Potential Impacts of Climate Change on the Built Environment: ASHRAE Climate Zones, Building Codes, and National Energy Efficiency

Presented at:

3rd Annual Congress on Pollution and Global Warming

Atlanta, GA

Presented by:

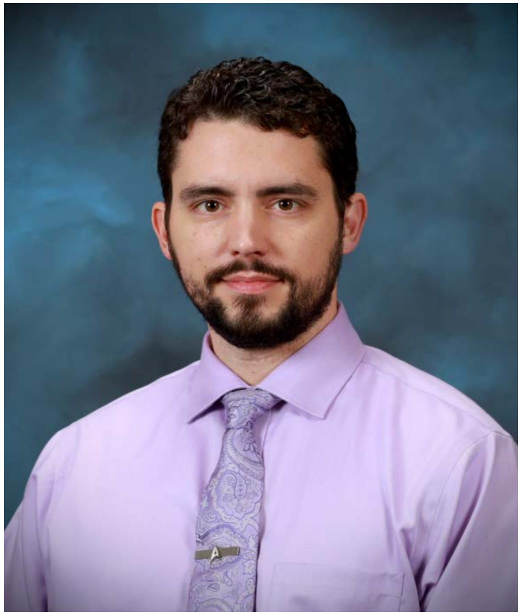
Joshua New, Ph.D., CEM
Oak Ridge National Laboratory
Joint Faculty, The University of Tennessee

October 17, 2017

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

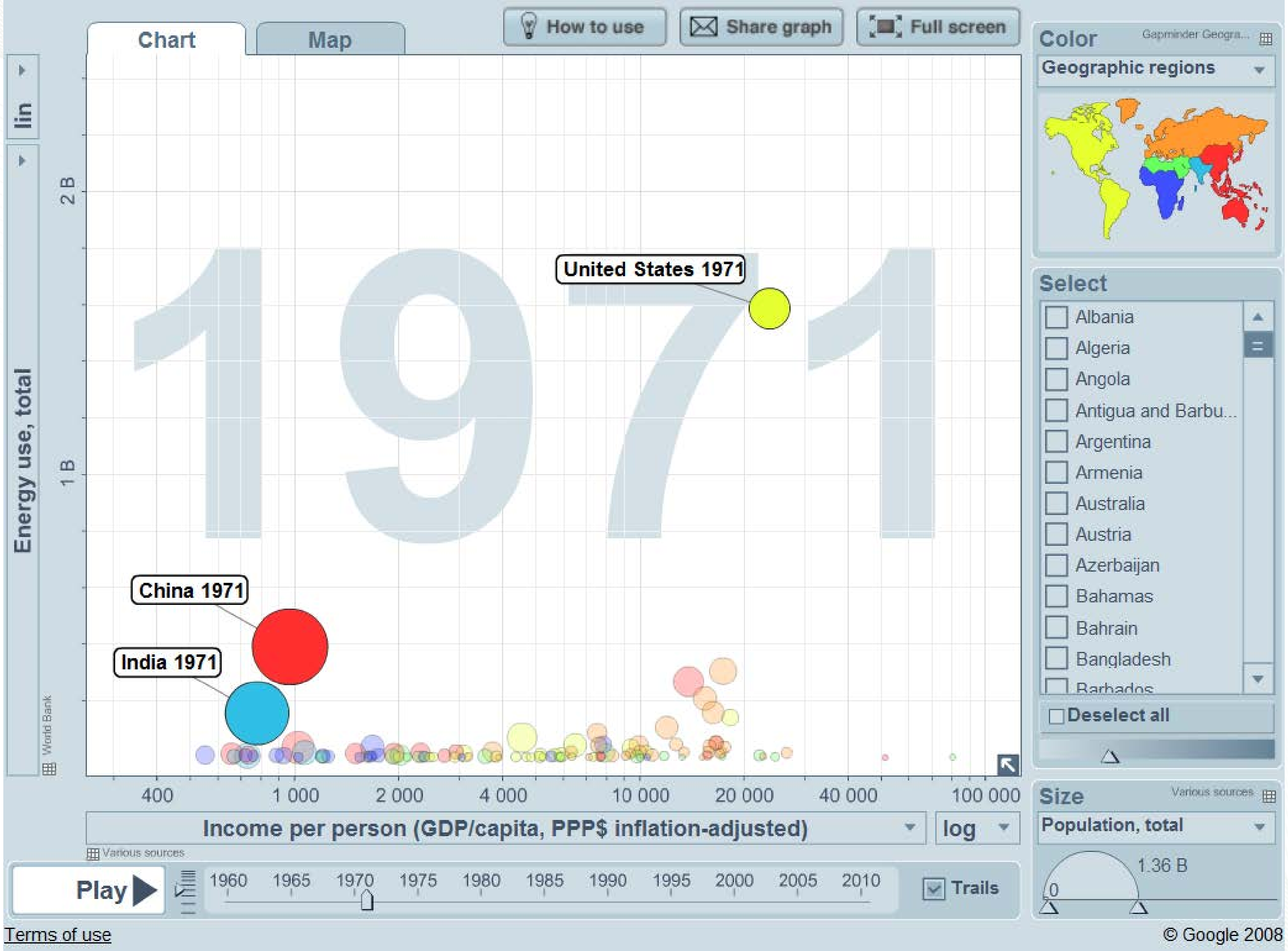
Joshua New, Ph.D., C.E.M.

- **Career**
  - 2009+ Oak Ridge National Laboratory, R&D staff
    - ETSD, Building Technology Research & Integration Center (BTRIC), Building Envelope & Urban Systems Research Group (BEUSR)
  - 2012+ The University of Tennesee, Joint Faculty
- **Education**
  - The University of Tennessee, (2004-2009), Knoxville, TN
    Ph.D. Computer Science.
  - Jacksonville State University, AL (1997-2001, 2001-2004)
    M.S. Systems&Software Design, B.S. Computer Science, Mathematics and Physics minor.
- **Professional Involvement**
  - IEEE, Senior Member
  - ASHRAE, defines international building codes
    - TC1.5, Computer Applications, Voting member and officer
    - TC4.7, Energy Calculations, 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



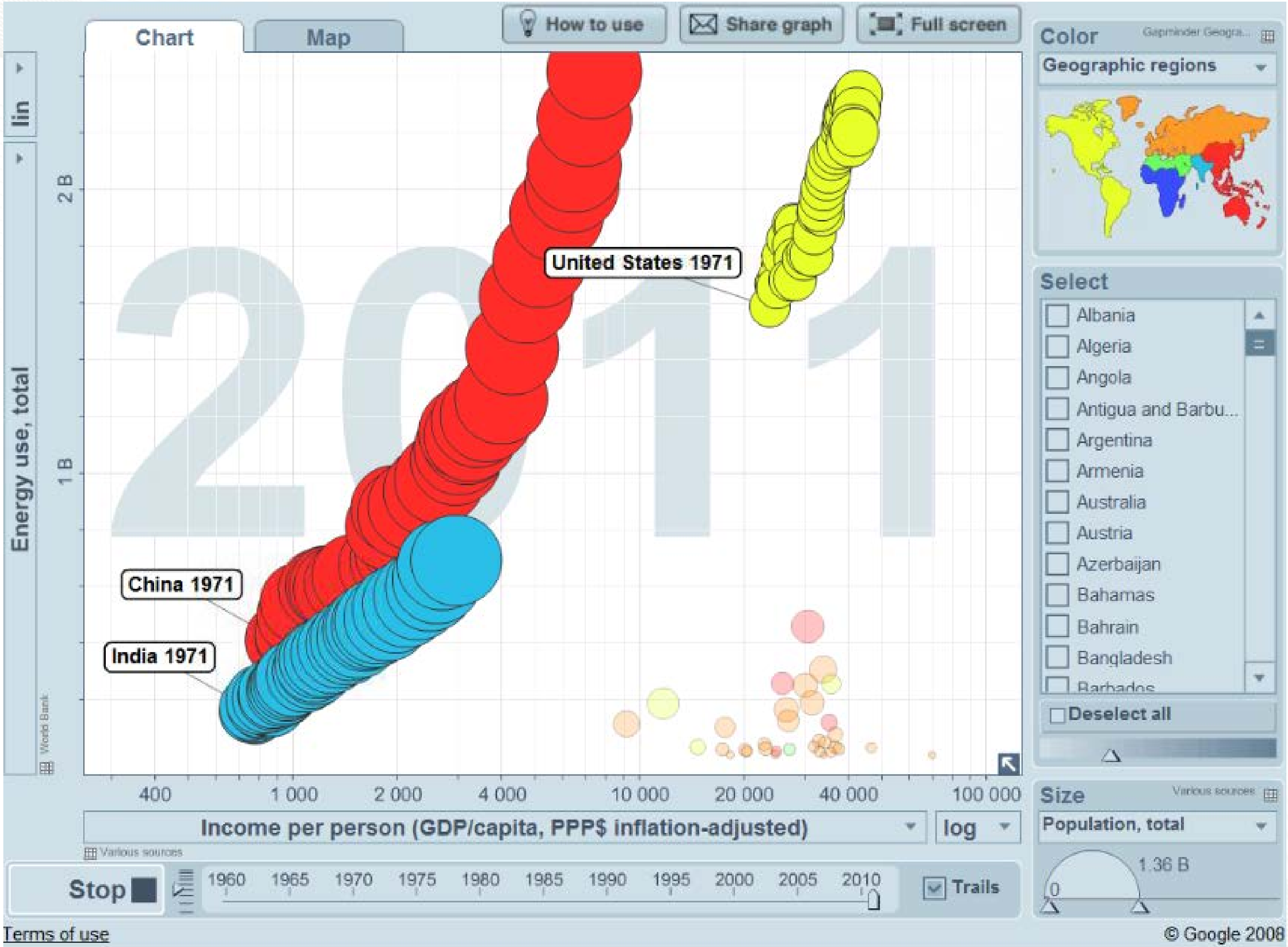
Oak Ridge National Laboratory | Building Technologies Research and Integration Center

40 Years: Energy and Quality of Life



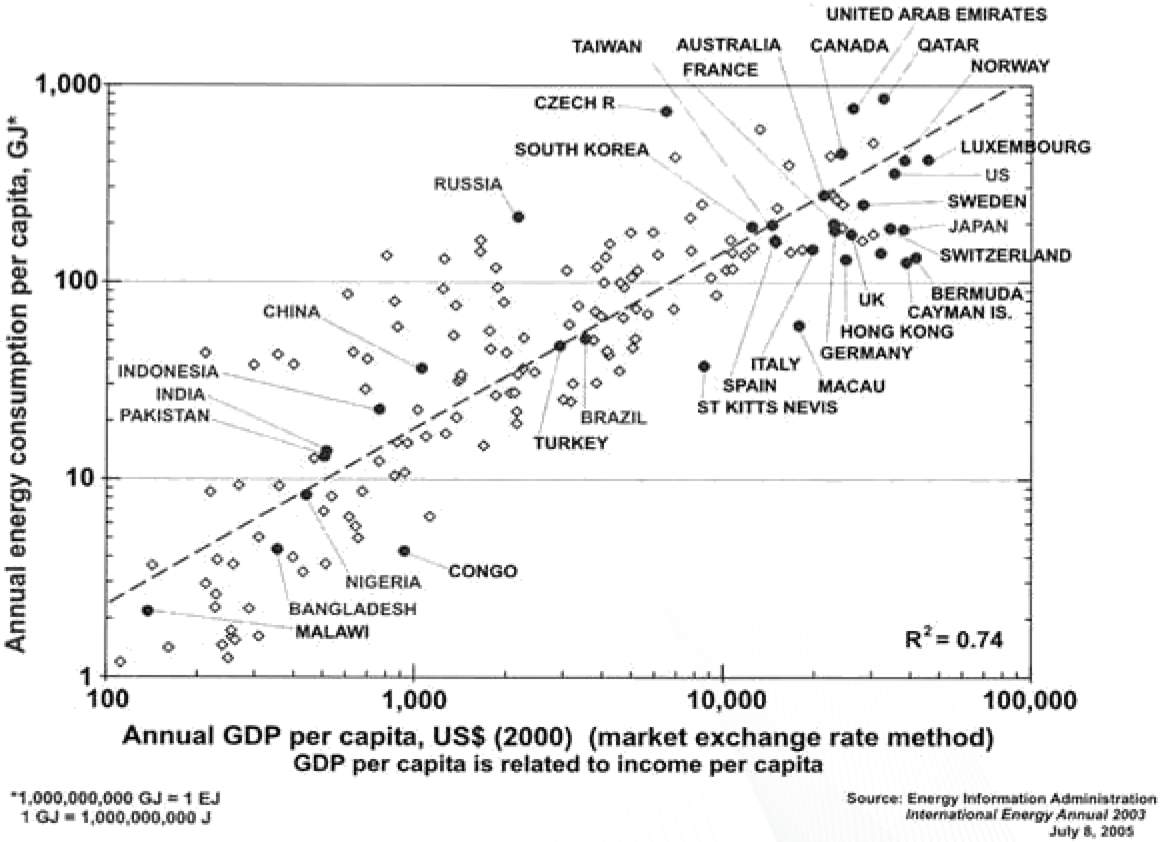
OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

A brief history of energy and life quality



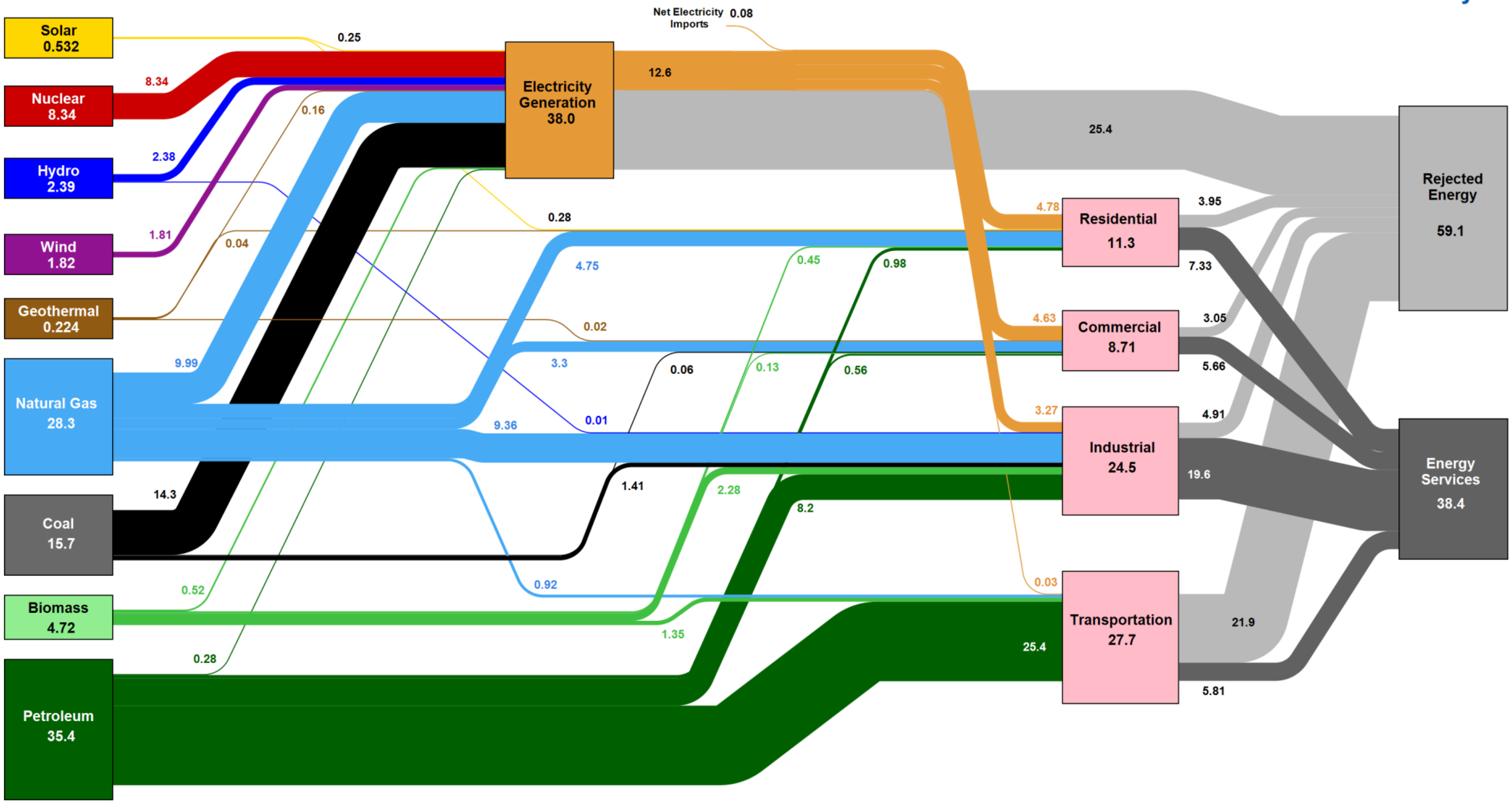
Sustainability is the defining challenge

- Buildings in U.S.
  - 41% of primary energy/carbon 73% of electricity, 34% of gas
- Buildings in China
  - 60% of urban building floor space in 2030 has yet to be built
- Buildings in India
  - 67% of all building floor space in 2030 has yet to be built



US Energy Consumption

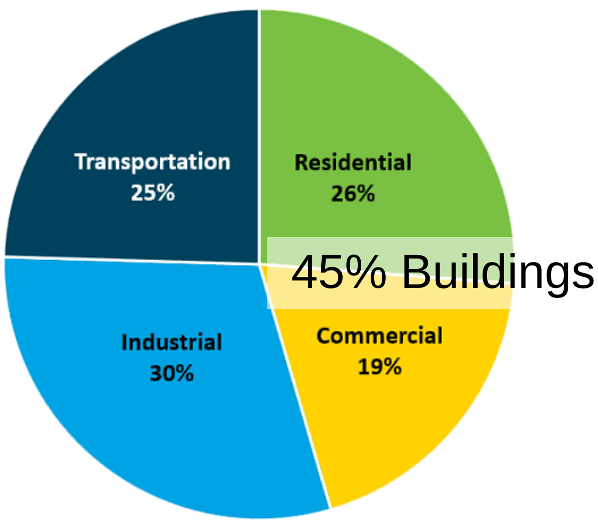
Estimated U.S. Energy Consumption in 2015: 97.5 Quads



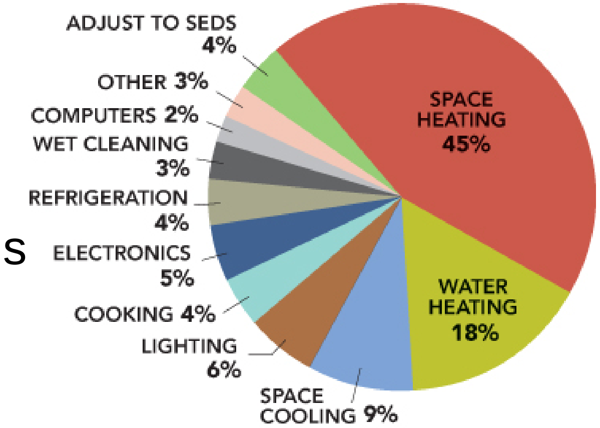
Source: LLNL March, 2016. Data is based on DOE/EIA MER (2015). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527

Energy Consumption and Production

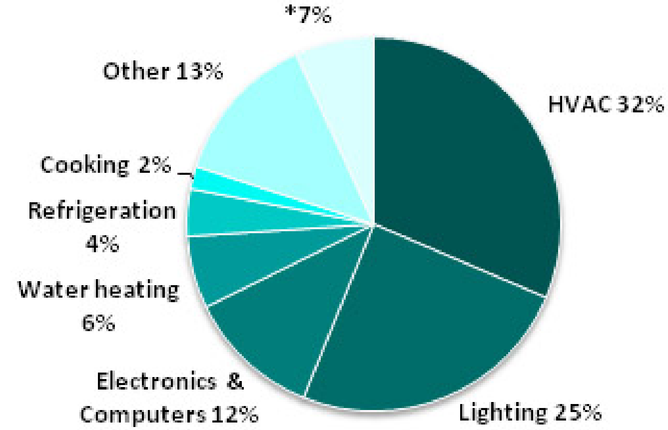
U.S. Energy Consumption by Sector



RESIDENTIAL SITE ENERGY CONSUMPTION BY END USE



Commercial Site Energy Consumption by End Use



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.

130 million U.S. buildings
$435 billion/yr energy bills

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

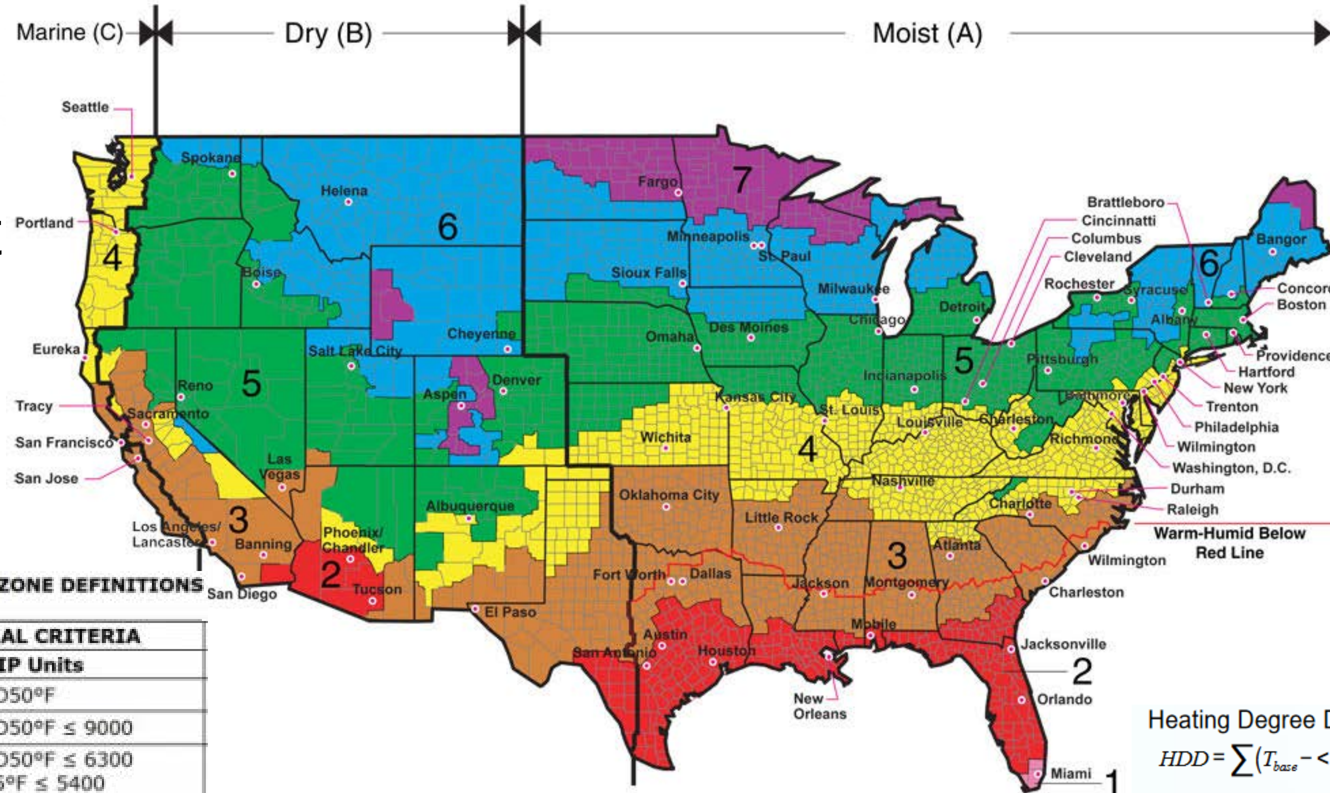
Building Energy Modeling – building descriptions + weather = estimated building energy consumption

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

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

ASHRAE Climate Zones

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



Heating Degree Days:

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

T_{base} = 18°C (65°F)

Cooling Degree Days:

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

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

OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

ASHRAE Design Conditions

DESIGN CONDITIONS FOR SELECTED LOCATIONS

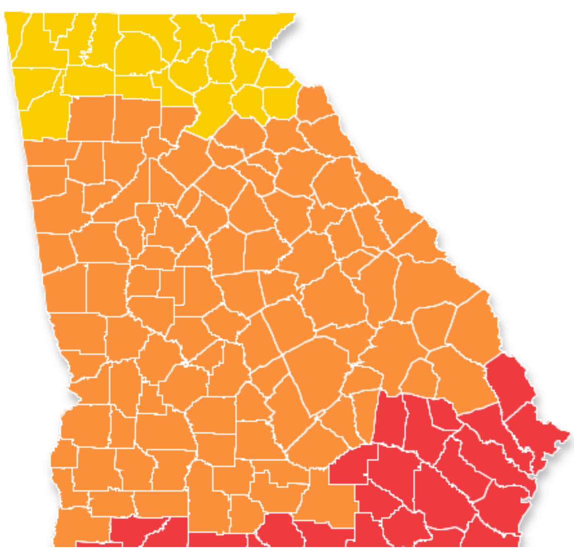
Meaning of acronyms: *Lat: Latitude, °* *Long: Longitude, °* *Elev: Elevation, ft*
DB: Dry bulb temperature, °F *WB: Wet bulb temperature, °F* *DP: Dew point temperature, °F* *HR: Humidity ratio, grains of moisture per lb of dry air* *WS: Wind speed, mph*
MCWB: Mean coincident wet bulb temperature, °F *MCDB: Mean coincident dry bulb temperature, °F* *HDD and CDD 65: Annual heating and cooling degree-days, base 65°F, °F-day*

Station	Lat	Long	Elev	Heating DB		Cooling DB/MCWB						Evaporation WB/MCDB				Dehumidification DP/HR/MCDB						Extreme Annual WS			Heat./Cool. Degree-Days	
						0.4%		1%		2%		0.4%		1%		0.4%			1%							
				99.6%	99%	DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	DP	HR	MCDB	DP	HR	MCDB	1%	2.5%	5%	HDD	CDD 65
United States of America																									*541 sites, 544 more on CD-ROM*	
Alabama																									*11 sites, 3 more on CD-ROM*	
AUBURN-OPELIKA APT	32.62N	85.43W	774	23.7	27.7	93.0	73.5	90.7	73.7	89.5	73.6	77.4	87.2	76.5	85.7	74.7	133.9	81.3	73.3	127.4	79.8	17.5	15.2	12.8	2383	1859
BIRMINGHAM MUNICIPAL AP	33.56N	86.75W	630	19.6	24.0	95.0	75.1	92.6	74.9	90.6	74.6	78.5	88.4	77.6	87.6	76.1	139.4	82.8	74.9	133.8	81.9	18.3	16.4	14.5	2693	1948
CAIRNS AAF/OZARK	31.28N	85.72W	299	26.9	30.3	95.4	76.4	93.4	76.1	91.3	75.6	80.3	89.6	79.1	88.3	77.8	146.1	83.7	76.8	141.3	82.8	16.9	14.4	12.5	1767	2415
DOTHAN MUNICIPAL	31.32N	85.45W	322	27.3	31.1	95.3	76.3	93.2	75.7	91.2	75.4	80.1	89.3	78.8	87.9	77.5	144.9	83.4	76.7	140.7	82.6	19.2	17.5	15.5	1727	2481
GADSEN MUNI (AWOS)	33.97N	86.08W	568	18.6	22.1	93.4	74.7	91.2	74.5	89.9	74.3	78.0	88.8	77.0	87.7	74.9	133.4	83.7	73.3	126.5	82.0	16.7	14.2	12.3	3215	1557
HUNTSVILLE INTL/JONES FIELD	34.64N	86.79W	643	17.0	21.6	94.6	75.1	92.2	74.7	90.1	74.2	78.3	88.1	77.4	87.2	75.8	138.1	82.6	74.6	132.8	81.5	21.5	18.9	17.0	3140	1742
MAXWELL AFB/MONTGOM	32.38N	86.37W	174	27.9	31.5	97.2	76.5	95.2	76.6	93.3	76.3	80.5	90.8	79.6	89.9	78.0	146.3	85.0	77.0	141.3	84.2	18.0	15.6	13.1	1813	2598
MOBILE REGIONAL AP	30.69N	88.25W	220	26.9	30.7	93.5	76.7	91.8	76.4	90.3	76.0	80.1	88.4	79.0	87.0	77.9	146.0	83.4	76.9	141.5	82.4	20.6	18.5	16.8	1662	2463
MONTGOMERY DANNELLY FIELD	32.30N	86.39W	203	23.7	27.3	96.2	76.5	94.0	76.1	92.1	75.8	79.7	90.8	78.5	89.2	76.7	140.3	84.4	75.8	135.8	83.3	18.6	16.5	14.3	2143	2282
MUSCLE SHOALS REGIONAL AP	34.75N	87.61W	561	17.8	22.1	95.5	75.4	93.1	75.2	90.9	74.8	78.7	89.1	77.8	88.2	76.0	138.6	82.9	75.0	134.0	82.0	18.7	16.8	14.6	3084	1822
TUSCALOOSA MUNICIPAL AP	33.21N	87.62W	187	20.6	25.0	95.7	76.5	93.4	76.3	91.4	76.0	79.8	90.2	78.7	88.9	77.1	142.2	83.6	75.9	136.5	82.9	17.5	14.8	13.0	2509	2101
Alaska																									*7 sites, 66 more on CD-ROM*	
FAIRB																	74.2	65.1	56.7	69.6	64.1	17.7	15.5	12.6	13528	71
FT. RI																	67.7	64.2	54.5	64.0	62.1	19.0	14.5	11.5	10726	3
ANCH																	69.5	61.6	55.2	65.3	60.6	18.8	15.6	12.8	10360	11
LAKE																	69.0	62.8	55.3	65.3	62.2	18.7	16.3	13.6	9824	16

« Back to U.S. map

GEORGIA

Click a county to see the requirements for its climate zone.



Climate Zone 2

Climate Zone 3

Ceiling R-value	30
Wood Frame Wall R-value	13
Mass Wall R-value [i]	5/8
Floor R-value	19
Basement Wall R-value [c]	5/13[f]
Slab R-value [d], Depth	0
Crawlspace Wall R-value [c]	5/13
Fenestration U-Factor [b]	0.50[j]
Skylight U-Factor [b]	0.65
Glazed fenestration SHGC [b, e]	0.30

Climate Zone 4 (Except Marine)

a. R-values are minimums. U-factors and SHGC are maximums. R-19 batts compressed into a nominal 2x6 framing cavity such that the R-value is reduced by R-1 or more shall be marked with the compressed batt R-value in addition to the full thickness R-value.

Purpose of the work

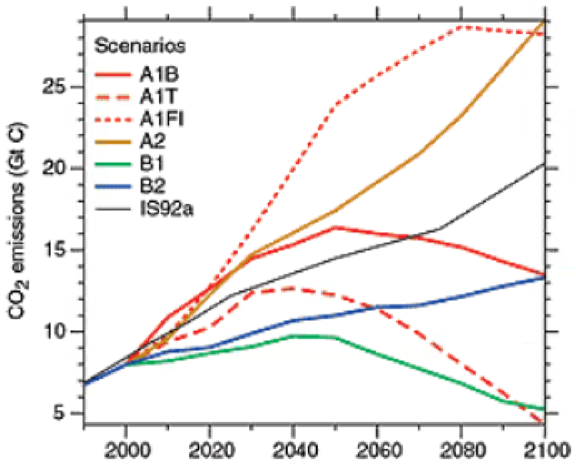
- Open Questions:
  - What would scientifically-defined CZs look like?
  - What is the difference between current CZs and today's climate?
  - What about the changing climate?

- Objectives:
  - Statistical, multivariate definition of CZs
  - Assessment of ASHRAE's CZs for the contemporary climate
  - Impact of CZ differences using advanced scientific data
    - High-resolution weather data
    - IPCC climate models
    - Building density

Redefine CZs using model data

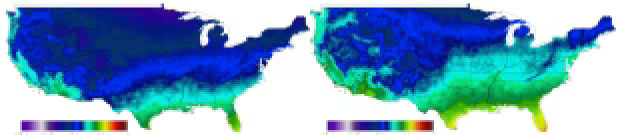
- Resolution: 2 km x 2 km grid cells
- Extent: Continental United States
- Present Conditions (1950-2000): WorldClim
- Future conditions (2050, 2100): PCM and Hadley GCMs; for multiple scenarios (IPCC AR4 A1FI, B1)

1. Precipitation during the hottest quarter
2. Precipitation during the coldest quarter
3. Precipitation during the driest quarter
4. Precipitation during the wettest quarter
5. Ratio of precipitation to potential evapotranspiration
6. Temperature during the coldest quarter
7. Temperature during the hottest quarter
8. Sum of monthly Tavg where Tavg >=5 deg C
9. Integer number of consecutive months where Tavg >= 5 deg C (Length of potential growing season)
10. Solar interception
11. Day/night diurnal temperature difference
12. Elevation



- 12 energy-related variables
  - Temperature
  - Humidity
  - Radiation
  - Elevation

Contemporary period (WorldClim)



OAK RIDGE National Laboratory | BUILDING TECHNOLOGIES RESEARCH AND INTEGRATION CENTER

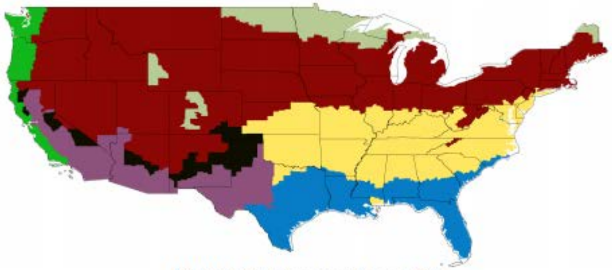
Clustering and Similarity

- Similarity/Dissimilarity: Euclidean distance of any location (P_j) from the mean climatic condition ($\bar{P}_i$) of its Climate Zone.

$$Sim_j = \sqrt{\sum_{i=1}^{n} (P_{i,j} - \bar{P}_i)^2}$$

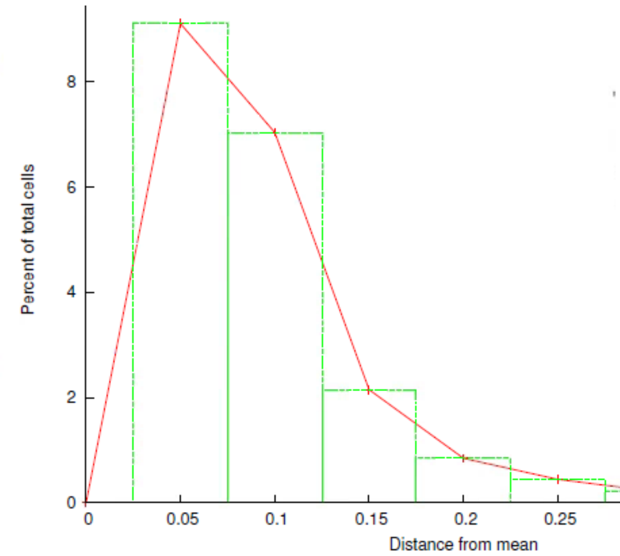
- where, = 1-12 (climate variables),
- $P_{i,j}$ = climate conditions at point j ,
- P= mean climate state for the zone
- Assumption: Building codes are designed for mean climate conditions for the zone.
- Desired: Optimal clustering of grid cells so that cell locations within a zone are maximally similar to the mean climate conditions for the CZ (Lower the Euclidean distance in multi-variate space the better).

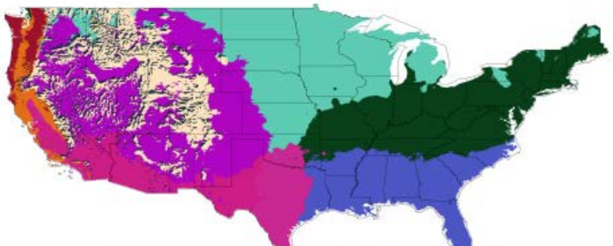
Data-derived CZs and assessment



ASHRAE Climate Zones (7)

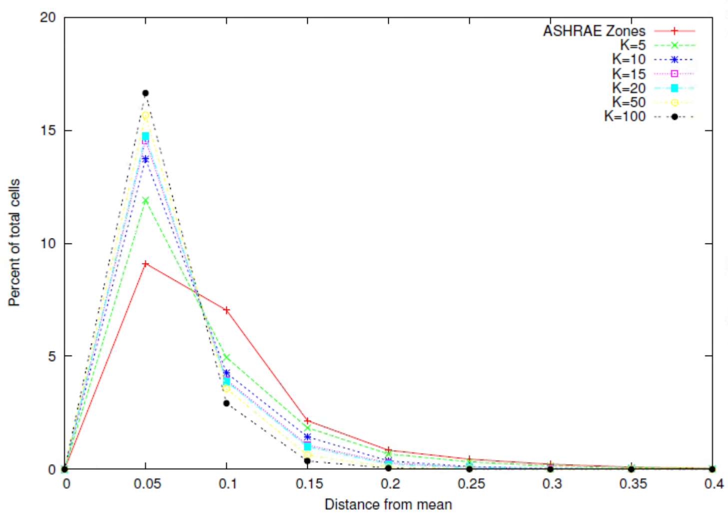
Clustering-based Climate Zones (K=5)

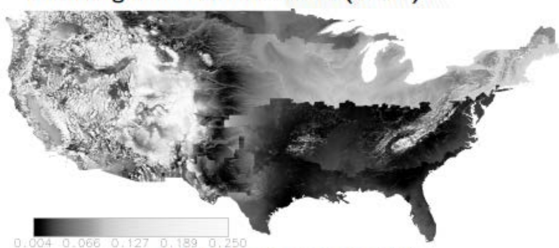




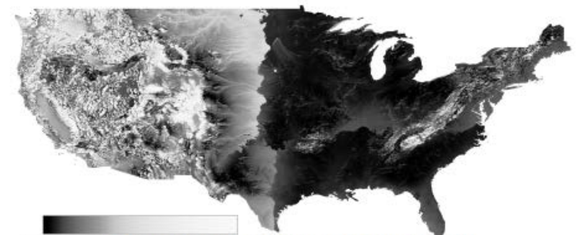
Clustering-based Climate Zones (K=10)

Clustering-based Climate Zones (K=20)

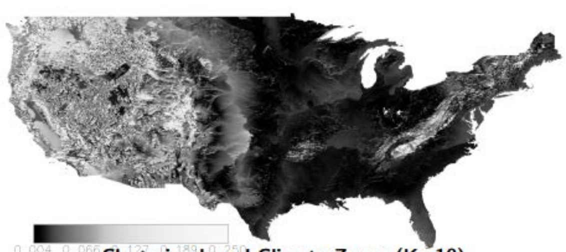




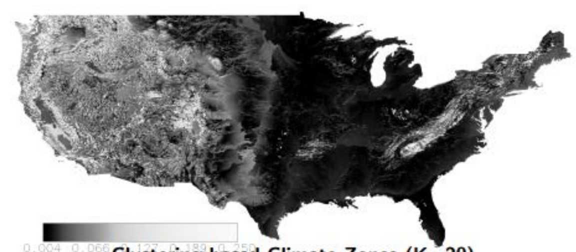
ASHRAE Climate Zones (7)



Clustering-based Climate Zones (K=5)

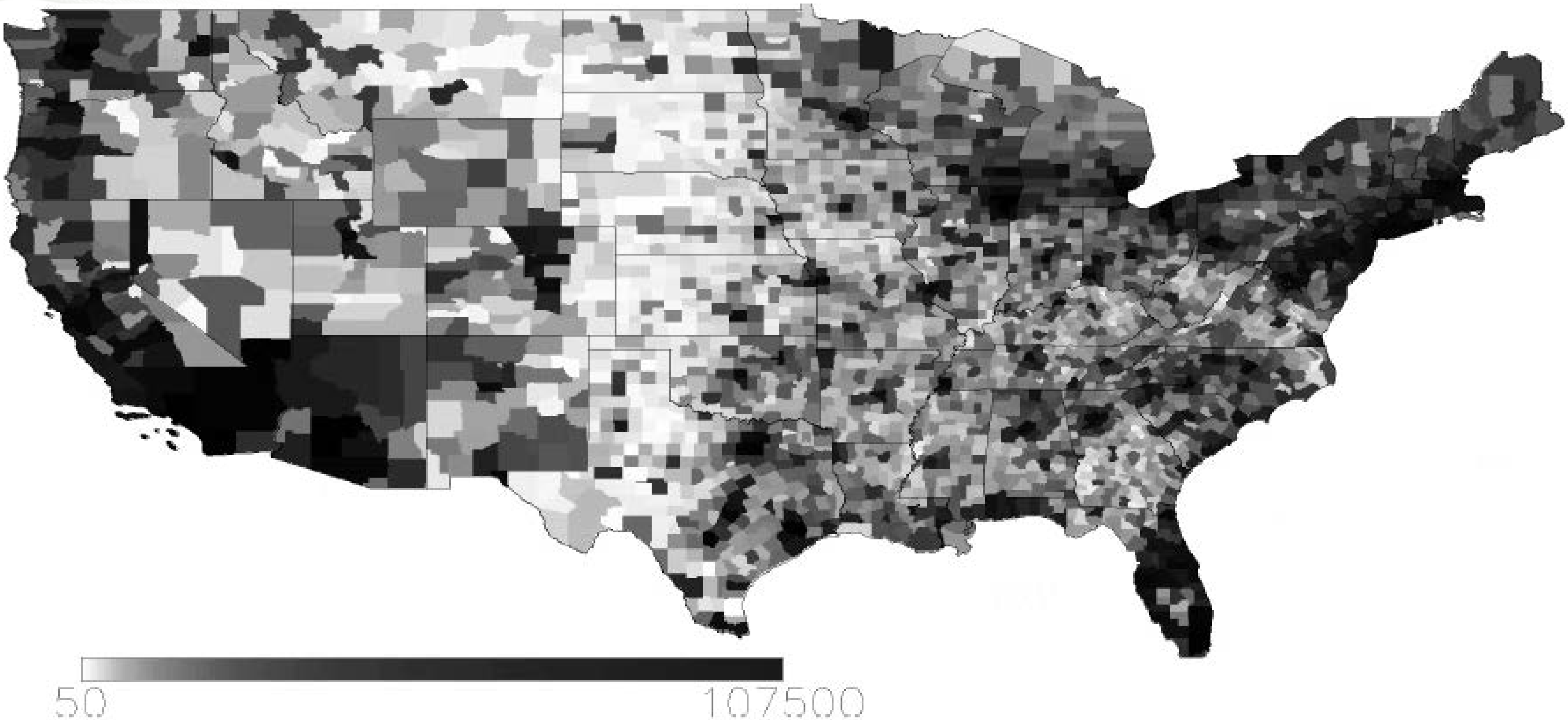


Clustering-based Climate Zones (K=10)



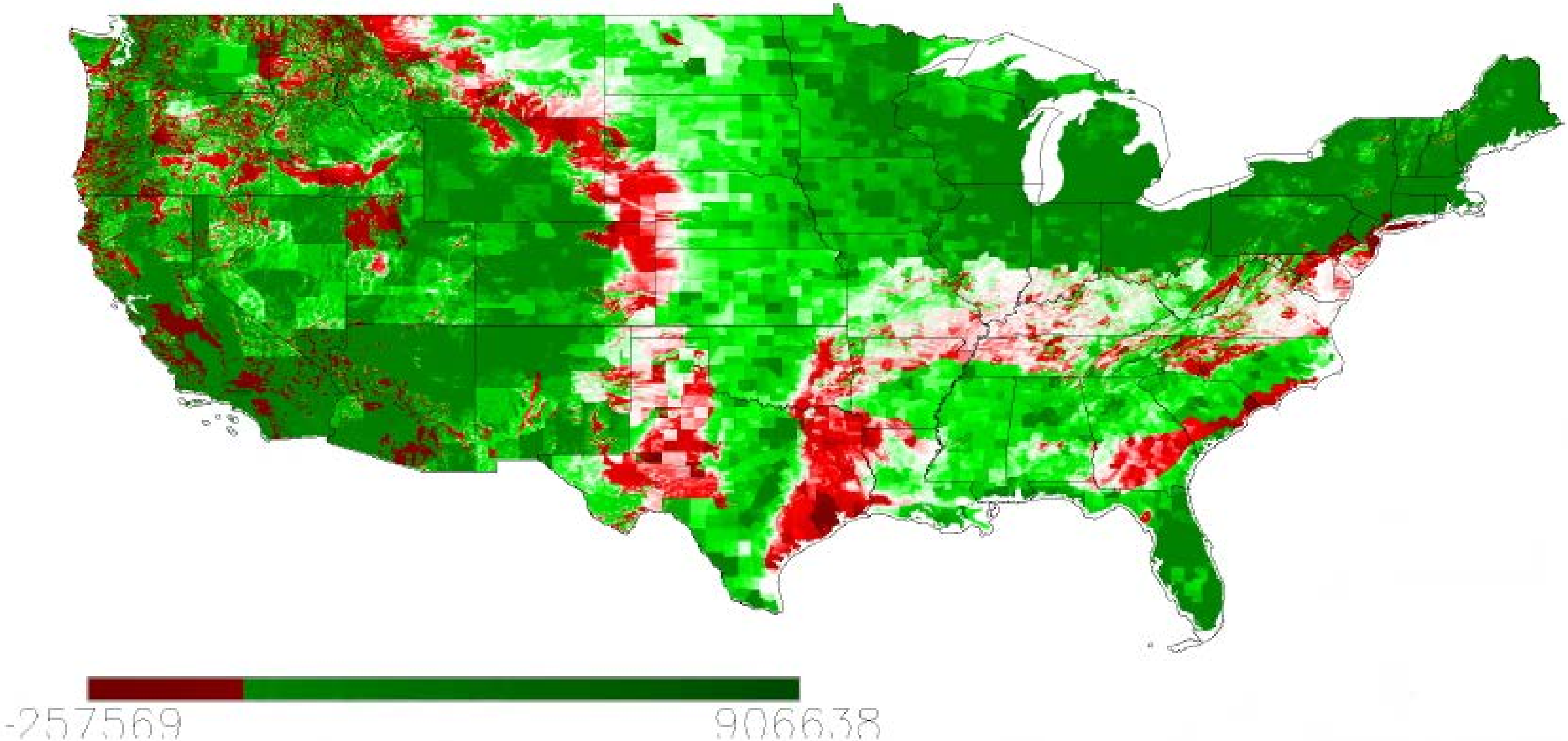
Clustering-based Climate Zones (K=20)

Make it accurate where the buildings are



Housing Units Distribution for US (US Census 2010)

Building-adjusted CZ improvement



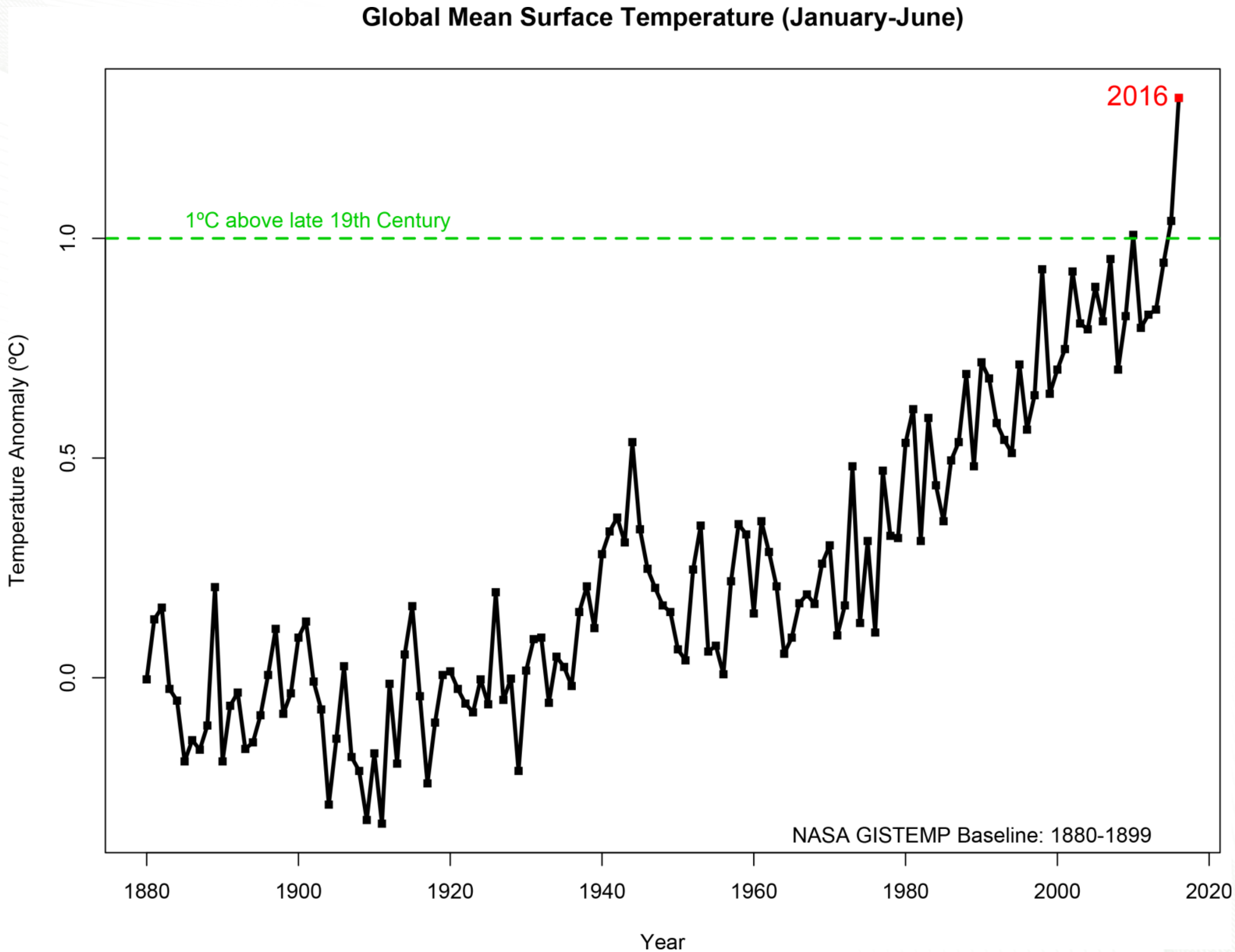
$\Delta EE < 0$: Areas in Red will have poor energy efficiency in re-designed zones compared to ASHRAE

$\Delta EE > 0$: Areas in Green will have improved energy efficiency in re-designed zones compared to ASHRAE

What about the future?

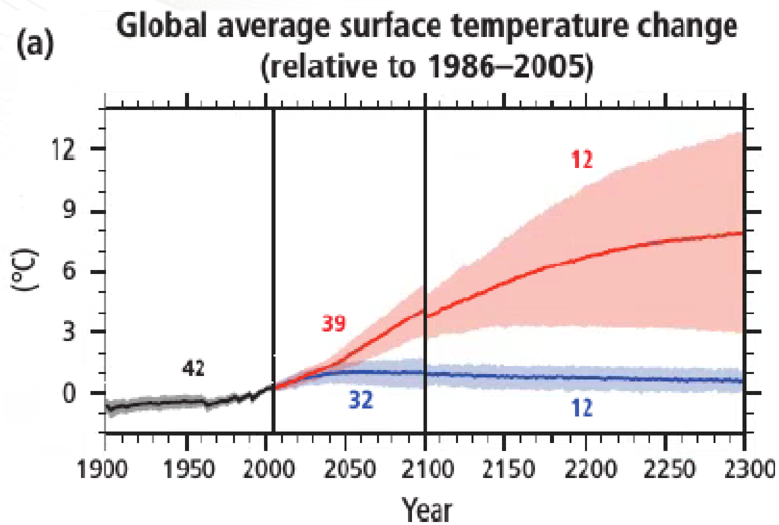
- Buildings are designed for 30-100 year life span
- BUT our climate zones are based on historical climate data
- What's the applicability of these zone for predicted climate change future scenarios?
- Can we use our best understanding of predicted climate to design these zones not for the present but for the future?
  - Current plan is to redefine climate zones in 2021 to account for climate change by extrapolating historical trends, rather than using the latest climate models

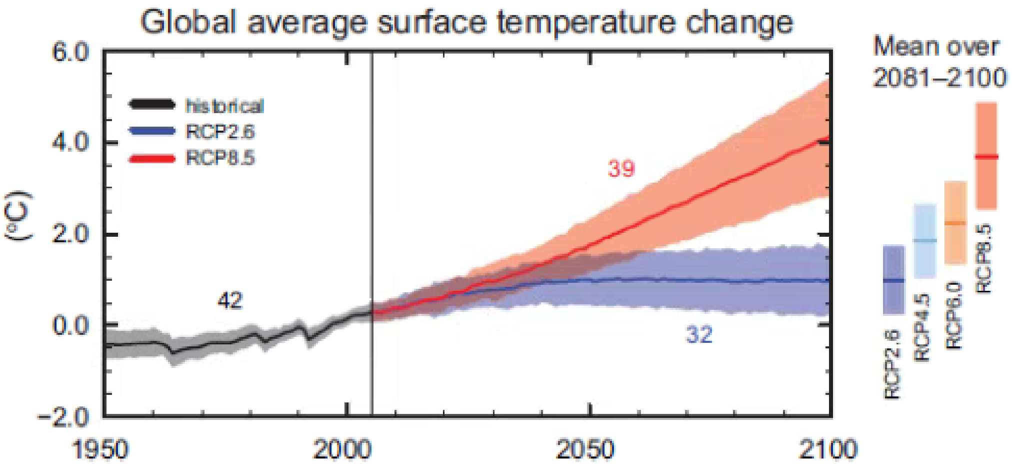
Why does it matter?



Source: https://www.nasa.gov/sites/default/les/thumbnails/image/2016temperature.png

Why does it matter?



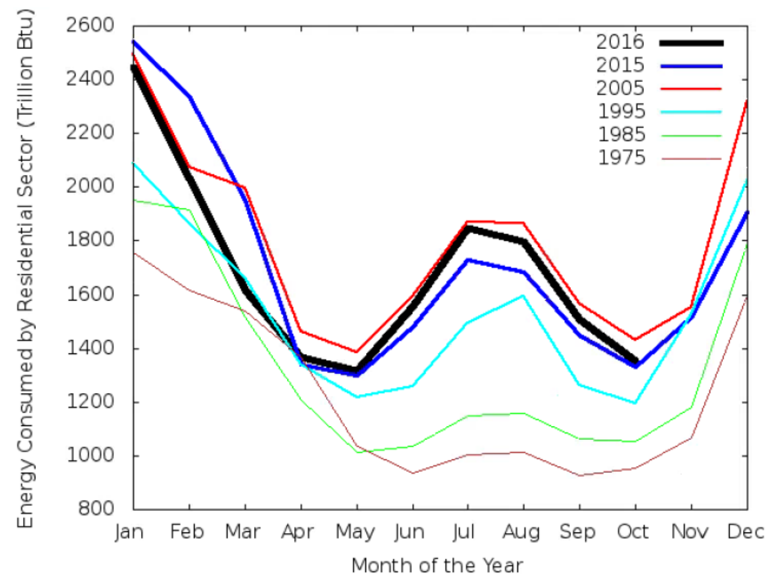


Climate models predict a significant warming in the future under business as usual and various emission scenarios for future (IPCC Fifth Assessment Report)

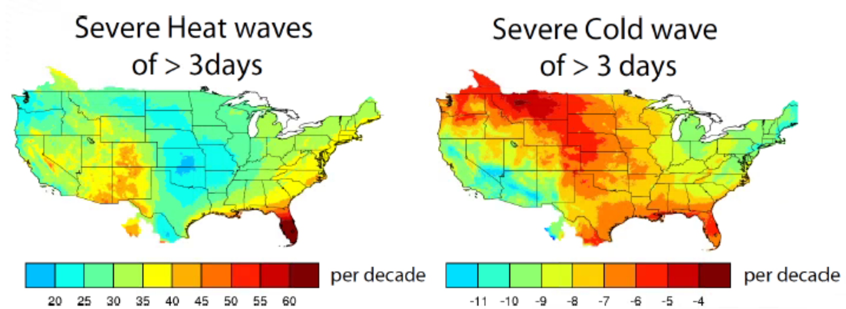
Definitions, analysis, and standards around weather data for buildings:
Typical Meteorological Year (TMY)
Actual Meteorological Year (AMY)
Future Meteorological Year (FMY)
eXtreme Meteorological Year (XMY)

Why does it matter?

- As the climate changes, overall cooling demand will increase while the heating demand will decrease.
- Under a +3.7 C scenario by 2100, the worldwide reduction in heating energy demand due to climate change may reach 34% in 2100, while cooling demand may increase by 70% (IPCC AR5).
- Extremes are worse – equipment sizing, comfort, and death prevention become more challenging
- Electrical grid resiliency and buildings-to-grid impacts are not well understood

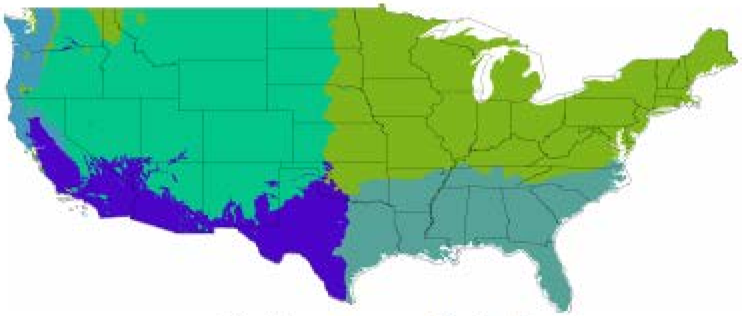


Future changes (2011-2050 minus 1966-2005) in climate extremes

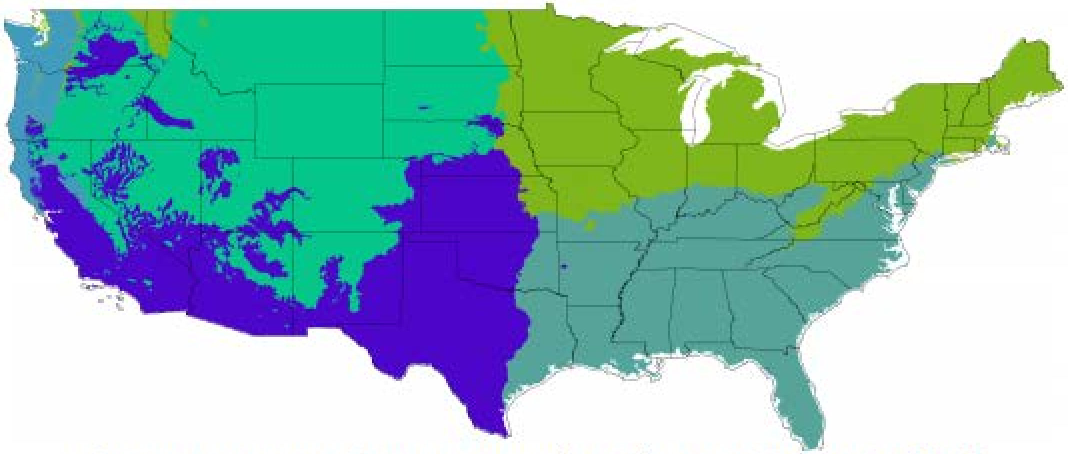


Increased frequency of extremes would drive the peak energy demands. Building design elements and equipments (HVAC etc.) would require careful provisioning.

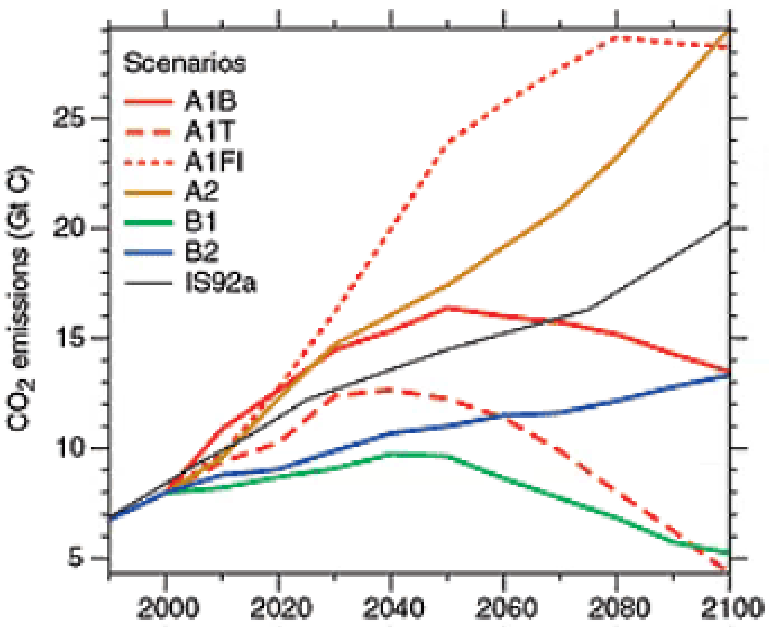
Climate Change Impacts

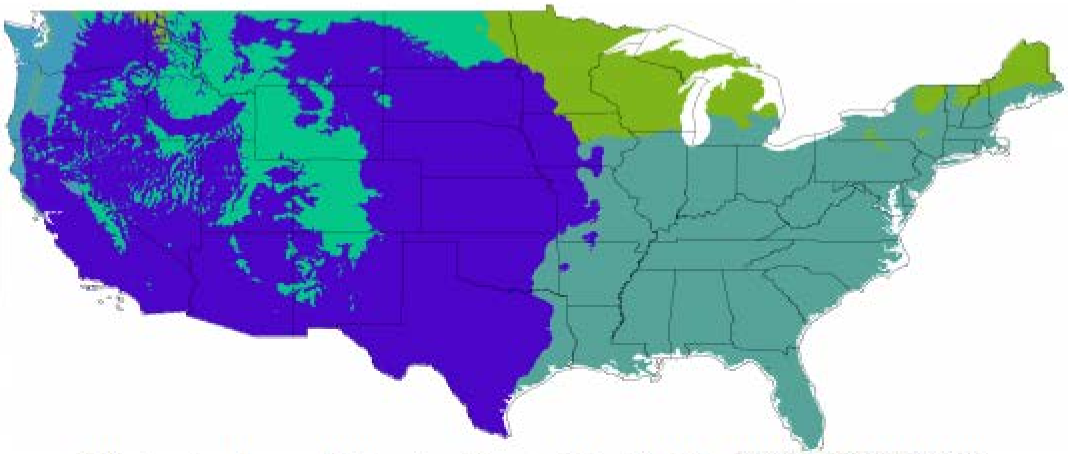


Contemporary Period



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





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

Future work

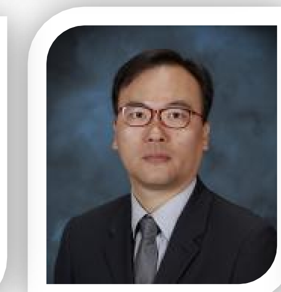
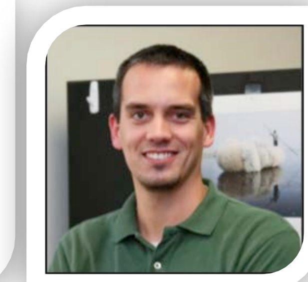
- What data sources should be leveraged?
- What climate variables should be included (or dropped)?
- What other (e.g. political) variables should be included?
- What weightings should be given each variable? (e.g. sensitivity analysis-informed study of impact to building energy consumption?)
- How does this shift with climate change?
- What building, or building component, lifetimes should CZs be optimized for?
- How could the nation's energy security and infrastructure resiliency be improved by incorporating future scenarios into policy and the built environment?
- **How much energy and $ could be saved by having a forward-looking climate policy?**

AutoBEM Acknowledgements

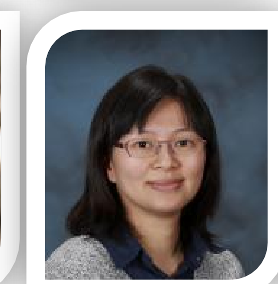
- U.S. Department of Energy
- National Nuclear Security Administration
- Oak Ridge National Laboratory
- Building Technologies Office
- Office of Electricity



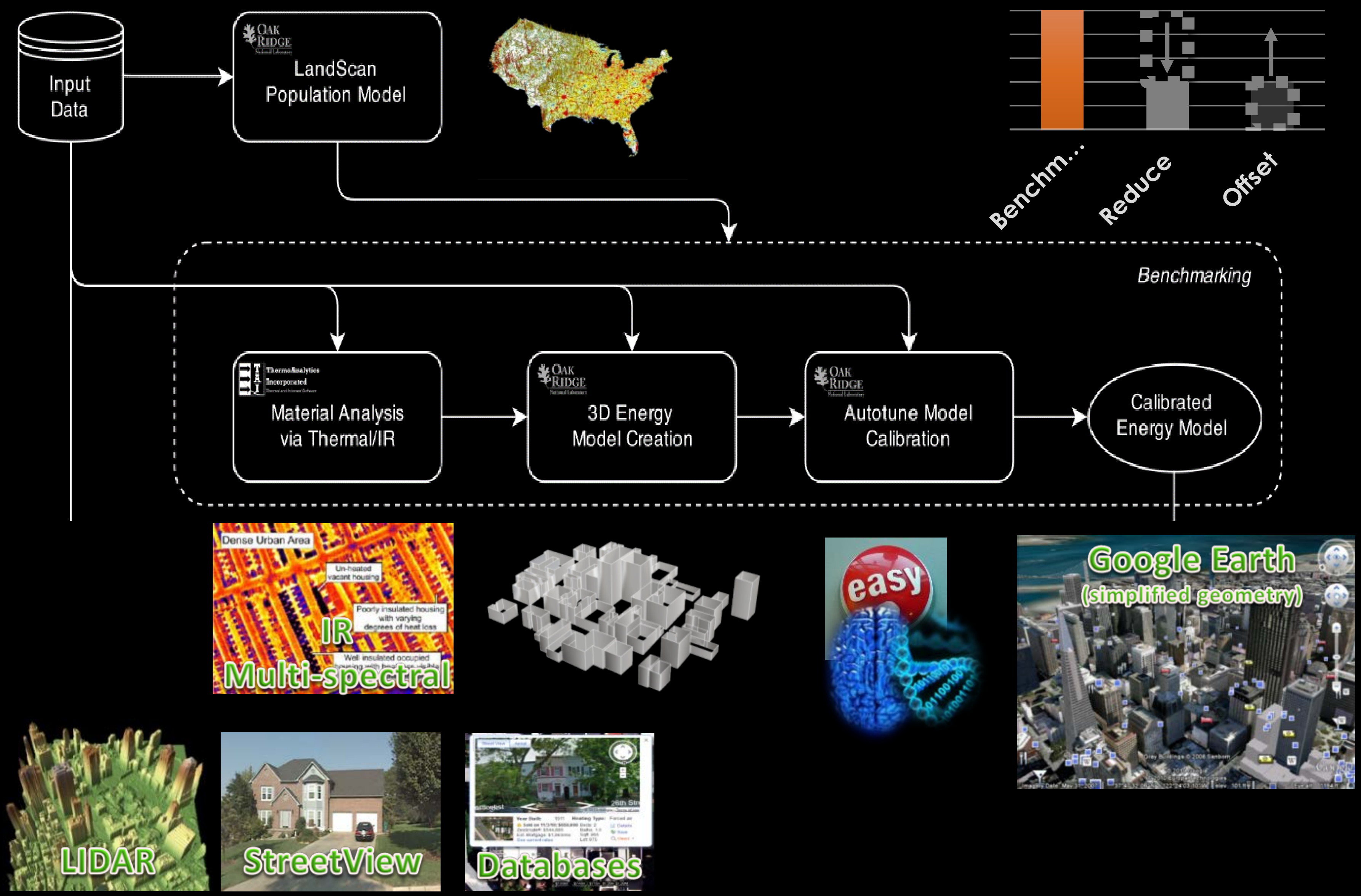







Model America - calibrated model for every US building

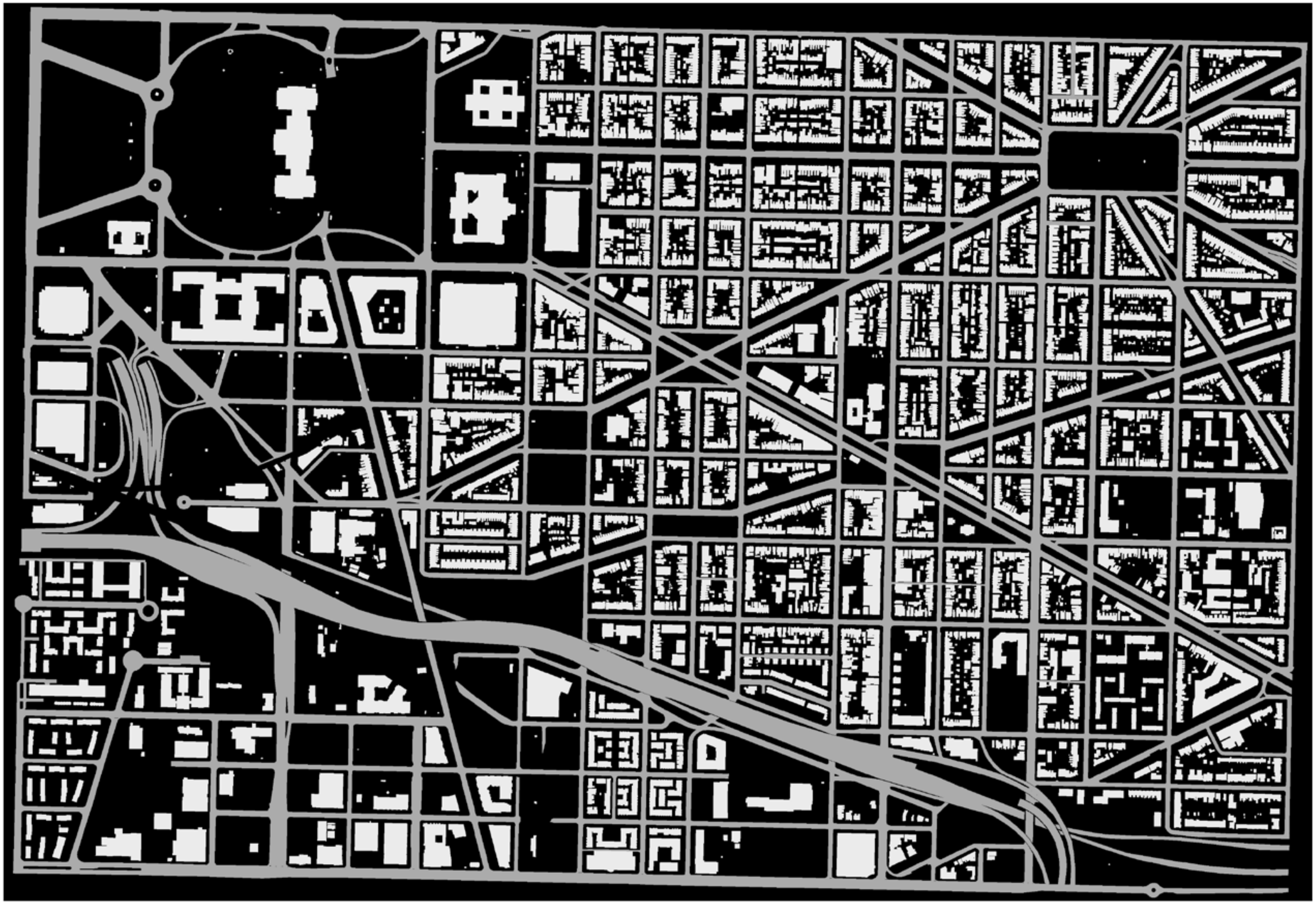


Data Sources

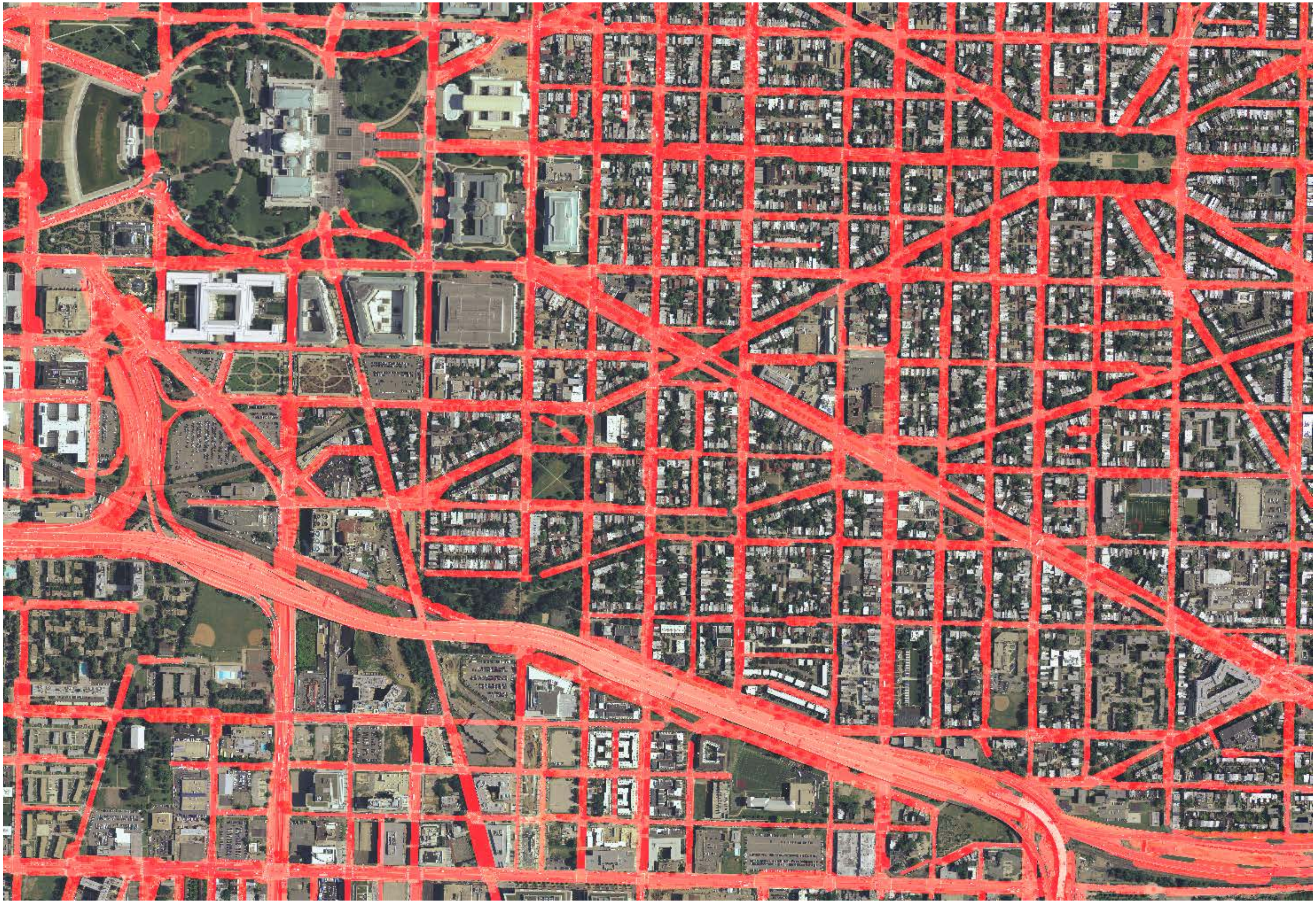
- Database and image sources for urban model generation
  - Satellite and airborne imagery
  - Cartographic data
  - Ground level images
  - Elevation data
  - Building information databases
  - 3D building model databases

	Short Title
Summary	Satellite imagery, including panchromatic and multispectral images
Data type	Image
Company	
Website	
Temporal resolution	Cities - 3-11 times per week
Spatial resolution	0.3 m
Measure accuracy	
Cost	$11 per sq. km
Format	GeoTiff
Mapping to building input variables	Building footprints
Mapping to area properties	Vegetated areas, road surface, buildings, parking lots
Mapping to material properties	Road pavement materials (e.g., concrete, asphalt), parking lots (e.g., gravel, soil)
Coverage of US	Over 10 million km^2 of coverage of the contiguous US
Orientation	Aerial
Existing internal software	N/A
Existing expertise	Remote sensing data analysis tool
Restrictions	N/A
Comments	

Manual Segmentation of DC



Automatic Road Extraction

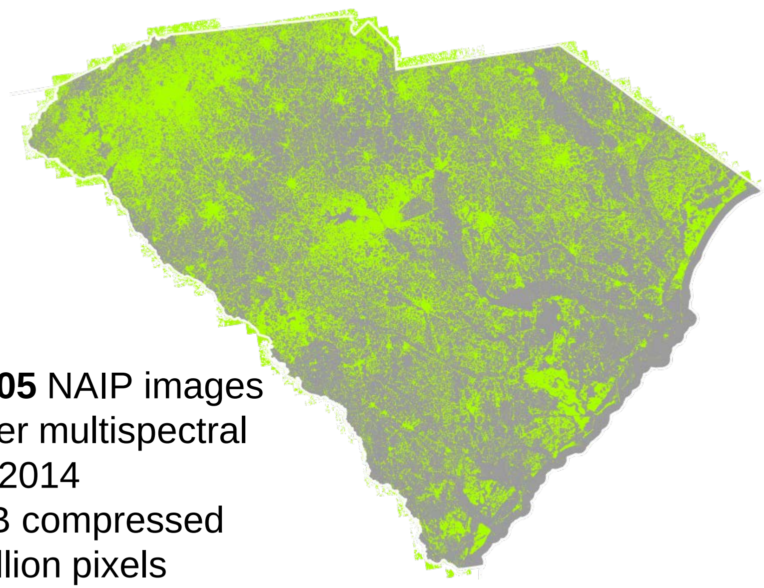


Automatic Building Footprint Extraction

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

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

Automatic Building Footprint Extraction



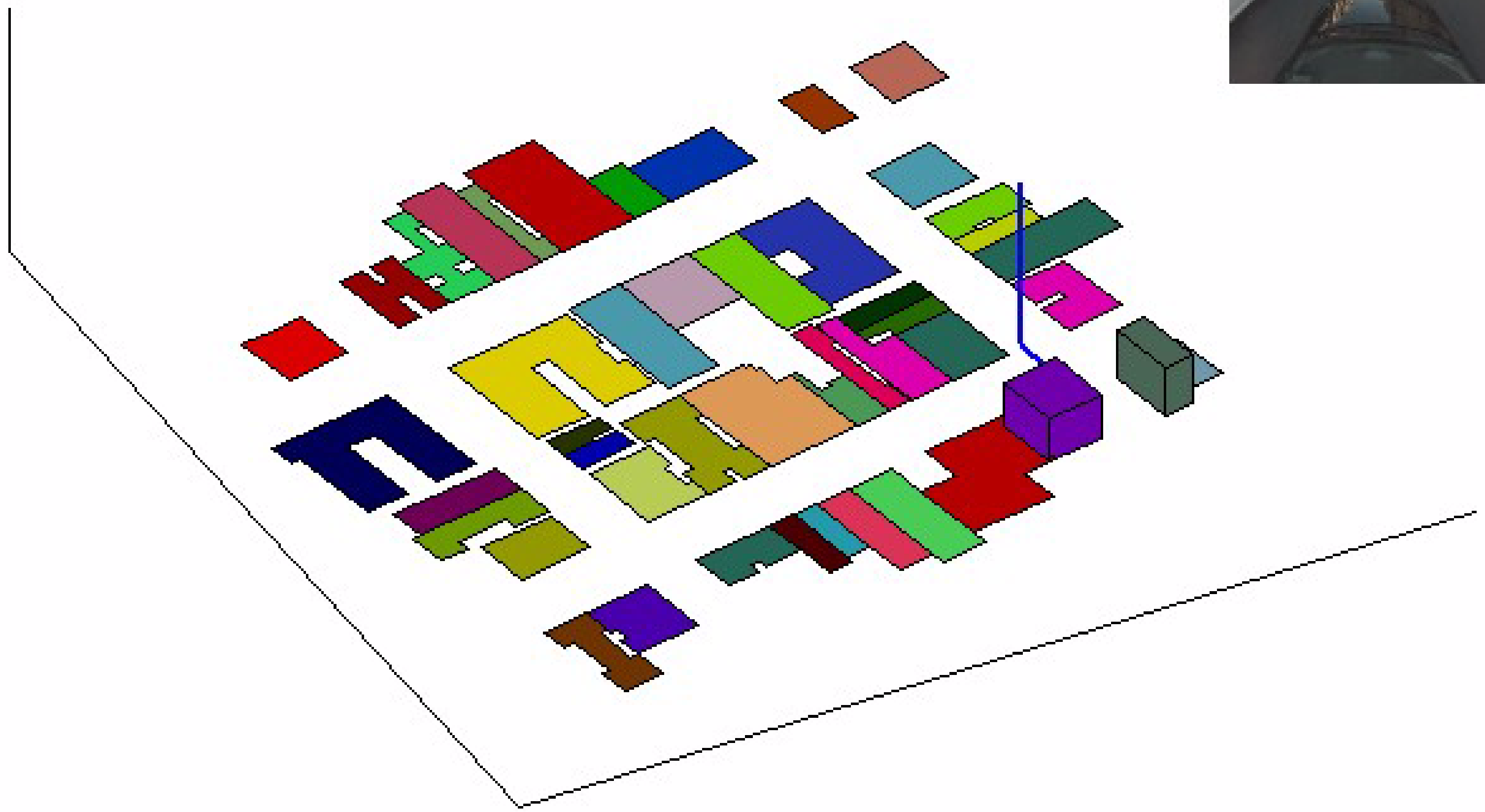
- **220,005** NAIP images
- 1 meter multispectral
- 2012-2014
- 5.8 TB compressed
- 9.8 trillion pixels

Portland, OR (25,393 m^2)
Imagery: June – July 2012
Lidar: September 2010

Frankfort, KY (14,801 m^2)
Imagery: June 2012
Lidar: June 2011

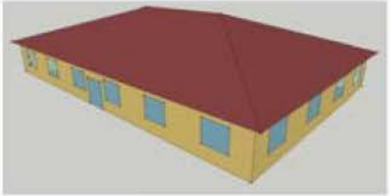
Part of Knox County, TN (18,527 m^2)
Imagery: June 2012
Lidar: October 2014

Processing Street-Level Imagery

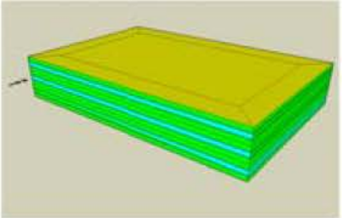


Prototype Buildings

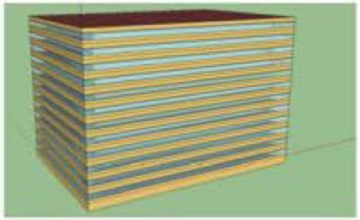
Small Office



Medium Office

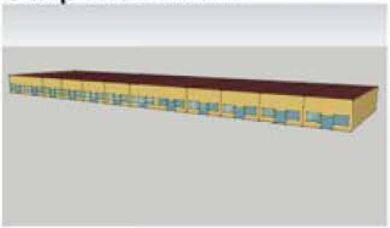


Large Office

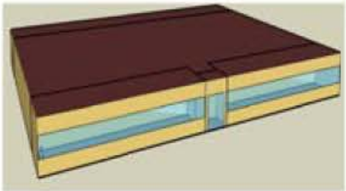


Warehouse

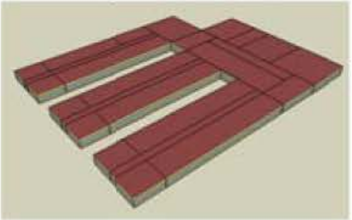
Strip Mall Retail



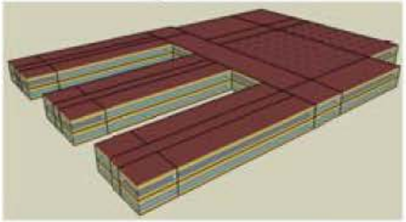
Standalone Retail



Primary School

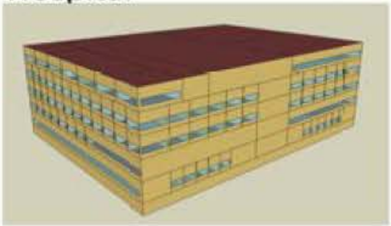


Secondary School



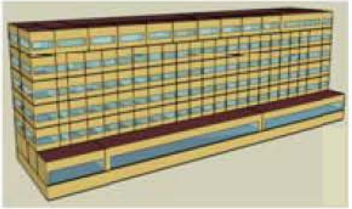
Outpatient Healthcare

Hospital

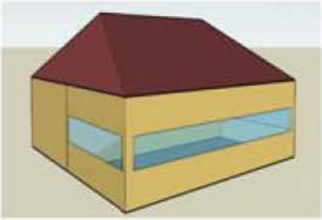


Small Hotel

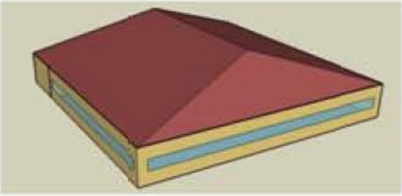
Large Hotel



Quick-service Restaurant

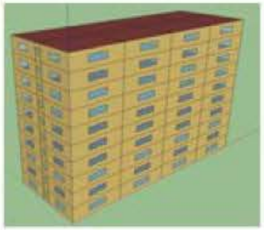


Full-service Restaurant

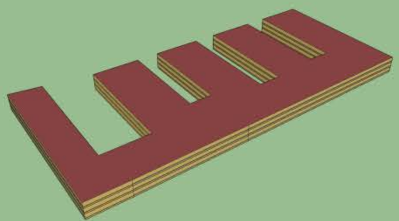


Mid-rise Apartment

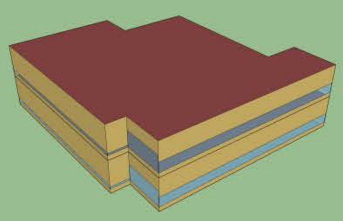
High-rise Apartment



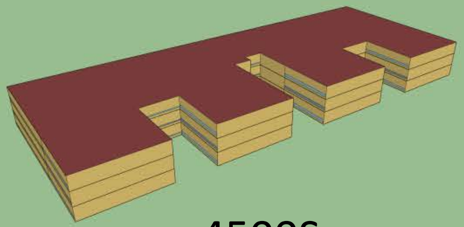
Oak Ridge National Laboratory



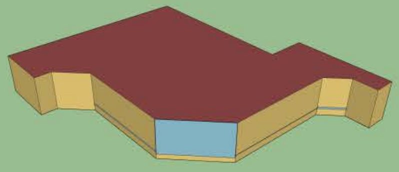
4500N



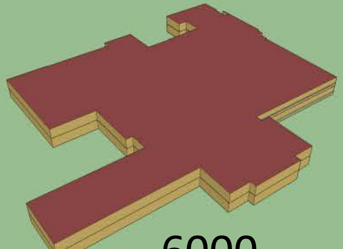
4020



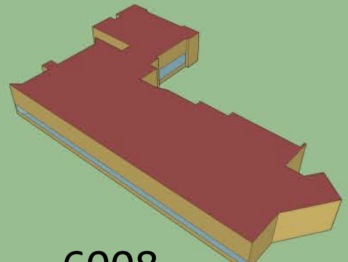
4500S



4512

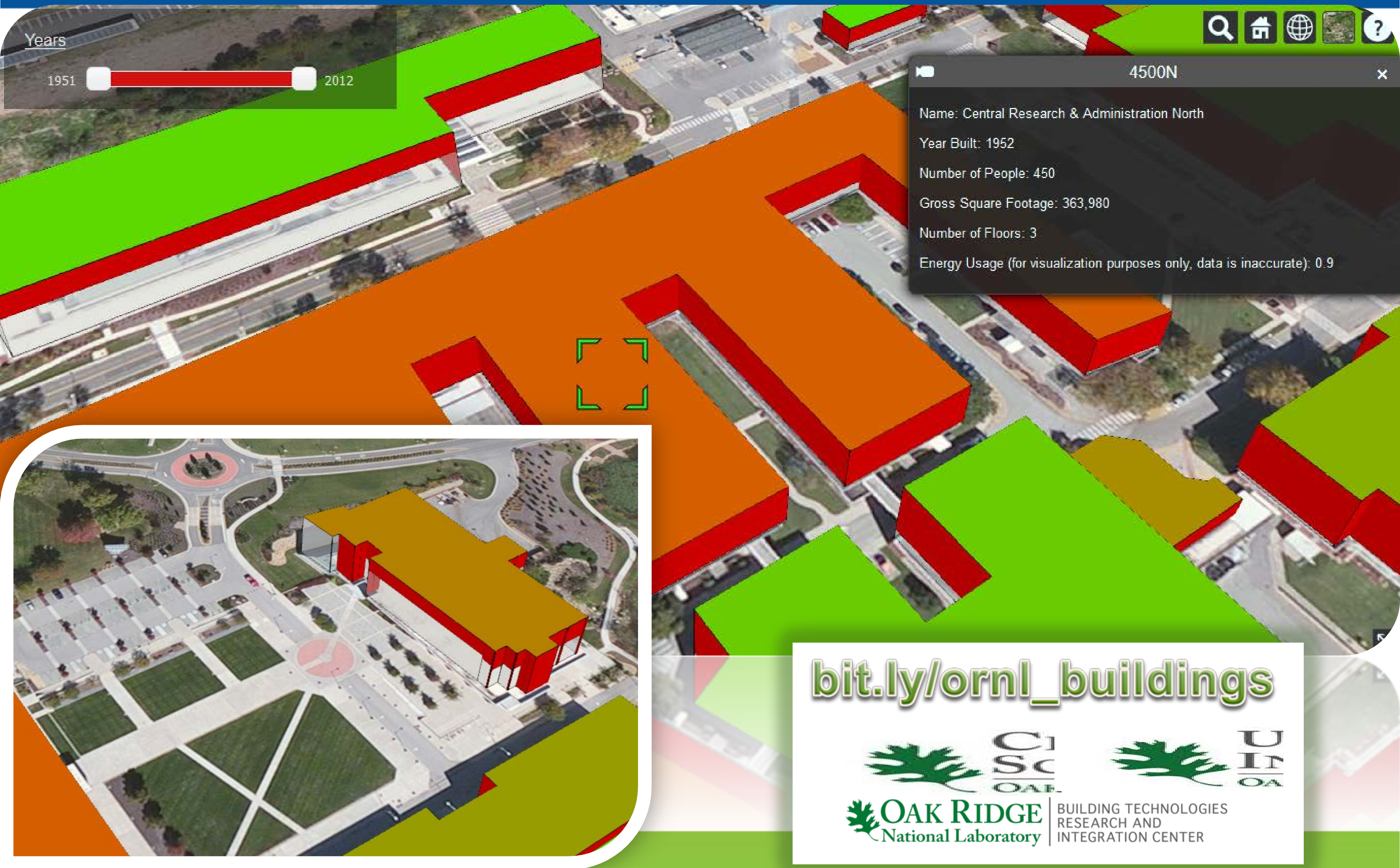


6000

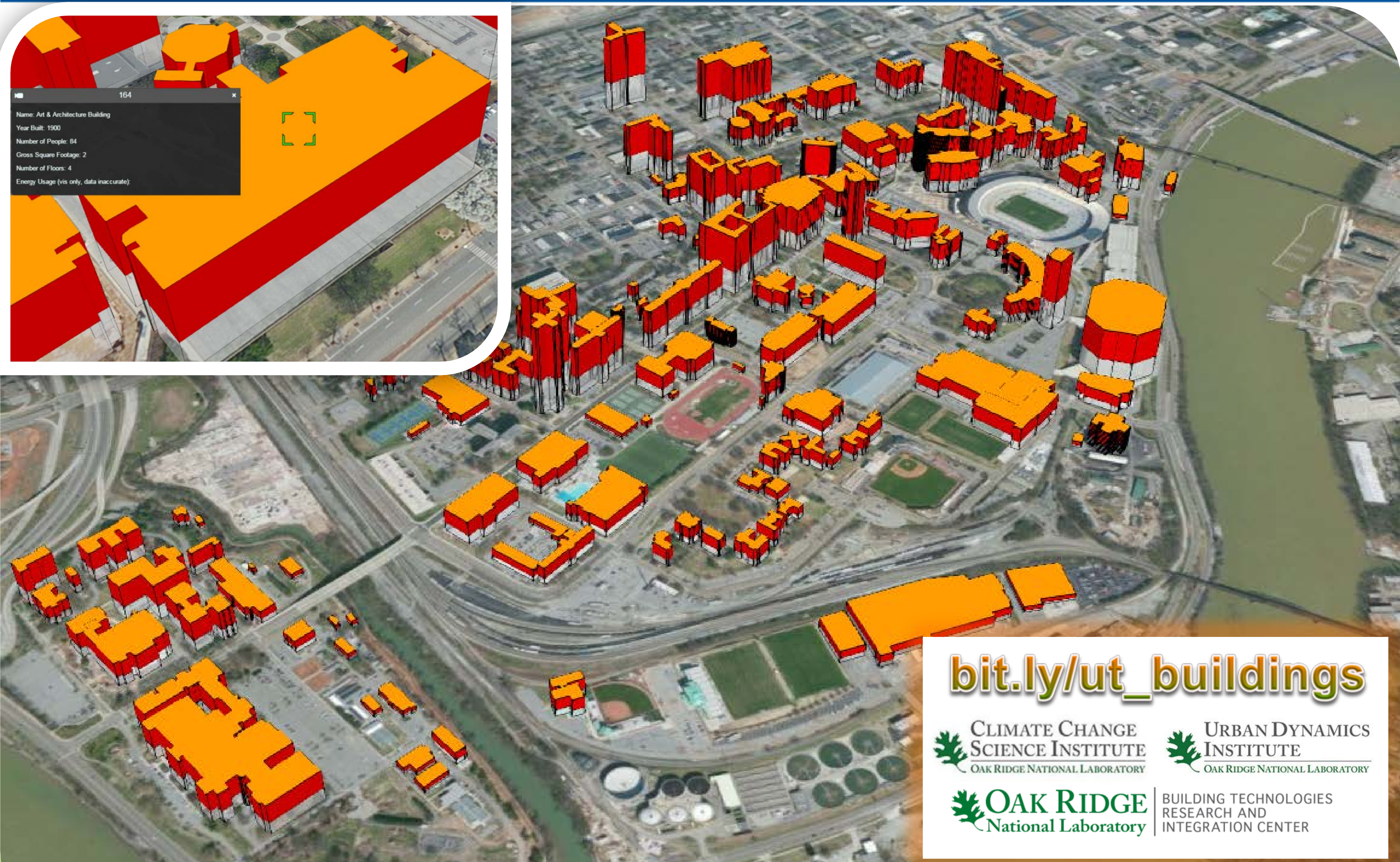


6008

Oak Ridge National Laboratory (interactive)



The University of Tennessee (2 days)



bit.ly/ut_buildings

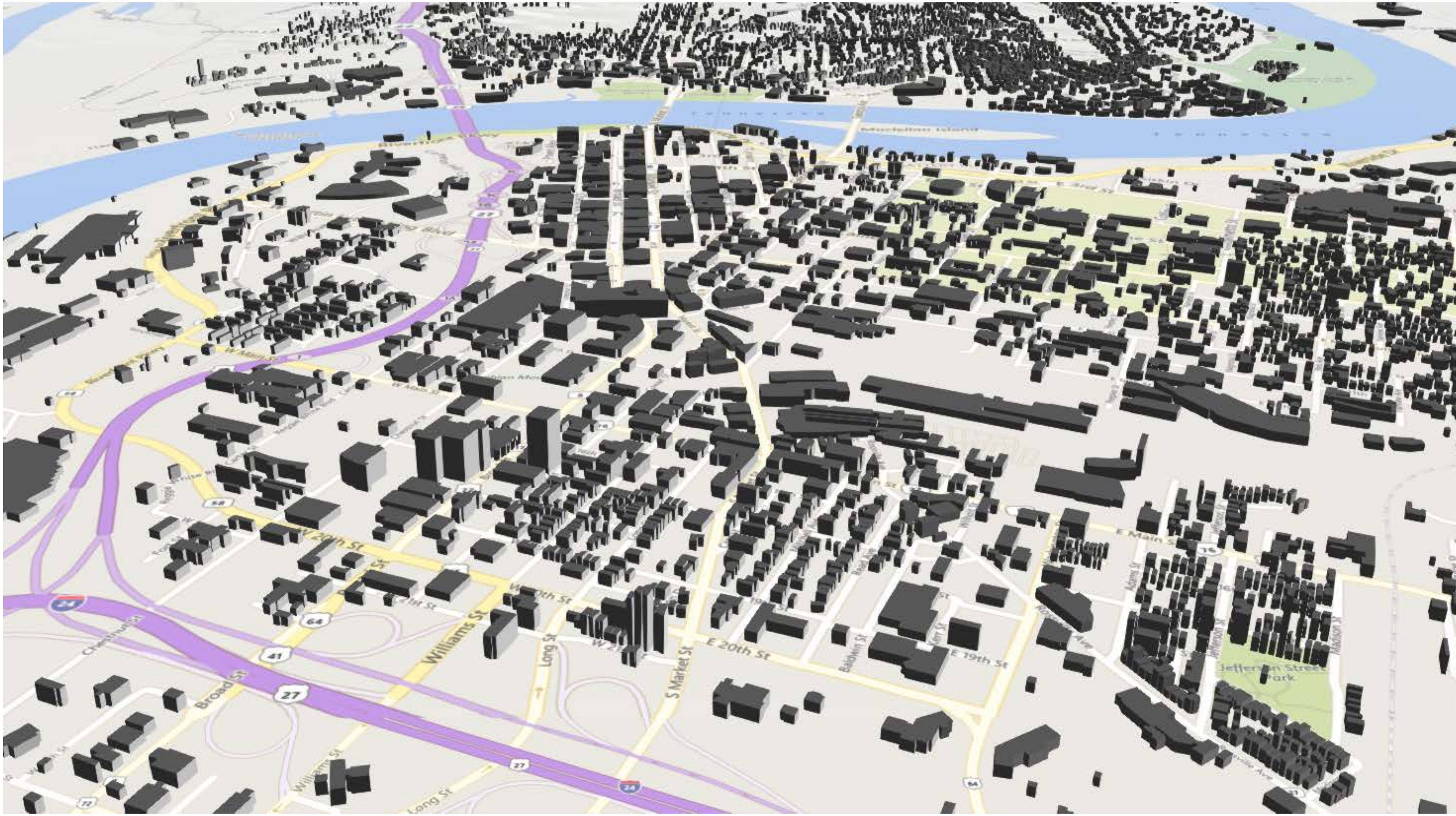
Climate Change Science Institute
Oak Ridge National Laboratory

Urban Dynamics Institute
Oak Ridge National Laboratory

Oak Ridge National Laboratory

Building Technologies Research and Integration Center

Chattanooga, TN (100,000+ buildings)

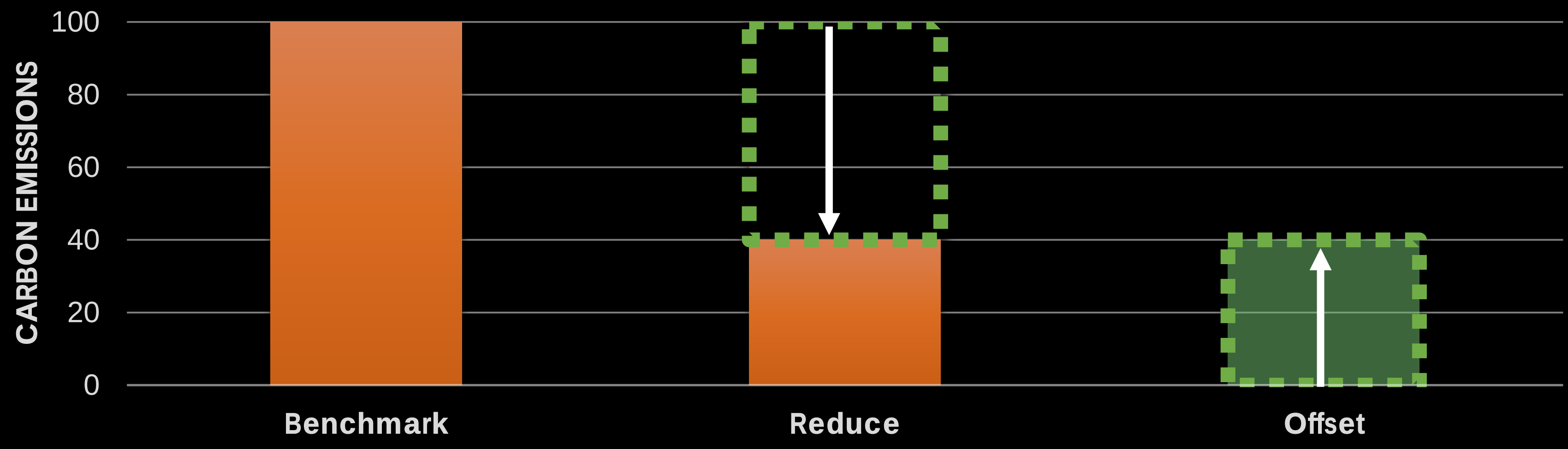


A unique process focused around three steps…

1) Benchmark – understanding existing energy consumption associated with existing and projected building infrastructure is an important first step to plan for retrofit reductions and offset measures.

2) Reduce – using expertise in existing building energy modeling, retrofit libraries are applied to prioritize energy conservation measures, leading to large-scale reductions in demand across the city, and phase strategies for more efficient energy supply.

3) Offset – for remaining carbon emissions, we apply strategic workflows and toolsets to evaluate new forms of energy generation.



Discussion

Joshua New

Oak Ridge National Laboratory

newjr@ornl.gov