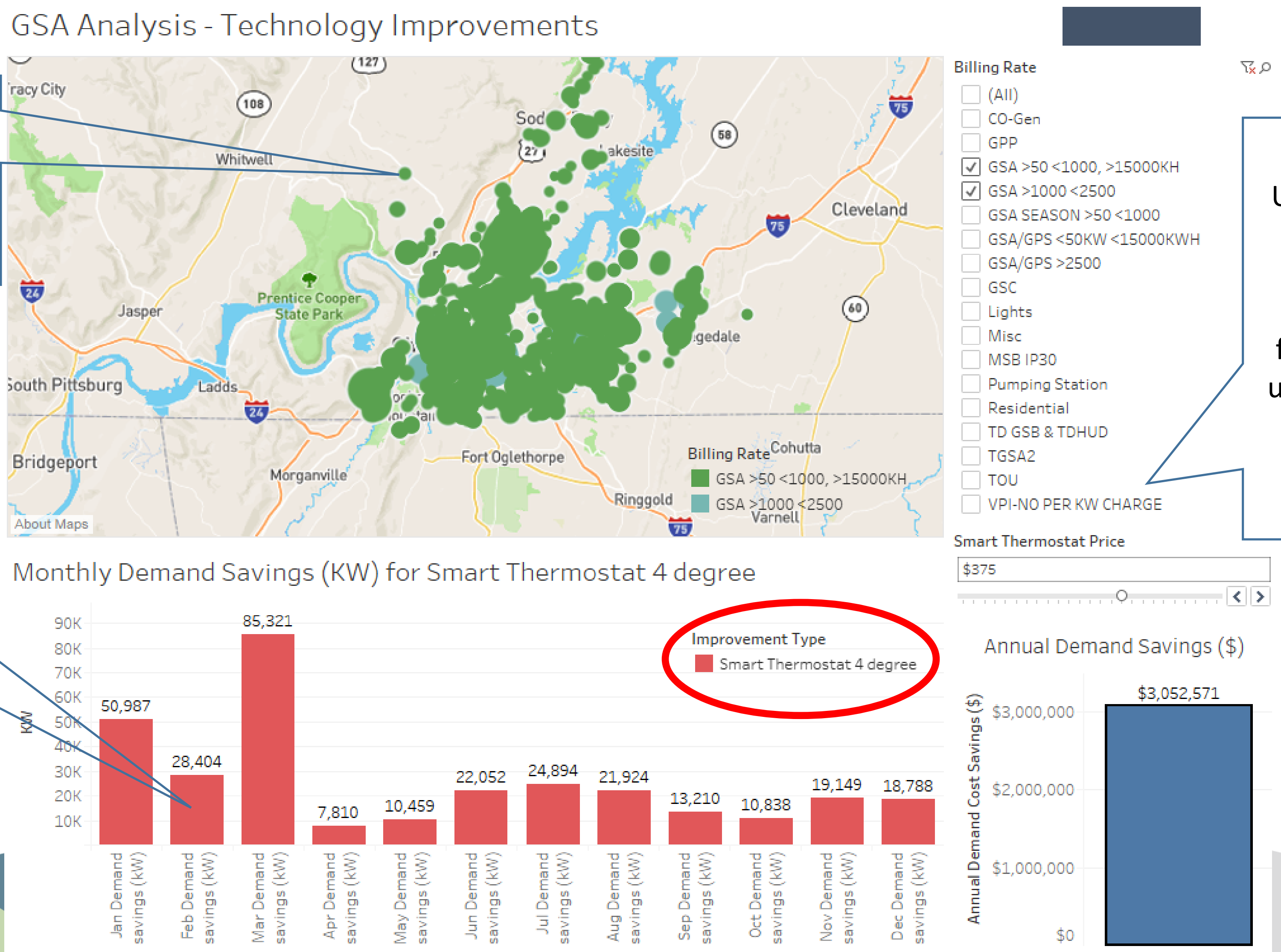


Chart showing monthly demand value

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

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Tech Commercialization Fund with Google

- Environmental Insights Explorer
  - https://insights.sustainability.google/

ENVIRONMENTAL INSIGHTS EXPLORER

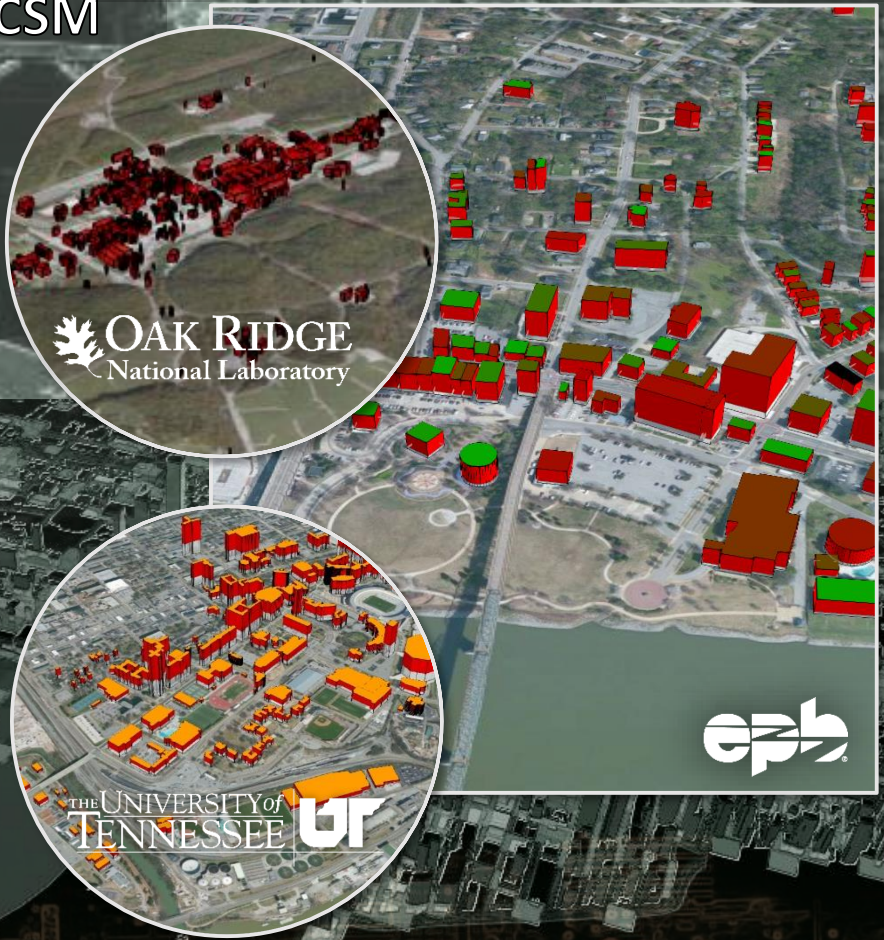
Impact begins with insights.
Explore data to make informed decisions
and inspire action.

Discussion

HPC Tools for
Modeling and Simulation
Capturing building energy consumption

Joshua New, Ph.D., CEM, PMP, CMVP, CSM
BTRIC, Software Tools & Models
Oak Ridge National Laboratory

newjr@ornl.gov



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