Nation-scale building energy modeling, climate change, and potential grid impacts

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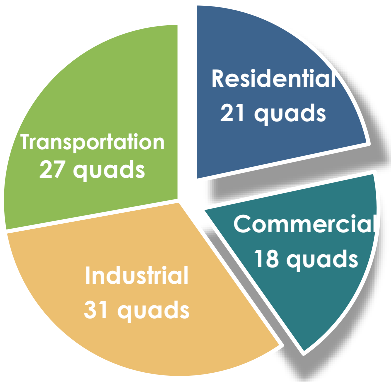
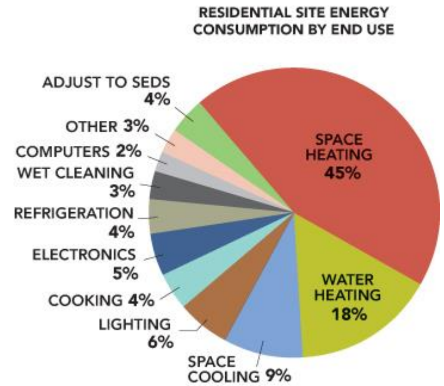
U.S. Energy and Buildings Overview

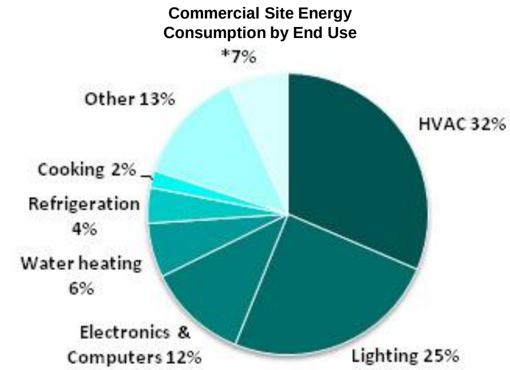


40% energy use
39% emissions

125 million buildings

$412 billion
in 2019 energy bills





Buildings consume 73% of the nation's electricity
80% of energy during peak hours

 # Buildings: 96% residential **4% commercial**
Energy use: 54% residential **46% commercial**

Goal of the DOE Building Technologies Office:
30% energy reduction per sq. ft.
by 2030 compared to 2010 baseline

Office of Electricity vision:
Harness innovation for a stronger, more resilient and reliable North American energy system while maintaining energy independence.

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

Grid-interactive Efficient Buildings (GEB) Vision: integration and continuous optimization of DERs for the benefit of building owners, occupants, and the grid.

Computational tools

Simulation Engine and Analysis Platform
U.S. Dept. of Energy
$100+M, 1995–?

EnergyPlus

OpenStudio

Free, open-source (GitHub), free support
100 – 2,000 improvements per building

Theta is the world's fastest buildings energy model (BEM) simulator

>500k building simulations in <1 hour

130M US buildings could be simulated in 2 weeks

8M simulations of DOE prototypes (270 TB)

ALCC: 19.2M core-hours awarded
1,068,813 bldgs/hr
6 EPBs per hour

Titan supercomputer

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
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

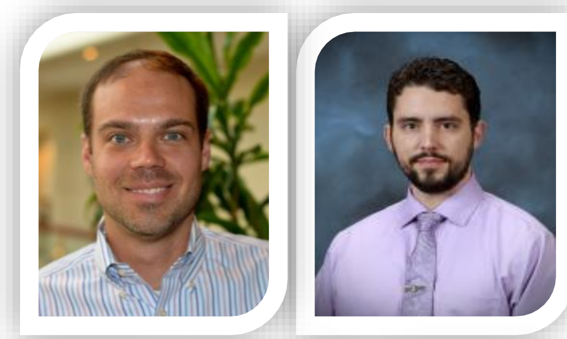
Theta supercomputer

CPU Cores	Wall-clock Time (mm:ss)	Data Size	EnergyPlus Simulations
57,344	20:44	440 GB	229,376
114,688	$\boxed{28:20}$	880 GB	$\boxed{458,752}$

OAK RIDGE National Laboratory

Acknowledgements

- EPB/ORNL partnership
- U.S. Department of Energy
  - EERE/Building Technologies Office
  - Office of Electricity
  - National Nuclear Security Administration
- Oak Ridge National Laboratory

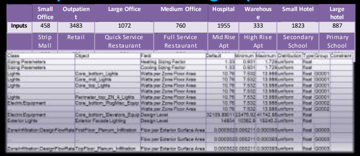


5-year vision

Digital Twin of every U.S. building in 2020

Methodology: Scalable compute, data, simulation, and empirical validation

1. Quantitatively rank most important building inputs

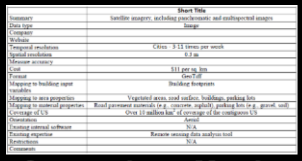


Sensitivity Analysis

2. Time on world's #1 fastest high-performance machines

Supercomputers

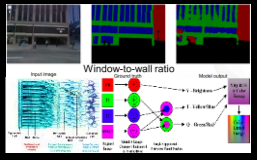
3. Identify and compare data sources for important inputs



Comparison Matrix

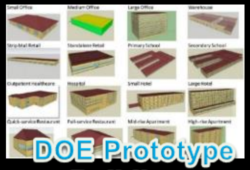
4. Establish partnerships and APIs for scalable data retrieval

5. Algorithms to extract building properties

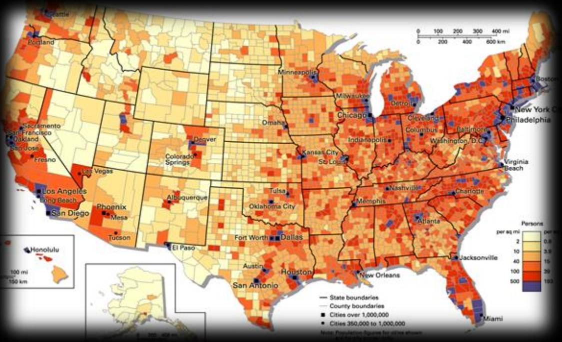


Computer Vision

6. Create OpenStudio & EnergyPlus models



DOE Prototype Buildings

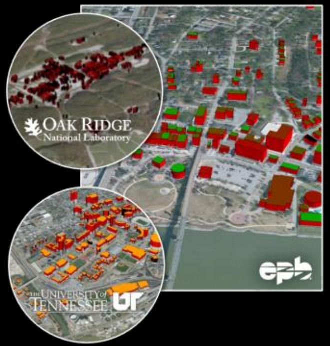


7. Make models freely available

Download BEM via street address

HPC Tools for Modeling and Simulation

Capturing building energy consumption



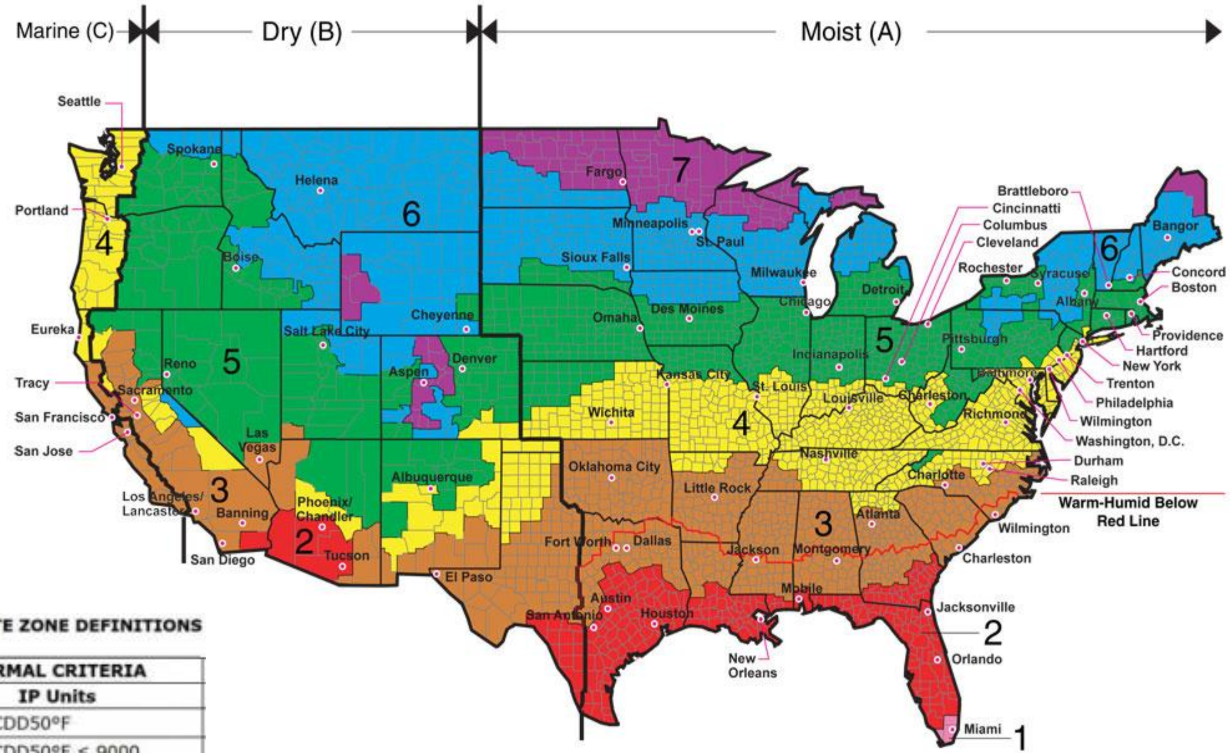
Demonstrate and stimulate opportunities toward a sustainable built environment

Use cases:

- City-scale energy impacts
  - Google's Environmental Insights Explorer
- Simulation-informed analysis design
  - AIA 2030 – BEM in 64% of projects
    - BEM 64% projects, 75% of gross ft^2
    - No-BEM: 41% better CBECS 2003
    - BEM is 51% better than
  - SmithGroup, Bentley Systems
- Sales/marketing leads
- Utility program formulation
- Resilience
- Automated financing
- Business model evaluation

ASHRAE Climate Zones – every U.S. county

- Climate zones based on 18+ years of quality data from 8,000+ met stations
- Most state building codes based on weather data from 1961-1990
- Redefining climate zones, include trends



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)

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

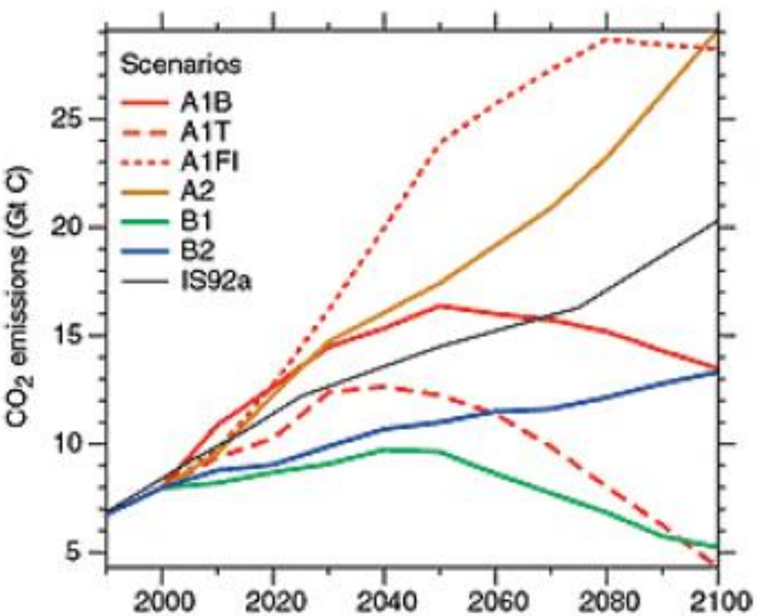
Updated every 4 years (2021)
Climate zones are moving north

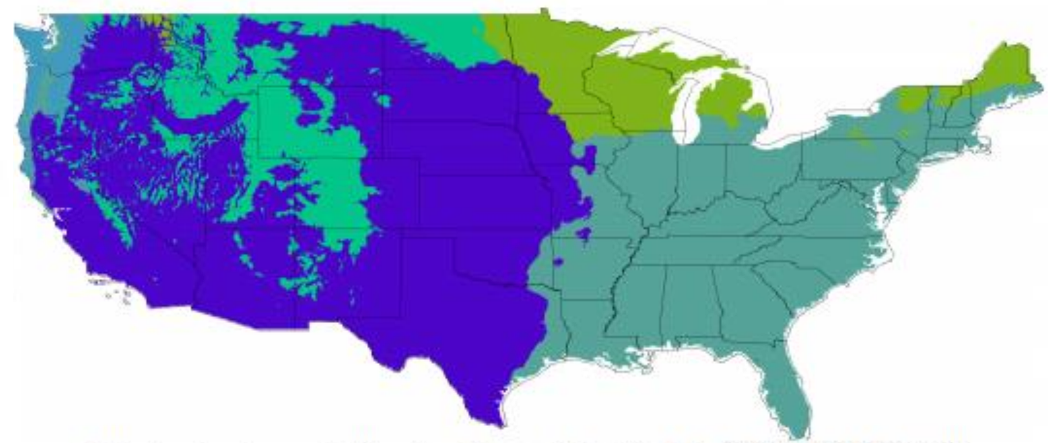
2017 - Climate Zone 0 (extremely hot):
10,800 < CDD 50°F
Int'l Energy Conservation Code (IECC)
adopts for 2018 code

Climate Change Impacts

Contemporary Period

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



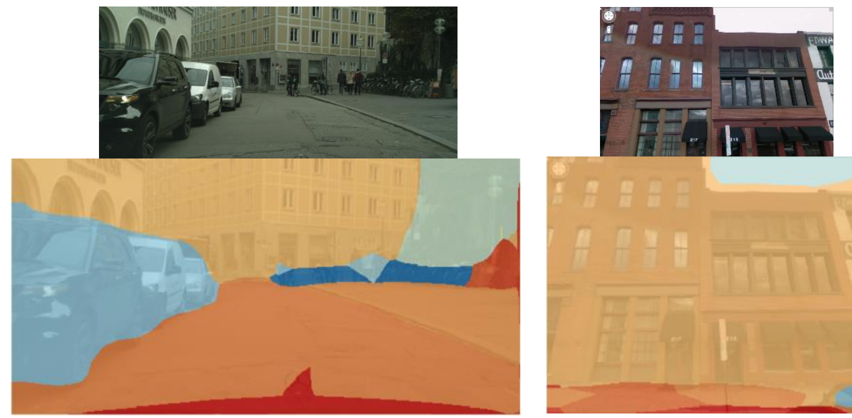


Clustering-based Climate Zones (K=5): HadGCM A1FI 2100

Computer Vision – street-level imagery

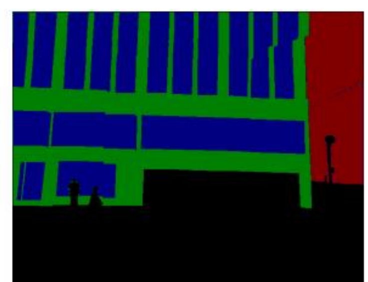
CV DEMO

Façade Type



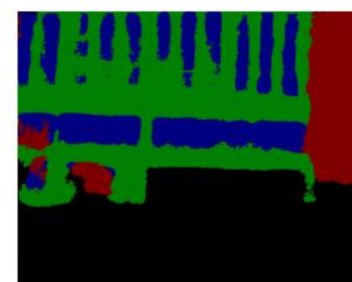
Windows (blue)
Façade (green)
Street/open (black)
Other building (red)

Input image



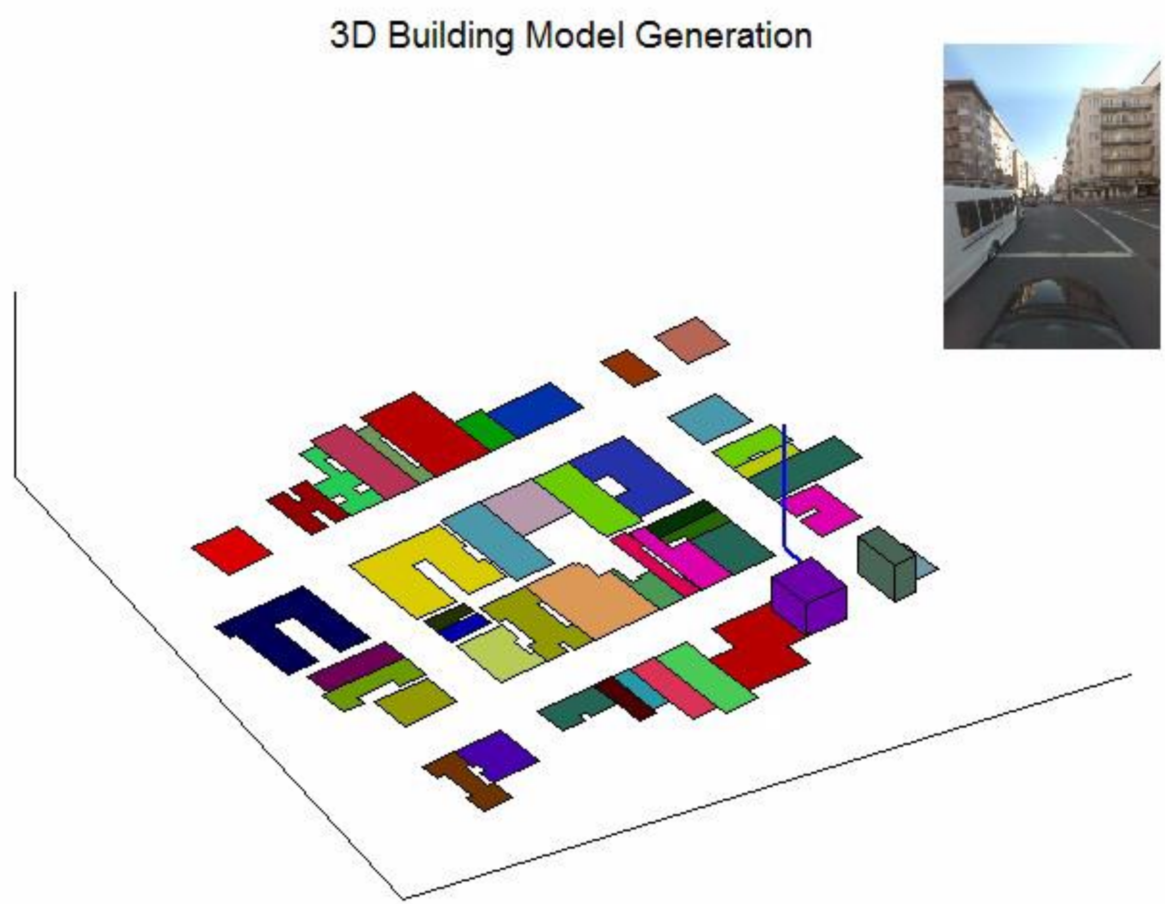
Window-to-wall ratio

Ground truth



Model output

Computer Vision – street-level imagery



Utility impacts

#	Description	Category	Value	Source
1	Insulate Roof	Envelope	R-16.12 to R-28.57	IECC-20
2	Reduce Space Infiltration	Envelope	Reduce 25% from vintage	EnergyS whole-h
3	Adjust Thermostat Setpoint (4F)	HVAC	4°F 2 hrs prior to peak	EPB
4	Smart Thermostat (8F)	HVAC	8°F 4 hrs prior to peak	EPB
5	Change Electric HVAC COP	HVAC	COP to 3.55 (heating) 3.2 (cooling)	IECC-20
6	Change Lighting Power Density	Lighting	LPD 0.85 W/ft^2	IECC-20
7	Change to Gas Water Heater	Water	Efficiency 80% (assumes electric)	IECC-20
8	Change to Gas HVAC	HVAC	Efficiency 80% (assumes electric)	IECC-20

Supercomputing at scale

EnergyPlus

ALCC: 19.2M core-hours awarded
1,068,813 bldgs/hr
6 EPBs per hour

Tools at (HPC) scale

- 1M/hr for larger geographic scales
- HPC clustering (fastest c-means)
- Several optimization frameworks
  - Cost, energy, ?
- Control optimization (with controls)
  - EnergyPlus -> SOEP
  - Grid-interactive Buildings (GEB)
  - AI for buildings
  - DEI for data and applications

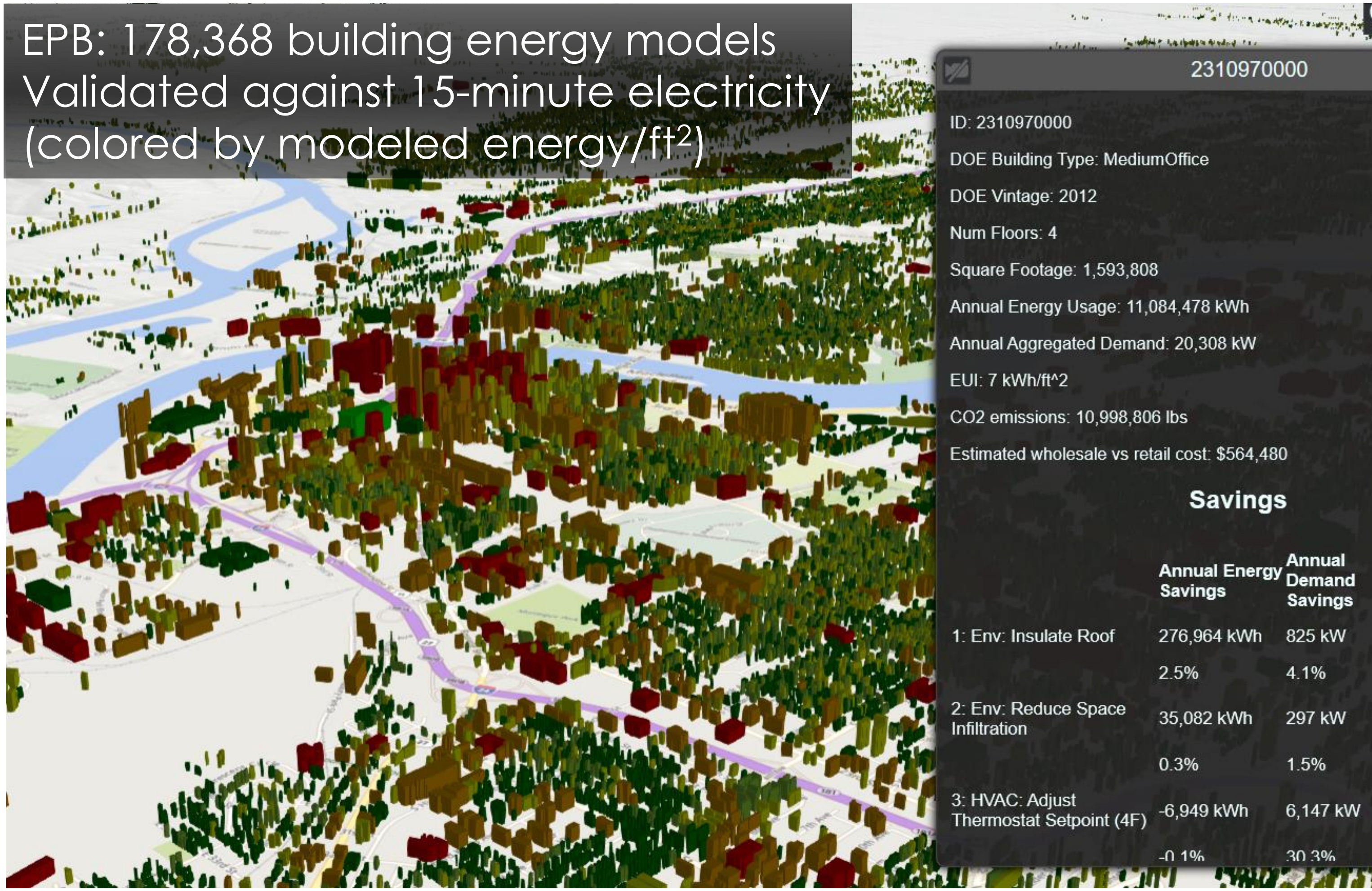
ALCF's Theta

CPU Cores	% HPC	Wall-clock Time (mins)	# Buildings Annual Sim	Data Size (zipped)
114,688	40	121.57	917,504	14.9 GB
140,544	50	109.59	1,124,352	18.3 GB
168,704	60	122.1	1,349,632	22.0 GB
193,920	69	121.6	1,551,360	25.3 GB
224,896	80	79.7-122.3	1,799,168	29.3 GB

Digital Twin: Energy, Demand, Emissions, $ Savings

Results: Digital Twin of a Utility (every building)

EPB: 178,368 building energy models
Validated against 15-minute electricity
(colored by modeled energy/ft²)



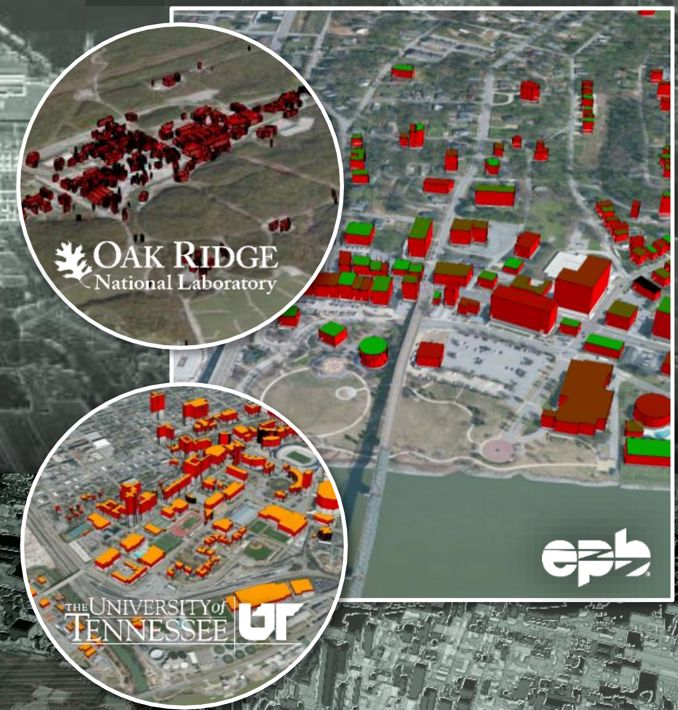
http://bit.ly/virtual_epb

Nation-scale…

- **A model of every U.S. building.**
- 125,714,640 buildings (Google), 124,178,694 (98.8%) simulated (not released), 122,930,327 (97.8%) shared
- OpenStudio (v3.1.0) and EnergyPlus (v9.4)
- 45 million core-hours on Argonne's Theta supercomputer
- Automatic Building Energy Modeling (AutoBEM) software
  - Related publications: bit.ly/AutoBEM
- Get state_county.zip here (free Globus Connect Personal):
  - New, Joshua R., Adams, Mark, Bass, Brett, Berres, Anne, and Clinton, Nicholas (2021). "Model America – data and models of every U.S. building." ORNL Constellation, https://doi.ccs.ornl.gov/ui/doi/339, April 14, 2021.

Discussion

HPC Tools for Modeling and Simulation
Capturing building energy consumption



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