Digital Twin of a Utility: Beyond Urban-Scale Building Energy Modeling

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Presented at: ETSD's June "Energy Talks"

June 11, 2020

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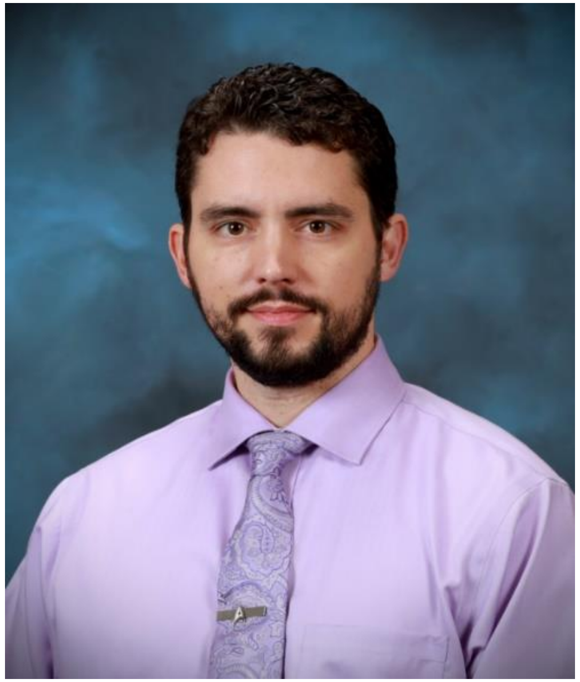
- **Career**
  - 2009+ Oak Ridge National Laboratory, R&D staff
    - ETSD, Building Technology Research & Integration Center (BTRIC), Building Integration & Control Research Group
    - Climate Change Science Institute, Urban Dynamics Institute
  - 2012+ The University of Tennessee, Joint Faculty
- **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

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Overview

- Context: ORNL's program, sponsor missions, why buildings?
- Buildings subprogram "Software Tools and Models" project overview
- Virtual EPB project (Electric Power Board of Chattanooga, TN)

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ORNL's BTO Subprogram Managers

EERE/Building Technologies Office (BTO)

- Building Energy R&D
  - Equipment HVAC&R, Appliances
  - Windows & Envelope
  - Buildings-to-grid
  - Modeling
  - Lighting
- Integration
  - Residential
  - Commercial
- Codes & Standards

ORNL Buildings Program

Director
Ron Ott

BERD
Antonio Bouza

Equipment
Ayyoub Momen

BERD
Sven Mumme

Envelope
Diana Hun

BERD
Erika Gupta

Sens & Ctrl/B2G
Teja Kuruganti

BERD & CBI
Amir Roth

Tools/Models
Joshua New

RBI
Joan Glickman

Residential
André Desjarlais

CBI
Amy Jiron

Commercial
Melissa Lapsa

Standards
John Cymbalsky

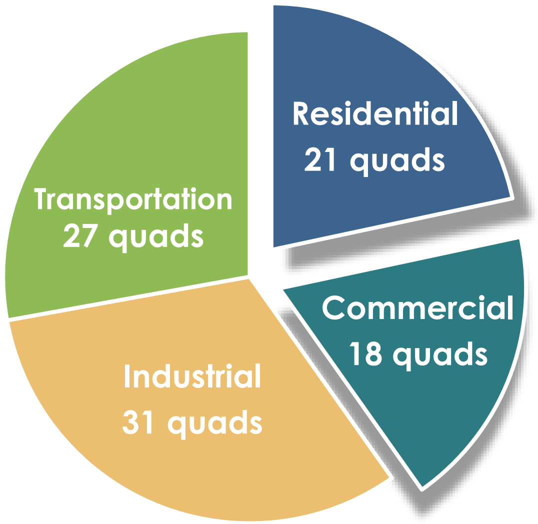
Standards
Ron Ott/Jeff Munk

Crosscut
Mary Hubbard

Tech-2-Market
Melissa Lapsa

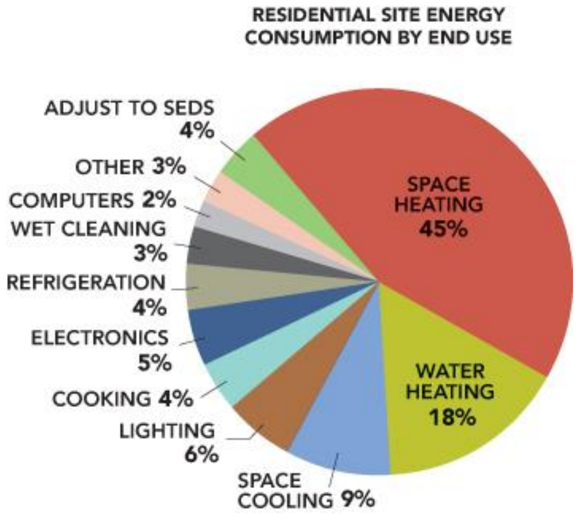
BERD – Building Energy R&D | RBI – Residential Buildings Integration | CBI – Commercial Buildings Integration

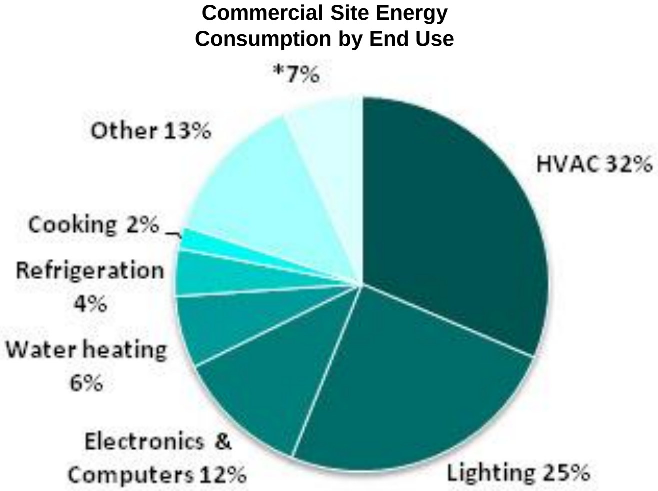
Energy and Buildings Overview



40% Buildings

**125 million buildings
$412 billion in 2019
energy bills**





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

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.

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System/building integration: Research facilities (residential)

- Residential (~15 min. data)
  - Yarnell (37 sensors)
  - Wolf Creek (4x 356 sensors/building)
  - Campbell Creek (3x 144 sensors/bldg.)
    - Temperatures
    - Plugs
    - Lights
    - Range
    - Washer
    - Radiated heat
    - Dryer
    - Refrigerator
    - Dishwasher
    - Heat pump air flow
    - Shower water flow
    - Etc.

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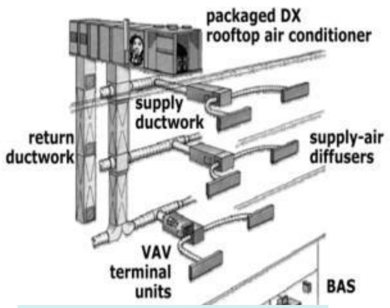
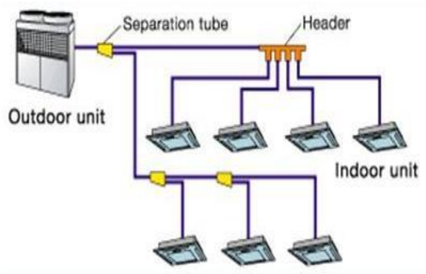
Measured performance of multiple HVACs

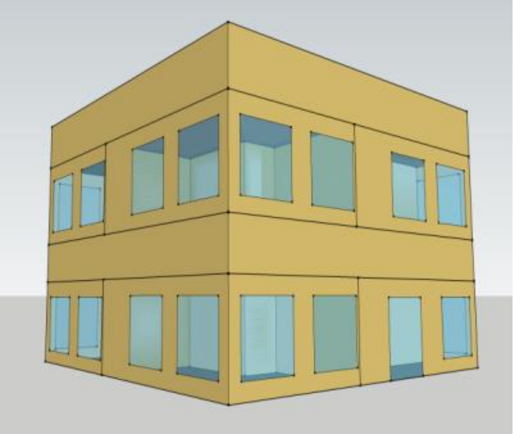
(same building, occupancy, weather)

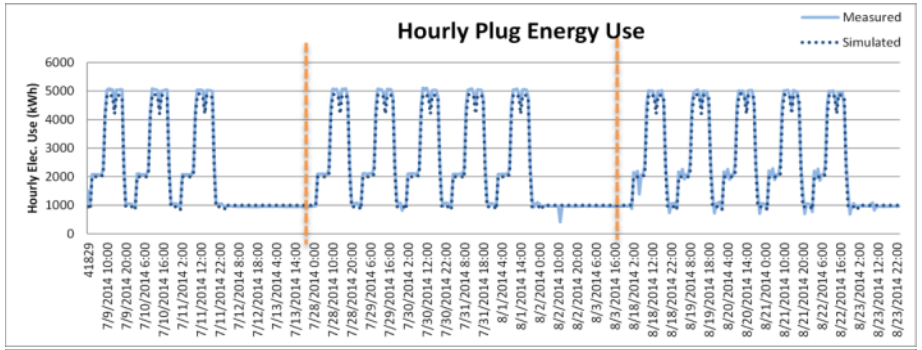


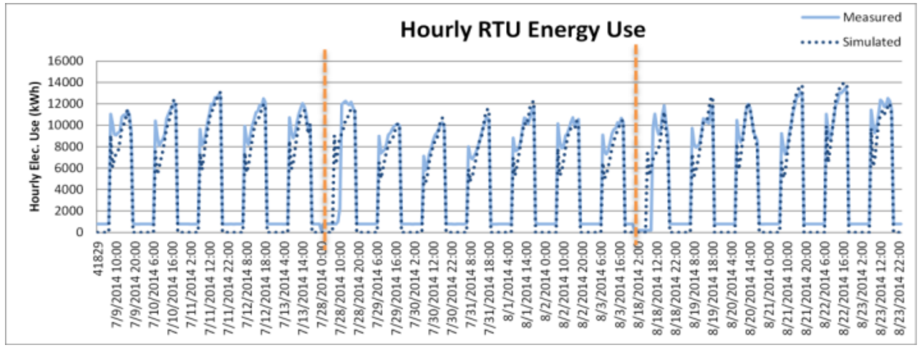
RTU/VAV

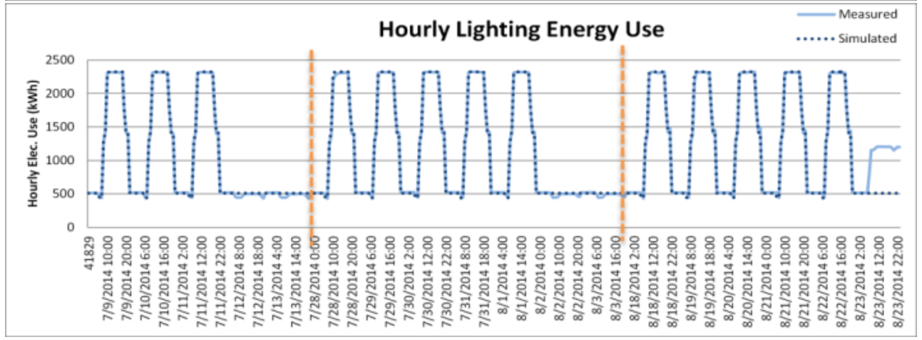


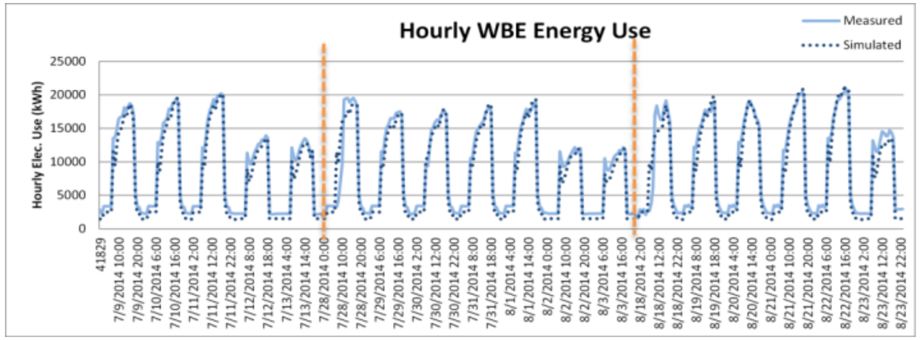
VRF











(~1,000 sensors @ 30-second resolution)

Professional Involvement – ASHRAE Climate Zones

- 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

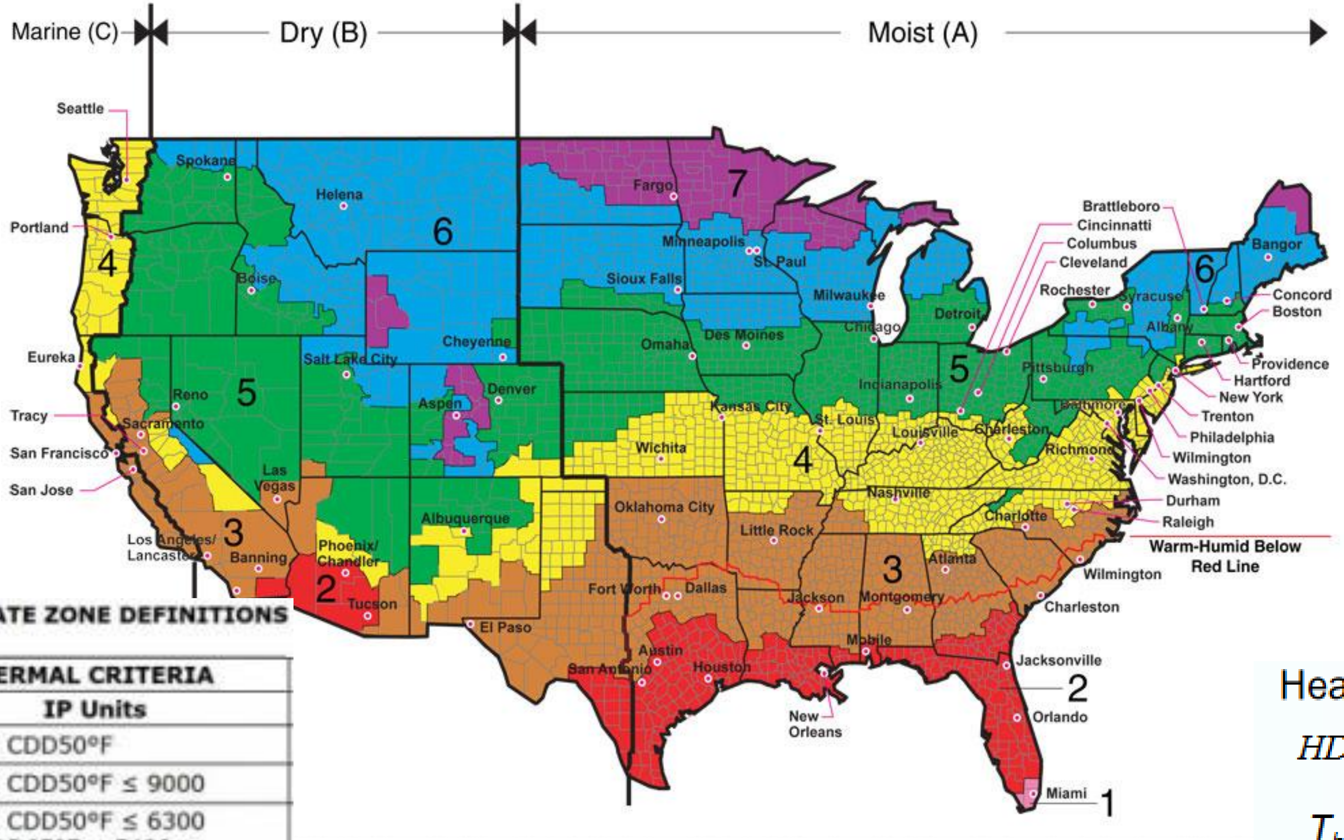


TABLE 301.3(2) INTERNATIONAL CLIMATE ZONE DEFINITIONS

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)

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

Heating Degree Days:

$$HDD = \sum \left(T_{base} - \langle T_i \rangle\right)^+$$

T_{base} = 18°C (65°F)

Cooling Degree Days:

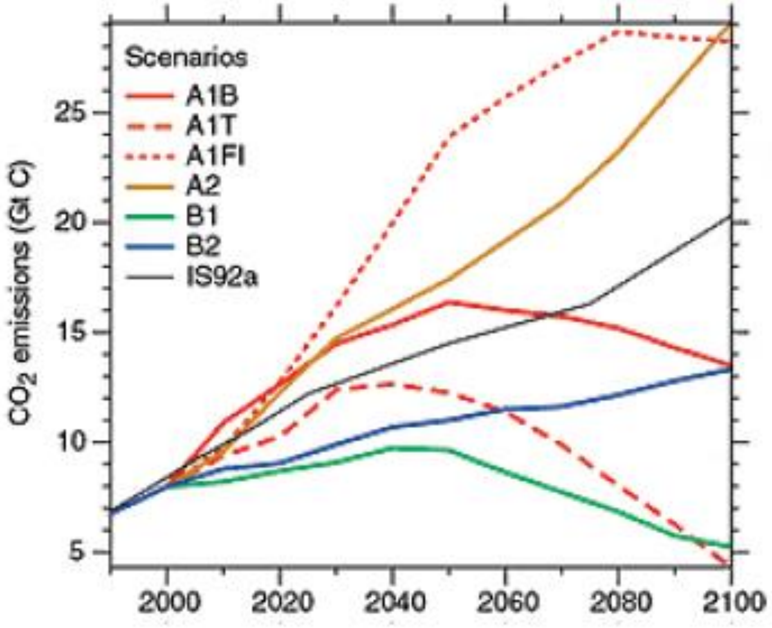
$$CDD = \sum \left(\langle T_i \rangle - T_{base}\right)^+$$

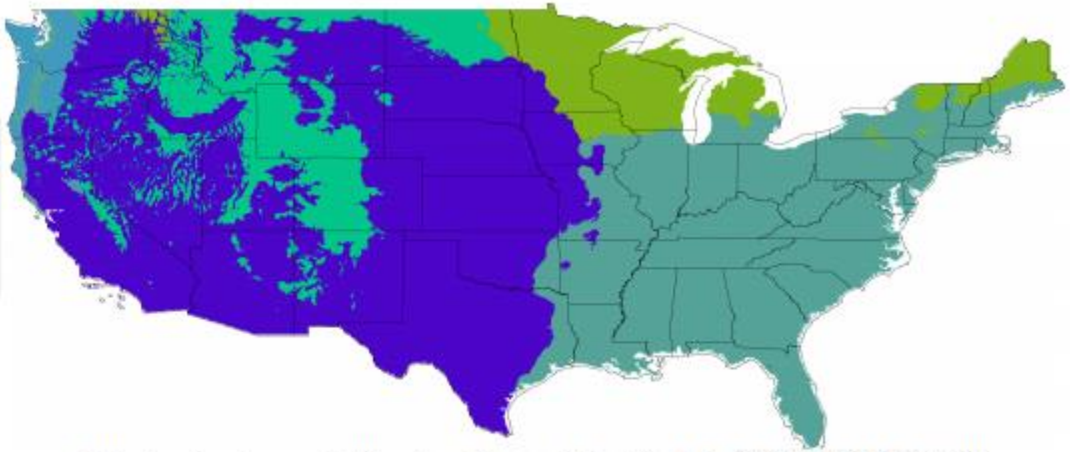
T_{base} = 10°C (50°F)

Climate Change Impacts

Contemporary Period

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





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

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Introduction to Building Energy Modeling

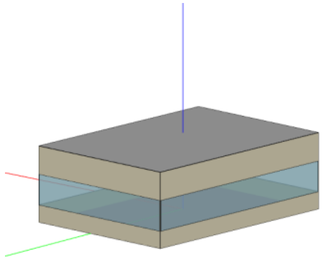
Simulation Engine and Analysis Platform

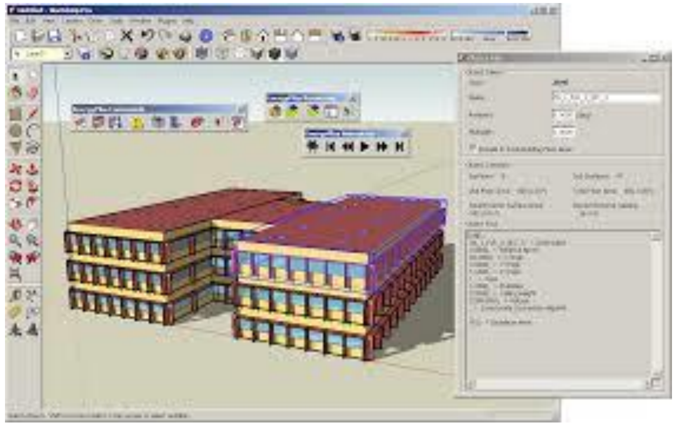
U.S. Dept. of Energy
$100+M, 1995–?

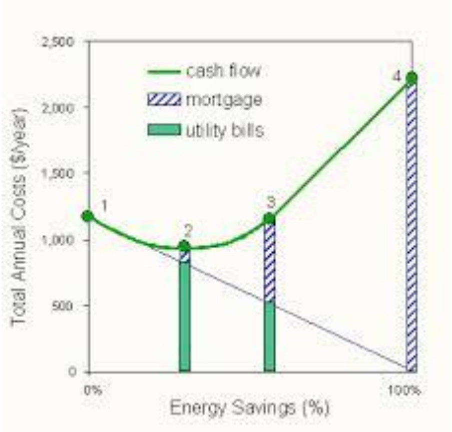
EnergyPlus **OpenStudio**

Free, open-source (GitHub),
free support community (unmethours.com) for
Q&A forum, propose/upvote feature requests

100-2,000 building improvements

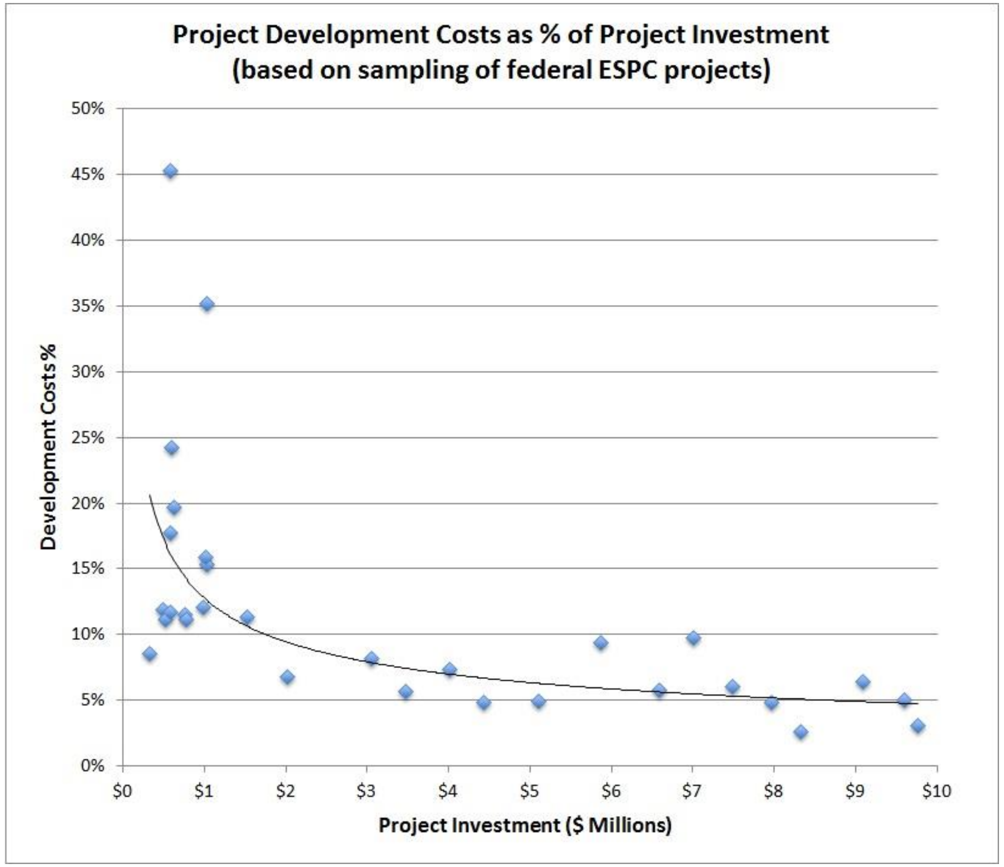






Optimal Return on Investment
(for building energy savings)

Individual Energy
Conservation Measures
(ECMs)
(5-20% savings)
vs.
Holistic optimization
(30-50% savings)



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ORNL at the forefront in Computing:
#1 Jaguar, Titan, Summit, Frontier?

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 Award
19M core-hours
June 2, 2020

OLCF's Titan

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

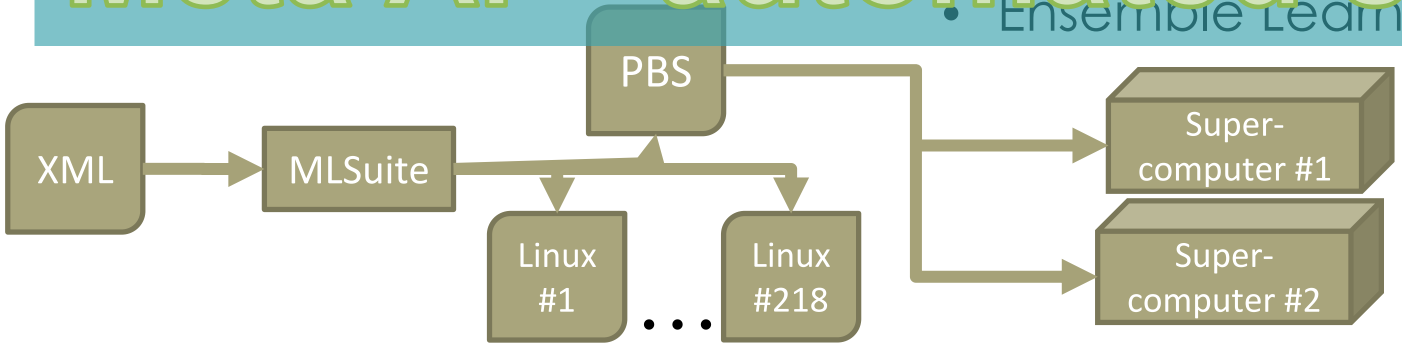
ALCF's Theta

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

MLSuite: HPC-enabled suite of Artificial Intel.

- Linear Regression
- Feedforward Neural Network
- Support Vector Machine Regression
- Non-Linear Regression
- K-Means with Local Models
- Gaussian Mixture Model with Local Models
- Self-Organizing Map with Local Models
- Regression Tree (using Information Gain)
- Time Modeling with Local Models
- Recurrent Neural Networks
- Genetic Algorithms
- Ensemble Learning

Meta AI – automated science



Acknowledgments:

Dr. Lynne Parker (Deputy Chief Technology Officer of the US, White House Office of Science and Technology Policy; previously Deputy Director of White House's AI Initiative);

Dr. Richard Edwards (doctoral student, now Amazon's ad analytics)

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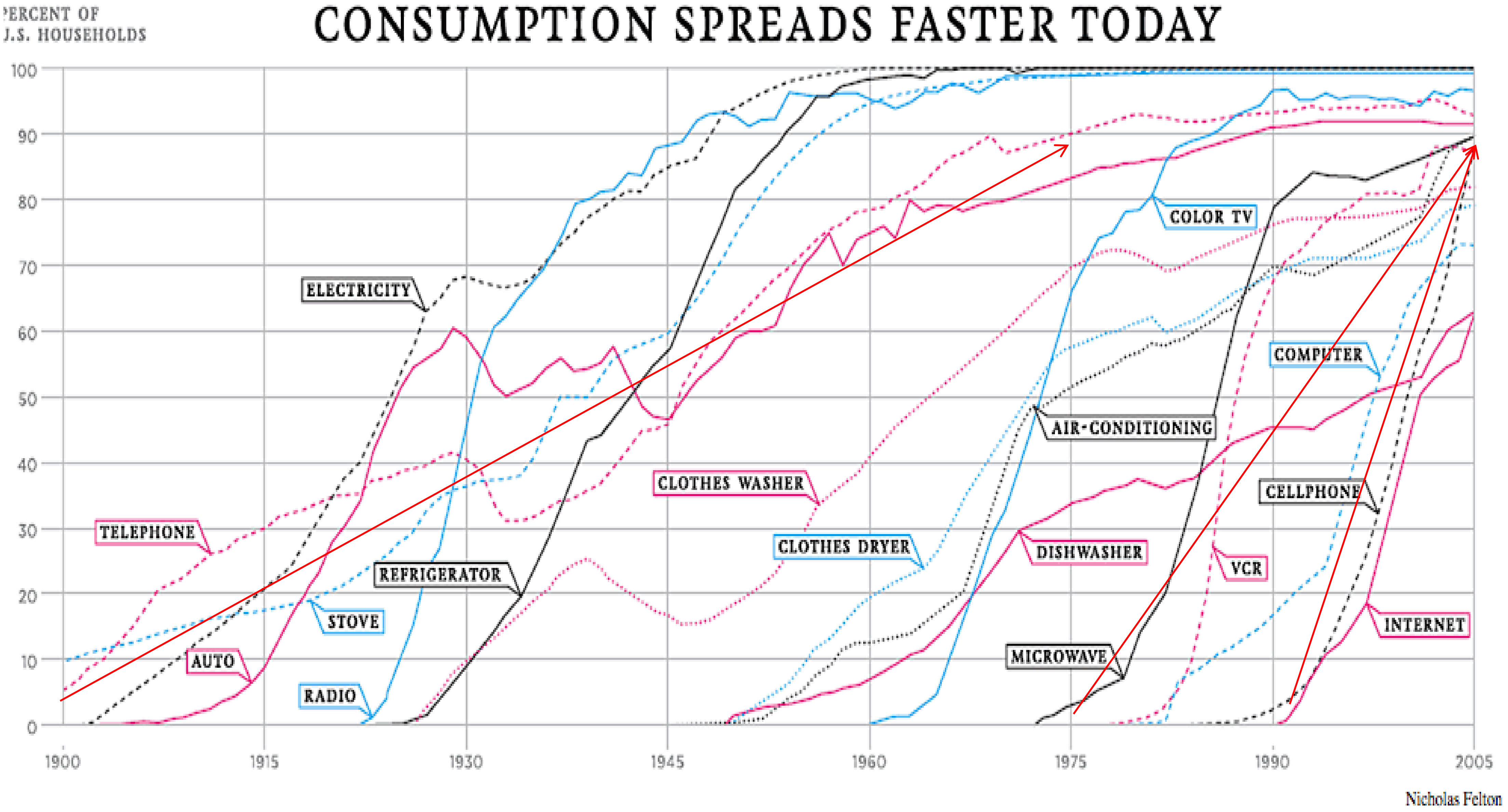
Strategic Research

Technology Adoption Rates Accelerate



Wireless Broadband IoT Age Is Upon Us

Strategic Research

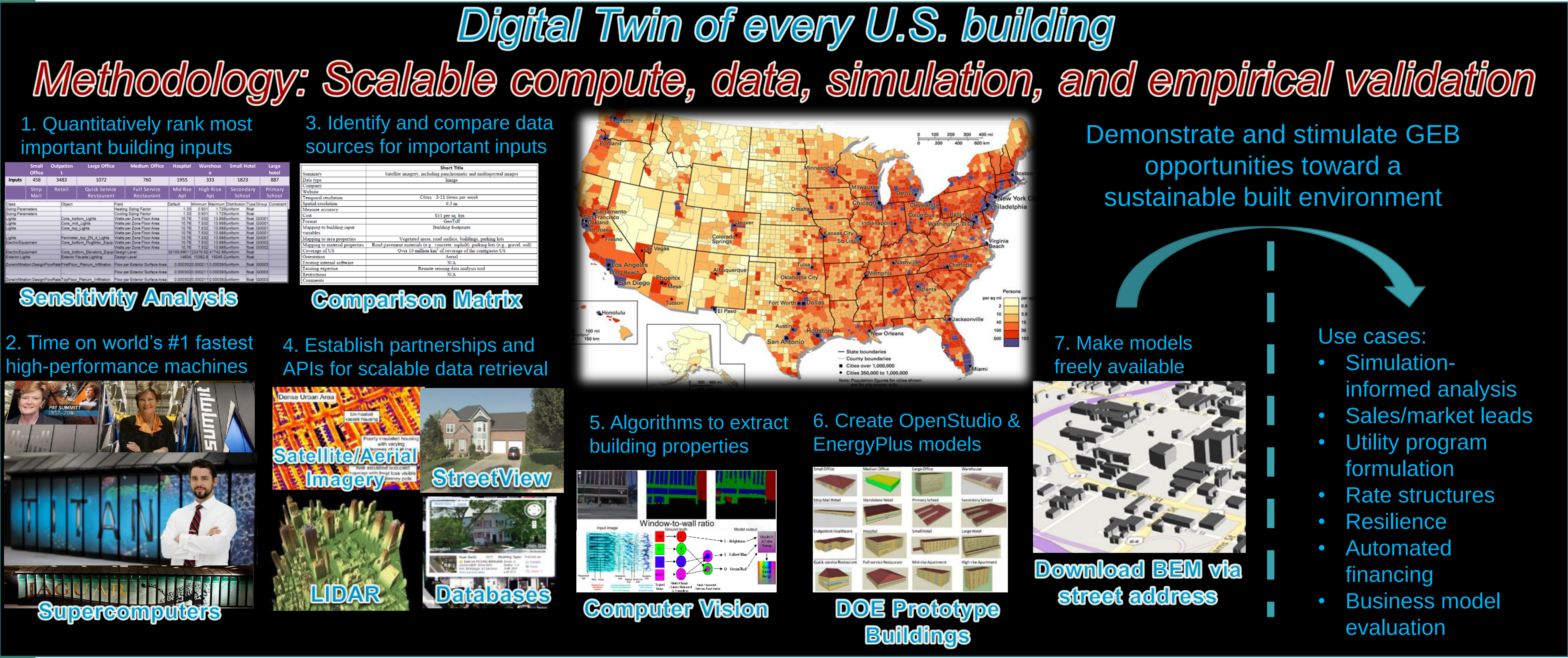
Papal Conclave 2005

Strategic Research

Wireless Broadband IoT Age Is Upon Us

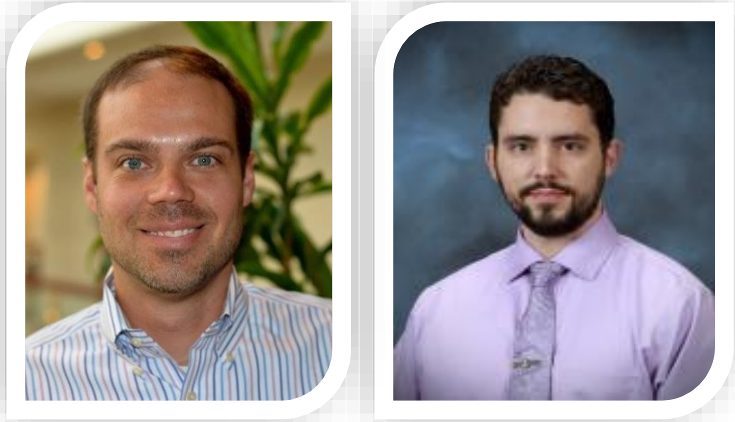
Papal Conclave 2013

Technical overview



Acknowledgements

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



Virtual EPB – in a nutshell

"A digital twin of every building"

- Capability: quantify **energy**, **demand**, **emissions**, **and $** (wholesale and retail) savings potential for EPB's top-priority building technologies
  - Geospatial: Building-specific, aggregated to any area of interest
  - Temporal: 15-min, monthly, annual

- Final Deliverable: Simulation-informed data and valuation for each building in EPB's service area for 5 prioritized use cases covering 9 monetization scenarios
  - **Database** of savings for business intelligence integration
  - Web-based visualization and reports of saving potential

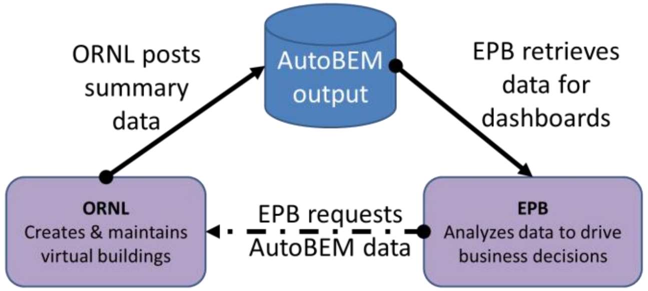
TOTAL DOE INVESTMENT - $1.14M (40% OE, 60% BTO)

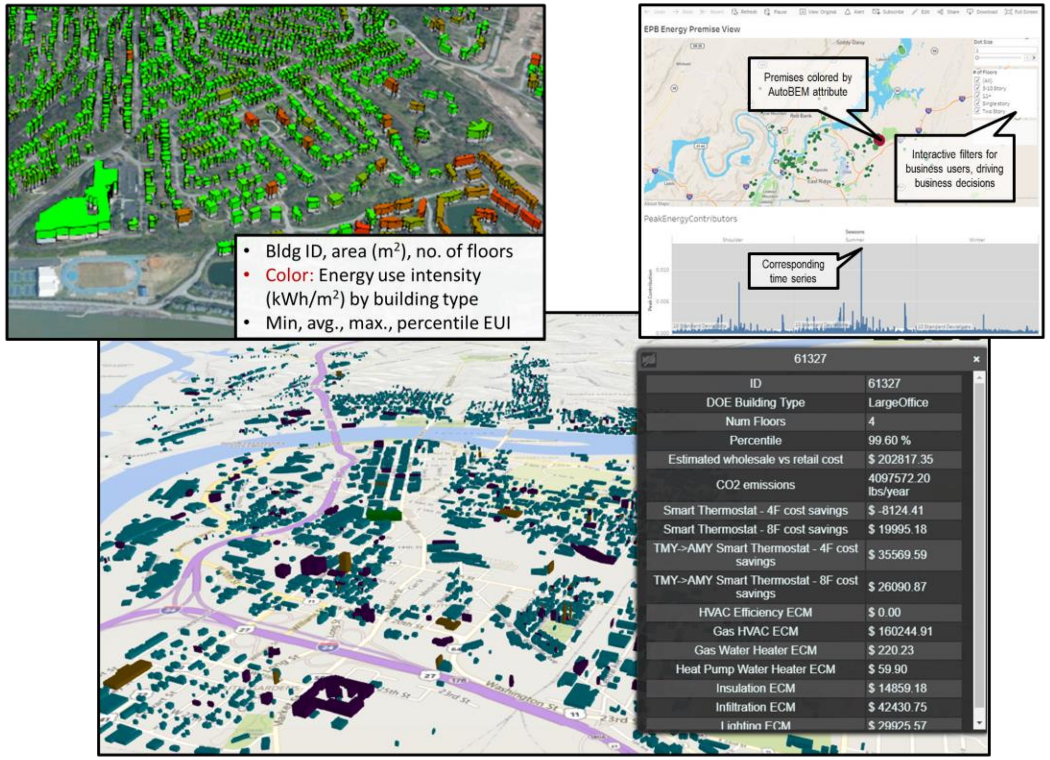
Overview – uses and building technologies

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

Use Case - Scenarios

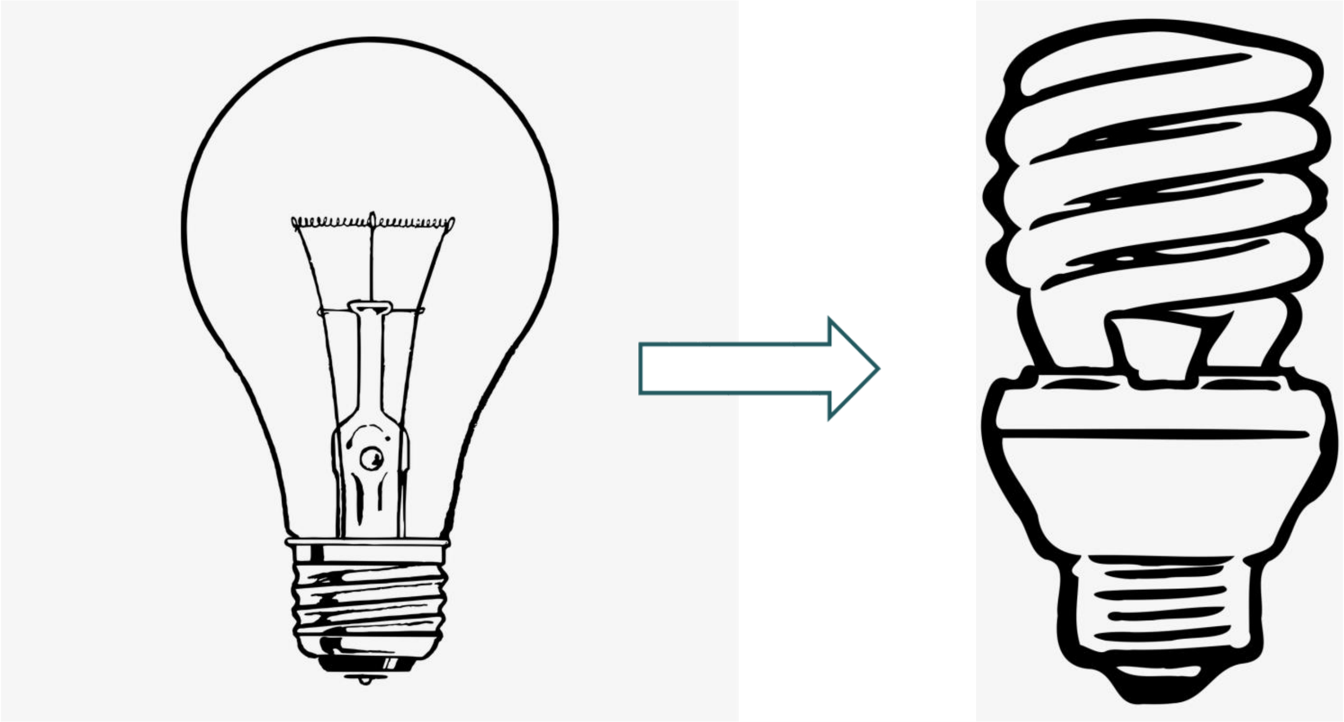
- Building-specific estimates of energy, demand, and cost savings totaling **$11-$35 million per year** based on 9 scenarios prioritized by EPB.

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.

Energy Conservation Measure: Change Lighting Power Density

Reduce lighting power density assuming all lighting fixtures are LED.

LPD: 0.85 W/sf (IECC-2012).



https://www.seekpng.com/png/detail/325-3252829_drawn-light-bulb-public-domain-incandescent-light-bulb.png
https://www.pngkit.com/png/detail/19-194908_colorful-light-bulb-vectors-led-light-bulb-drawing.png

Energy Conservation Measure: Insulate Roof, Seal space

Improve airtightness of the building envelope (i.e. reduce the gaps at the doors and windows).

Reduce by 25% (EnergyStar whole-house).

Adding insulation layer to the existing roof structures following the latest ASHRAE 90.1 Appendix G guidelines.

R-value: 16.12 (avg) to 28.57 (IECC-2012).

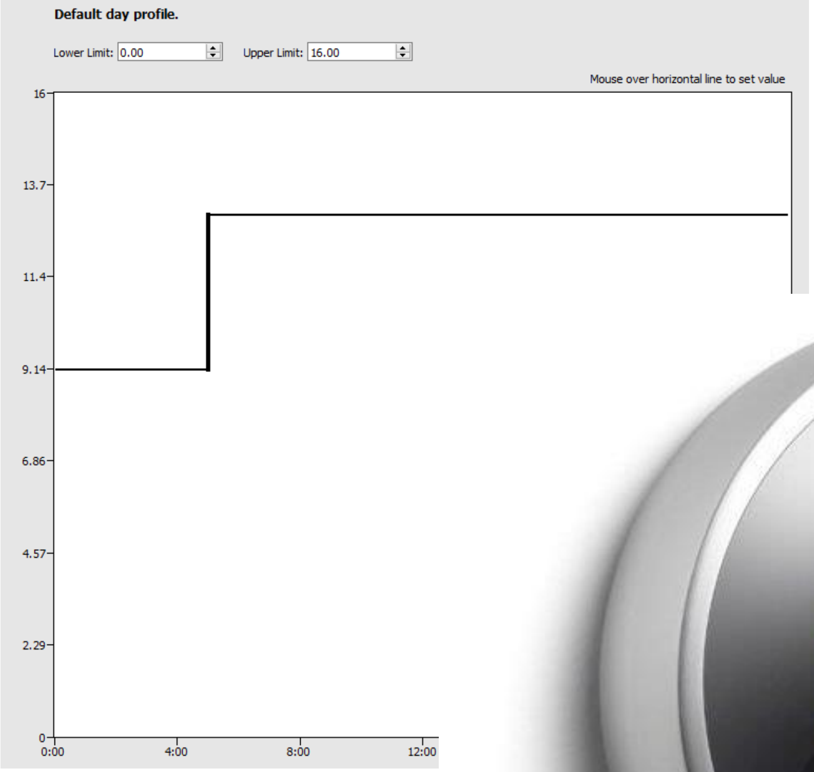
https://www.idi-insulation.com/wp-content/uploads/2018/08/Creating-a-Seal.png

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.dea5.net%2Ftips-on-how-to-choose-the-best-local-insulation-specialist%2F&psig=AOvVaw0jfTQxBkhHEpxCrh7FOIcU&ust=1591106479177000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCIjoptbj4OkCFQAAAAAdAAAAABB5

Energy Conservation Measure: Adjust Thermostat Setpoint (4-8°F)

Buildings as thermal batteries

Pre-conditioning the space by 4°F two hours before, or 8°F four hours before when peak demand hour occurs.



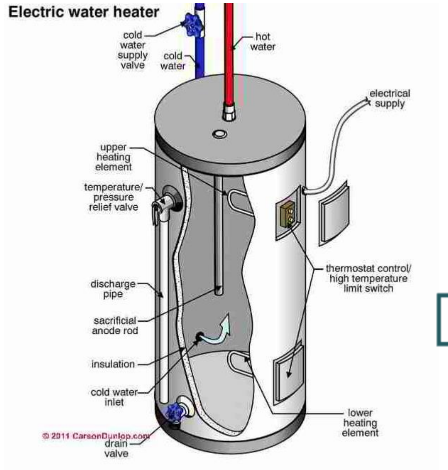
https://gearmoose.com/wp-content/uploads/2019/05/nest-2-thermostat1.jpg

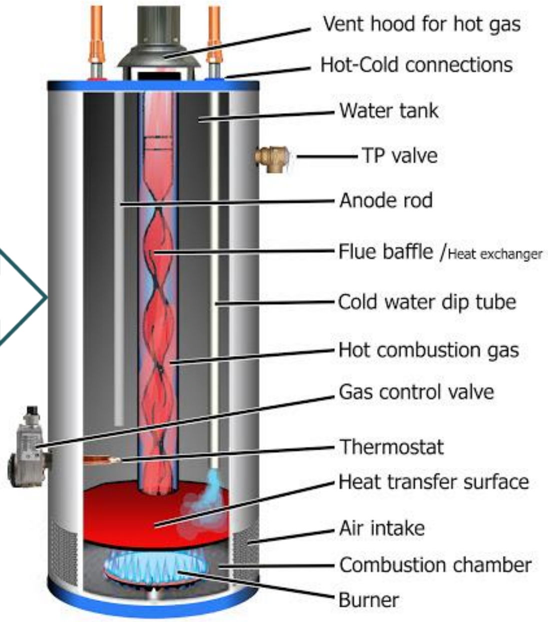
Measure: Change to Gas Water Heater or HVAC

Replace electric water heater with gas water heater.

Replace electric heating coils inside the HVAC unit with gas heating coils.

Efficiency: 80% (IECC-2012).





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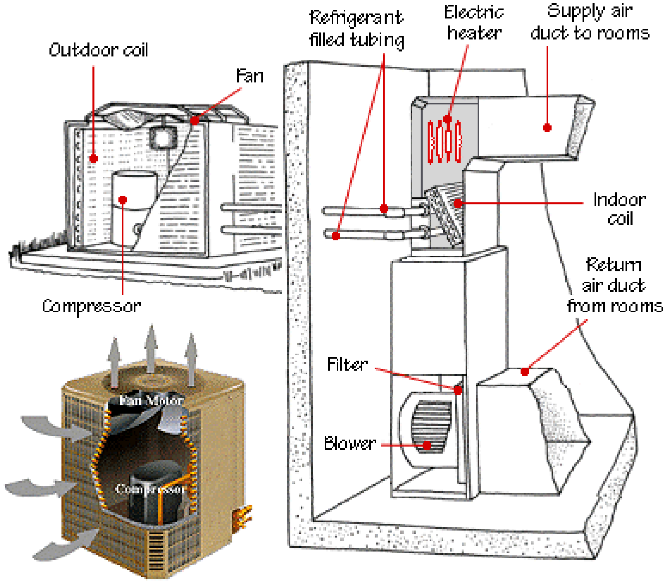
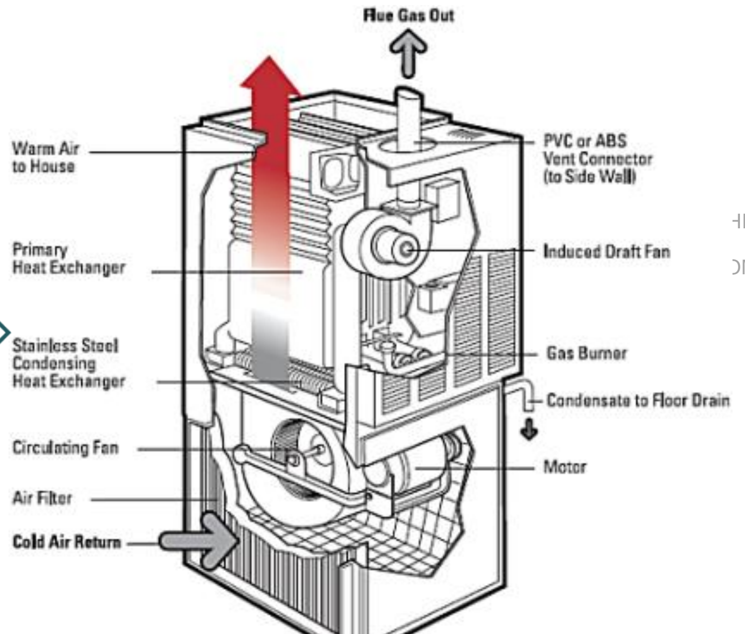




https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.alsplumbing.com%2Fhi-e-gas-furnace-diagram%2F&psig=AOvVaw0cmf8l-if4y3W6KxJFCUYN&ust=1591107866058000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCKDmtevo4OkCFQAAAAAdAAAAABAK

https://i.pinimg.com/originals/27/e4/48/27e44826faf30db3ca455e7de2fa27a9.gif

ECM Overview

#	Description	Category	Value	Source
1	Insulate Roof	Envelope	R-16.12 to R-28.57	IECC-2012
2	Reduce Space Infiltration	Envelope	Reduce 25% from vintage	EnergyStar whole-house
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-2012
6	Change Lighting Power Density	Lighting	LPD 0.85 W/ft^2	IECC-2012
7	Change to Gas Water Heater	Water	Efficiency 80% (assumes electric)	IECC-2012
8	Change to Gas HVAC	HVAC	Efficiency 80% (assumes electric)	IECC-2012

Automatic Detection and Building Energy Model Creation (AutoBEM)

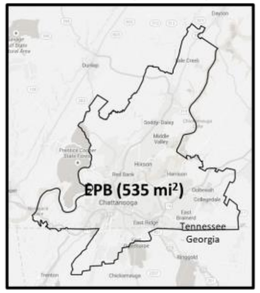
Data Sources

- 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

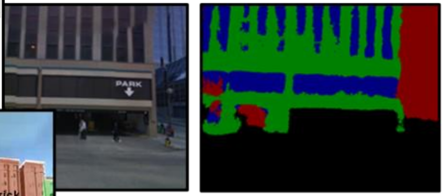
	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints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

Occupancy



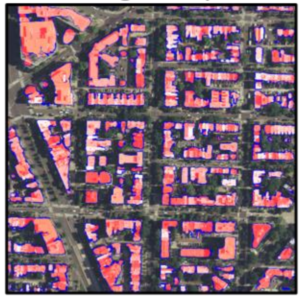
Façade

Street-level data

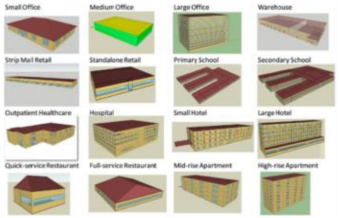


Window-to-wall ratio

Building footprints



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	



Software Tools

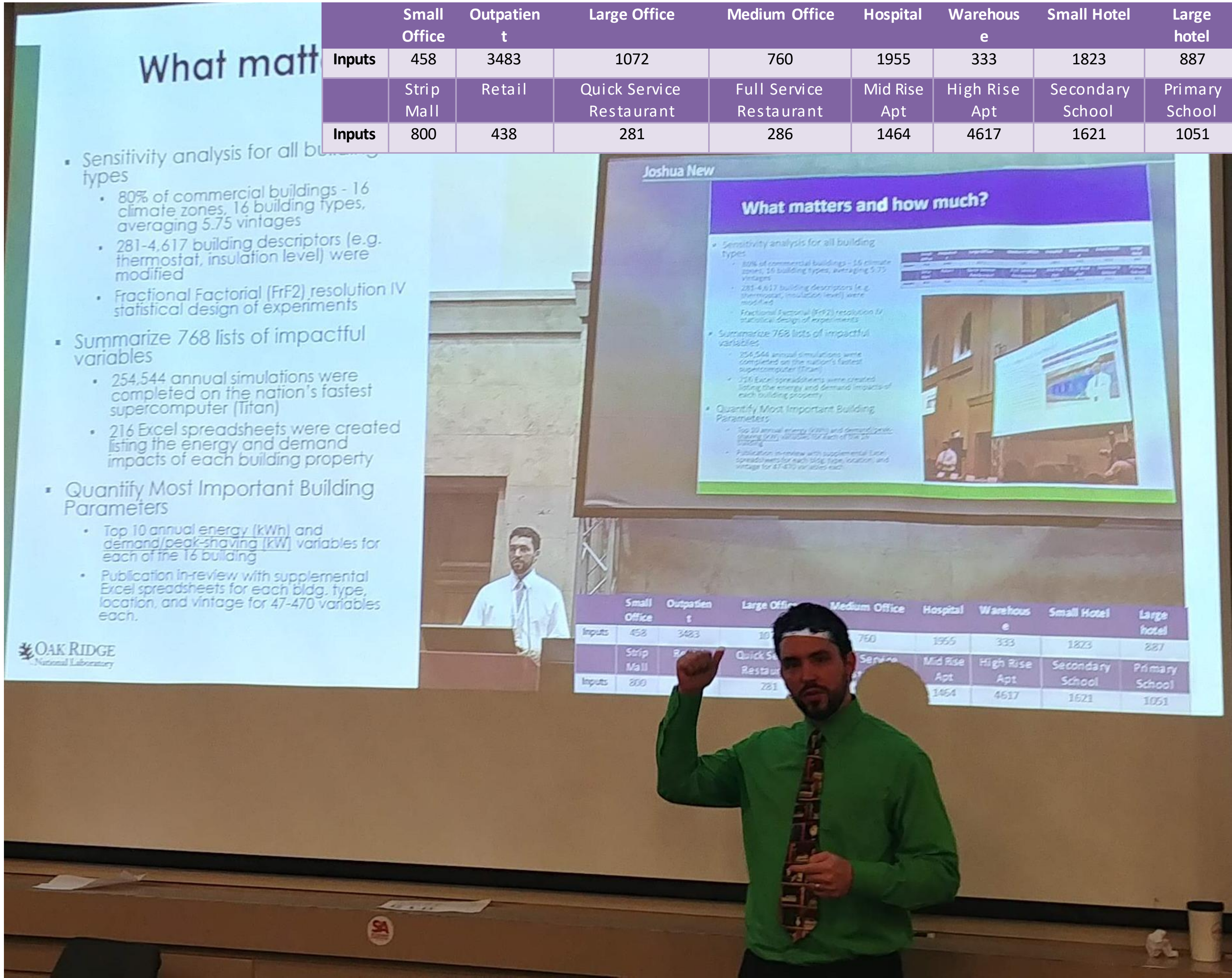
- Occupancy (every 90m)
- Aerial - best footprints
- Street - height, type, WWR
- LiDAR - geometry
- GIS - database API
- Building type
- Model generator
- Fastest buildings simulator
- Web-based visual analytics

Result: Simulated buildings for any area of interest that match 15-minute electrical data more accurately than most manually created models

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



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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
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	

Platform capabilities – imagery and population updates, challenges

Building Footprints

LiDAR acquisition date can lead to discrepancies

HVAC Detection

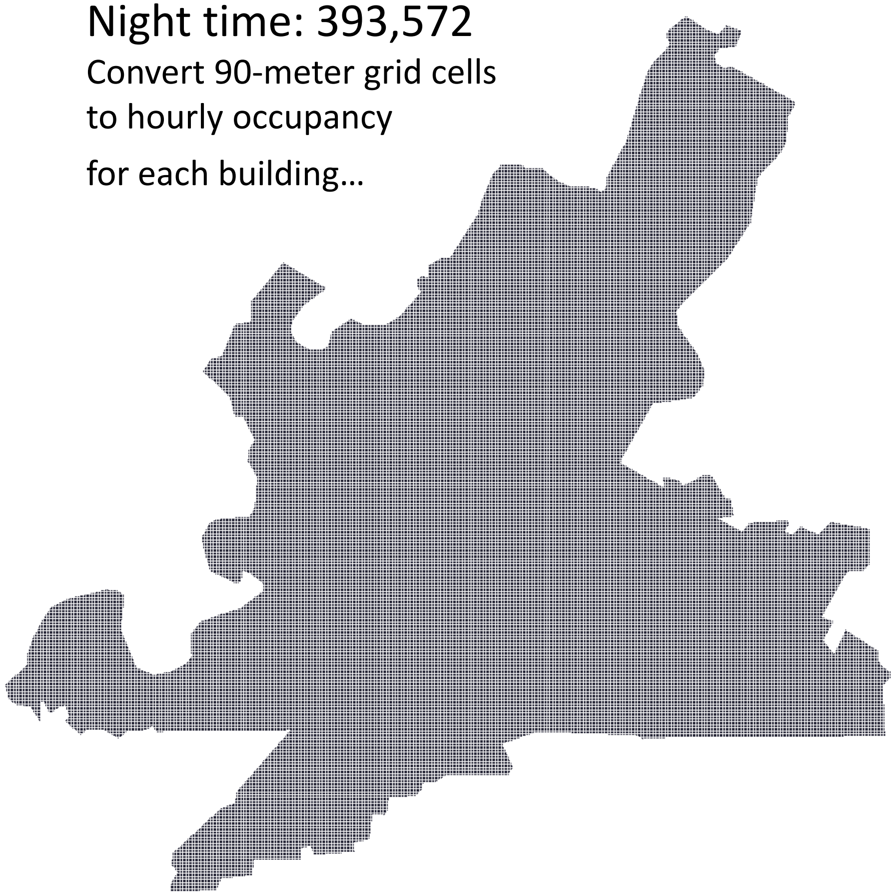
Aerial HVAC classification requires higher-resolution imagery (~10cm/pixel)

LandScan Population in Utility's Area

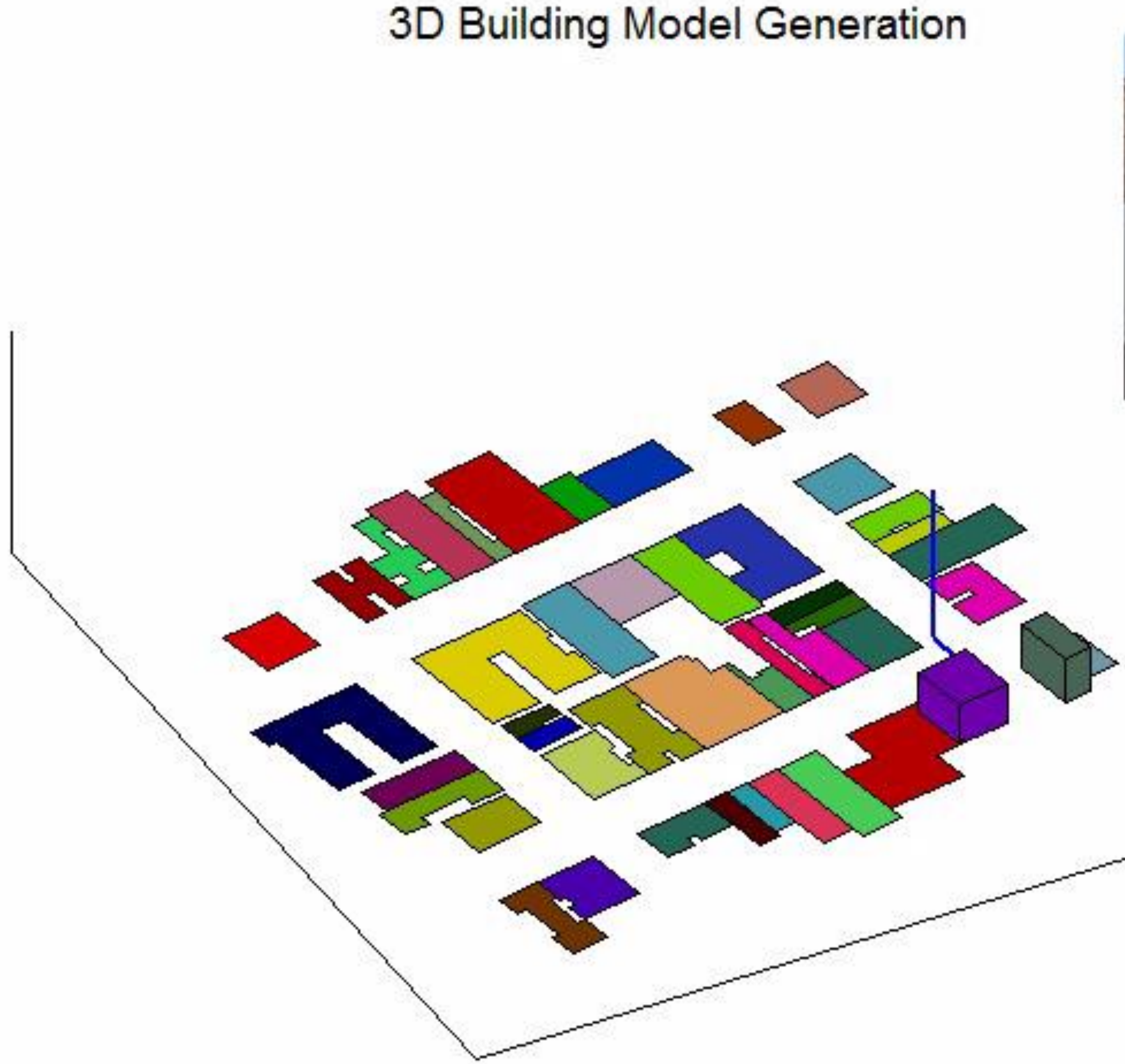
Day time: 434,725

Night time: 393,572

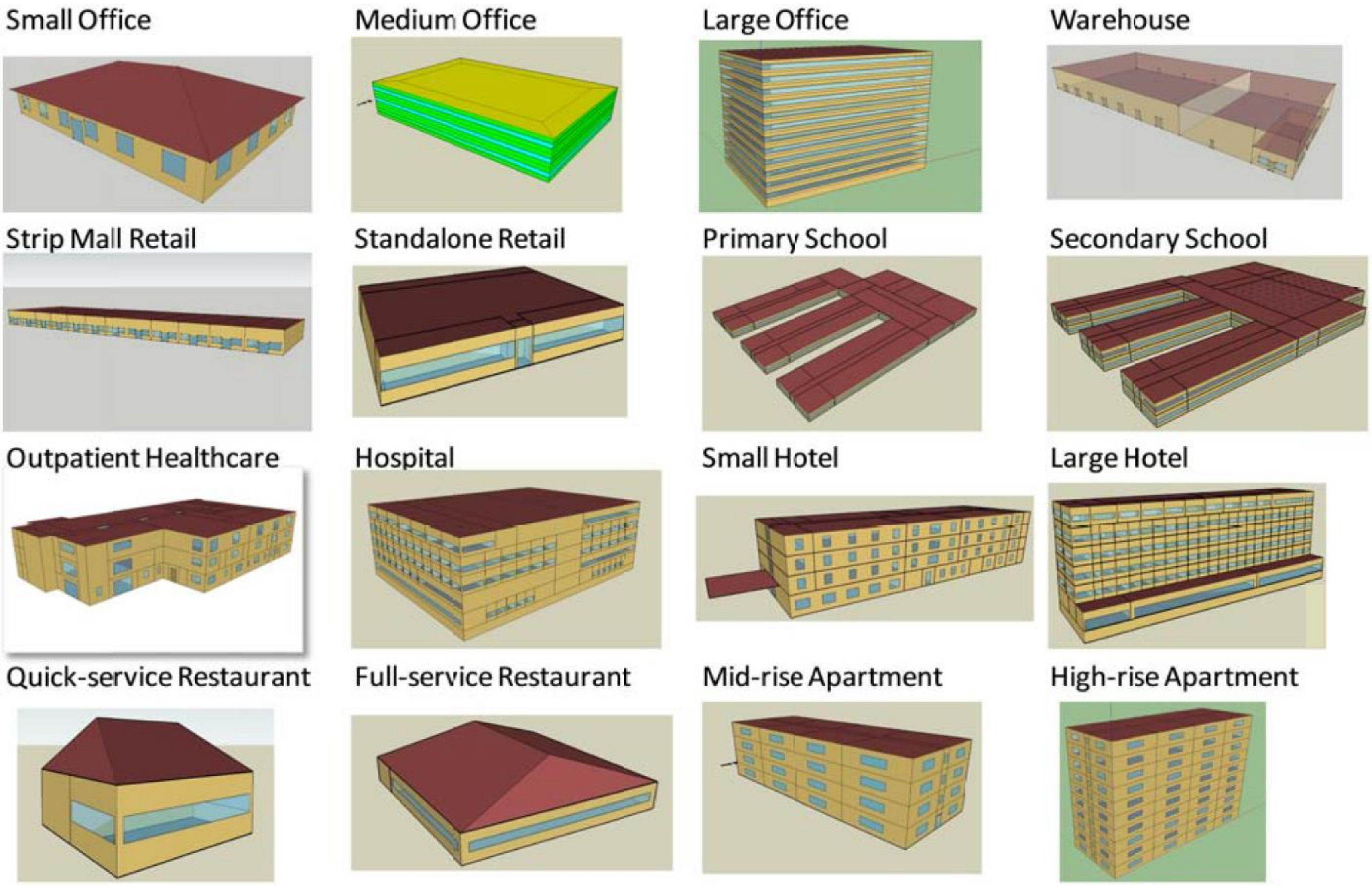
Convert 90-meter grid cells to hourly occupancy for each building…



Processing Street-Level Imagery (Jiangye Yuan)



Prototype Buildings



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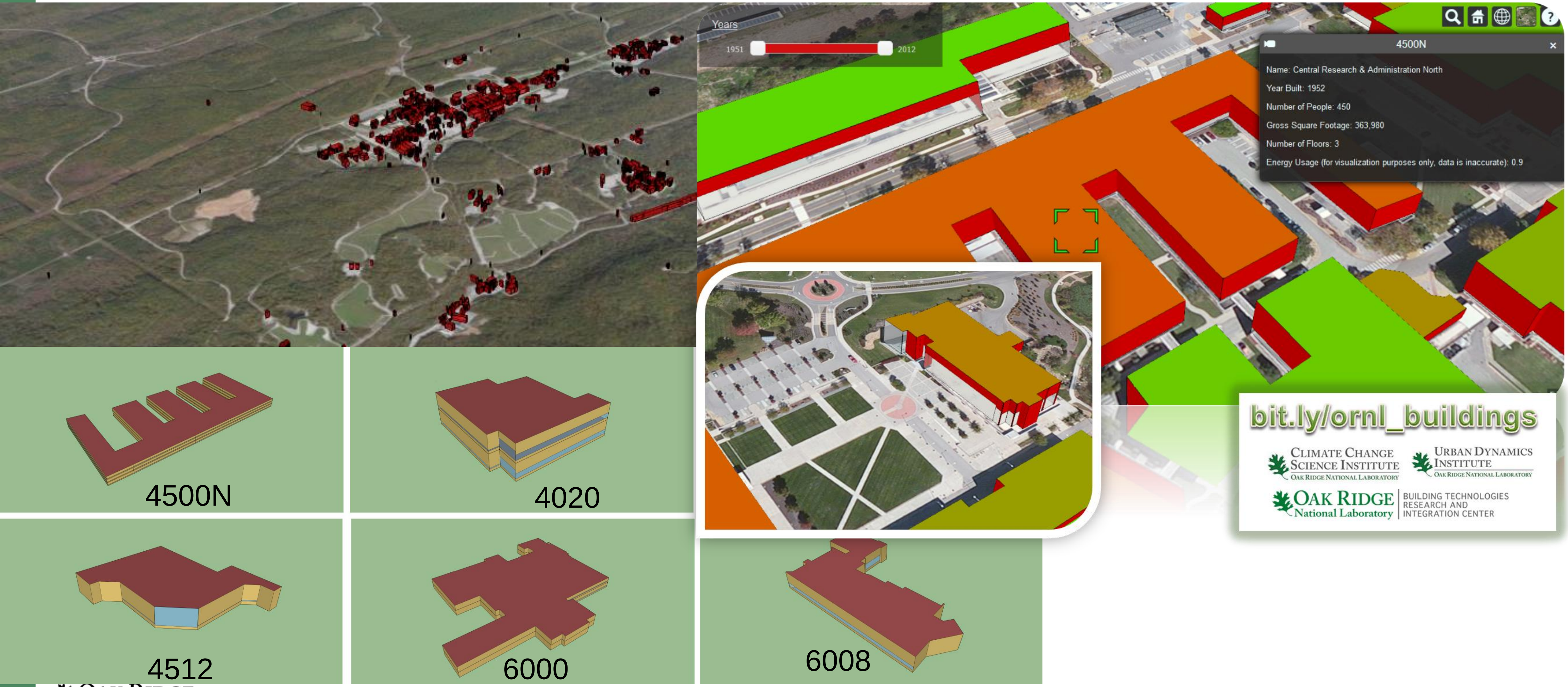
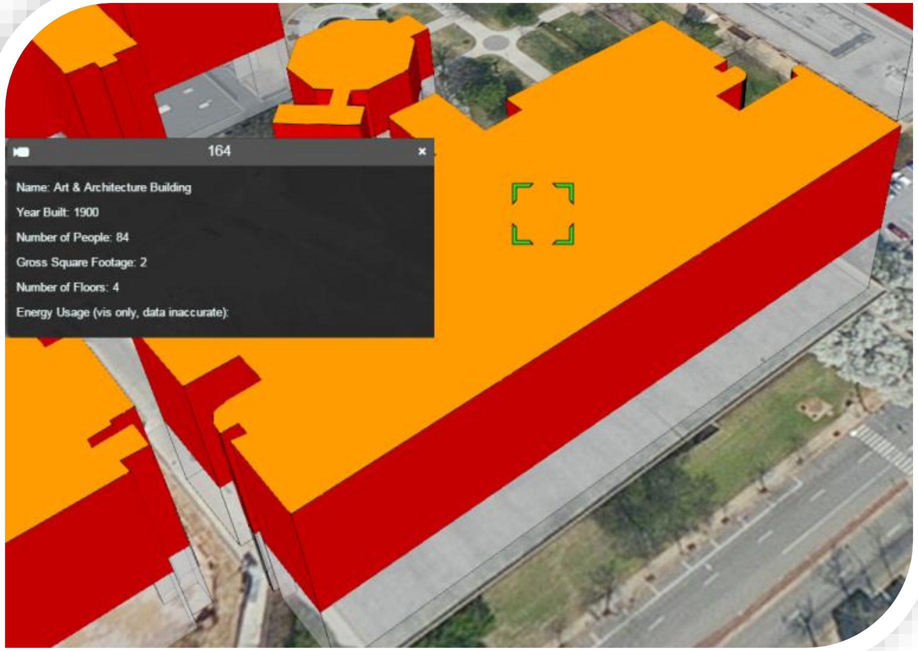


The University of Tennessee (2 days)



bit.ly/ut_buildings

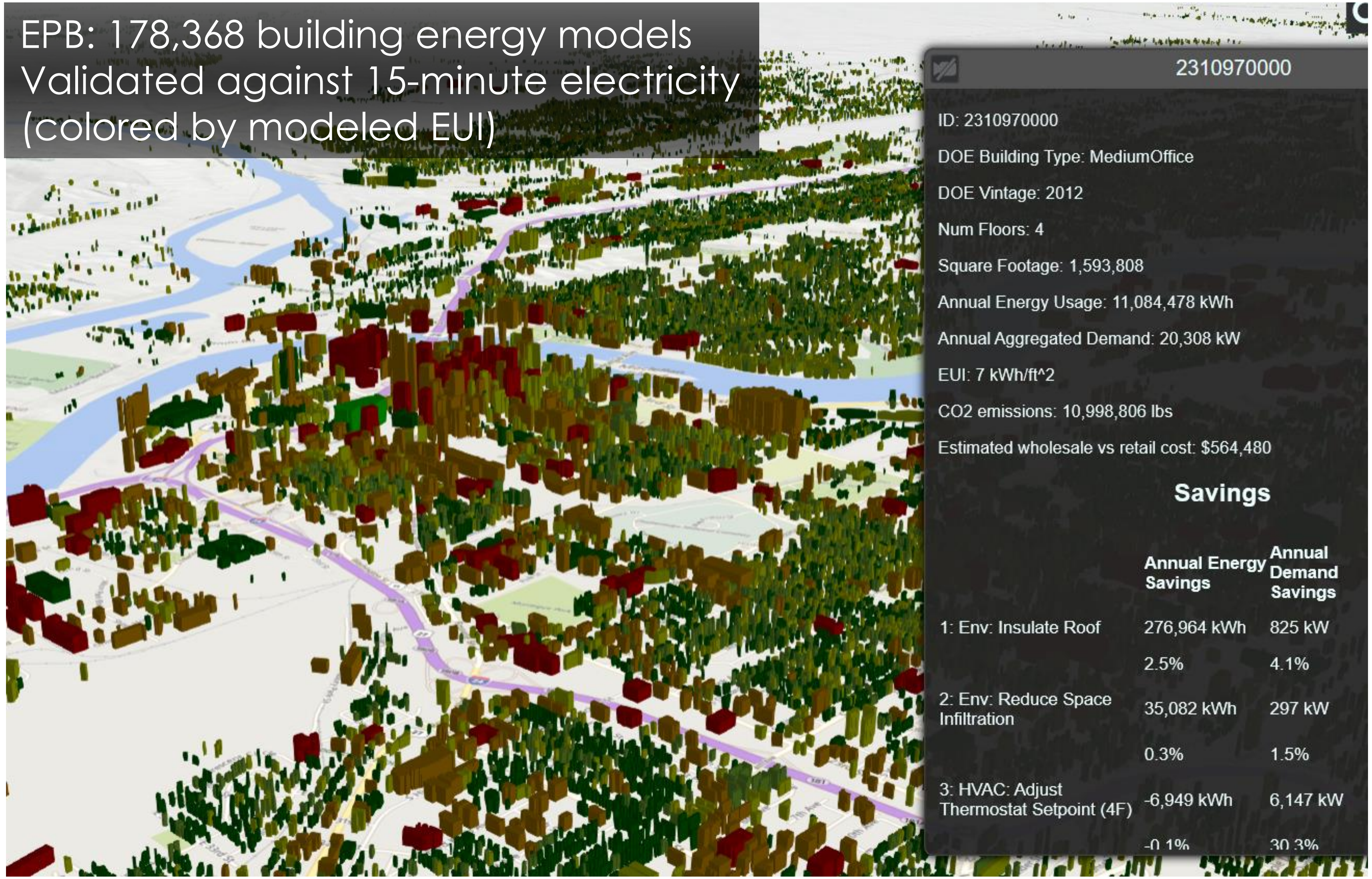
Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

Oak Ridge National Laboratory
Building Technologies Research and Integration Center

Results: Digital Twin of a Utility (every building)

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



http://bit.ly/virtual_epb

Capabilities – flexible digital twin

178,368 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+ million EnergyPlus building energy models using AutoBEM technology, Titan, cloud, and local servers to produce and analyze 15+ TB of simulation data.

1. Generate baseline building – 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. Simulation time – 30-45 mins (5mins/sim = 1.4 years to simulate EPB on 1 core)
6. Data transfer – 40 mins (160GB of tar.gz)
7. Uncompress – 10-15 mins
8. Reformat data – 20-30 mins (pickle)
9. Analysis – 5-10 mins (64-node AWS instance with solid state drives)

Time for creation, annual simulation, and analyzing "all" EPB buildings
6.5 hours (6.1h –36.5h) **; 3.7 ECMs for every building simulated in 28.3 mins!**

Empirical Validation

- Hamilton, Rhea, Marion county tax assessor data
  - Created map to DOE building types, building properties

STANDARD LAND USE CODES

subdivision	division	category
100 RESIDENTIAL	110 Household Units	111 One Family Household Unit
		112 Two Family Household Unit (Du
		113 Multi-Family (4-9 unit Apartm
		114 Two Family Units (Duplex Owne
		115 Triplex
		116 Condominium,
		117 Apartment: 10 units or more
	120 Group Quarters	Rooming and boarding houses, fratern lodgings. Nursing homes, college dor homes, religious quarters, orphanage
	130 (Reserved for future use)	
	140 Mobile Homes	141 Mobile Homes (Single Trailer)
		142 Mobile Home Park
		143 Mobile Home Park (Privately Owned)
	150 Transient Lodging	Motels, tourist courts, lodges, hote
200 MANUFACTURING	210 Food Manufacturing	
	220 Textile Mill Products Manufacturing	
	230 Apparel Manufacturing	
	240 Lumber and Wood Products Manufacturing	
	250 Furniture and Fixtures Manufacturing	
	260 Paper products Manufacturing	
	270 Printing, Publishing and Allied Industries	
	280 Chemicals and Allied Products	
	290 Petroleum Refining Manufacturing	
	290 Petroleum Tank Farms	
	290 Paving and Roofing Materials	
	291 Paving Equipment	
300 MANUFACTURING	310 Ancillary to Manufacturing	
	311 office Building Ancillary to Manufacturing	
	312 Warehouse Building Ancillary to	
	313 Service or Parking Building Ancillary to	
	314 Retail or wholesale ancillary to	
	320 Stone, Concrete and Glass Products	Flatglass, glass containers, cement,
	330 Iron, Steel and Metal Manufacturing	Blast Furnaces, steel works rolling
	340 Fabricated Metal Products Manufacturing	Guns and accessories, general indust
	350 Professional, Scientific, and Controlling Instruments, Photographic and Optical Goods, Watch and Clocks Manufacturing	Engineering, laboratory and scientif instruments and lensest ophthalmic g operated devices, dental equipment.
	390 Miscellaneous Manufacturing.	391 Jewelry, silverware and plated war
		392 musical instruments and parts
		393 Toys, amusement, sorting and athle

Size Adjusted Area	%	Story Height	%	Land Use code	%	Heat Type Description	%
1,000-1,499	32.6	1	74.5	RESID	82.3	CENTRL HEAT&	75.4
1,500-1,999	22.1	2	17.4	COMM	7.9	<EMPTY>	12.6
2,000-2,499	12.2	1.5	7.1	MFG	4.7	GRAVITY	7.4
5,000+	9.8	3	0.6	IN	2.4	NO HVAC	3.4
500-999	8.3	>7	0.6	AG	1	FORCED HOT A	0.9
2,500-2,999	6.6	2.5	0.1	EX	0.8	GHA	0.1
3,000-3,499	3.8	4	0.1	DU	0.4	CENTRAL A/C	0.1
3,500-3,999	2.1	5	0.0	EID	0.2	REV CYCLE UN	0.0
4,000-4,499	1.3	6	0.0	RLS	0.1	CENT HEAT &	0.0
4,500-4,999	0.8	7	0.0	BCMT	0.1	NONE	0.0
Roof Structure Description	**%**	**Roof Cover Description**	**%**	**Decade**	**%**	**Prime/Second Wall Description**	**%**
HIP/GABLE	86.0	SHINGLE ASPH	81.9	2000	13.7	<EMPTY>	41.9
WOOD RAFTERS	2.8	SHEET METAL	3.5	1960	13.6	WOOD FR W SH	15.5
BAR JOISTS	2.4	BUILT-UP	3.4	1970	13.5	VINYL	13.5
OPEN STEEL S	2.1	METAL	2.9	1990	11.6	BRICK	13.1
STEEL TRUSS	1.8	<EMPTY>	1.7	1950	11.4	WOOD FR ASBT	2.7
<EMPTY>	1.7	ASPHALT SHIN	1.7	1980	10.8	CONC BLK PLA	1.6
NONE	0.8	CORRUGATED M	1.3	1940	7.6	ALUMINUM	1.4
WOOD TRUSS	0.6	NONE	0.9	2010	6.9	HARDIE BOARD	1.4
FLAT/SHED	0.5	ROLL COMP	0.6	1930	4.8	BRICK VENEER	1.2
GAMBREL	0.3	BUILT UP T &	0.4	1920	3.8	CORRUGATED M	1.2

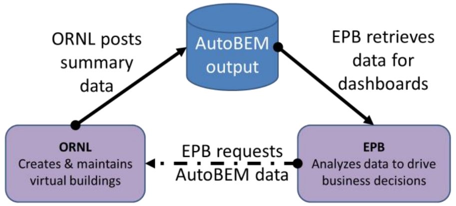
Accuracy compared to real 15-minute data for each building

- 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]

Load Factor summary

Monthly AutoBEM Data

- **Premise Number**
- **Improvement Type**
- **Total Cost Savings ($)**
- **Monthly Costs Savings ($)**
- **Monthly Demand Svgs (KW**

~2.1M records per year, all bldgs

Join on Premise Number

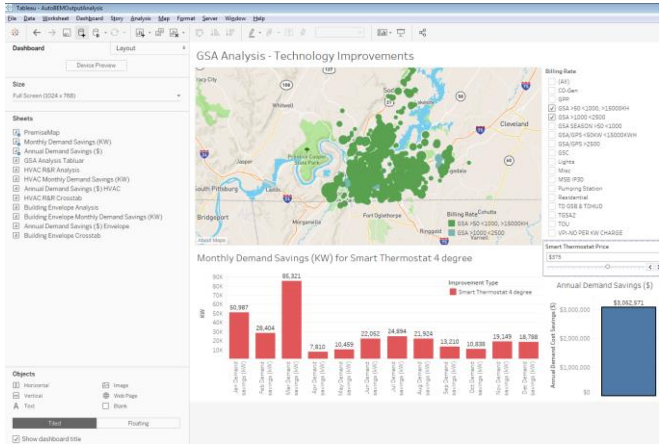
EPB System Attribute Data

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

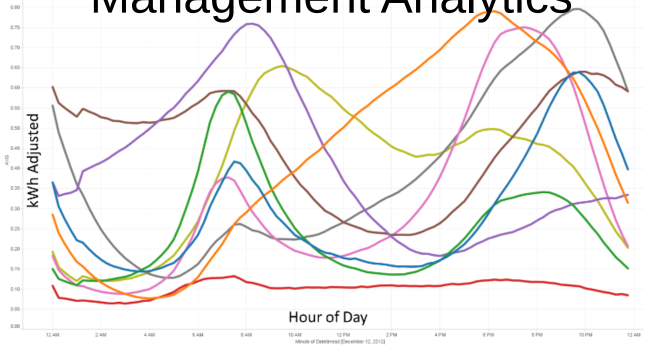
Data feeds to other EPB Systems

Distribution System Capacity Planning

Data Visualization Tools

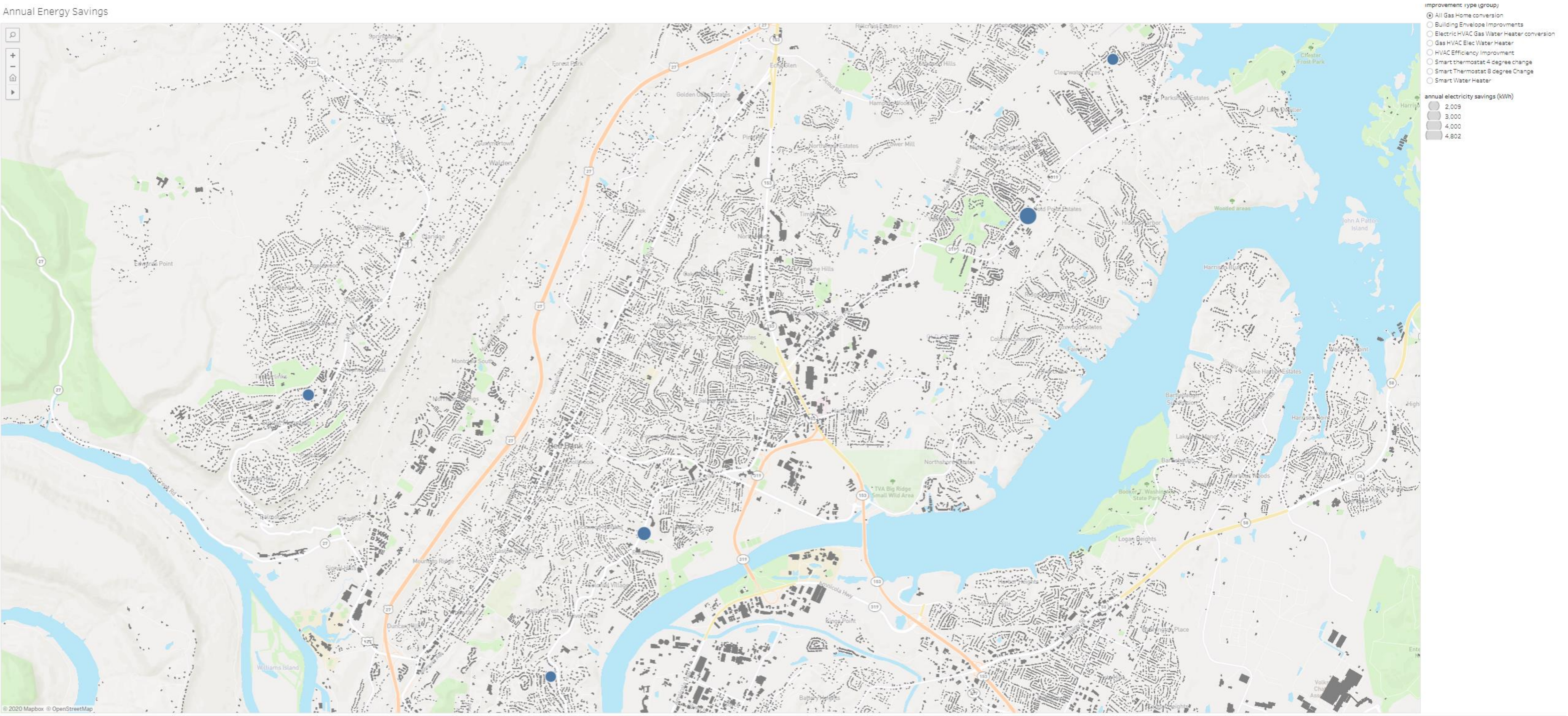


Customer Clustering & Demand Side Management Analytics



AutoBEM data in action

Annual Energy Savings



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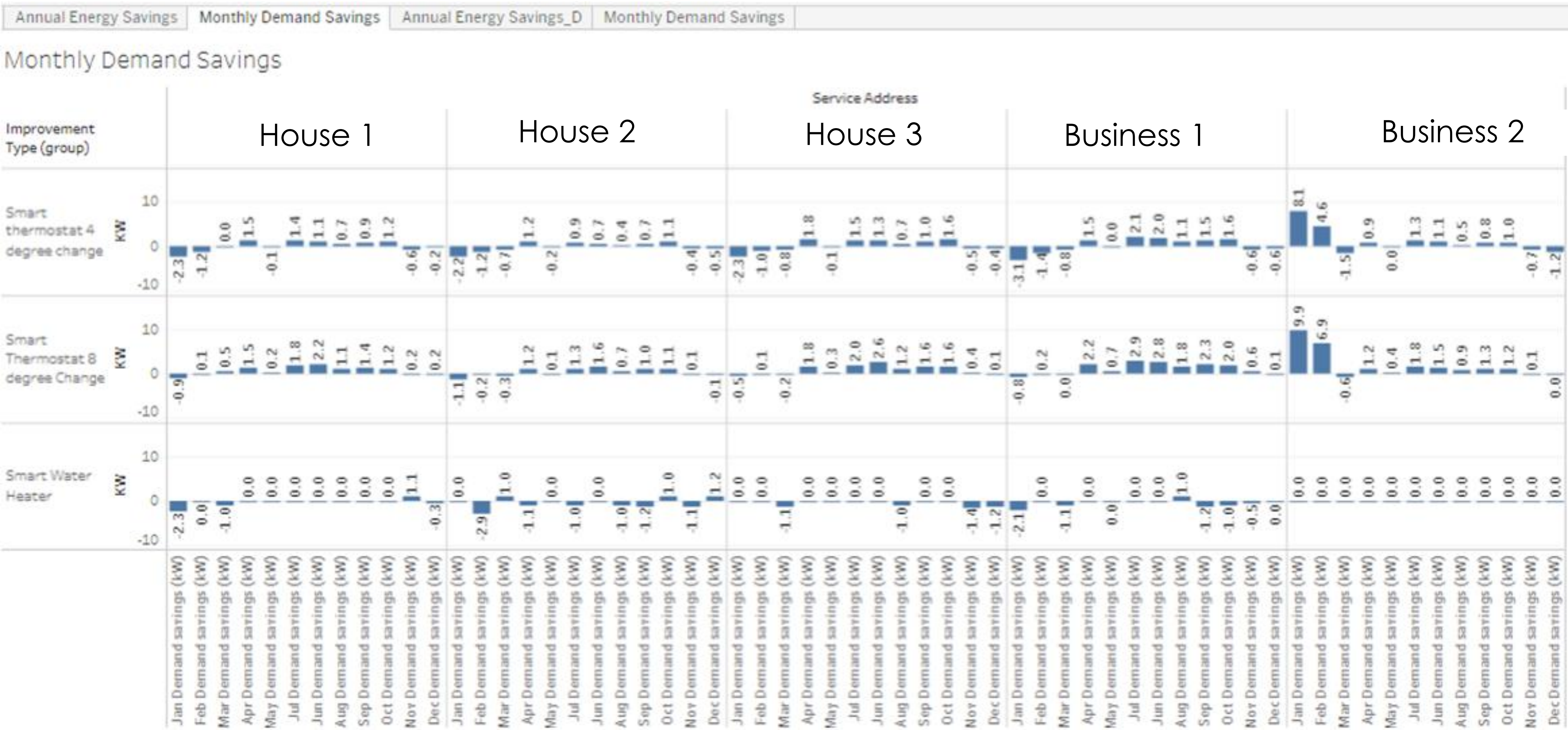
AutoBEM data in action



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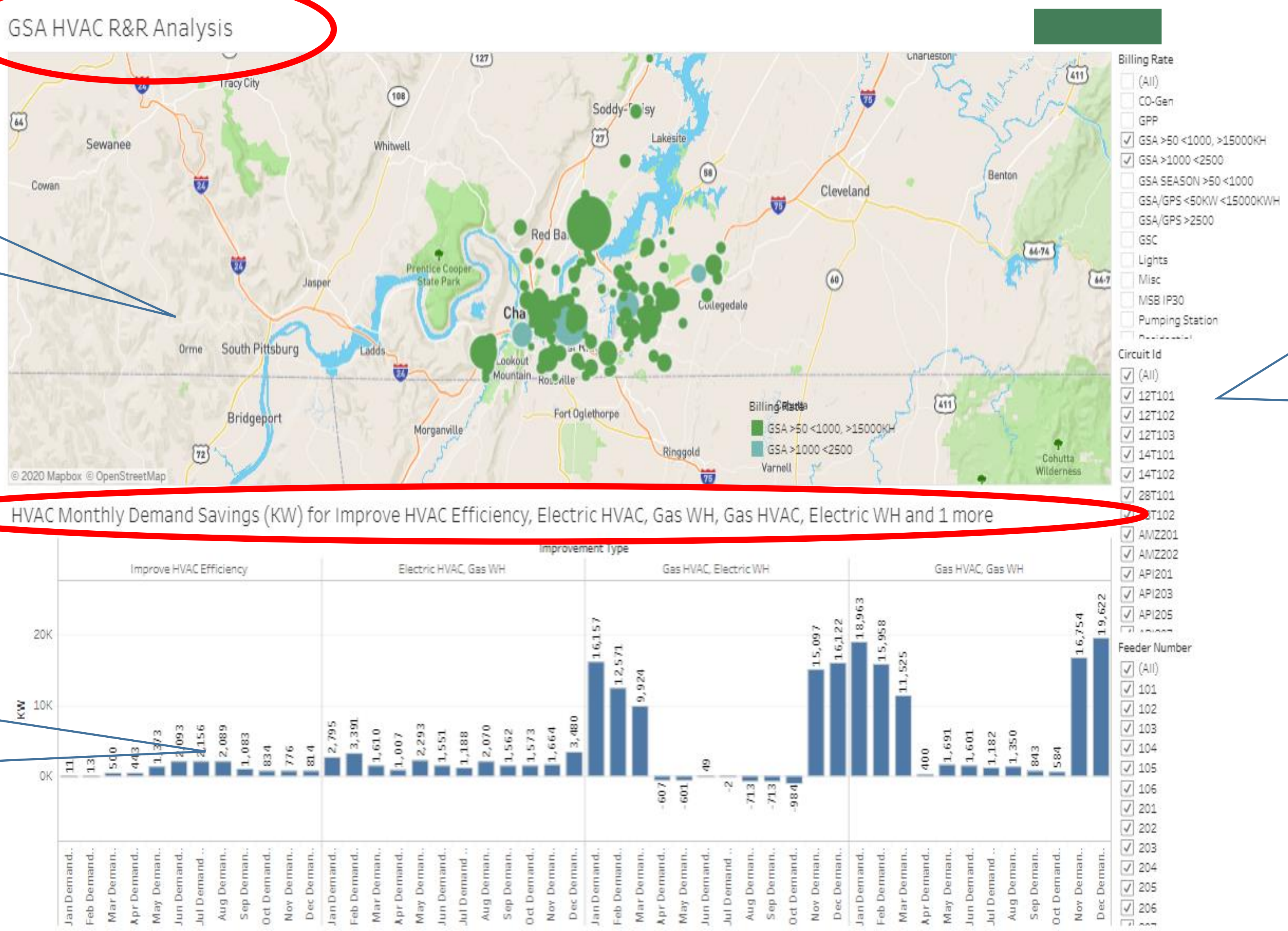
AutoBEM data in action – EPB Dashboards

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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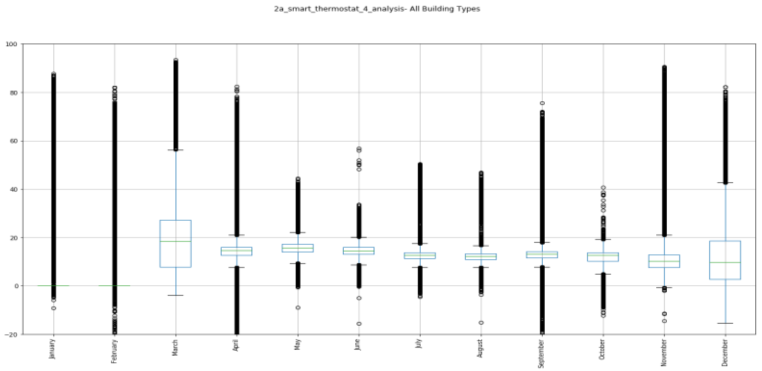
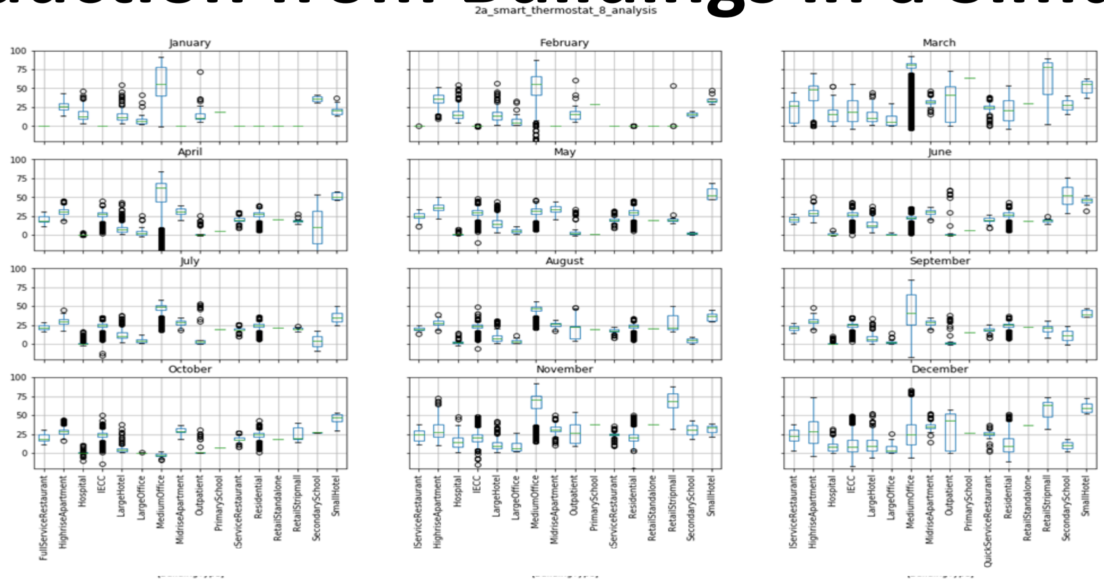
Potential Demand Reduction from Buildings in a Simulated Utility



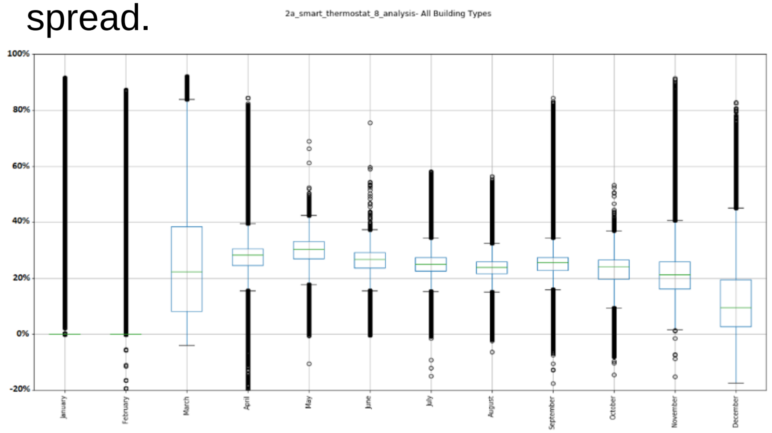
4°F pre-conditioning shows an average **13%** peak demand reduction across 178,368 residential and commercial buildings.



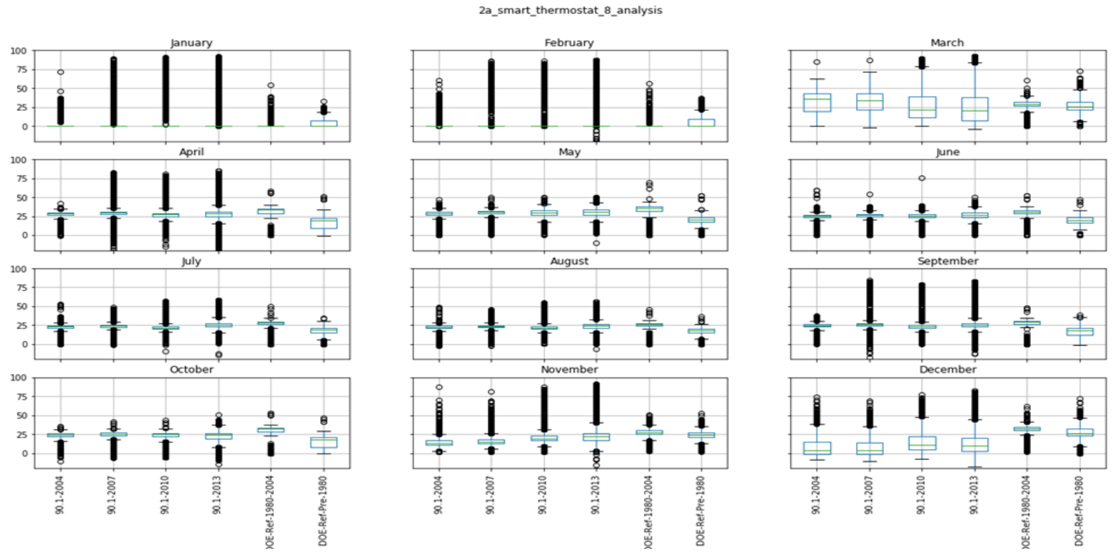
8°F breakdown of quartiles by **building type** for each calendar month with medium offices and strip malls as high, but time-sensitive, value deployments.

Analysis: Demand Reduction Breakdowns

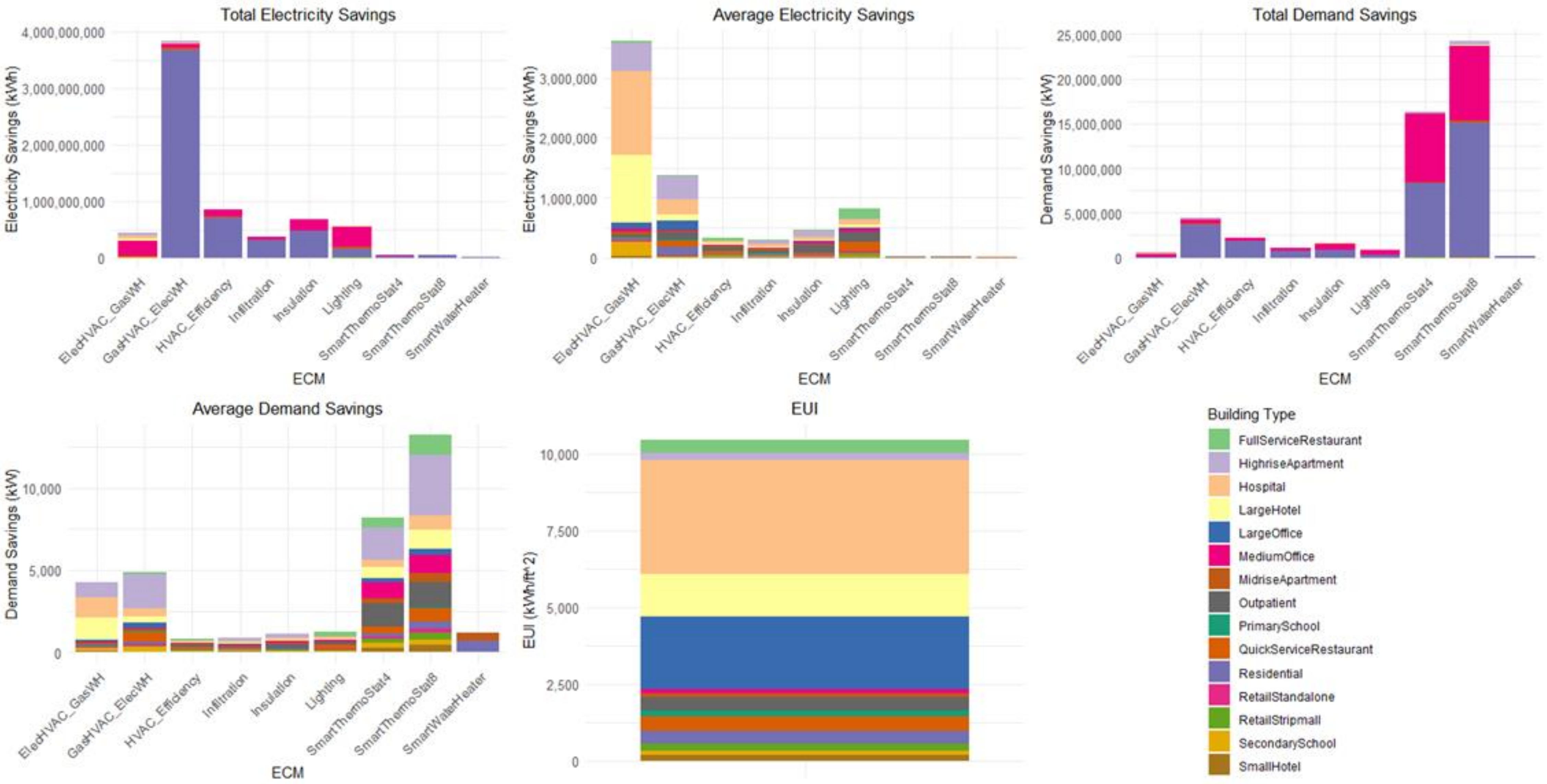
8°F shows an average **22%,** significant spread.



8°F breakdown of quartiles by **vintage** (age) for each calendar month shows slight increases with newer vintages.



Results (by building type)



Tech Commercialization Fund with Google

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

ENVIRONMENTAL INSIGHTS EXPLORER

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

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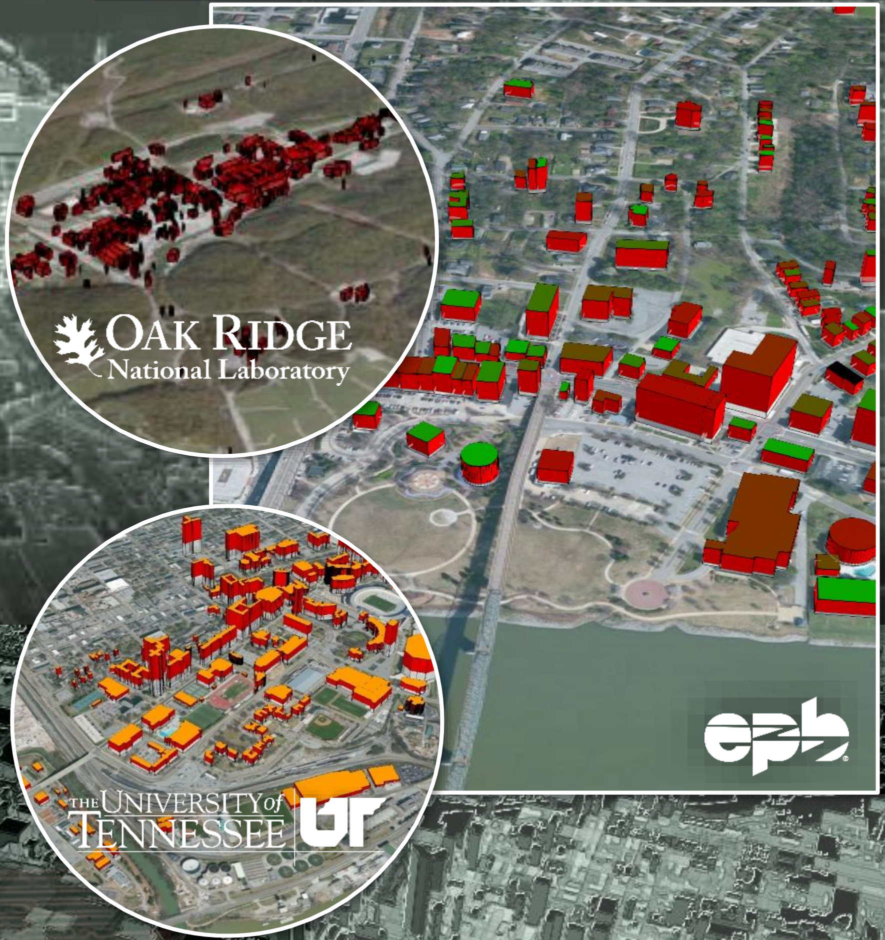
Discussion

Joshua New, Ph.D., CEM, PMP, CMVP, CSM

Subprogram manager for Software Tools & Models
Building Technologies Research and Integration Center (BTRIC)
Oak Ridge National Laboratory

newjr@ornl.gov

HPC Tools for Modeling and Simulation
Capturing building energy consumption



Results (by vintage)

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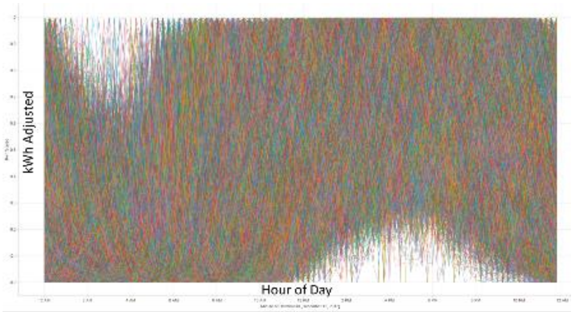
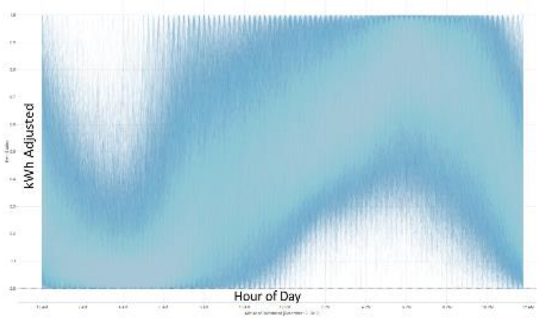
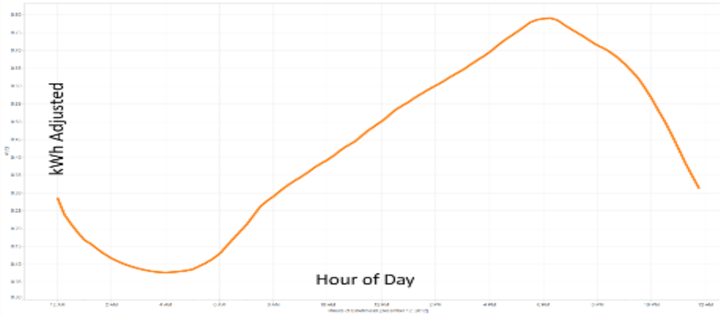
Clustering of (real) 15-min electrical data



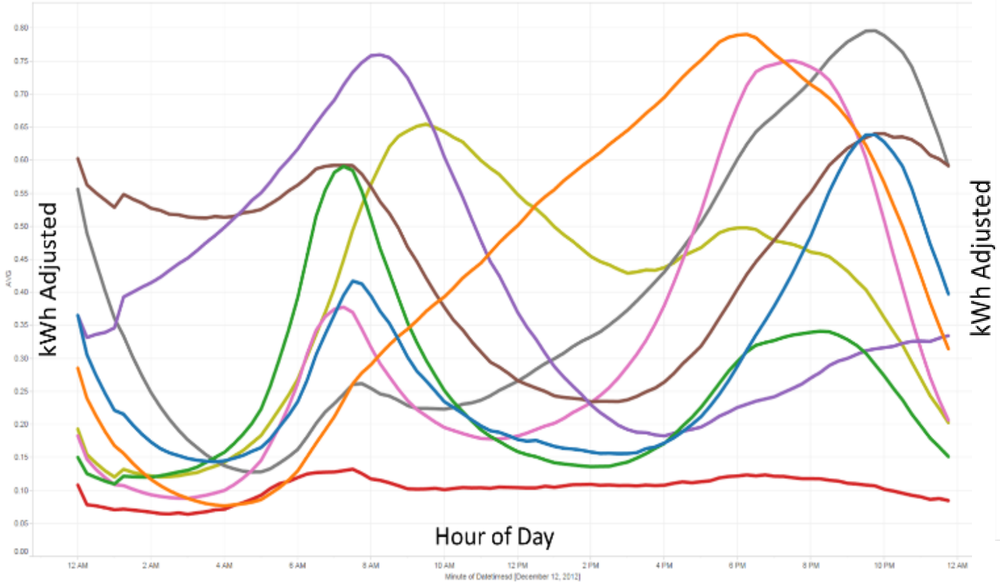
180,000 buildings measured
Whole-building electricity



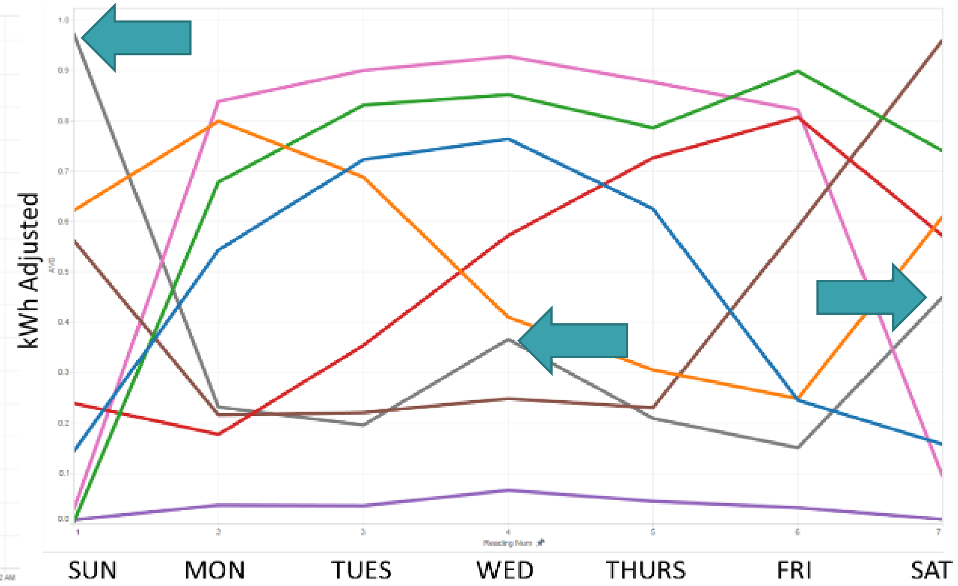
96d clustering (24h)



26,048 residential buildings with peaks typically between 5 and 7pm



9 residential clusters



8 commercial clusters (GSA1-3, 8am-5pm)

Load Factor summary

- Utility load factor $LoadFactor = Total(kWh)\ /\ (kWpeak * numHours)$
  - Close to 0, more opportunity for energy storage

	Vintage	Num Bldgs	% of all Bldgs	Avg. Load Factor
Residential	2006	16217	9.1%	0.170
	2009	6357	3.6%	0.177
	2012	149247	84.0%	0.163
Commercial	Pre-1980	670	0.4%	0.405
	1980-2004	1064	0.6%	0.296
	90.1-2004	1478	0.8%	0.255
	90.1-2007	268	0.2%	0.338
	90.1-2010	1224	0.7%	0.208
	90.1-2013	1808	1.0%	0.256

Building Type	Num Bldgs	% of all Bldgs	Avg. Load Factor
IECC Residential	171821	96.35%	0.164
Warehouse	799	0.45%	0.166
MidriseApartment	851	0.48%	0.261
SmallHotel	1557	0.87%	0.261
HighriseApartment	2068	1.16%	0.263
LargeHotel	408	0.23%	0.365
QuickServiceRest.	318	0.18%	0.380
Hospital	319	0.18%	0.399
Outpatient	59	0.03%	0.501