Urban Information and Energy Modeling

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Ben Polly	*National Renewable Energy Laboratory*
Christoph Reinhart	*MIT*

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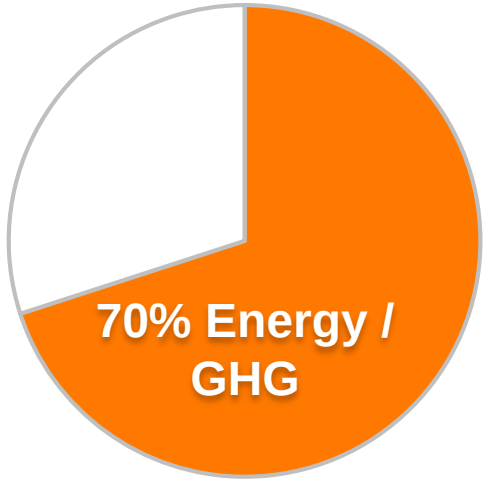
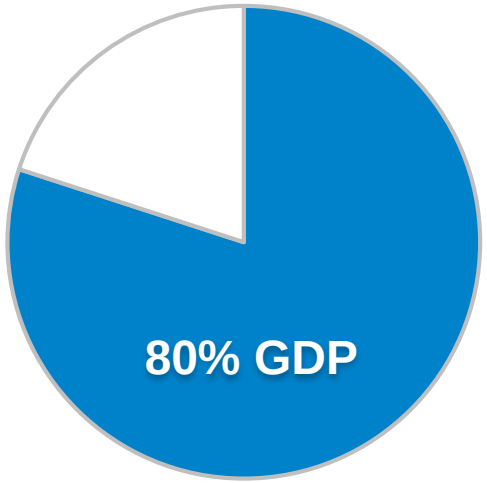
Presentation Date	2019-09-02
Presentation Time	11:35am – 12:35pm

BS 2019
2 - 4 SEPT
ROME

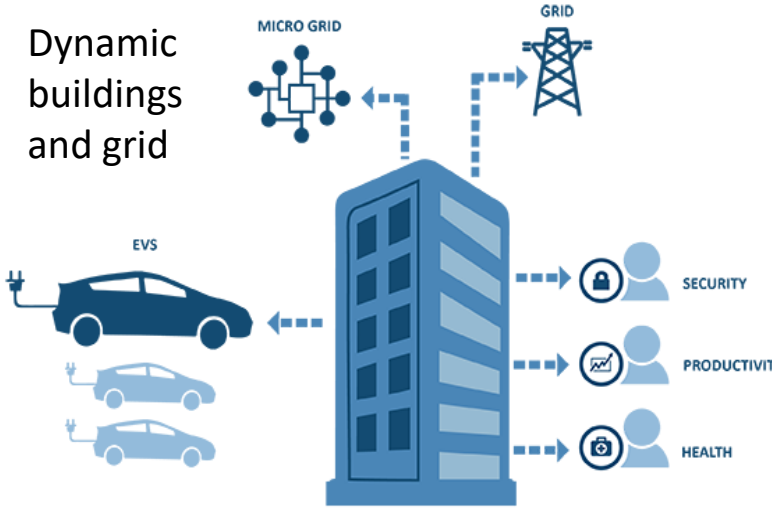
Urban Megatrend

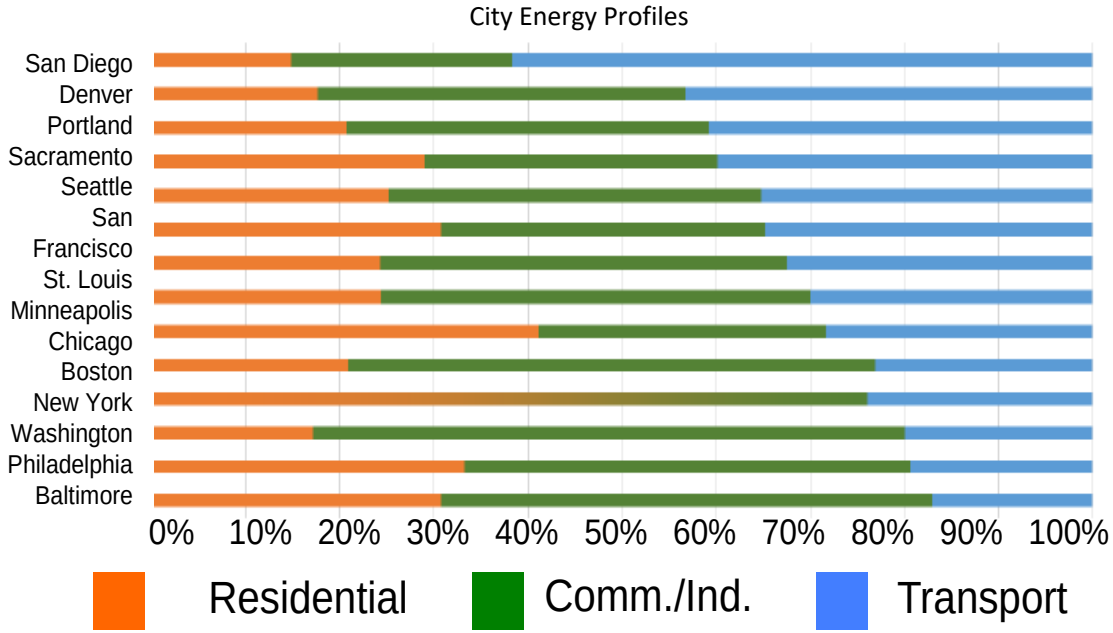
Cities drive our economy and dominate energy and environmental challenges



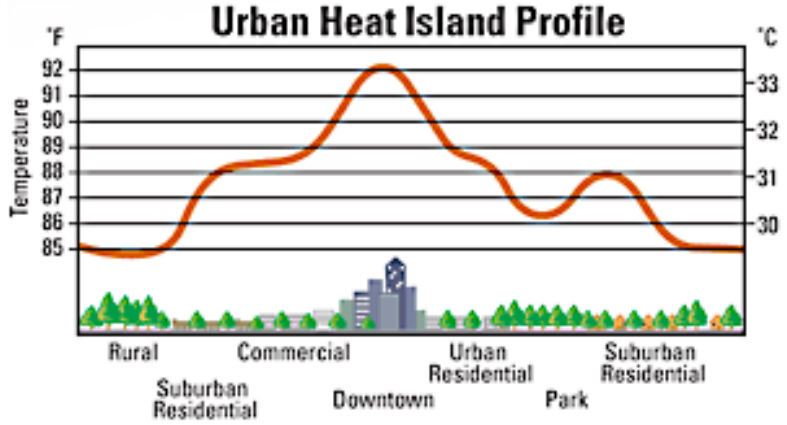


Dynamic buildings and grid

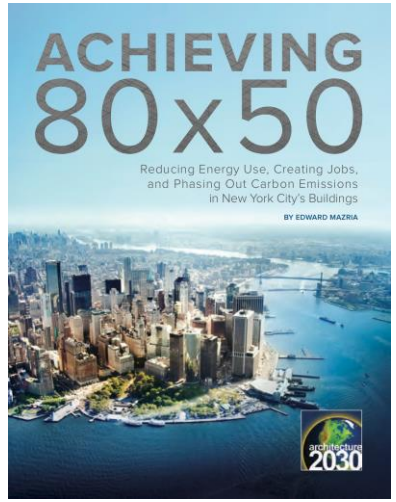




Changing urban climate



Need for city-scale and deep savings

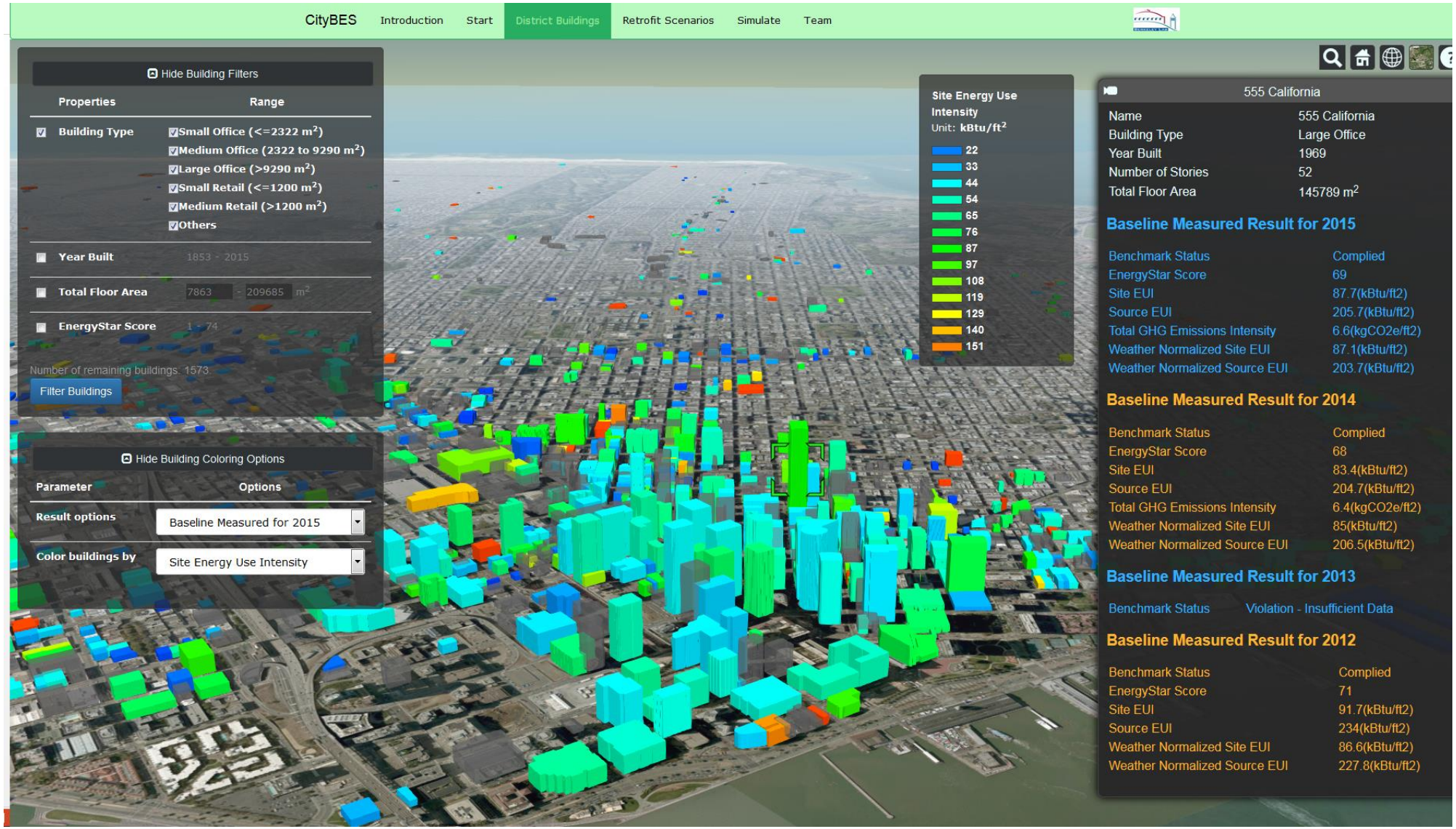


Sierra Club "Ready for 100"

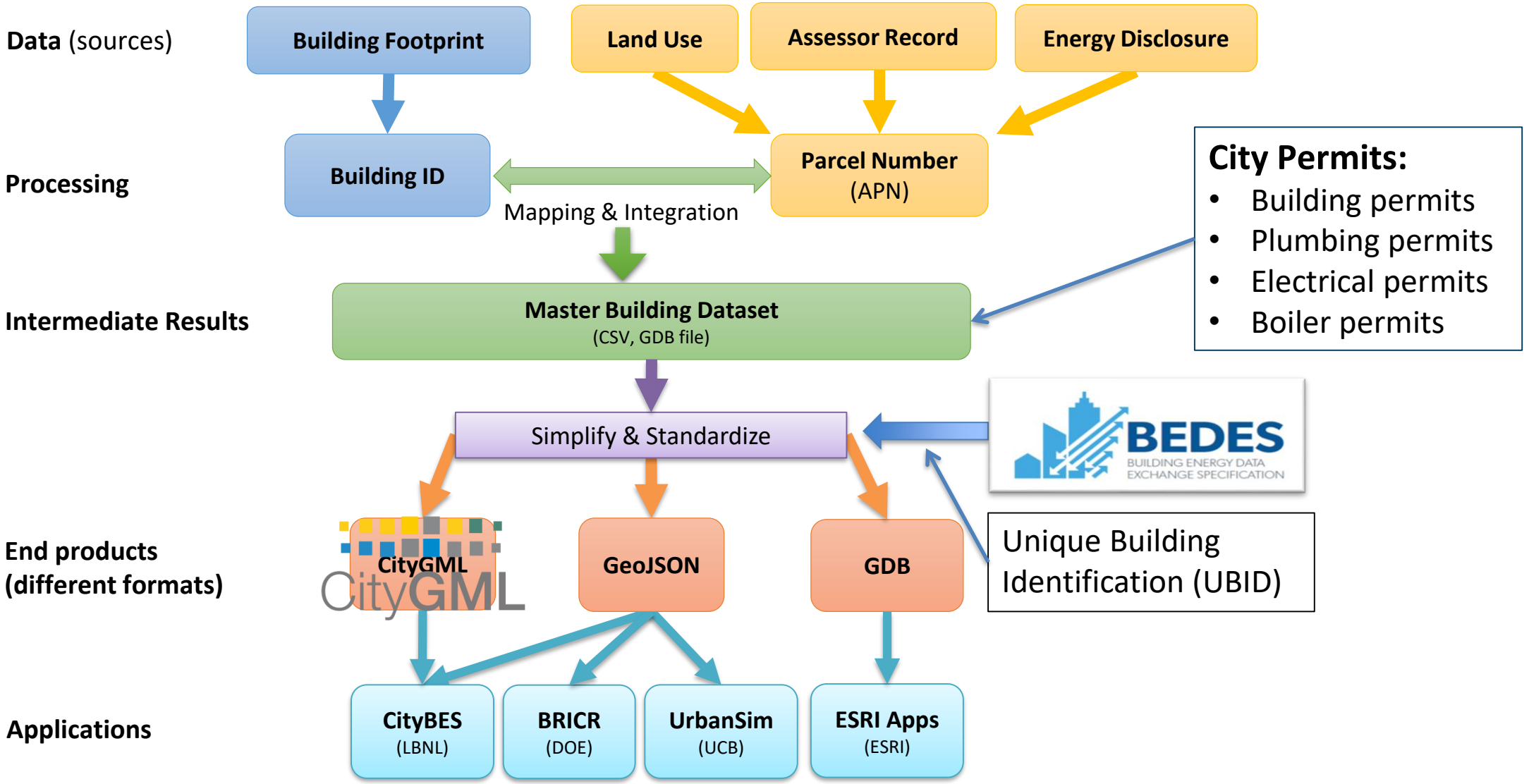
CityBES: A Data and Computing Platform for Urban Buildings

Tianzhen Hong *LBNL*

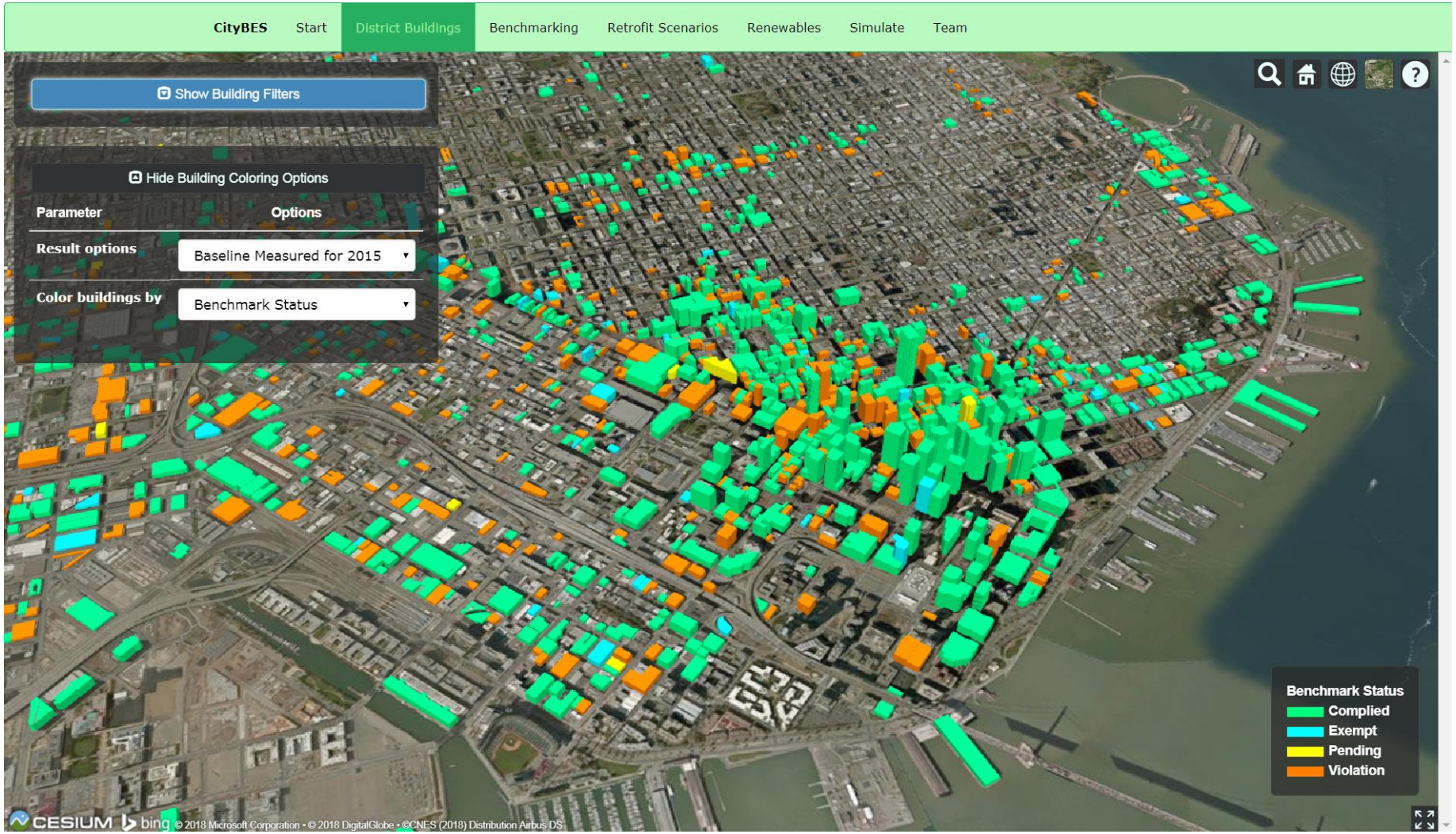
CityBES.LBL.gov



Integrating City Data in Open Standards

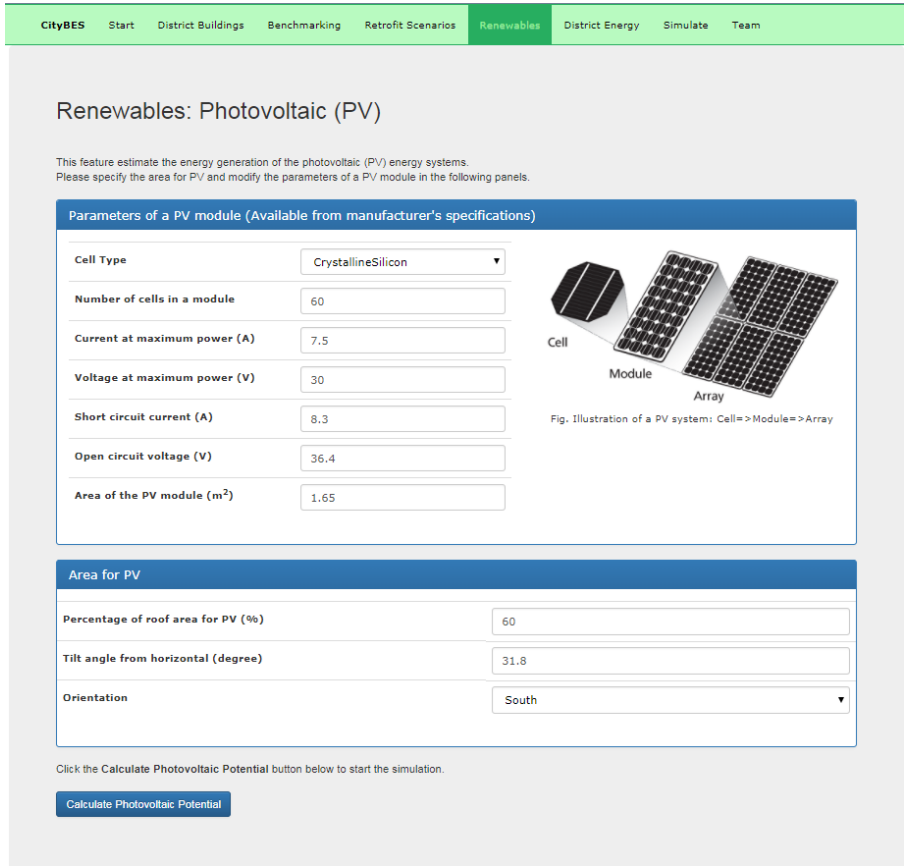


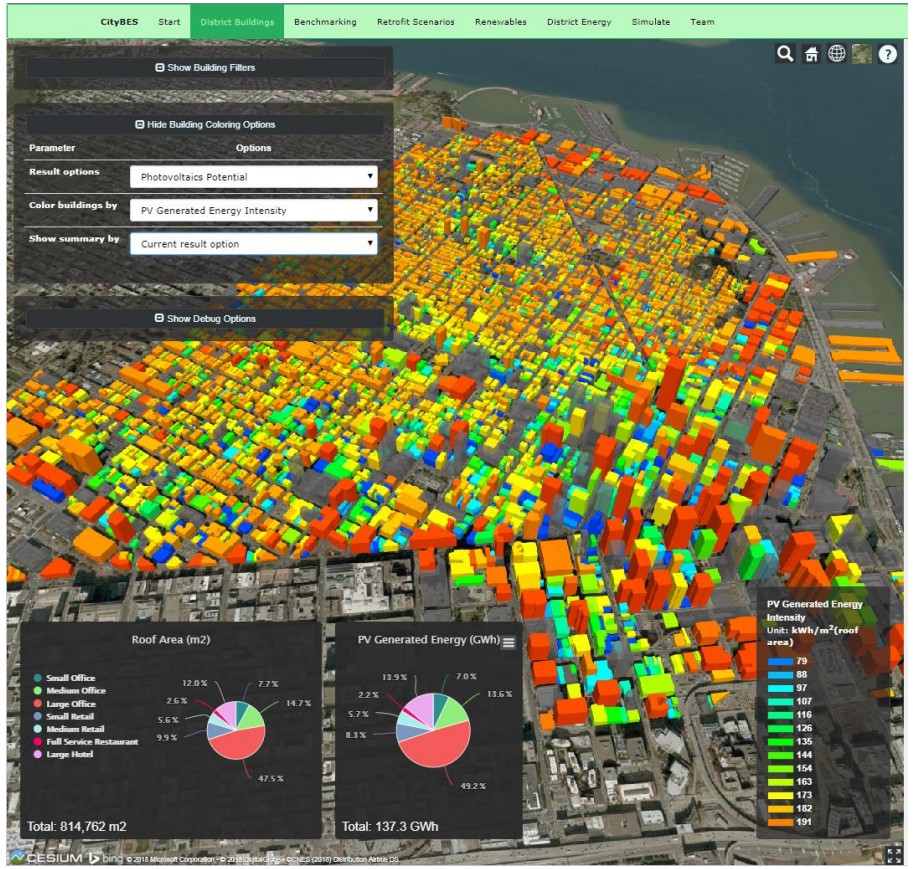
Visualize Building Energy from City Ordinance



https://citybes.lbl.gov/?sf_ecbo=1

Evaluate Photovoltaic Potential

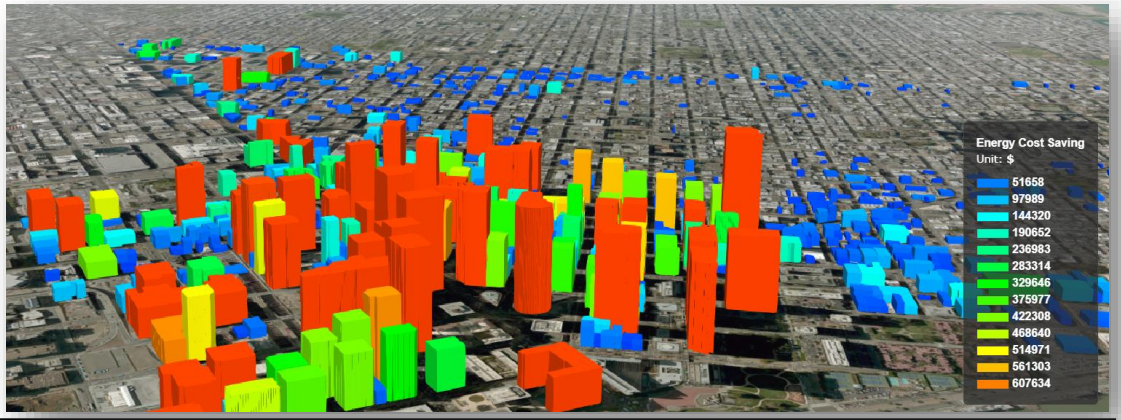


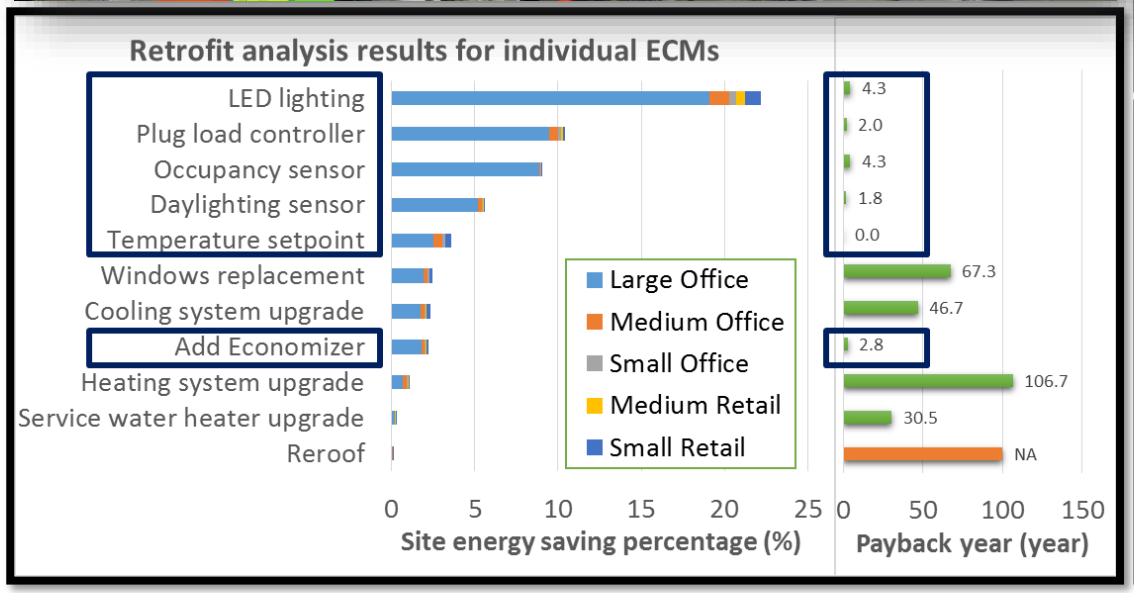


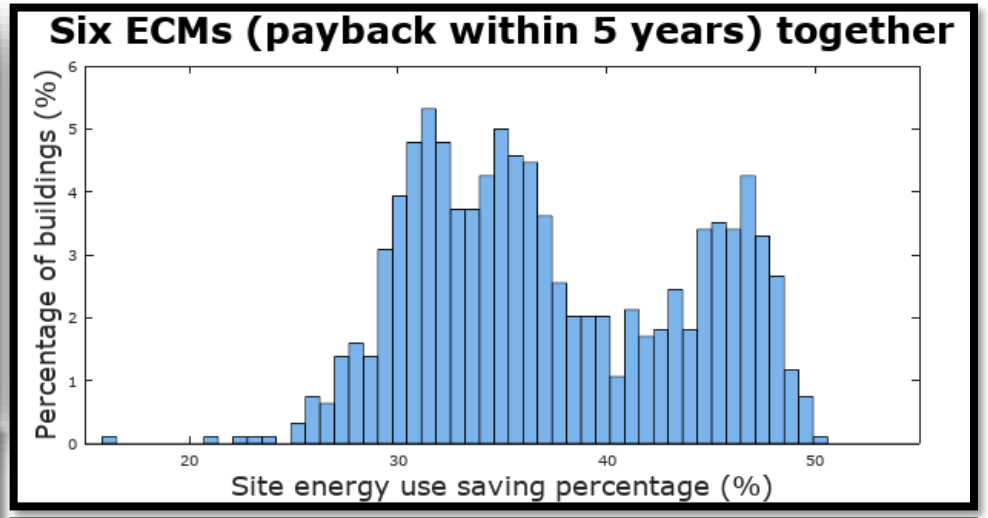
Evaluate the photovoltaic potential of 8,665 buildings in Northeast San Francisco

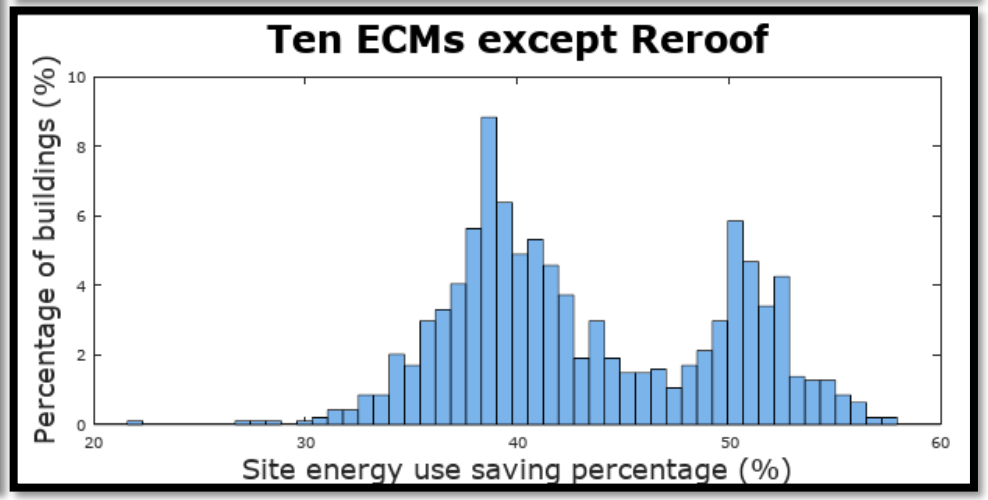
Evaluate building retrofits at large scale:

940 office and retail buildings in Northeast San Francisco

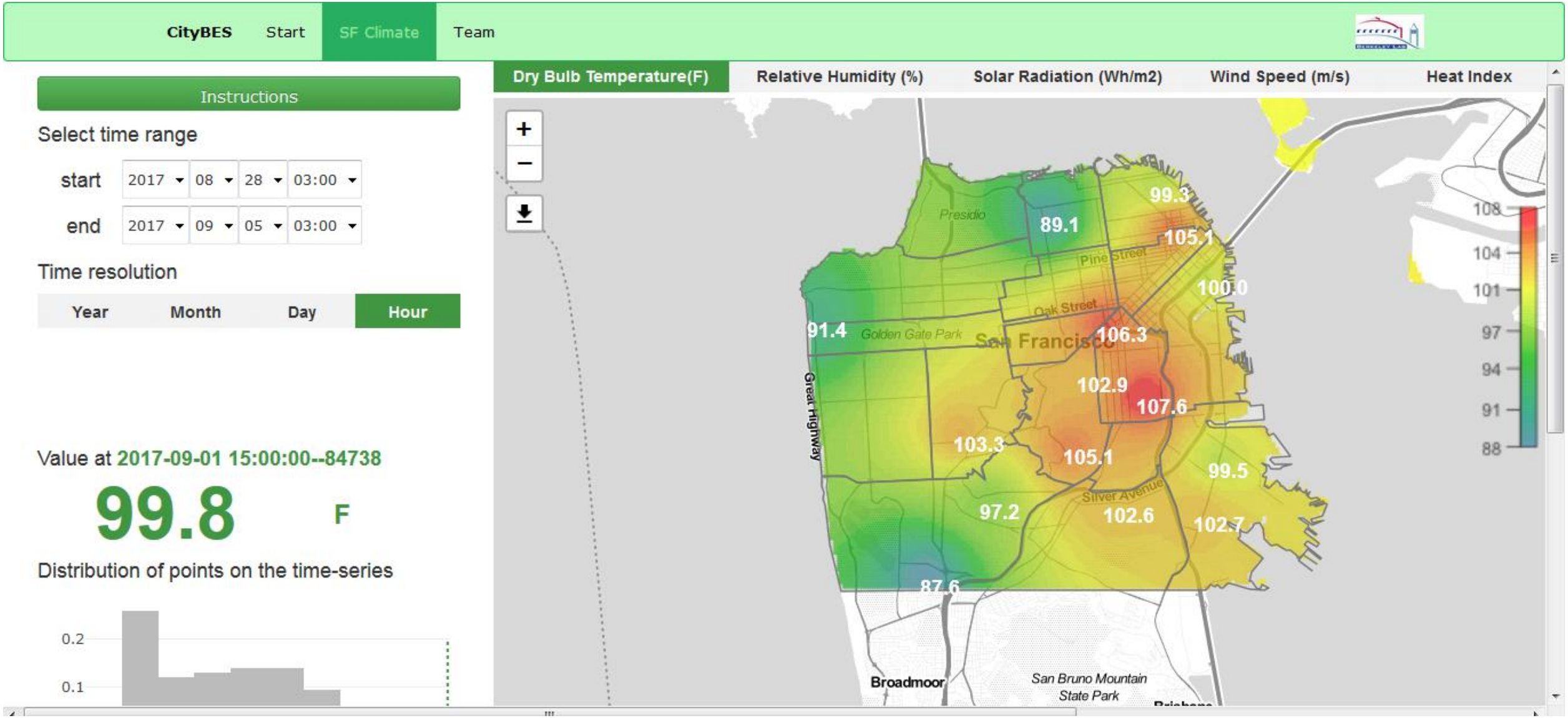








Visualize San Francisco Climate



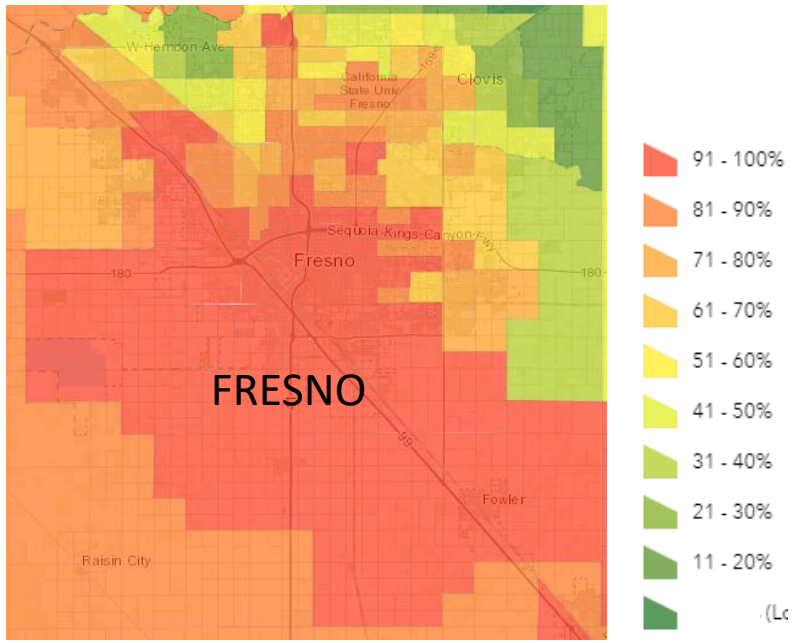
CAL-THRIVES: *A California Toolkit for Heat Resiliency in Vulnerable Environments*

- A project funded by the California Strategic Growth Council
- Project location: Fresno, California
- Partners: West Fresno Family Resource Center, Indicia Consulting, USC

CALIFORNIA STRATEGIC GROWTH COUNCIL

CALIFORNIA CLIMATE INVESTMENTS
Cap and Trade Dollars at Work

CalEnviroScreen 3.0 Results



Note: Higher score is more disadvantaged community

Project Objectives:

- Increase resilience to heat waves in vulnerable disadvantaged communities
- Provide tools and resources that help local governments, communities, and utilities
- Incorporate community needs and inputs throughout the project

Technologies and Strategies:

- Assess viable passive cooling measures
- Assess viable, low-GHG active cooling measures
- Map extreme heat vulnerability within the disadvantaged communities
- Improve efficacy of cooling shelters

Data-driven Urban Energy (DUE-) - Simulation (S), Benchmarking (B), Analytics (A)

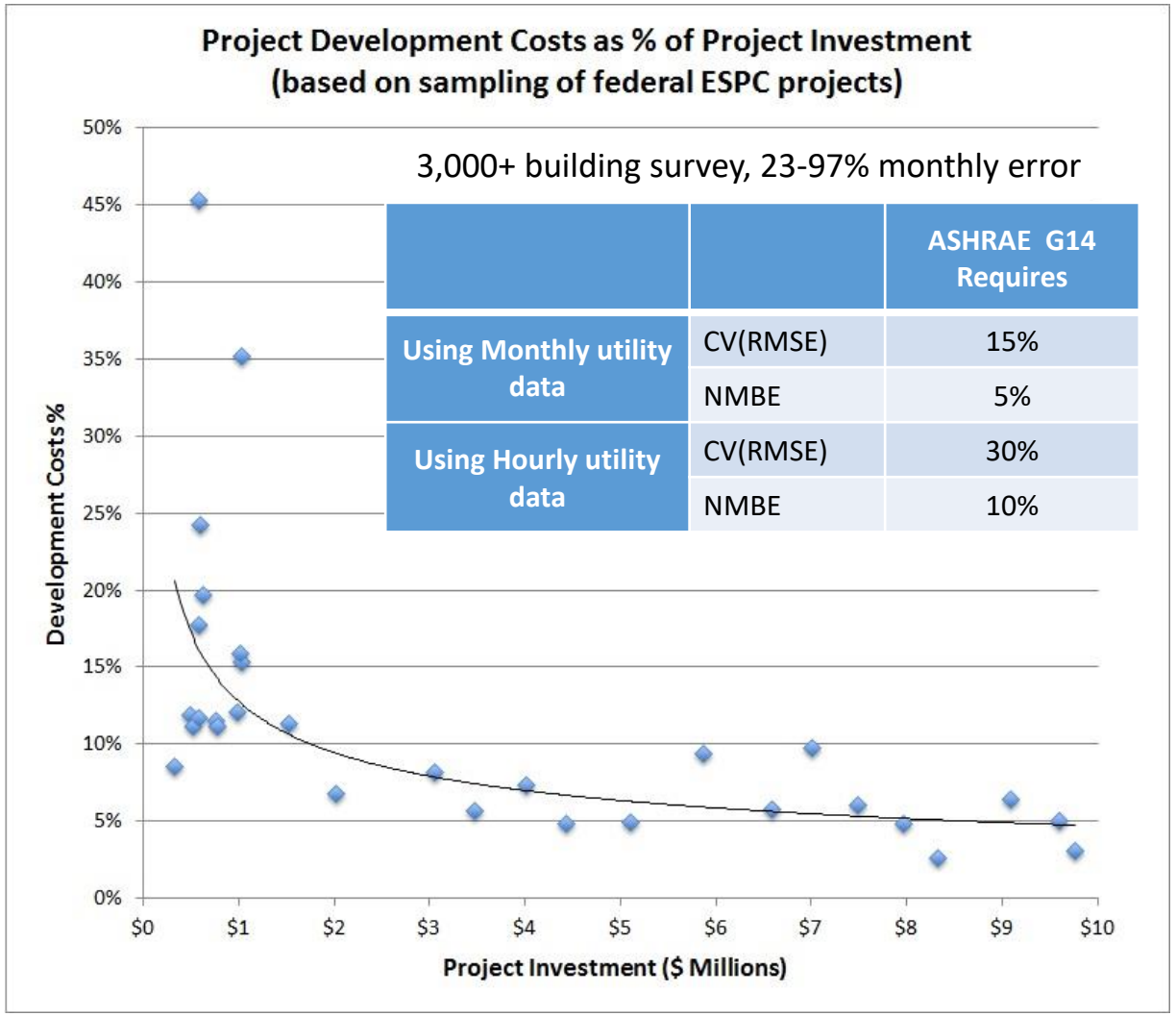
Rishee Jain *Stanford University*

Digital Twin – a virtual utility for analyzing building energy

Joshua New *ORNL*

Building Energy Modeling

- Option D (BEM) only used in **~8%** of federal performance contracts
- Only cost-effective for large projects **(>$2 million**)
- What about **cities**?



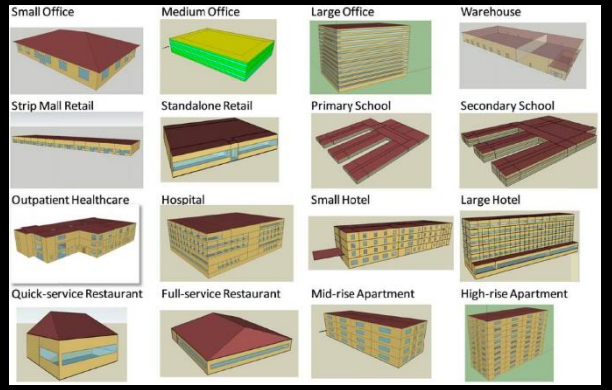
		ASHRAE G14 Requires
Using Monthly utility data	CV(RMSE)	15%
	NMBE	5%
Using Hourly utility data	CV(RMSE)	30%
	NMBE	10%

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

Goal: Stimulate private sector activity for efficient buildings

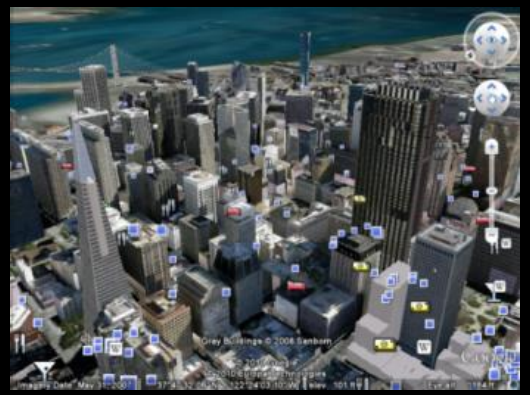
1. Extract important inputs from available data

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

Overview of data and software

- 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

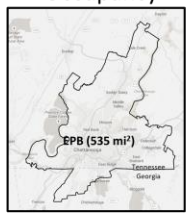
- Imagery (satellite, aerial)
- Street-level imagery
- Cartographic layers
  - Elevation, GIS
- Tax assessors
- Ranking of descriptors EE and Demand impacts (281–4,617 per building type)

Data comparison matrix

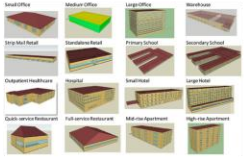
	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
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 km² of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A

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

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

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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 energy (kWh) and demand/peak-shaving (kW) 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
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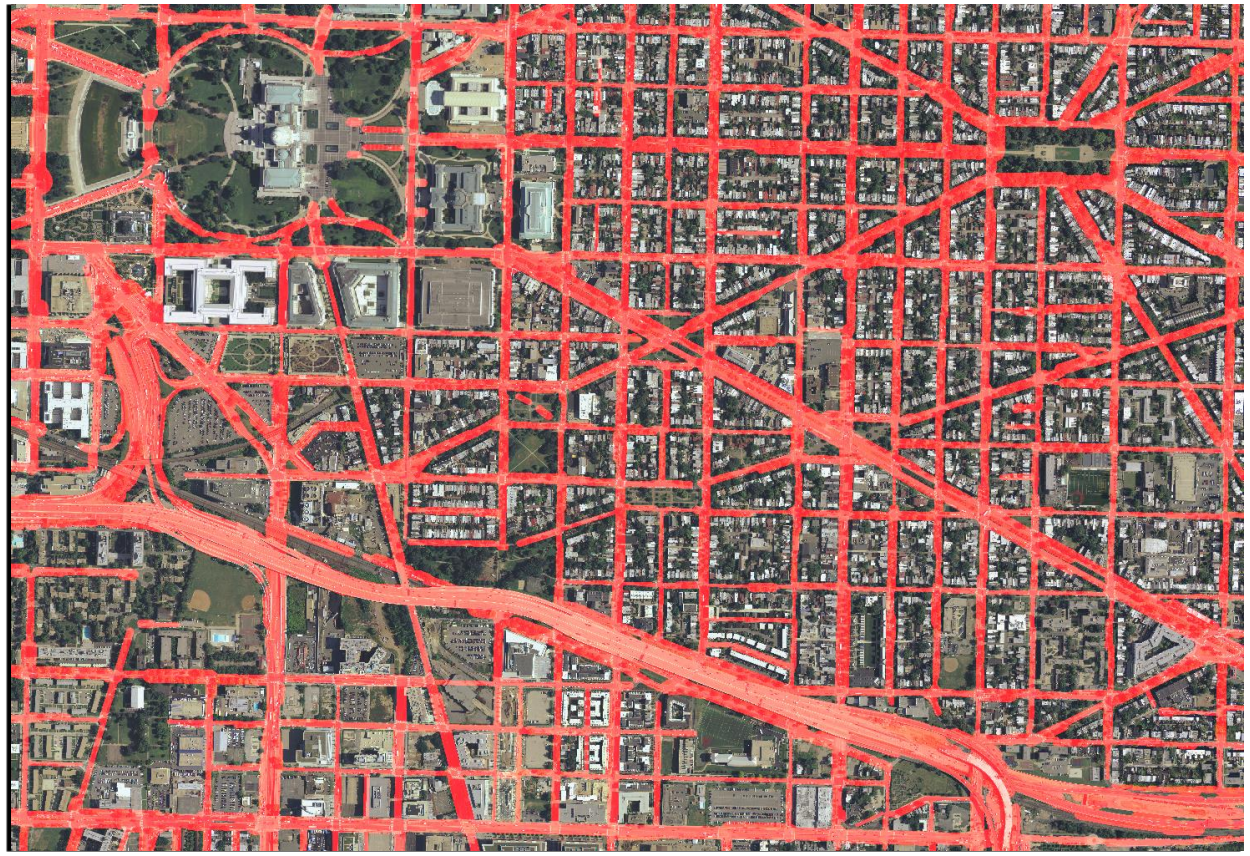
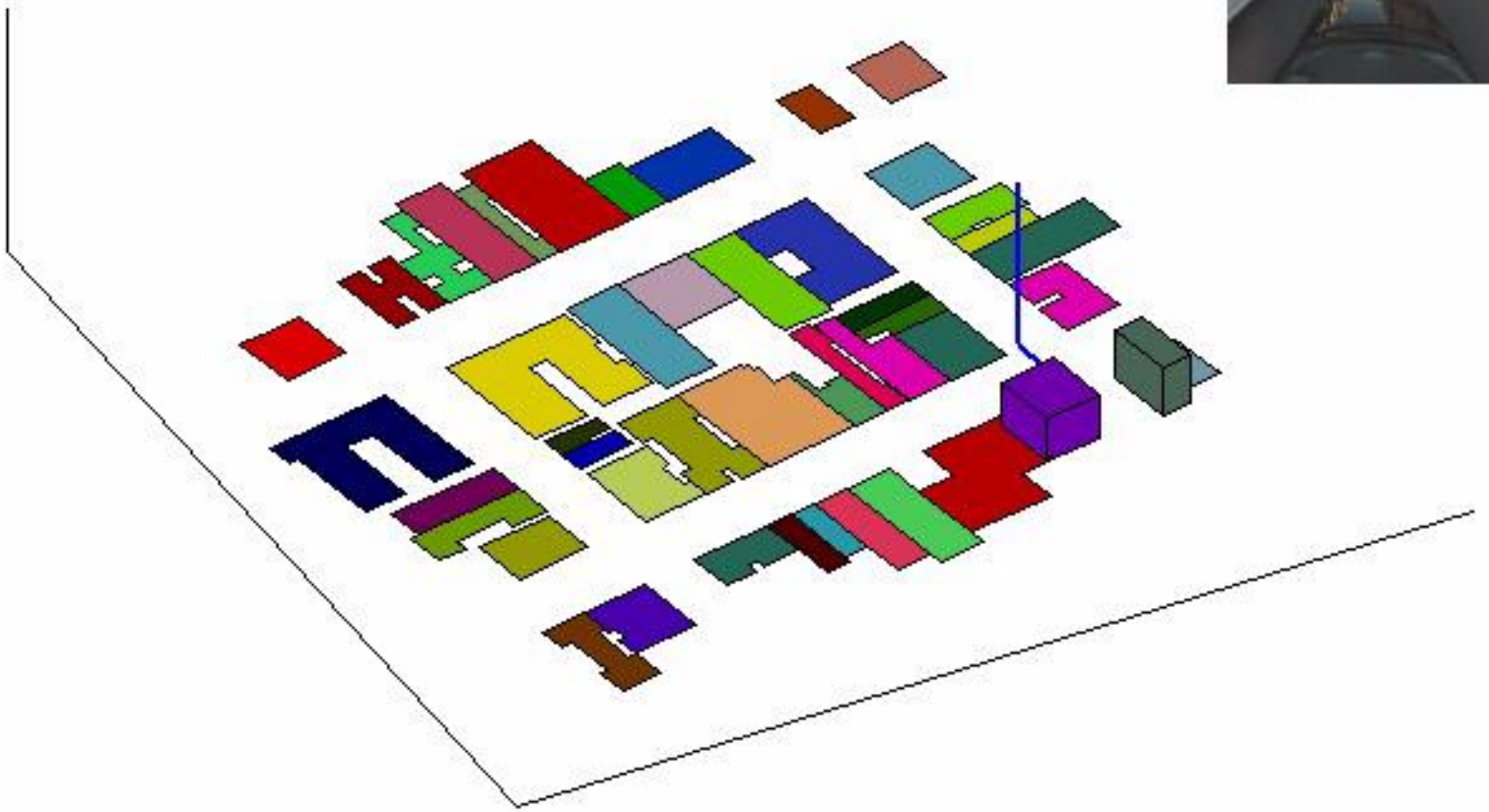
Coverage of US	Over 10 million km^2 of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A
Comments	

Computer Vision for DC

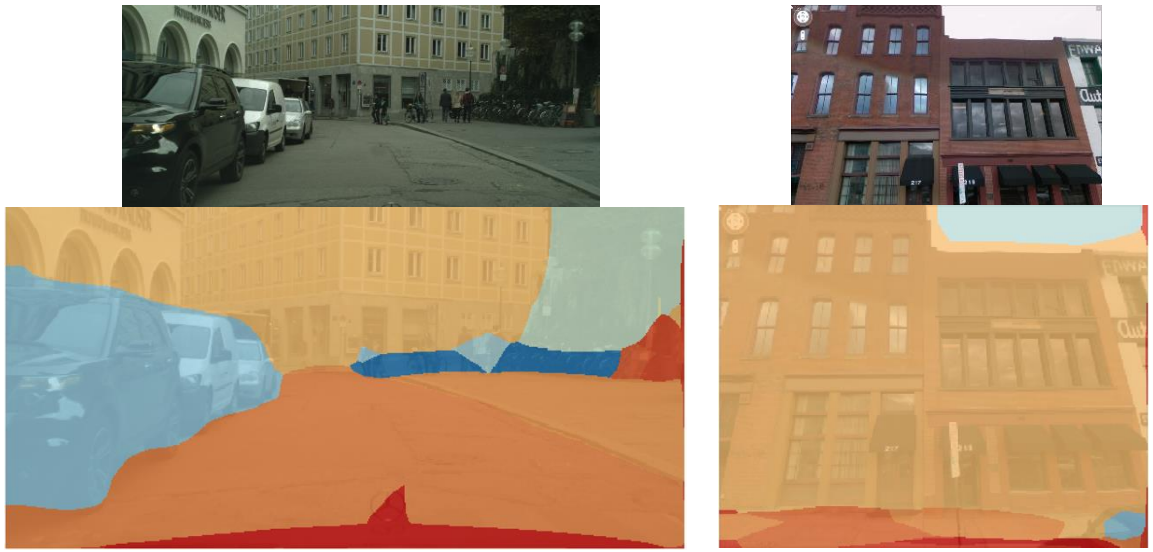


Open Competition Precision/Recall – 30/35
ORNL Current Precision/Recall – 60+/60+

Street-level Image Processing (height)

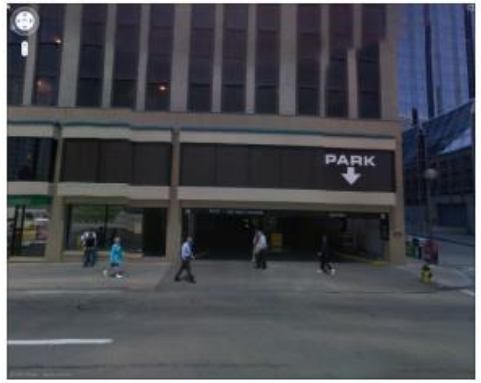


Street-level details

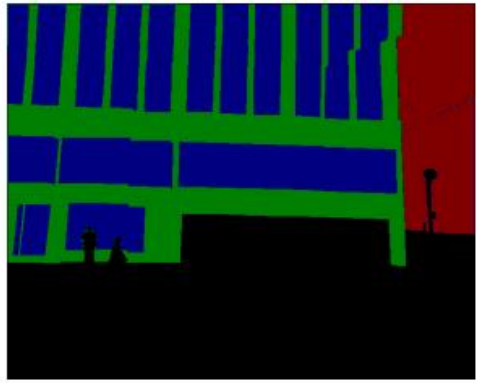


Façade Type

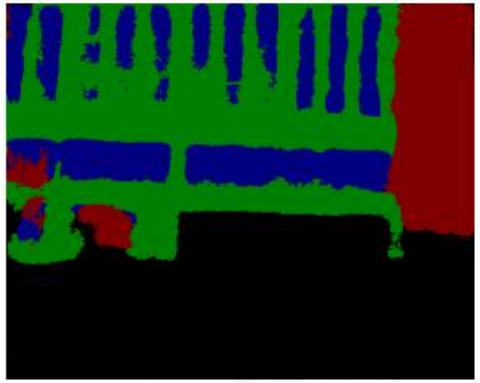
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)



Input image



Ground truth



Model output

Window-to-wall ratio

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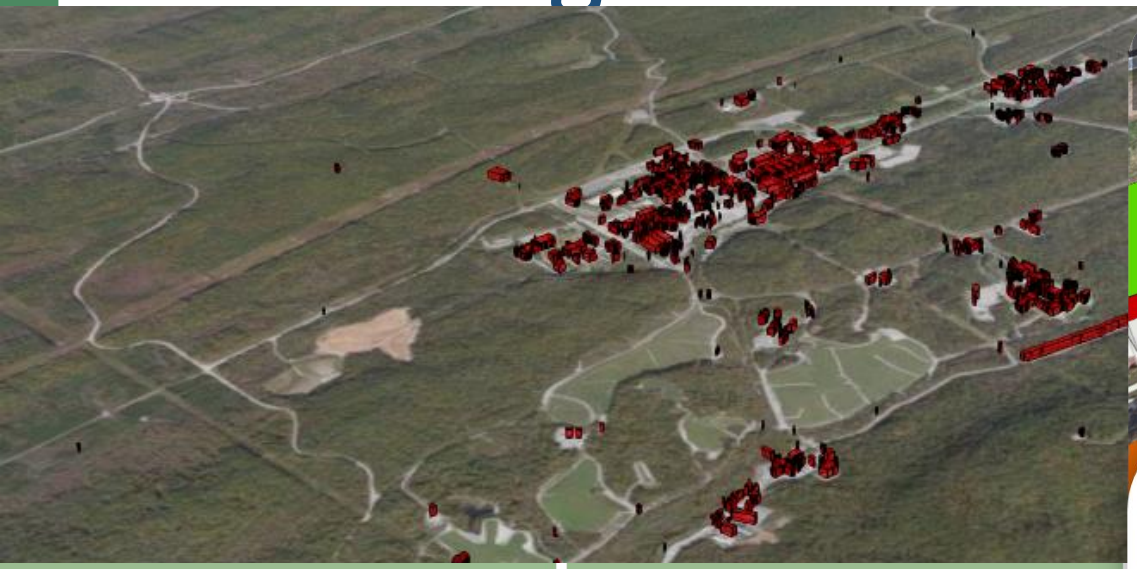
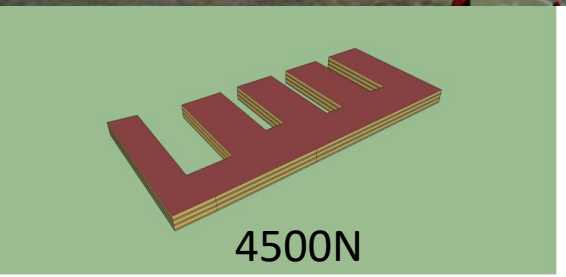
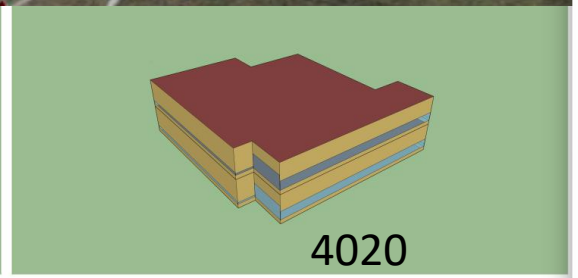
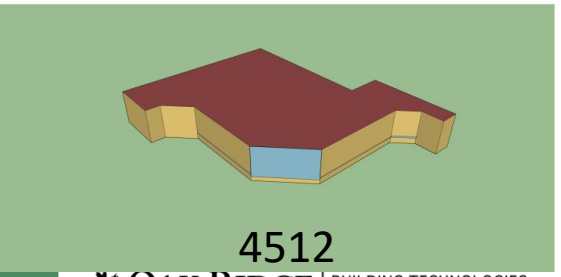
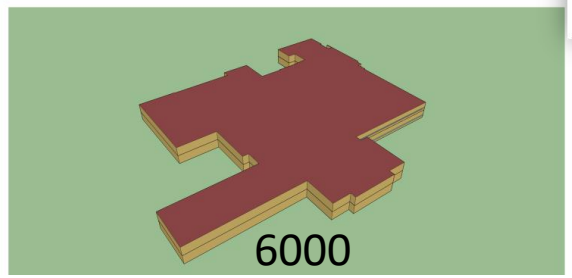
Oak Ridge National Laboratory

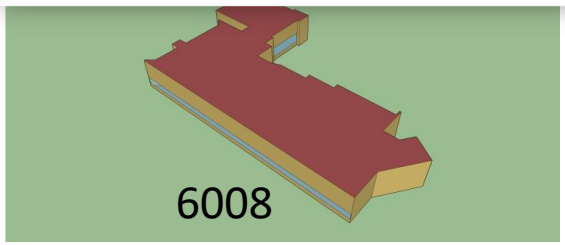










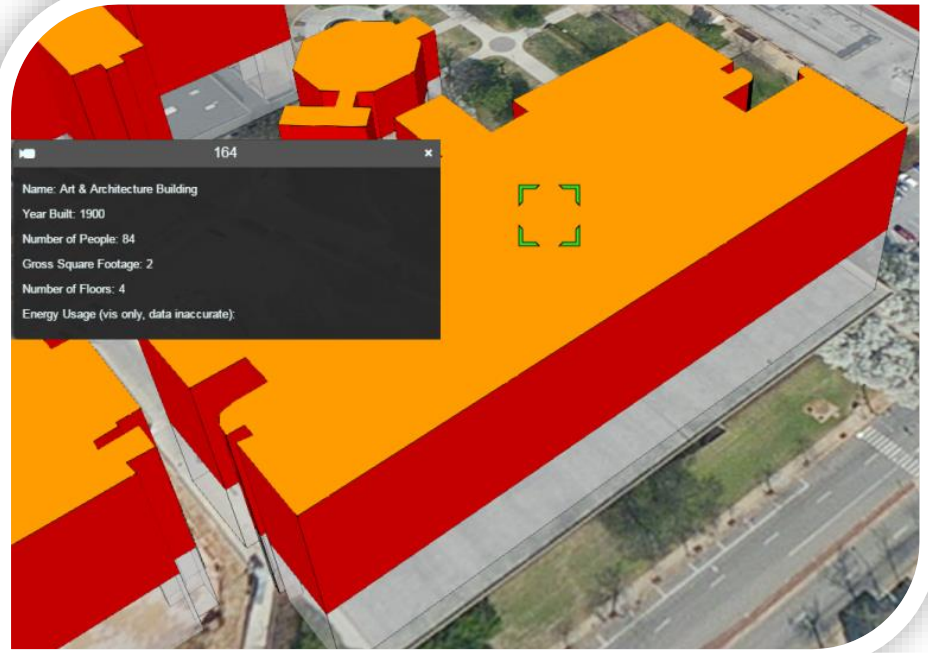


bit.ly/ornl_buildings

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

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

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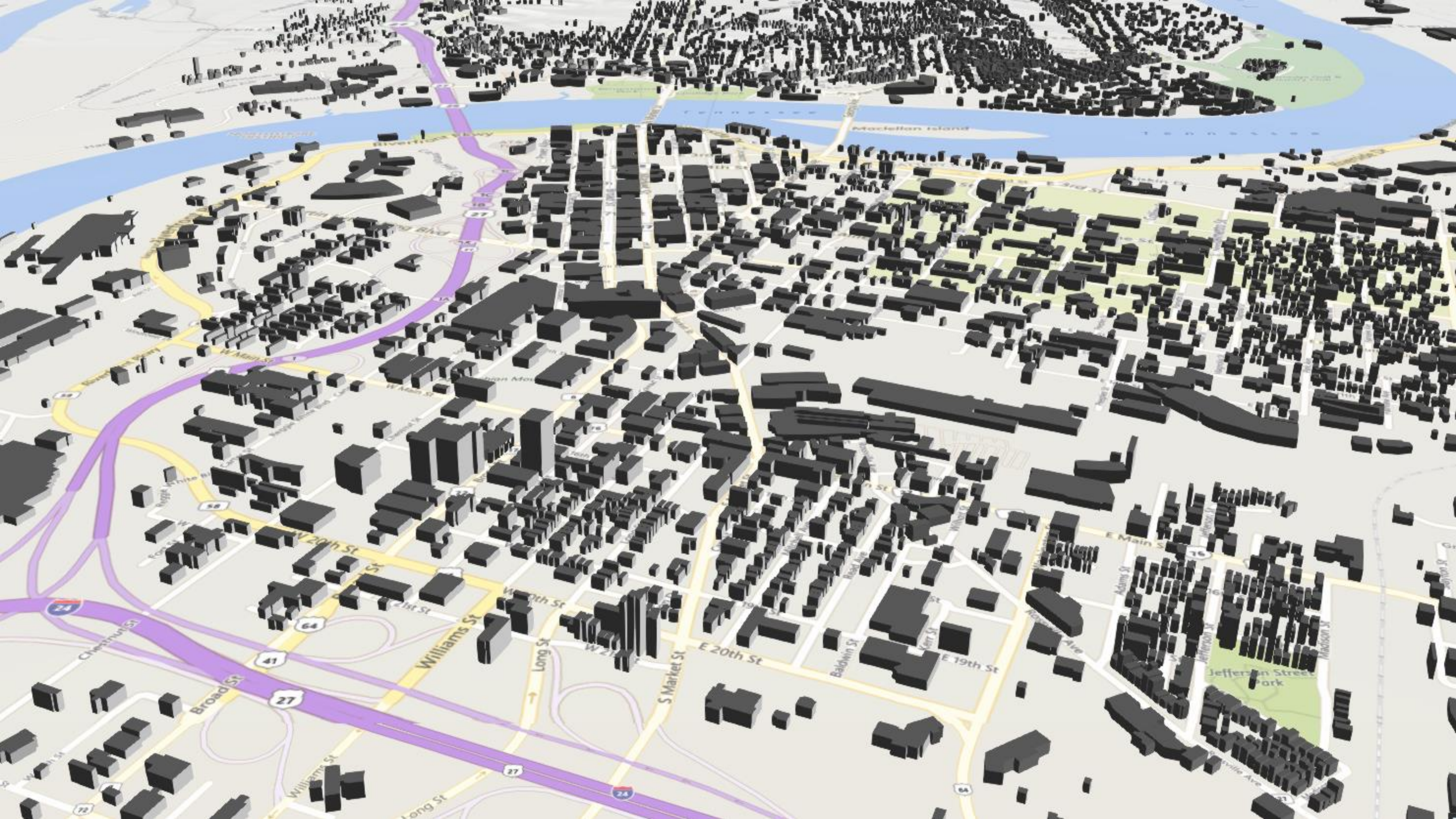


Maclellan Island
E Main St
W Main St
W 20th St
E 20th St
E 19th St
S Market St
Long St
Williams St
Broad St
Chestnut St
Baldwin St
Adams St
Jefferson St
Madison St
Jefferson Street Park
24
27
41
64
58

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

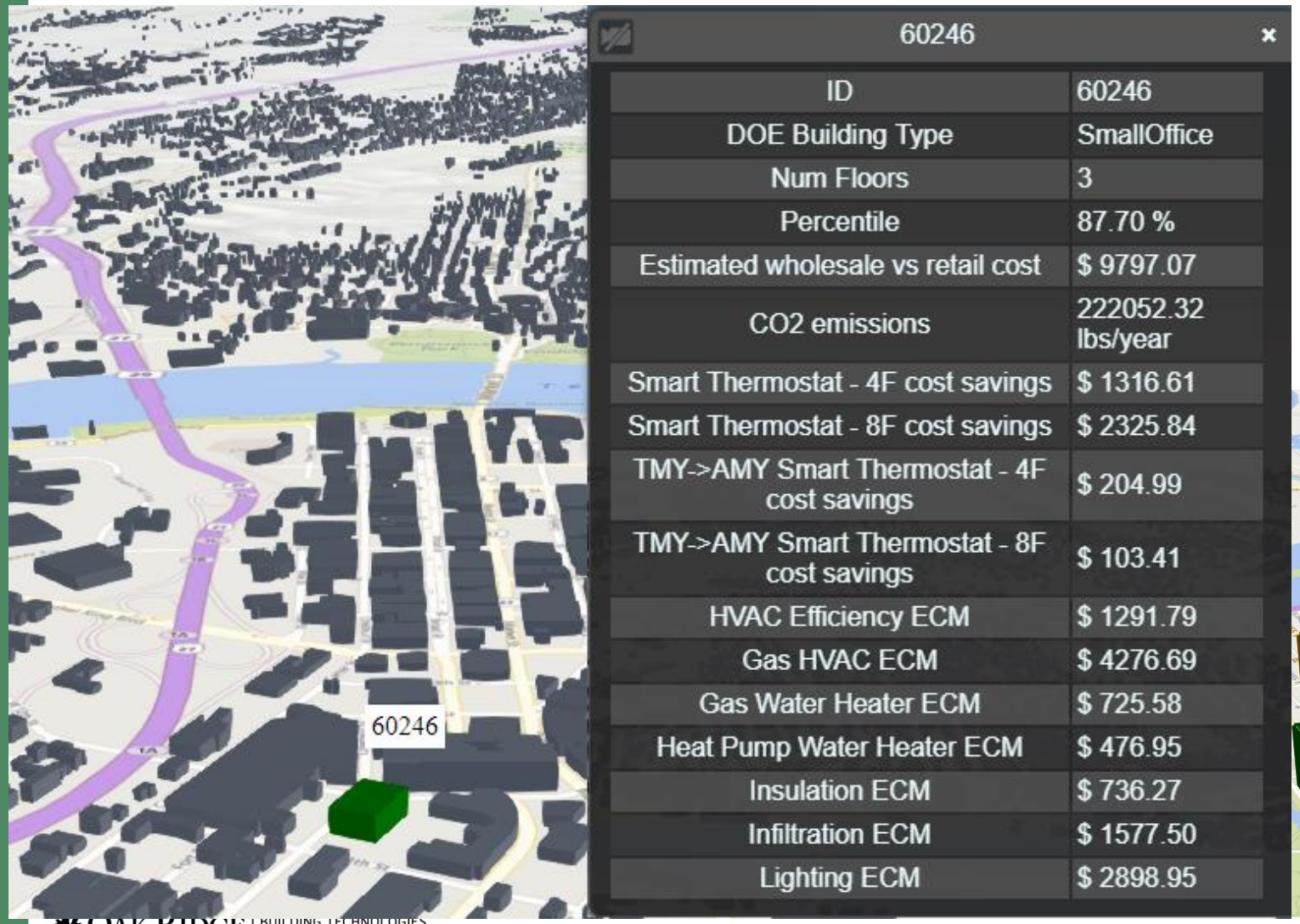
QA/QC: will show how close our simulations are to 15-min data

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)

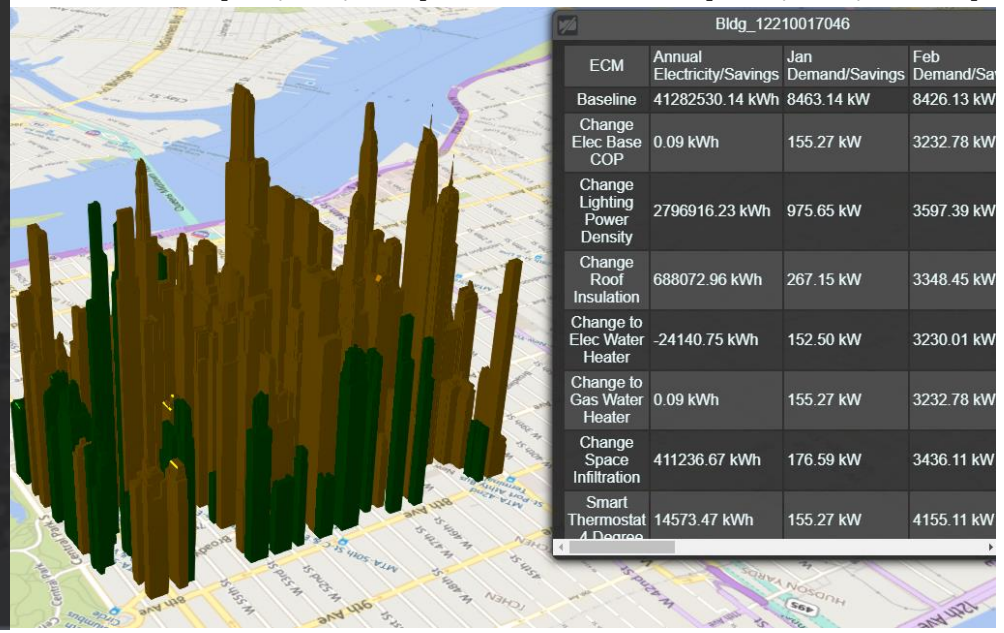
Virtual Utility – interactive results



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]



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

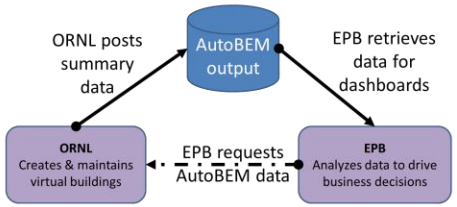
Accuracy compared to 15-minute data

- 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



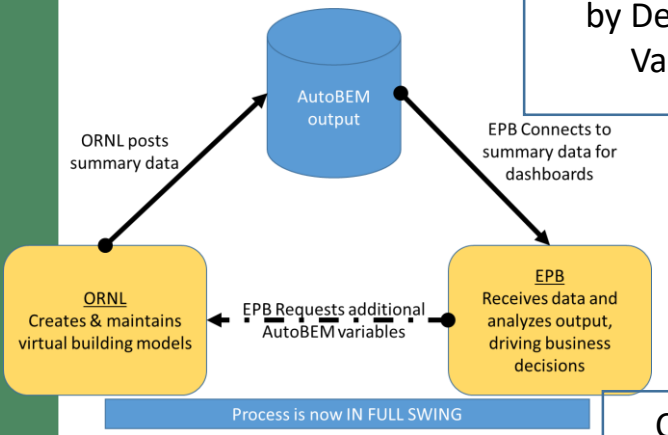
Measures

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

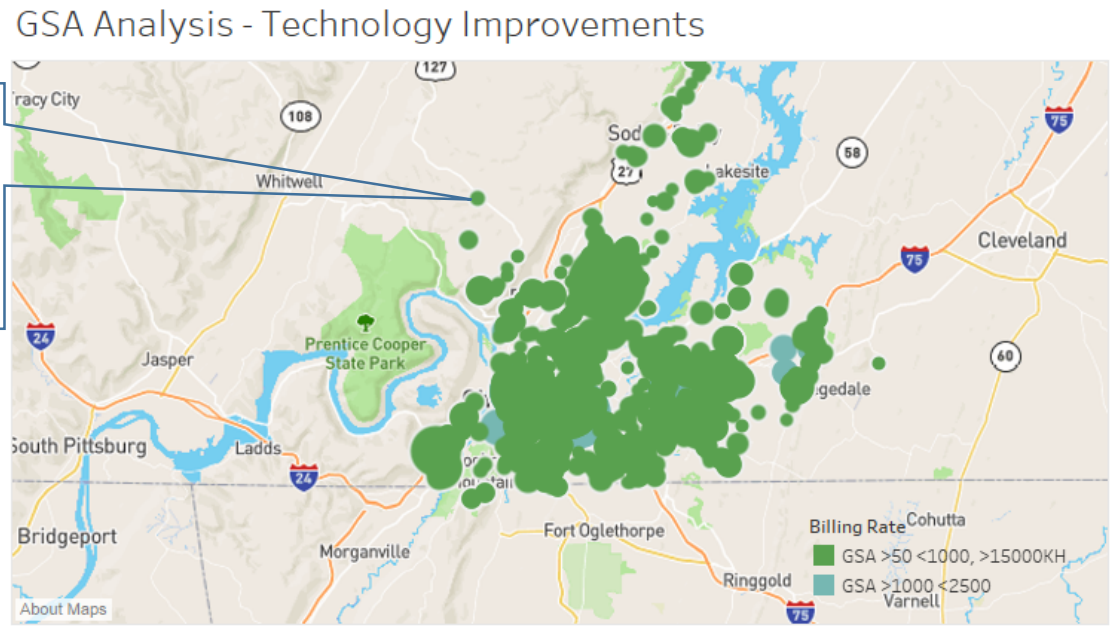
Result: $11–35 million/year in potential savings identified via simulation-informed data and valuation for *energy, demand, emissions, and cost impact* to EPB and each customer for each building under five use cases covering nine monetization scenarios

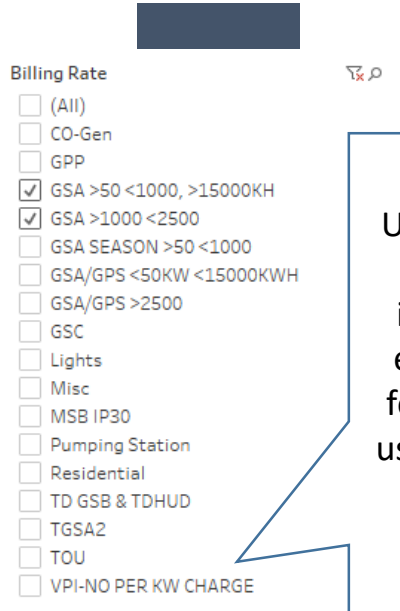
[1]Garrison, Eric, New, Joshua R., and Adams, Mark (2019). "Accuracy of a Crude Approach to Urban Multi-Scale Building Energy Models Compared to 15-min Electricity Use." Best PhD Student Paper award. In *Proceedings of the ASHRAE Winter Conference*, Atlanta, GA, Jan. 12-16, 2019. [PDF] [PPT]

Virtual Utility Integration



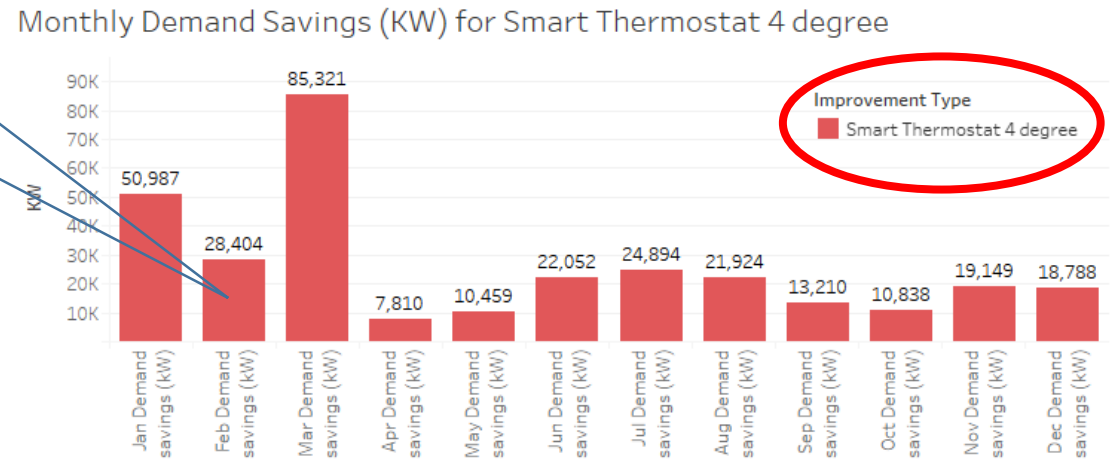
Map showing premises, sized by Demand Value

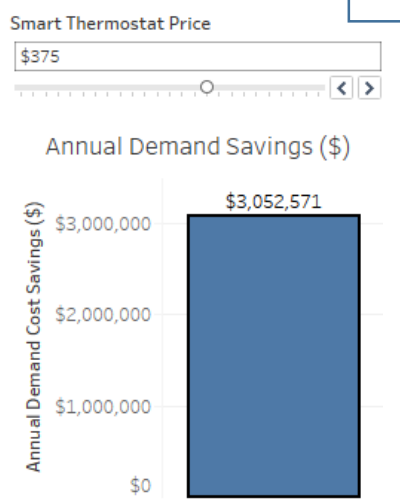




Use of filters create an interactive experience for business users, driving business decisions

Chart showing monthly demand value





Tech Commercialization Fund with Google

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

AutoBEM ROM Estimates

Cost estimation*:

- $50,000/building - Typical cost of walkthrough audit and model creation (medium size and complexity)
- $5,000/building – high-fidelity model creation and visual analytics incorporating street-level imagery
- $900/building – AutoBEM model creation and visual analytics
- $7/building – Utility-scale AutoBEM model creation and visual analytics

*this is only a ROM estimate. Final costs are determined by the funding mechanism, applicable overhead rates, and the final statement of work. Strategic Partnership Projects (SPPs), formerly known as Work For Others (WFO), recommends $50,000 minimum per project.

URBANopt: An Open Source Software Development Kit For Urban Energy Modeling

Ben Polly *NREL*

Urban building energy modeling methods

Christoph Reinhart *MIT*

Panel Discussion

- **Modeling approaches: physics vs data-driven**
- **3D city models: data and standards; interoperability**
- **Multi-physics co-simulation: tight vs loose coupling**
- **Uncertainty: quantification and reduction**
- **Multi-scale: city block, district, neighborhood, city, urban area**

Questions and Discussion

Tianzhen Hong	*Lawrence Berkeley National Laboratory*
Rishee Jain	*Stanford University*
Joshua New	*Oak Ridge National Laboratory*
Ben Polly	*National Renewable Energy Laboratory*
Christoph Reinhart	*MIT*

Lawrence Berkeley National Laboratory

Stanford University

Oak Ridge National Laboratory

NREL National Renewable Energy Laboratory

Massachusetts Institute of Technology

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