CAE 465/526 Building Energy Conservation Technologies

Fall 2023

August 24, 2023

Introduction to CAE 465/526 and IPRO 497

Built Environment Research @ IIT

Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

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INTRODUCTION

About Professor Heidarinejad

- B.S.E., Mechanical Engineering
  - ❑ Sharif University of Technology Tehran, Iran, 2006
- M.S.E., Architectural Engineering
  - ❑ The Pennsylvania State University, 2011
- Ph.D., Mechanical Engineering
  - ❑ The Pennsylvania State University, 2014

- Experience relevant to this course
  - ❑ ASHRAE, DOE, EPA, HUD, NSF, and industry projects
  - ❑ University of Maryland College Park
  - ❑ Licensed Professional Engineer
  - ❑ ASHRAE New Investigator
  - ❑ Developed and taught several courses at Illinois Tech
  - ❑ Recipient of the Michael J. Graff Award for Innovation in Teaching

About Professor Rodda

- BFA., Industrial Design/ Studio Arts
  - ❑ Rhode Island School of Design (RISD), Providence, RI, 2002
- MoD., Design for Emerging Technologies ARCH/ ID
  - ❑ School of the Art Institute of Chicago, 2010
- Professor of Practice, Institute of Design
  - ❑ Kaplan Institute, IIT 2016

- Experience relevant to this course
  - ❑ DOE, EPA, NSF, and industry projects
  - ❑ Argonne National Laboratory: Building Tech Group/ DIS/ MCS-
  - ❑ Fellow, Urban Center for Computation and Data, UChicago
  - ❑ Expert Rhino/ Grasshopper User and Teacher
  - ❑ Developed and taught several courses at Illinois Tech
  - ❑ Extensive Experience in Design Thinking and Innovation

Introduce Yourself

- Please introduce yourself
- Are you taking it as CAE 465/526 or an IPRO?
- Why did you choose this course?
- What do you expect from the course?
- How do you think the course will have impact your career?
- Do you have any relevant internship/work experience?
- Do you have any programming or modeling courses or experiences?
- Are you looking for internship or full-time job?
- Did you take your FE exam?

Course

Classroom and Meeting Time:

- IPRO 497-971: 15869 – In class
- CAE 465 Section 01: 15250 (undergraduate) – In class
- CAE 465 Section 02: 15239 (undergraduate) - Online
- CAE 526 Section 01: 15243 (graduate) – In class
- CAE 526 Section 02: 15244 (graduate) - Online

Classroom and Meeting Time:

- Location: SB 238
- Thursdays, 1:50 PM – 4:30 PM

Course Website:

- All content will be provided on Blackboard

Course

Last Year Lecture Notes

The Built Environment Resea

advancing energy, environmental, and sustainability research within the built environment at Illinois Institute of Technology

HOME PEOPLE PROJECTS PUBLICATIONS PRESENTATIONS FACILI

CAE 465/526 Building Energy Conservation Technologies will introduce students to both theory and hands-on applications of building energy conservation technologies to design energy efficient buildings.

Course Syllabus

- Course Syllabus (last updated, December 10, 2022)

Lecture Notes

- Lecture 01: Intro to CAE 465/526
- Lecture 02: Building consumption patterns and building performance analysis
- Lecture 03: Introduction to building energy simulation and OpenStudio training
- Lecture 04: Assignment feedback and coding in R and Python (recording)
- Lecture 05: OpenStudio and advanced HVAC systems
- Lecture 06: Model calibration and uncertainty analysis (Project assigned)
- Lecture07: Assignment feedback and intro to building energy audits and commissioning
- Lecture08: Building energy audits and commissioning (Ladybug Tools training – in person)
- Lecture 09: Building retrofit and energy efficiency measures (EEMs) – Part 1
- Lecture 10: Intro to building performance metrics & GREET Training (in person)
- Lecture 11: Building retrofit and energy efficiency measures (EEMs) – Part 2
- Lecture 12: Exam (Take home)
- Lecture 13: Life cycle analysis and measure installation
- Lecture 14: No class (Thanksgiving)
- Lecture 15: Buildings-to-grid integration and utility programs

http://built-envi.com/courses/cae-465-526-building-energy-conservation-technologies-fall-2022/

Course Catalog Description

- Identification of the optimal energy performance achievable with various types of buildings and service systems
- Reduction of infiltration
- Control systems and strategies to achieve optimal energy performance
- Effective utilization of daylight, heat pumps, passive and active solar heaters, heat storage and heat pipes in new and old buildings

Instructor's Course Objectives & Learning Outcomes

For CAE 465/526 students, students will:

1. Analyze energy consumption patterns in the buildings
2. Understand impacts of the building rating systems and sustainability measures to design energy efficient buildings
3. Become an expert in preparing calibrated building energy models to predict energy consumption patterns of building energy end-uses
4. Perform different building energy retrofit scenarios to provide opportunities to reduce energy and greenhouse gas emissions of buildings
5. Understand the impacts of influential parameters on energy end-uses of buildings
6. Visualize and analyze building performance data and applying statistical methods to compare the metered with the simulated results

Instructor's Course Objectives & Learning Outcomes

For IPRO students, they form a team will:

1. Utilize existing databases and GIS to visualize different layers of information for the building stock in Chicago
2. Create building energy models at scale using the Application Programming Interface of OpenStudio and will develop energy efficiency measures in these programming languages
3. Create building energy models using Rhino/Grasshopper and Ladybug Tools (LBT) to create the current building energy baseline in Chicago and then propose solutions to reduce energy associated with buildings and their impacts on air quality and environment
4. Leverage visualization tools (e.g., Grafana) to create database to store historical data for buildings in Chicago and overlay the predicted building energy data in noSQL and SQL based databases and enable a wide use of the predictions
5. Utilize virtual reality to visualize the buildings in a VR environment to demonstrate the City of Chicago Decarbonization effort on different communities in Chicago

Office Hours

Instructor:

- Stop by when you see my office door open to see if I'm free. I have an open-door policy. Or you can email me to schedule an appointment or if you have any questions.
  - Office: Alumni Memorial Hall Room 204
  - Email: muh182@iit.edu
  - Phone: (312) 567-3426

Office Hours

Teaching Assistant:

- TBD
  - ❑ Name: Jongki Lee, Ph.D. Student, Architectural Engineering
  - ❑ Email: jlee310@hawk.iit.edu

Textbook

- Lecture notes are sufficient for this course. I will also rely on several other materials in this course. These materials are entirely optional for the student; handouts will be given when necessary, so that no one is required to purchase these items.

- You should have a copy of the 2017 or 2021 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook of Fundamentals (IP unit version) for use from your CAE 331/513: Building Science or CAE 464/517: HVAC Systems Design courses. I may refer to this for some of the topic in this class

GRADING (CAE 465/526)

Course Grading

- CAE 465/526 students:

Grading	Quantity	% of Total for Each	% of Total
Assignments	5	5	25
Exam	1	35	35
Project Reports (Interim)	2	10	20
Final Report	1	13	13
Final Presentation	1	7	7

Grading scale	A	B	C	D	F
UG and G	90% and up	80.0-89.9%	70.0-79.9%	60.0-69.9%	<60.0%

Homework Assignments

- Homework sets will be assigned based on lecture coverages. The homework will involve hand calculations, development of spreadsheets, and/or learning the fundamentals and data analysis. You must work on the homework assignments individually.

- Homework assignments and project reports are due at the midnight on the day that it is due. Homework assignments and project reports will receive an ***absolute 5-point deduction*** for every day that it is late.

Project and Presentation

- The course project focuses on retrofitting an existing building.
- The project has three deliverables described in the project assignment document.
- Each student is responsible for working on the first two deliverable course project individually. The third deliverable will be a group project submission.
- Students are required to present their report at the end of the semester during the assigned university exam week.

Exam

- There will be one take home class exam during the semester of the fundamental concepts and applications learned in the course. Each student is responsible for working on exam individually.

GRADING (IPRO 497)

Course Grading

- CAE IPRO students:

Grading	Quantity	% of Total for Each	% of Total
Weekly Class Participation	15	2	30
Midterm Report (Individual)	1	12.5	12.5
Midterm Report (Group)	1	7.5	7.5
Final Report (Individual)	1	12.5	12.5
Final Report (Group)	1	7.5	7.5
Innovation Day Preparation & Presentation	1	30	30

Grading scale	A	B	C	D	F
UG and G	90% and up	80.0-89.9%	70.0-79.9%	60.0-69.9%	<60.0%

Course Grading

- CAE IPRO students:

Absence Number	Points Deducted	Additional Effect of Grade
1	1	
2	2	
3	5	With 3 absences, a student cannot received an “A” regardless of overall total points earned
4	10	
5	15	With 5 absence, a student cannot receive a “C” regardless of overall total points earned
6	20	

Course Topics

Week	Date	Topics	Assignment Due
1	08/24/23	Introduction to (i) course objectives, (ii) CAE 331/513 and CAE 464 review, and (iii) energy consumption in the building sector	
2	08/31/23	Building energy consumption patterns and building performance analysis	
3	09/07/23	Introduction to building energy simulation and OpenStudio Application training	Assignment #1
4	09/14/23	Introduction to building energy simulation and OpenStudio Application training (Rhino / Grasshopper / Ladybug Tools)	Assignment #2
5	09/21/23	Introduction to building energy simulation and OpenStudio Application training (SketchUp)	Assignment #3
6	09/28/23	Model calibration and uncertainty analysis **Project Assigned**	
7	10/05/23	OpenStudio and advanced HVAC systems	Assignment #4
8	10/12/23	Building energy audits and commissioning	

Course Topics

Week	Date	Topics	Assignment Due
9	10/19/23	Building retrofit and energy efficiency measures (EEMs) – Part 1	Project Deliverable #1
10	10/26/23	Building retrofit and energy efficiency measures (EEMs) – Part 2	
11	11/02/23	**Exam (Take Home)**	
12	11/09/23	Building retrofit and energy efficiency measures (EEMs) – Part 3	
13	11/16/23	Building performance metrics and life cycle analysis	Project Deliverable #2
14	11/23/23	**Thanksgiving – No Class**	
15	11/30/23	Building to grid integration and utility programs	Assignment #5
16	TBD	Student Project Presentations (During the Final Exam)	Final Presentation
17	TBD	Final Project Report	Final Report

Academic Honesty

- It is your responsibility to be familiar with IIT's Code of Academic Honesty. The Code of Academic Honesty can be found online: https://www.iit.edu/student-affairs/student-handbook/fine-print/code-academic-honesty

- You must submit your ***own work for homework***. You are encouraged to discuss and even work with other students on homework (unless explicitly told otherwise), but material that is submitted must be ***your own work***

Academic Honesty

- For a ***first violation*** of the IIT Code of Academic Honesty for a homework or project, the homework will receive a grade of ***zero for all involved students*** and the students will be reported to the Designated Dean for Academic Discipline (DDAD)

- For a first violation of the Code of Academic Honesty for a ***major project*** or an examination, the student will ***receive a failing grade*** for the course and the student will be reported to the DDAD. For a second violation, the student will receive also failing grade for the course and be reported to the DDAD

Personal Problems

- If you have illness or personal problems that will affect your performance during the course of the semester, please let me know ***as soon as possible***

- ***"After the fact"*** provides little protection unless there are extreme circumstances. Contact the instructors by phone or e-mail at any time

Personal Problems

- Academic Regulations: https://web.iit.edu/student-affairs/handbook/fine-print/academic-and-department-regulations

*"All students are **expected to attend classes regularly**. Excessive absences may be grounds for a failing grade. Non-attendance does not constitute an official withdrawal. When illness or emergency requires a student to miss an exam and/or more than two days of class, the student must notify the course instructor. It is also recommended that the student **contact the office of the Dean of Students (dos@iit.edu) to request an excused absence.** It will be necessary to provide written documentation of the reason for the absence(s). The Office of Student Affairs manages the process for requesting and documenting excused absences but the decision to excuse an absence is generally made by the Professor. Faculty members determine their own policies for attendance and make-up work."*

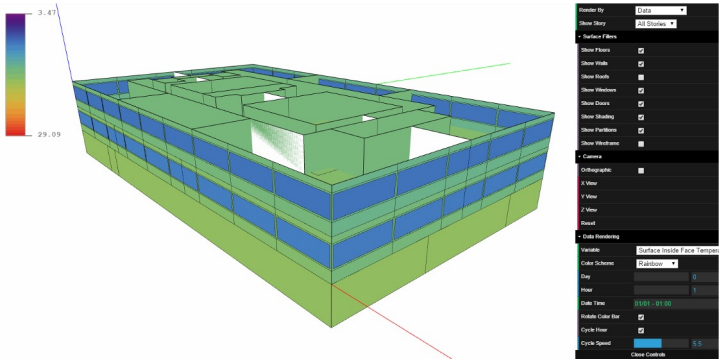
Students with Disabilities

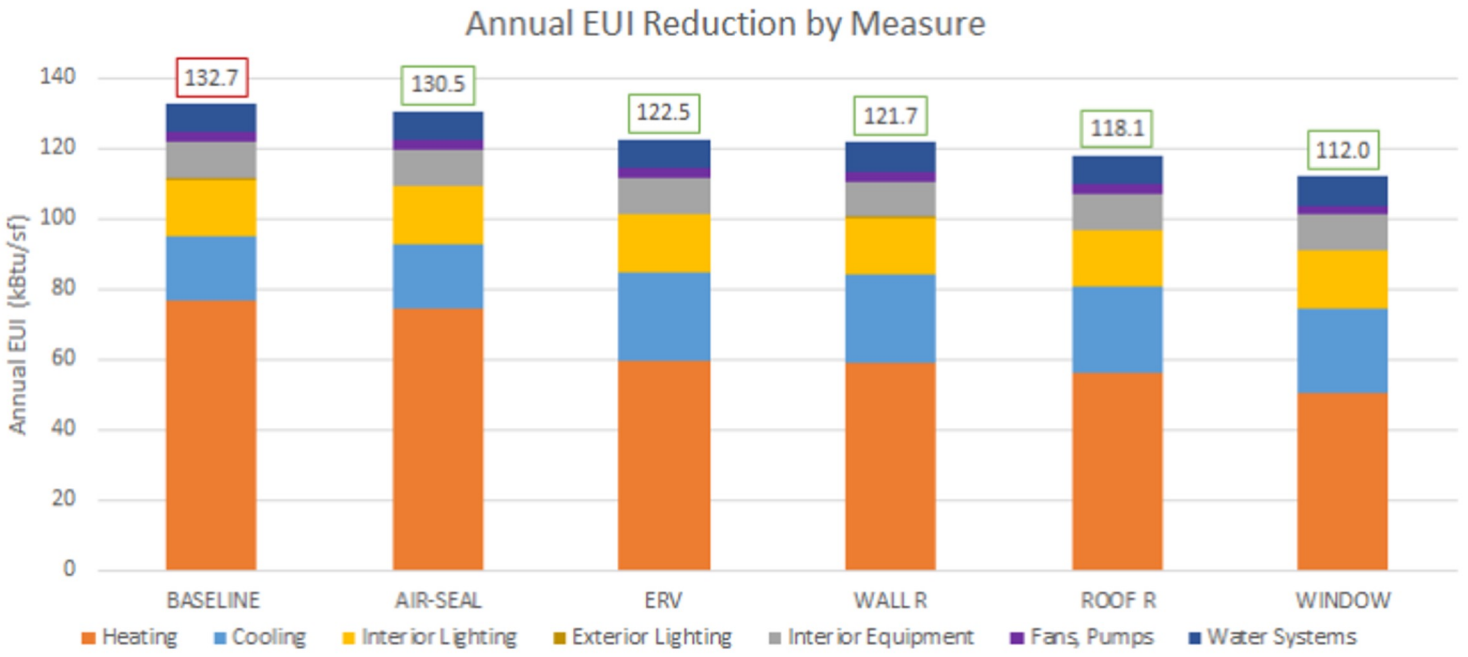
- Reasonable accommodations will be made for students with documented disabilities. In order to receive accommodations, students must obtain a letter of accommodation from the Center for Disability Resources

- The Center for Disability Resources (CDR) is located in Life Sciences Room 218, telephone (312) 567-5744 or email: disabilities@iit.edu

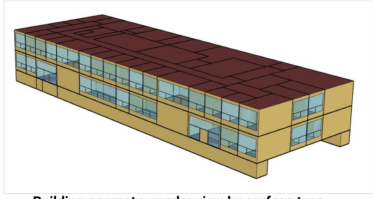
LAST YEARS PROJECTS

Final Project

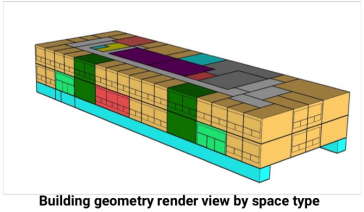




Final Project



Building geometry render view by surface type



Building geometry render view by space type

GROSS FLOOR AREA: 39,636 ft²

CONSTRUCTION INPUT:

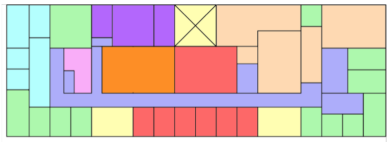
WALL	4" DOUBLE LAYERED BRICK
ROOF	R-9 INSULATED METAL ROOF
BASEMENT WALL	10" CONCRETE WALL
WINDOW TYP. 1	¼" SINGLE PANE
WINDOW TYP. 2	6.2 MM VACUUM GLASS
METAL DOOR	INSULATED METAL DOOR
GLASS DOOR	¼" SINGLE PANE

INTERNAL LOAD INPUT:

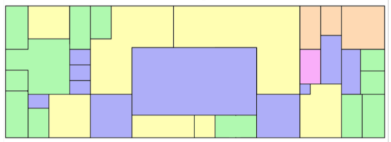
LIGHTING	ASSUMED LIGHTING RETROFIT IS ALREADY DONE (LED 18W)
PLUG	ADOPTED DOE PRE-1980 MID OFFICE DATASET

MAJOR SPACE TYPE

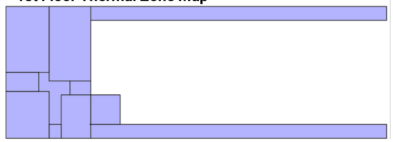
OFFICE · RESTROOM · CORRIDOR · MECH. ROOM · STAIR · LOBBY · LABORATORY · COMPUTER / BERG LABORATORY



2nd Floor Thermal Zone Map



1st Floor Thermal Zone Map



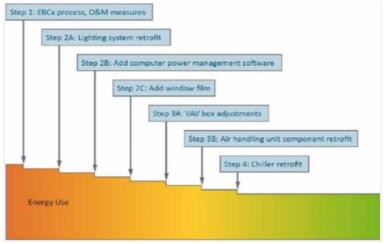
Basement Thermal Zone Map

HVAC EQUIPMENT INPUT

RTU	5
PTAC	24
Baseboard	39
EXHAUST FAN	2

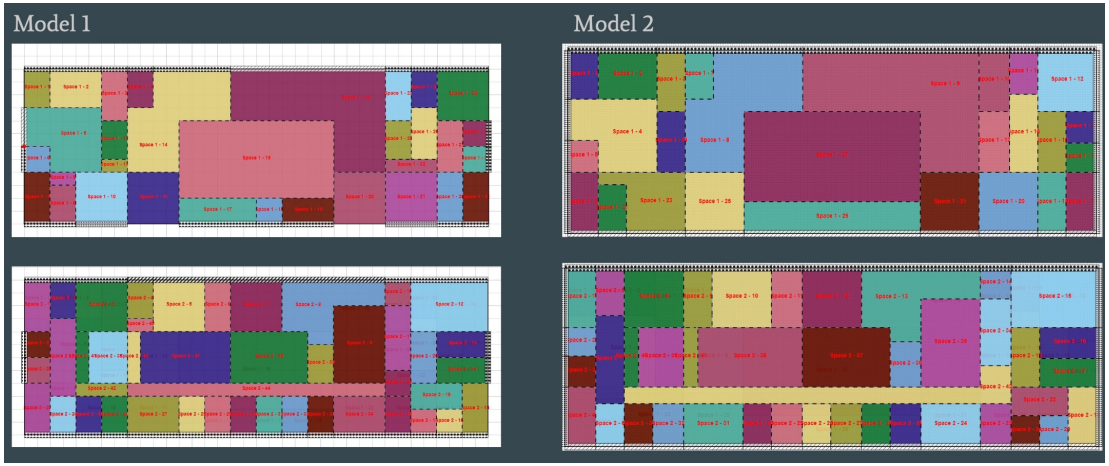
RTU 1 · RTU 2 · RTU 3 · RTU 4 · RTU 5 · PTAC W/ BASEBOARD · FAN ONLY BASEBOARD ONLY · UNCONDITIONED

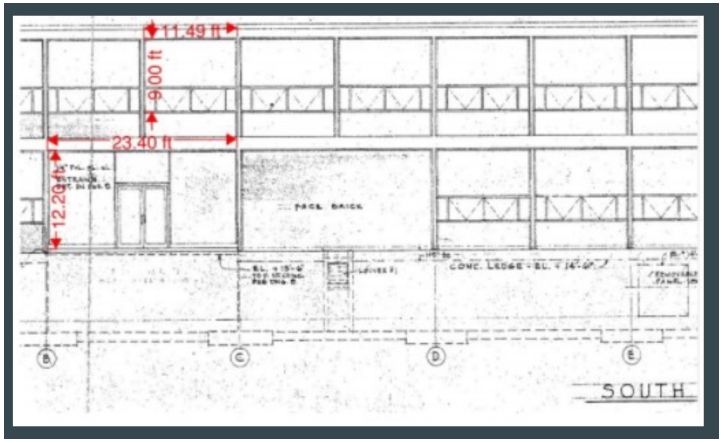
Scenario	Measure Combination
1 Control + Lighting + Equipment + PV	ECM1 + ECM2 + ECM3 + ECM4 + ECM9
2 Control + Lighting + Equipment + HVAC	ECM1 + ECM2 + ECM3 + ECM4 + ECM10
3 Control + Envelope	ECM1 + ECM2 + ECM5 + ECM6 + ECM7
4 Control + Envelope + PV	ECM1 + ECM2 + ECM5 + ECM7 + ECM9
5 Control + Envelope + HVAC	ECM1 + ECM2 + ECM5 + ECM7 + ECM10

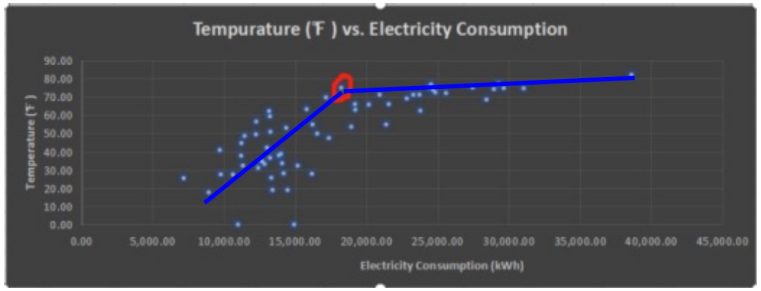


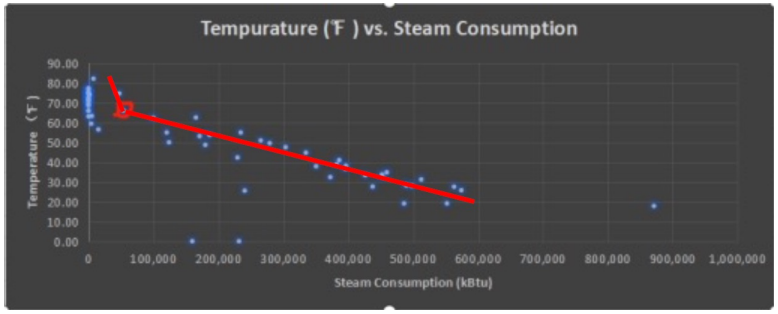
Scenario	Electricity		District Heating		Total Energy Saving Cost ($/yr)	Implementation Cost ($)	Rebate ($)	PayBack Years
	Energy Consumption Difference (kWh/yr)	Energy Saving Cost ($/yr)	Energy Consumption Difference (therm/yr)	Energy Saving Cost ($/yr)				
1	-15,450.76	1,283.96	-134.90	118.71	9,560.93	316,212.77	2,825.90	32.78
2	211,286.34	-17,557.90	-23,765.84	20,913.94	3,356.04	302,588.72	165.73	90.11
3	-15,020.22	1,248.18	-10,059.02	8,851.94	10,100.12	977,691.08	47.73	96.80
4	-5,994.72	498.16	-5,460.35	4,805.10	13,461.53	1,022,172.41	2,707.90	75.73
5	114,507.62	-9,515.58	-23,765.84	20,913.94	11,398.36	1,008,548.36	47.73	88.48

Final Project



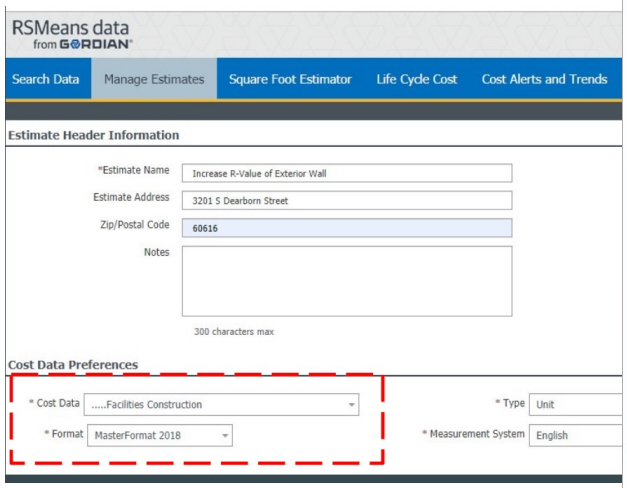


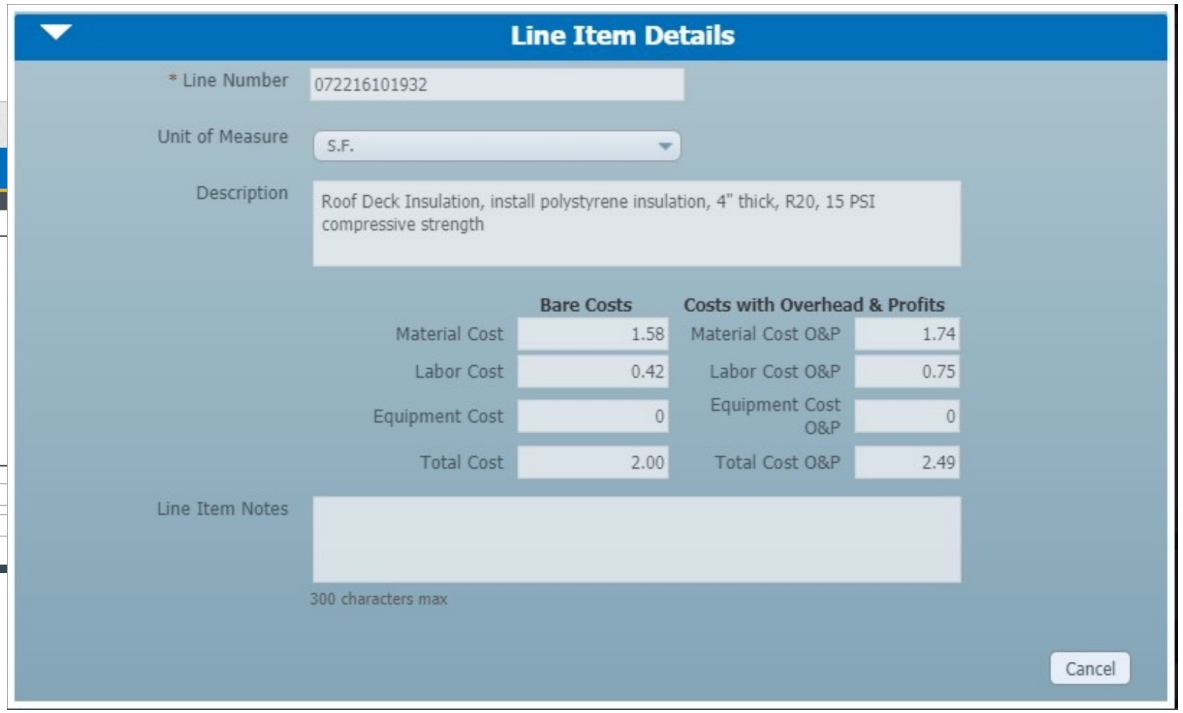




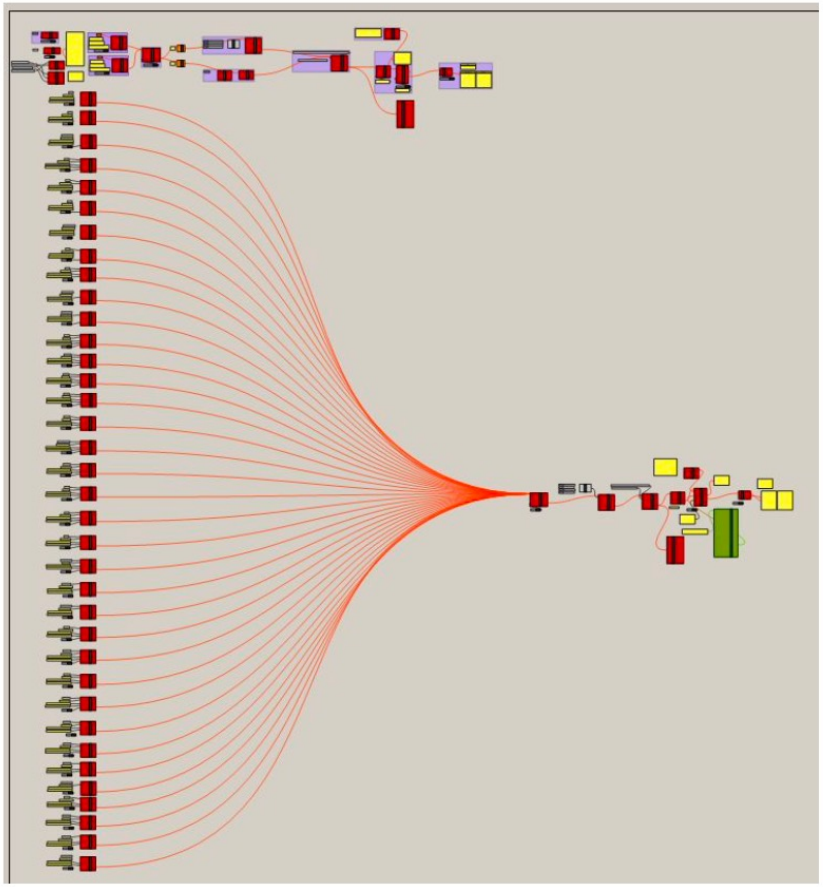
Final Project

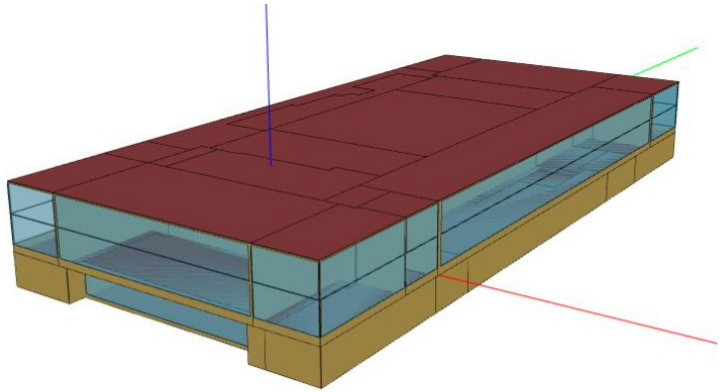
Measure Name	EUI (kBtu/ft²)	Total Electricity Use (kWh)	Total Steam Use (MBtu)	EUI Change (%)	Electricity Change (%)	Steam Change (%)
Baseline	67.9	274955.6	1352.9	-	-	-
Reduce Night Time Lighting Loads	67.2	267296.2	1356.6	-1.03%	-2.79%	0.27%
Reduce Night Time Electric Equipment Loads	66.6	253603.8	1382.8	-1.91%	-7.77%	2.21%
Increase R-value of Insulation for Exterior Walls to a Specific Value	65.2	271801.5	1272.8	-3.99%	-1.15%	-5.92%
Increase R-value of Insulation for Roofs to a Specific Value	49.8	248317.9	832	-26.72%	-9.69%	-38.50%
Set COP for Two Speed DX Cooling Units	66.3	259023.5	1352.9	-2.36%	-5.79%	0.00%
Reduce Electric Equipment Loads by Percentage	66.7	261599	1352.9	-1.77%	-4.86%	0.00%
Resize existing windows to match a given WWR	66.3	270208.7	1317.1	-2.30%	-1.73%	-2.65%
Add Exterior Lights	68.3	279319.6	1352.9	0.62%	1.59%	0.00%
Reduce Lighting Loads by Percentage	64.86	242101.8	1363.03	-4.48%	-11.95%	0.75%
Set Lighting Loads by LPD	65.3	249762.6	1351.8	-3.83%	-9.16%	-0.08%

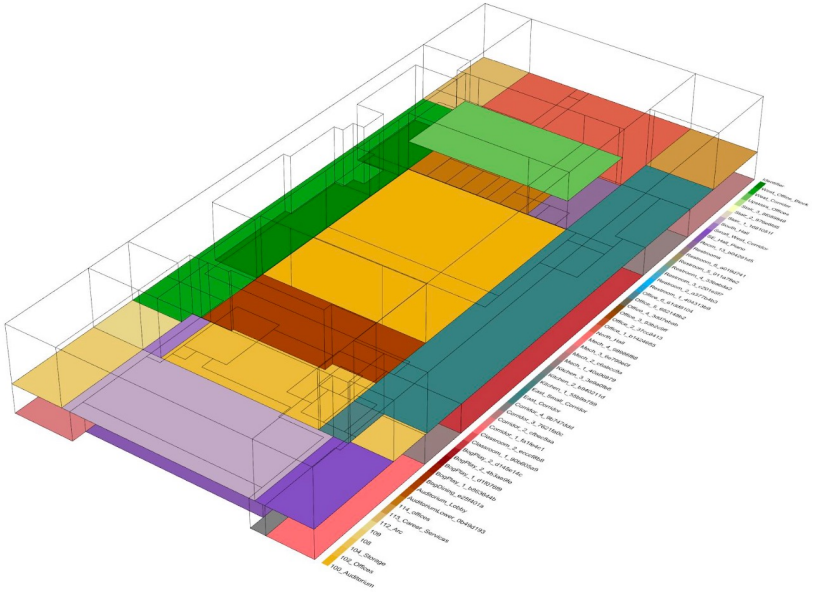




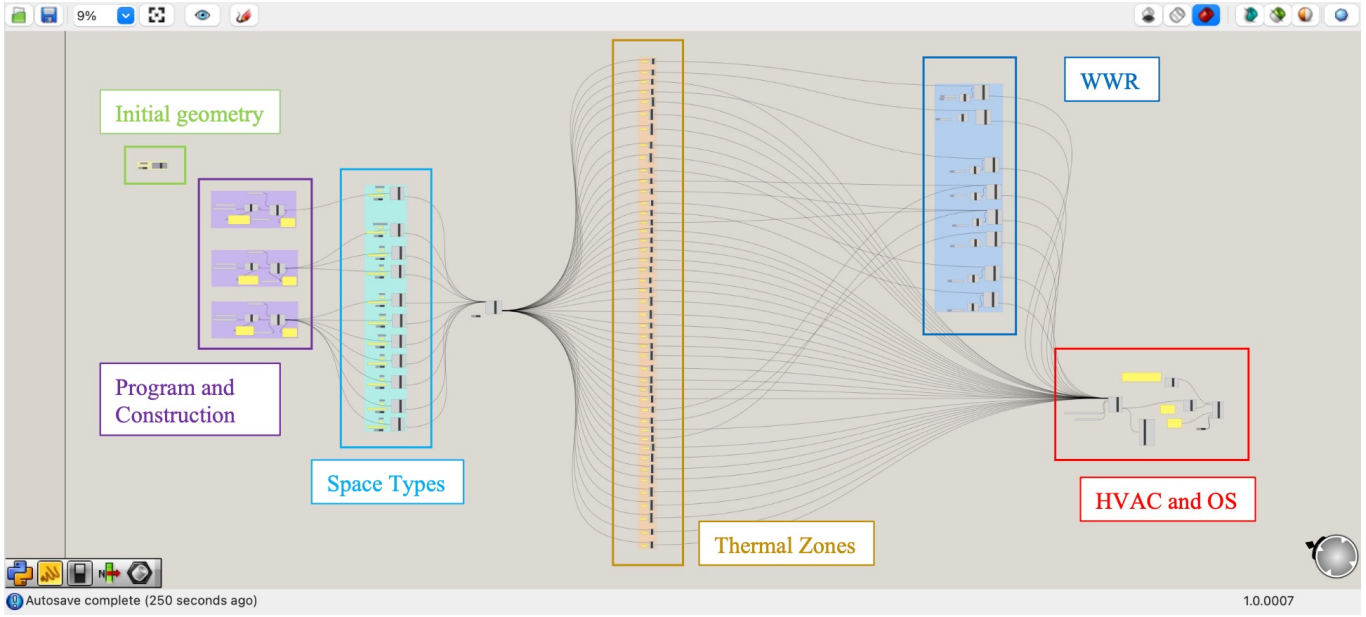
Final Project

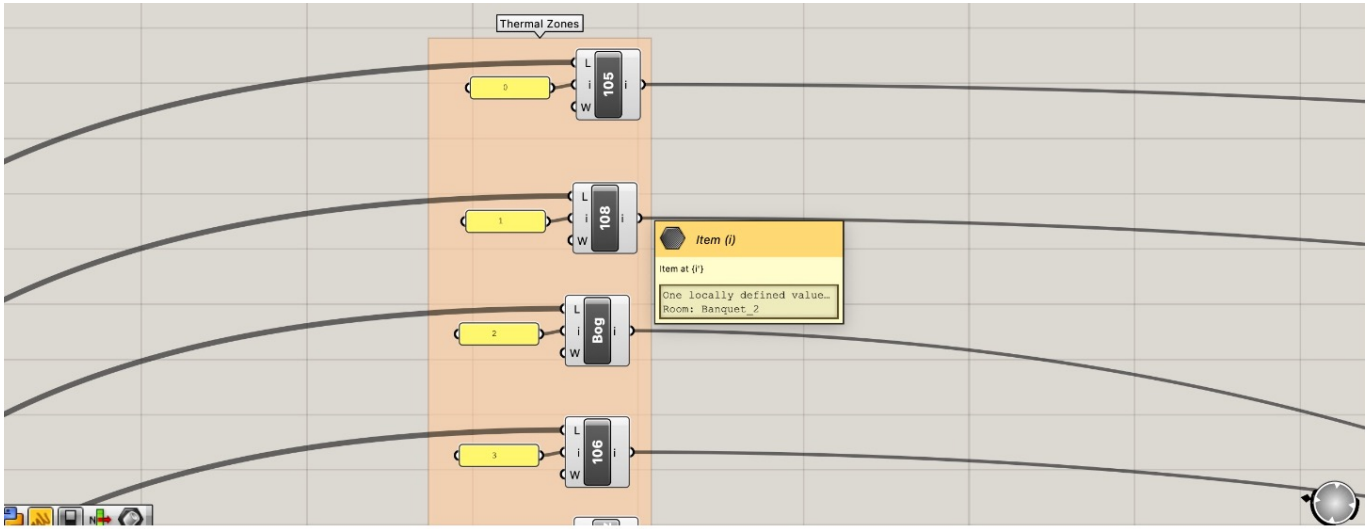






Final Project





Final Project

Part 3: 6 Retrofit Packages

1. Lowest Energy Cost

Measure 1: LED Lighting + Occupancy Sensors
Measure 2: Automated Window Shades
Measure 5: Roof Insulation
Measure 6: Solar Panel Installation
Measure 9: Electric Boiler
Measure 11: BAS Controls
Measure 12: Window Replacement

2. Lowest Heating & Cooling Loads

Measure 1: LED Lighting + Occupancy Sensors
Measure 2: Automated Window Shades
Measure 3: Demand Control Ventilation
Measure 4: Wall Insulation
Measure 5: Roof Insulation
Measure 9: Electric Boiler
Measure 12: Window Replacement

3. COVID-19 Considerations

Measure 1: LED Lighting + Occupancy Sensors
Measure 2: Automated Window Shades
Measure 3: Demand Control Ventilation
Measure 9: Electric Boiler
Measure 10: Efficient Filters
Measure 11: BAS Controls
Measure 12: Window Replacement

4. Decarbonization

Measure 1: LED Lighting & Occupancy Sensors
Measure 2: Automated Window Shades
Measure 6: Solar Panel Installation
Measure 7: Plug Loads
Measure 9: Electric Boiler
Measure 11: BAS Controls
Measure 12: Window Replacement

5. Automation

Measure 1: LED Lighting + Occupancy Sensors
Measure 2: Automated Window Shades
Measure 3: Demand Control Ventilation
Measure 6: Solar Panel Installation
Measure 7: Plug Loads
Measure 9: Electric Boiler
Measure 11: BAS Controls

6. Lowest Capital Cost

Measure 3: Demand Control Ventilation
Measure 4: Wall Insulation
Measure 5: Roof Insulation
Measure 6: Solar Panel Installation
Measure 9: Electric Boiler
Measure 10: Efficient Filters
Measure 11: BAS Controls

Final Project

```python
def cvrsme(meterData, simData):
    data = []
    n = len(meterData)
    y_bar = mean(meterData)
    for m,s in zip(meterData,simData):
        data.append((((m-s)**2)/(n-1)))
    CVRSME = 100*(1/y_bar)*(sum(data)**(1/2))
    return CVRSME

def nmbe(meterData, simData):
    data = []
    n = len(meterData)
    y_bar = mean(meterData)
    for m,s in zip(meterData,simData):
        data.append(m-s)
    NMBE = (((sum(data))/((n-1)*y_bar))*100)
    return NMBE
```

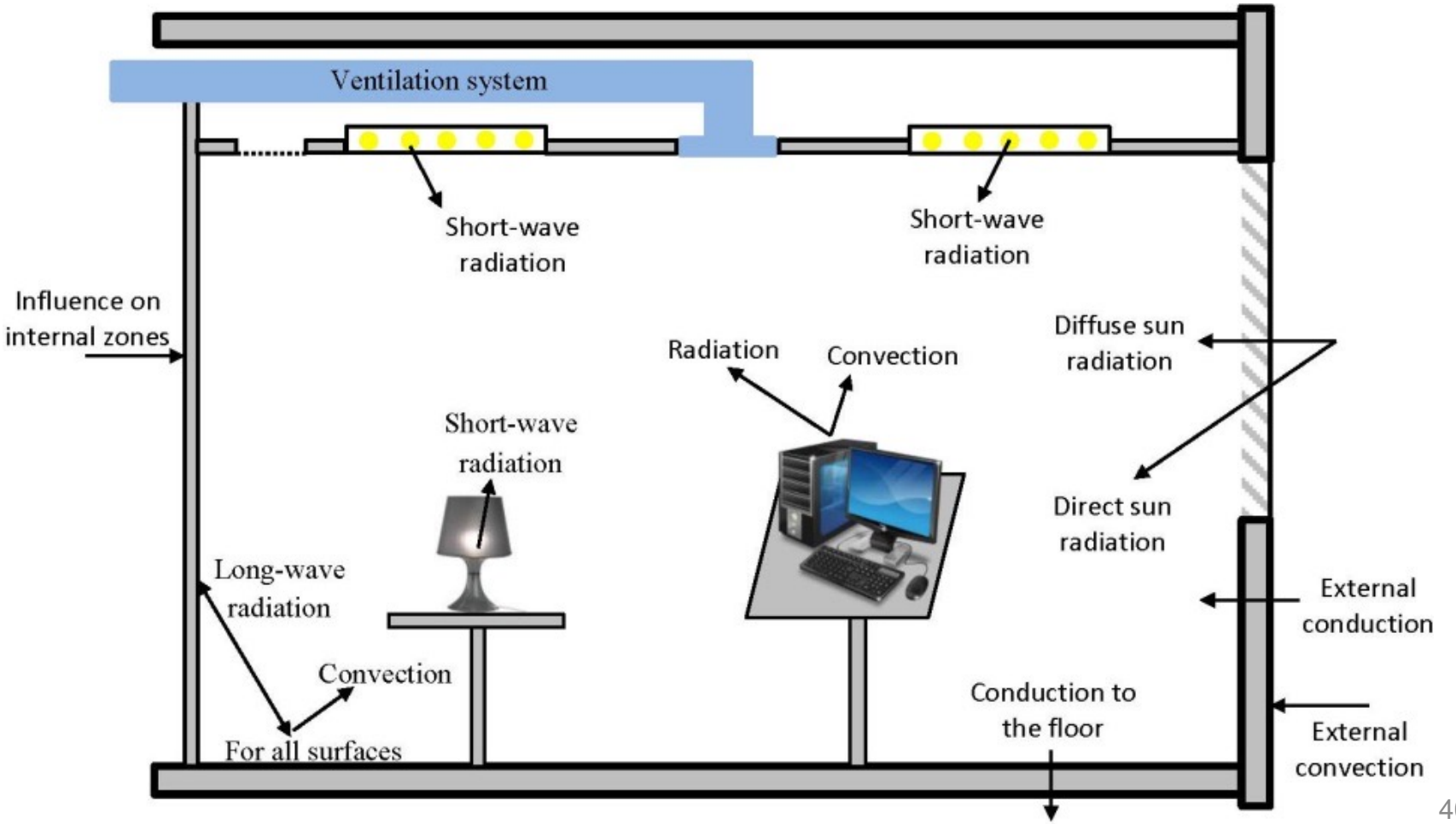
```python
    calibration =  ((abs(elecNMBE)) + (abs(heatNMBE)) + (abs(elecCVRSME)) + (abs(heatCVRSME))) # + (abs(chwNMBE)) + (abs(chwCVR
    return calibration


x0 = [1,1,1,1,1]
bnds = ((0.1,1.5),(0.25,1.5),(0.1,2),(0.1,2),(0.1,2))
# mvRes = minimize(f2, x0, method='Nelder-Mead')
mvRes = minimize(f2, x0, bounds=bnds, method='Nelder-Mead', options={'maxiter':200})
# res = minimize_scalar(f2, x0, bounds=(0.1, 2), method='bounded')

output = pd.DataFrame(final)
output.columns = ['u','shgc','leakage','lpd','people','elecCVRSME','chwCVRSME','heatCVRSME','elecNMBE','chwNMBE','heatNMBE']
output.to_csv('resultsOut.csv')
```

Final Project

REVIEW OF CAE 331/513 AND CAE 464

CAE 331, 464, 513

- How many of you have taken any of these courses?
  - ❑ Heat transfer processes

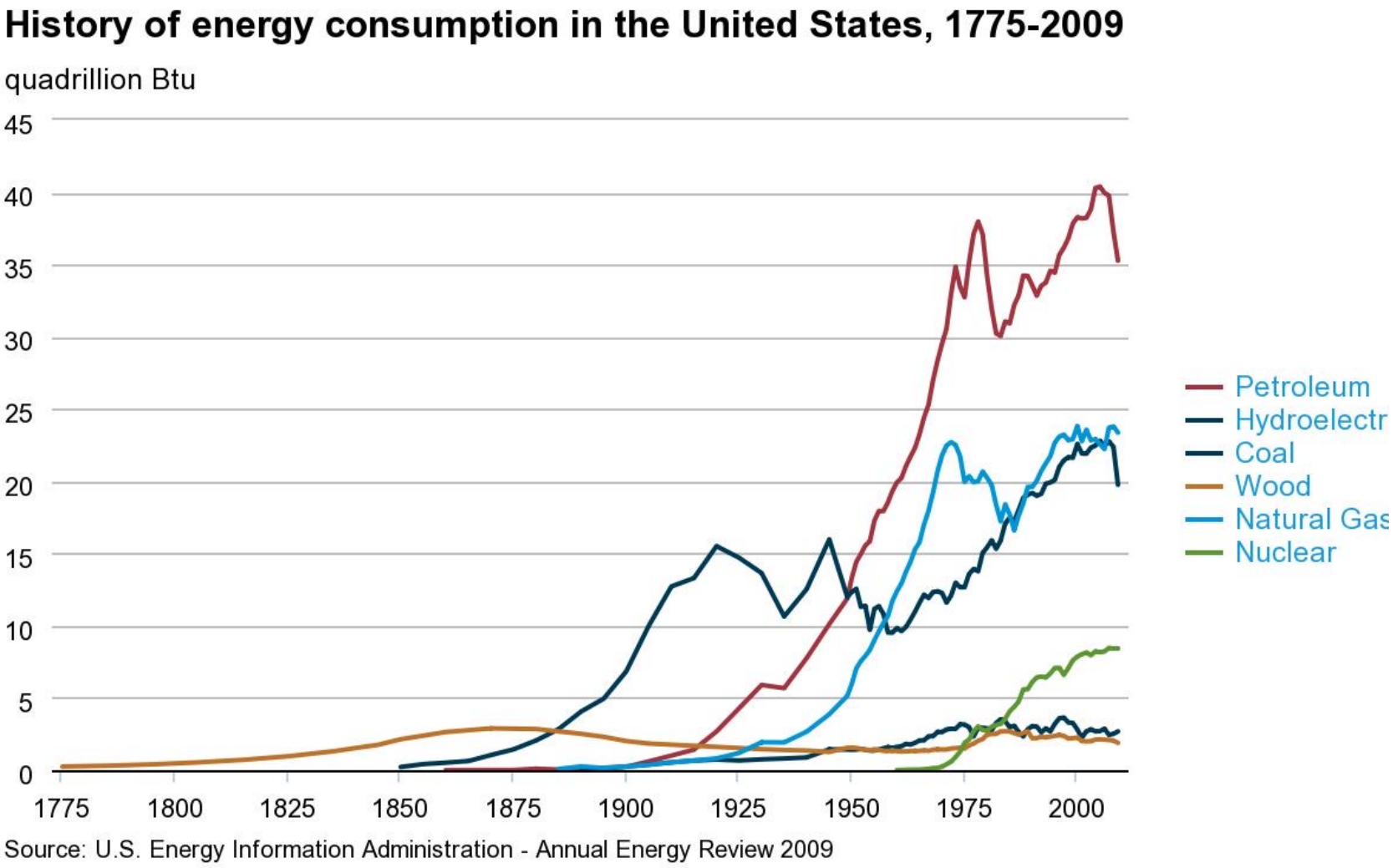


THE UTILITY OF BUILDING MEASUREMENTS

How do we consume energy in buildings?

What are the fuel sources?

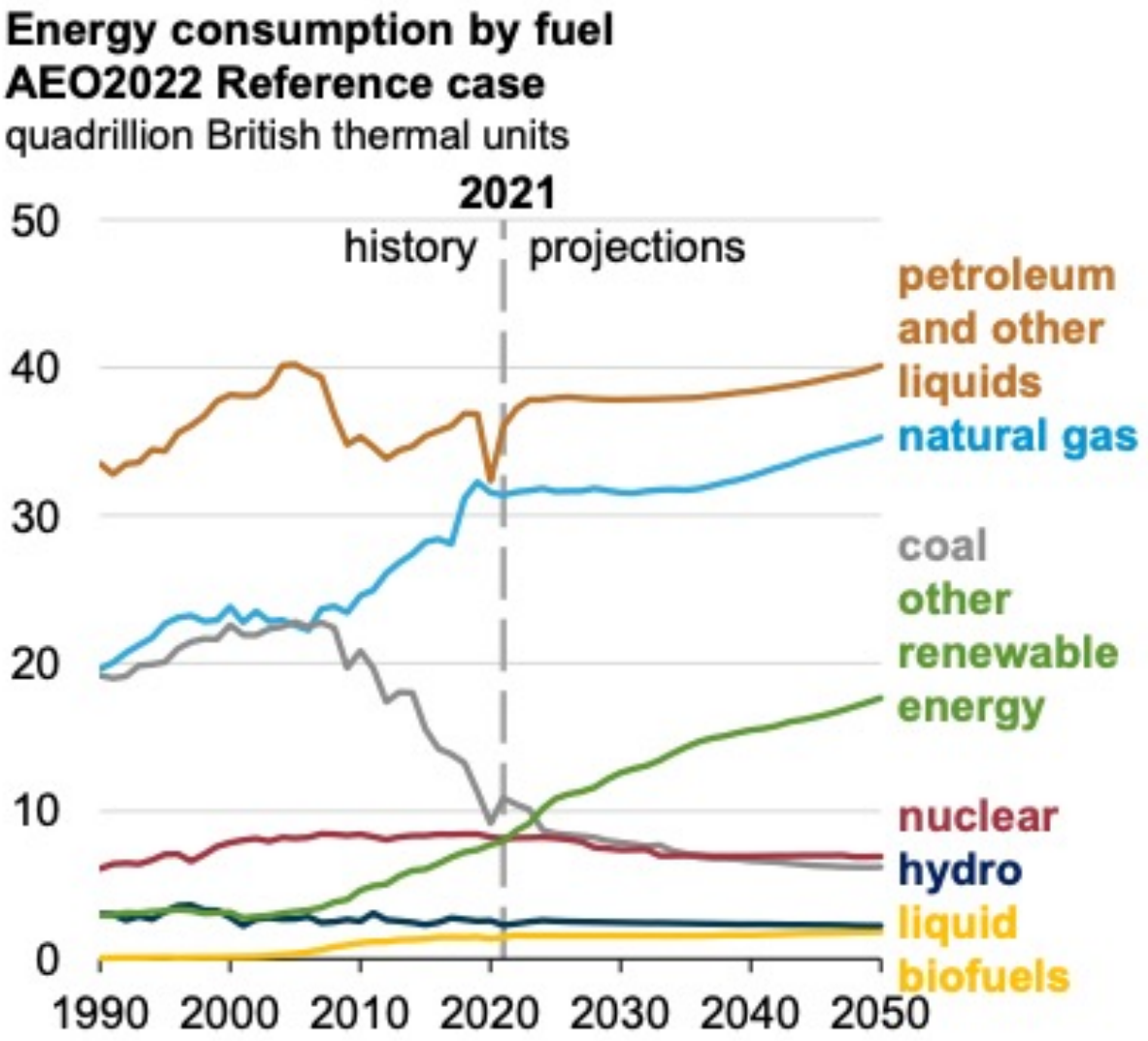
History of Energy Consumption in the U.S.



A quad (or quadrillion) = 10^{15} BTU or 1.055×10^{18} J

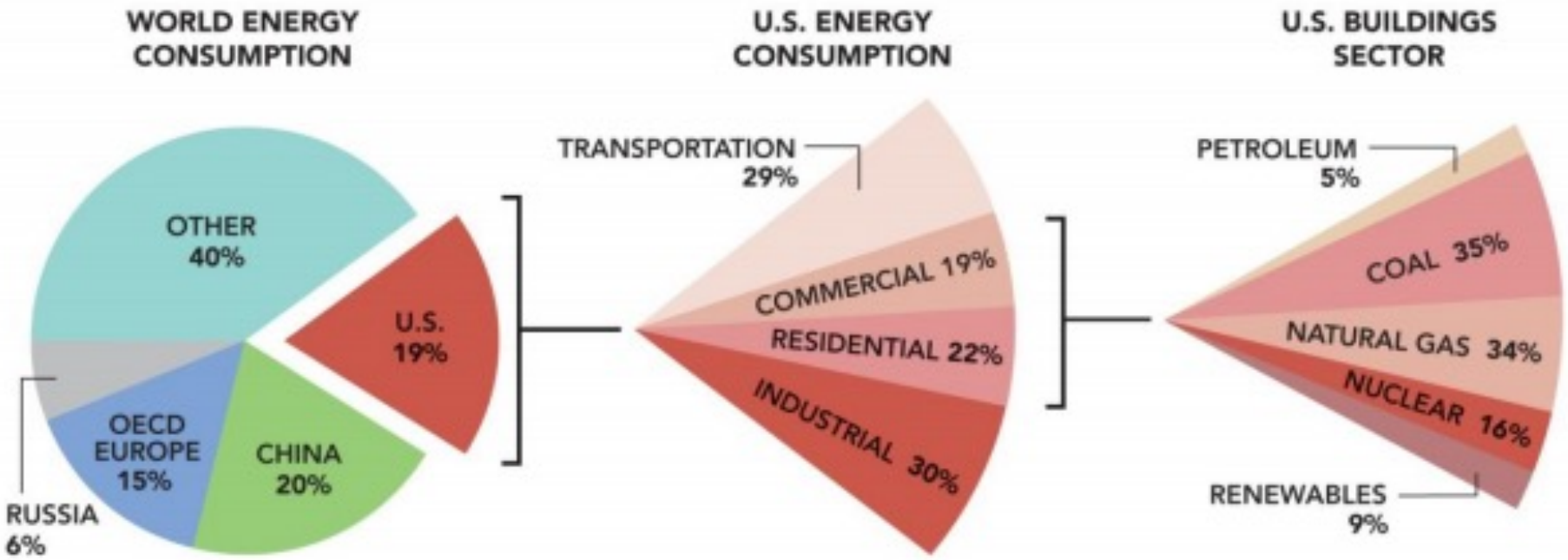
https://www.eia.gov/todayinenergy/detail.php?id=10

History of Energy Consumption in the U.S.



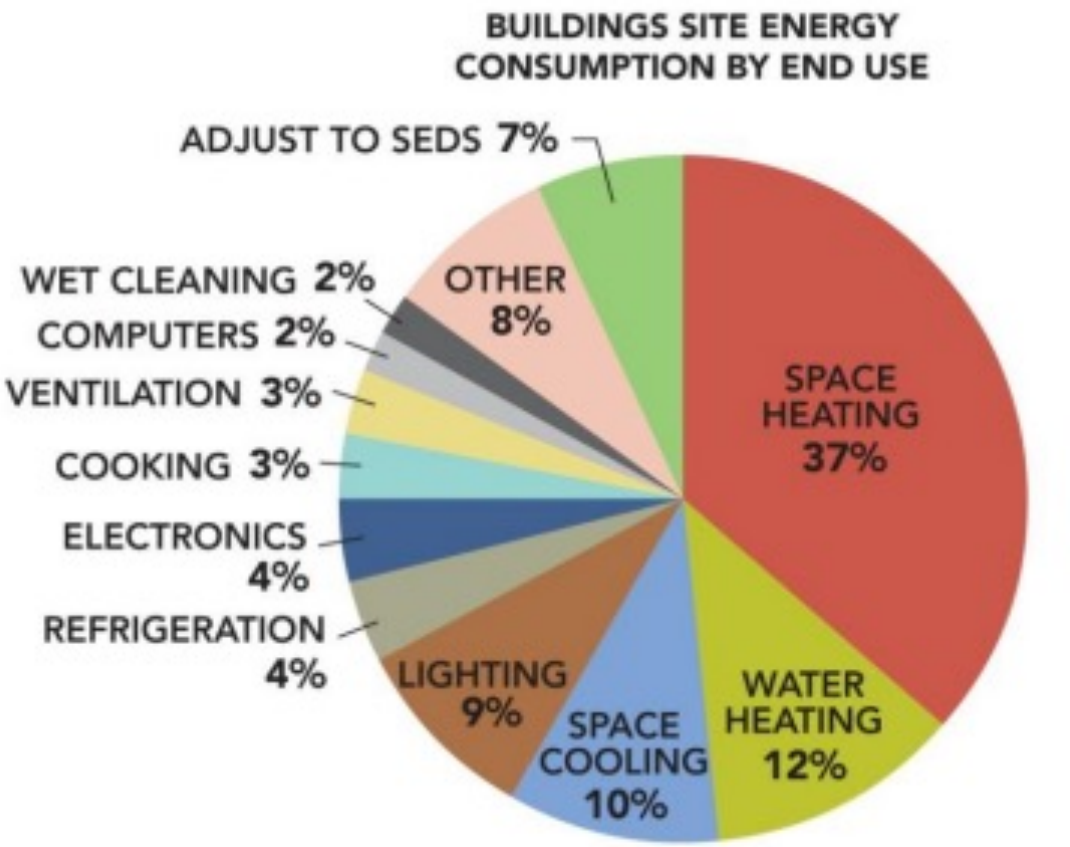
https://www.eia.gov/todayinenergy/detail.php?id=10

Energy Consumption Percentage



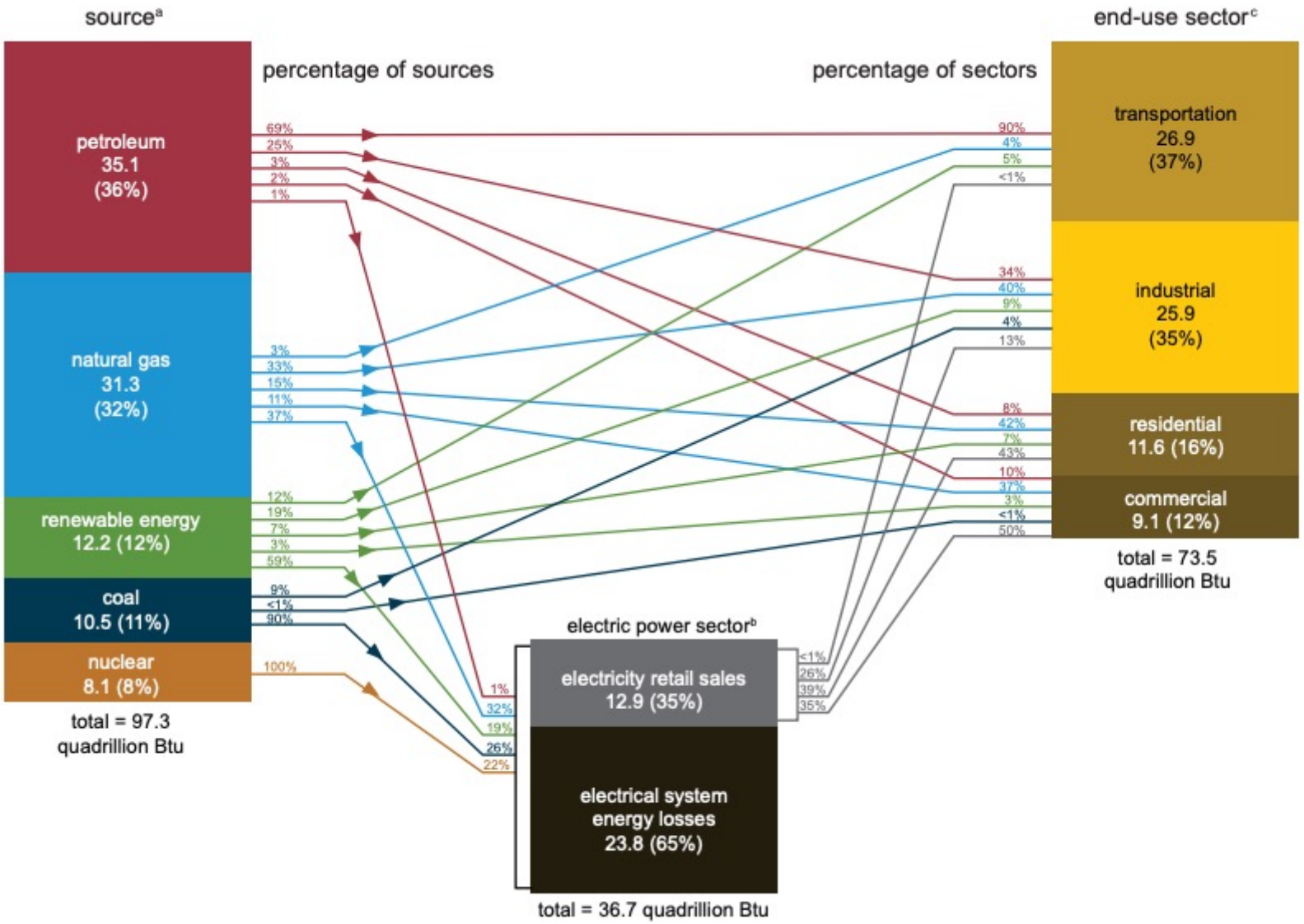
2011 Buildings Energy Data Book

Energy Consumption Percentage



2011 Buildings Energy Data Book

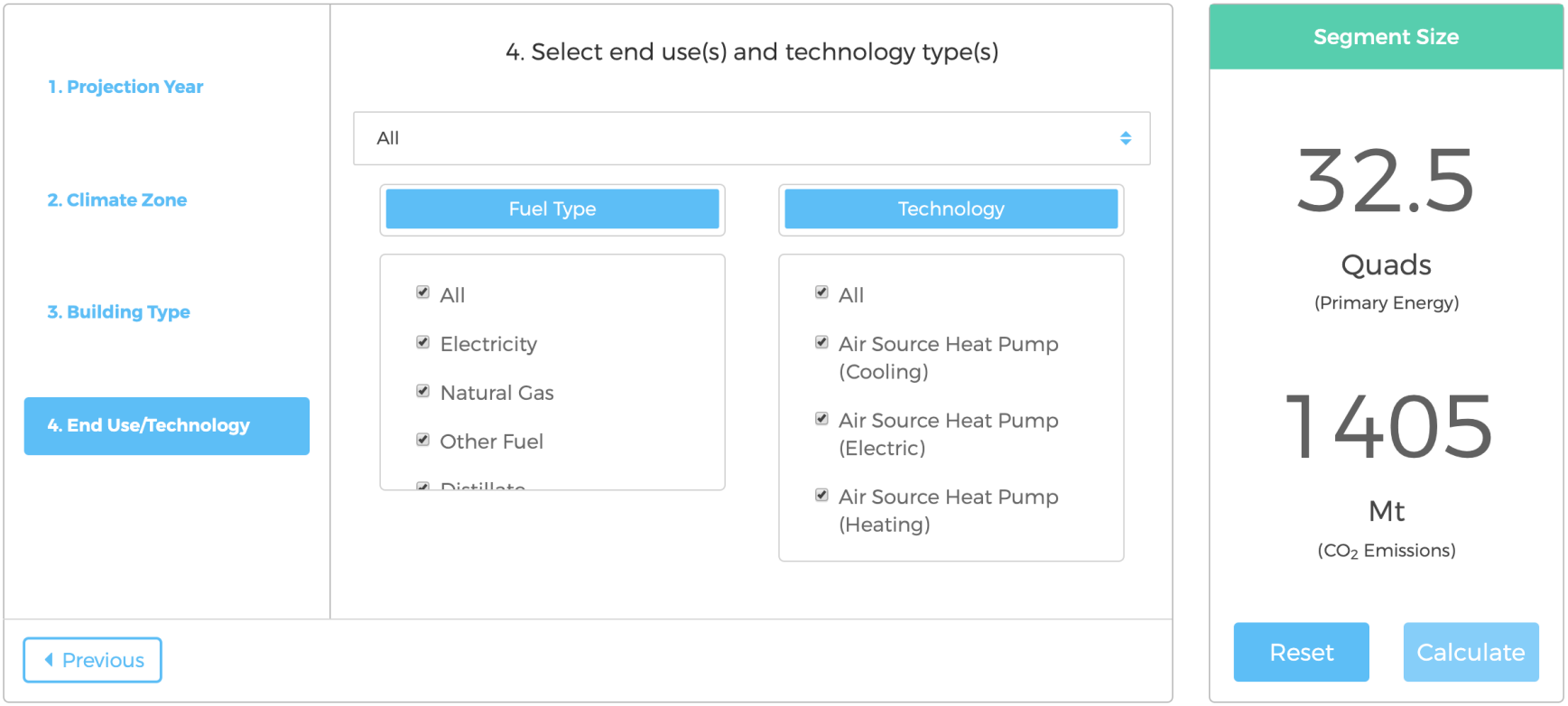
Energy Consumption Percentage



U.S. energy consumption by source and sector, 2021

Energy Consumption Percentage

- Scout by the Department of Energy is a good resource to identify future energy projections:



https://scout.energy.gov/baseline-energy-calculator.html

ENERGY DEFINITIONS

Definition

- Steam typically measured based on volume or heat/energy content:
  - therm
  - British Thermal Unit (BTU)
  - CCF
    - 1 CCF = 100 cubic feet = about 1 therm = 100,000 BTU
  - Pound of steam (klb)
  - Example of conversion factors:
    - 1klb = 1194 kBtu
    - 3.412 kBtu = 1 kWh

Definition

- Chilled water is typically in heat/energy content:
  - Ton-Hr, BTU

$$\dot{Q} = \dot{m} C_p \Delta T = \rho \dot{V} C_p \Delta T$$

- ρ = 999.78 kg/m^3
- C_p =4.19 kJ/kg-K

$$\dot{Q} = \dot{m} C_p \Delta T = \rho \dot{V} C_p \Delta T$$

- ρ = 61.14 lb/ft^3
- C_p =1.00076 Btu/lb-F

$$\frac{(GPM\ )\Delta T}{24} = Ton$$

Definition

- Electricity
  - Power = kW
  - Energy consumed = kWh
  - Relationship = kW × Time = kWh

Source vs. Site Energy

- Site energy or secondary energy is the energy consumed at the building site (e.g., electricity, steam, CHW)

- Source energy represents the raw amount of fuel, primary energy, that is required to operate the building (e.g., natural gas, fuel oil)

- Benefits of using of source energy:
  - Reduce likelihood of unintentionally penalized of one energy fuel type
  - Correlate more with the energy cost and impact on the climate

- Site energy also provides insights for the building energy use

Source vs. Site Energy

- There are conversion factors (source-to-site ratios) to convert the secondary energy to primary energy based on the location and fuel type

- The commonly accepted global conversion factors are presented by EPA:

Fuel Type	Source-to-Site Ratio	
	US	Canadian
Electricity (grid purchase)	2.8	1.96
Electricity (on-site solar or wind energy)	1.0	1.0
Natural Gas	1.05	1.01
Steam	1.20	1.33
Chilled Water	0.91	0.57

https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf

Energy Utilization Index

- Total energy use: HVAC and Non-HVAC
  - ❑ HVAC includes heating, cooling, fan, pump
  - ❑ Non-HVAC includes, Service Hot Water (SHW), lighting, receptacles, elevators, process

- EUI: Energy use intensity (kBtu/ft^2):

$$EUI = \frac{Energy\ Use}{Building\ Area}$$

COMMERCIAL BUILDING ENERGY CONSUMPTION SURVEY (CBECS)

CBECS

- CBECS is a national sample survey:
  - ❑ Collect information on the stock of U.S. commercial buildings. The scope is:
    - All buildings that at least half of the floorspace is used for a purpose that is not residential, industrial, or agricultural
    - Schools, hospitals, correctional institutions, and religious worship buildings
    - Traditional commercial buildings such as stores, restaurants, warehouses, and office buildings
  - ❑ Include information on:
    - Energy-related building characteristics
    - Energy usage data (consumption and expenditures)

https://www.eia.gov/consumption/commercial/about.php

CBECS

‹ CONSUMPTION & EFFICIENCY

COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY (CBECS)

OVERVIEW | DATA ▾ | ANALYSIS & PROJECTIONS | GLOSSARY › | FAQS ›

2018 Commercial Buildings Energy Consumption Survey building characteristics results

Newly released data tables from the 2018 Commercial Buildings Energy Consumption Survey (CBECS) provide building characteristics information for the estimated 5.9 million U.S. commercial buildings in 2018. Building characteristics data tables include number of workers, ownership and occupancy, structural characteristics, energy sources and uses, energy related building features, and more.

Data Tables

Report PDF PPT

CBECS Status

Background Information

- About the CBECS
- CBECS Survey Forms
- CBECS Maps
- CBECS Terminology
- Survey Background & Technical Information
- Building Type Definitions
- Archived Reports

CBECS

‹ CONSUMPTION & EFFICIENCY

COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY (CBECS)

OVERVIEW | DATA ▾ | ANALYSIS & PROJECTIONS | GLOSSARY › | FAQS ›

- 2018
- 2012
- 2003
- 1999
- 1995
- 1992
- Previous

2018 C ial Buildings Energy Consumption Survey
buildi cteristics results

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Data Tables

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- Building Type Definitions
- Archived Reports

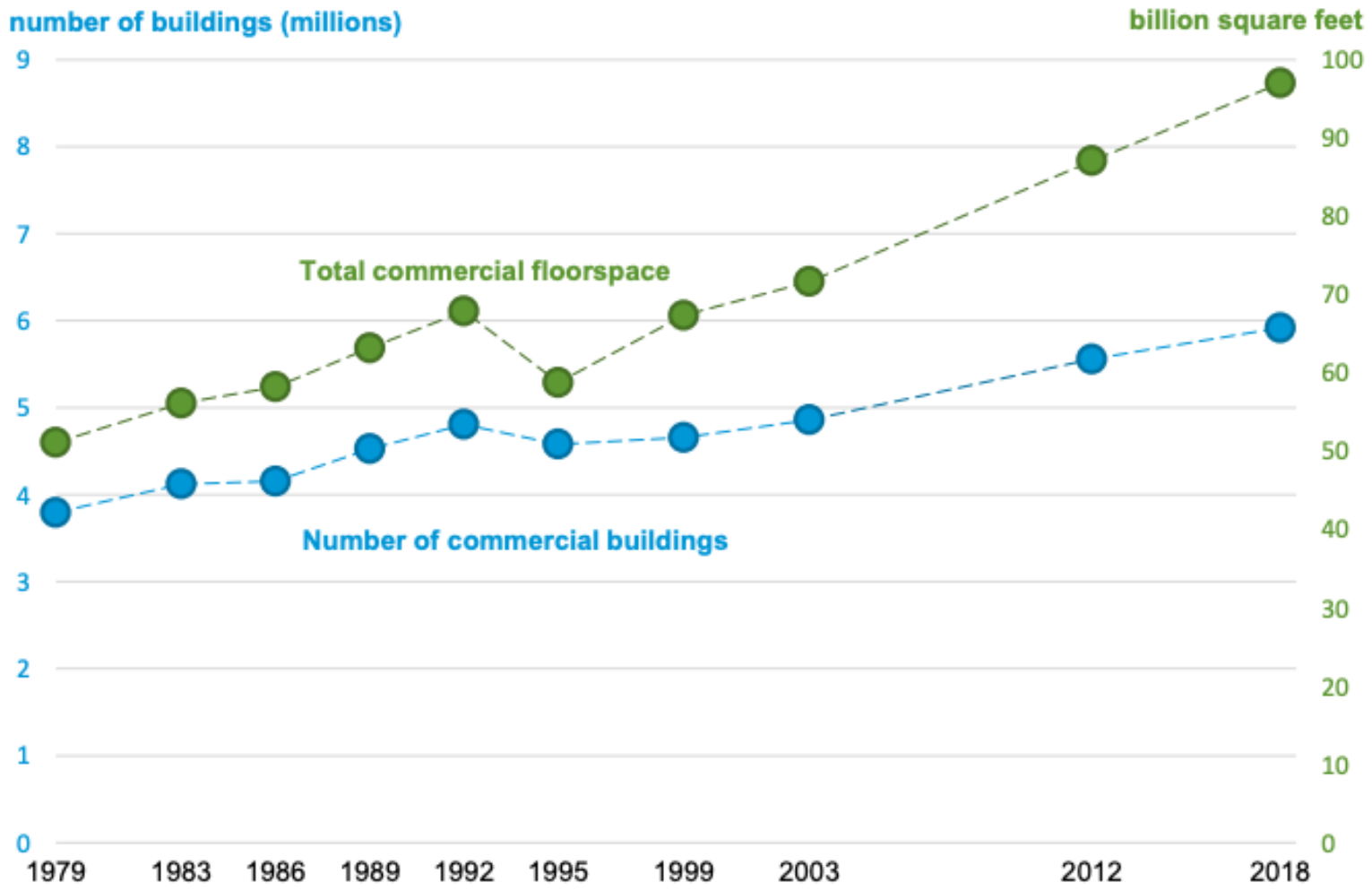
CBECS

Release date: September 2021

Table B11. Selected principal building activity: part 1, number of buildings, 2018

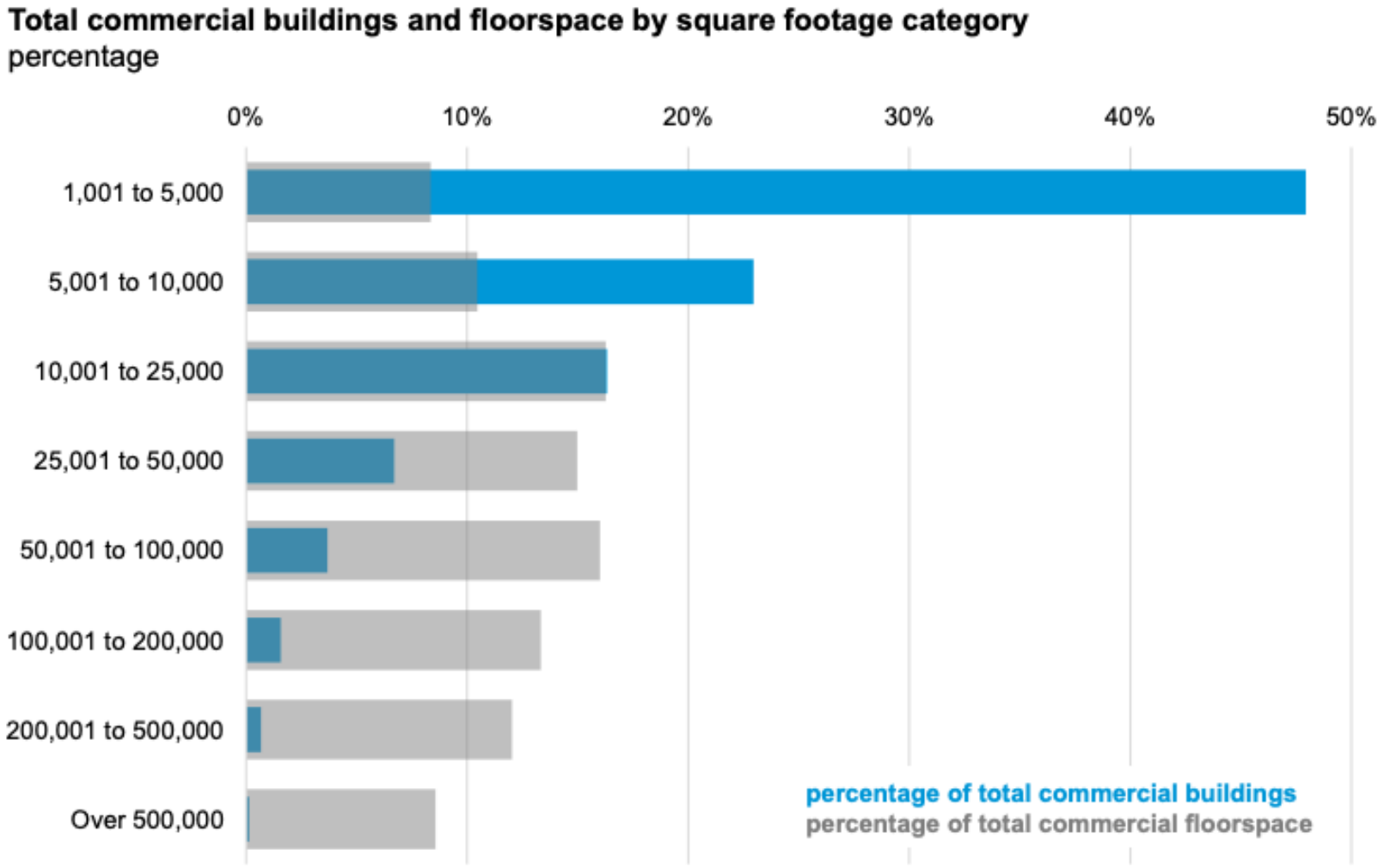
	Number of buildings (thousand)							
		Principal building activity						
	All buildings	Warehouse and storage	Office	Service	Mercantile	Public assembly	Religious worship	Education
All buildings	5,918	1,004	970	867	518	488	439	438
Building floorspace (square feet)								
1,001 to 5,000	2,837	444	518	515	181	215	169	148
5,001 to 10,000	1,358	249	198	218	107	115	100	98
10,001 to 25,000	966	194	135	96	142	95	118	62
25,001 to 50,000	397	60	54	28	47	43	42	40
50,001 to 100,000	218	33	35	9	23	14	8	57
100,001 to 200,000	93	15	17	Q	13	3	Q	25
200,001 to 500,000	40	8	9	Q	5	1	Q	7
Over 500,000	9	2	2	Q	1	1	N	0
Year constructed								
Before 1920	329	Q	85	Q	Q	64	57	Q
1920 to 1945	379	22	78	57	Q	40	Q	22
1946 to 1959	517	113	54	68	48	33	44	66
1960 to 1969	685	68	82	135	96	61	59	51
1970 to 1979	831	121	159	143	65	63	74	59
1980 to 1989	794	150	164	108	63	35	34	55
1990 to 1999	921	235	130	125	49	70	58	86
2000 to 2009	924	162	152	139	100	78	55	60
2010 to 2018	537	117	67	82	52	43	Q	26

CBECS



What do you see here?

CBECS



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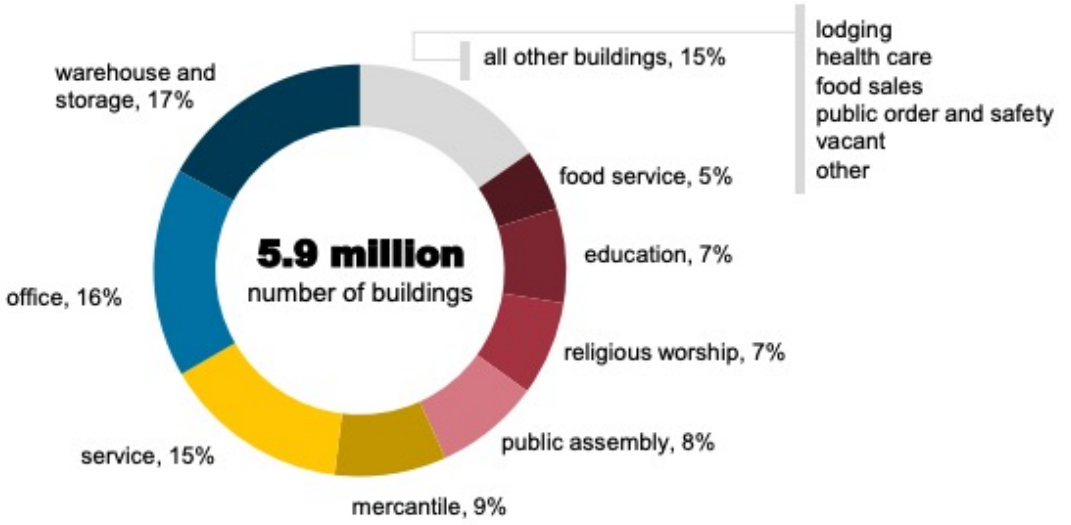
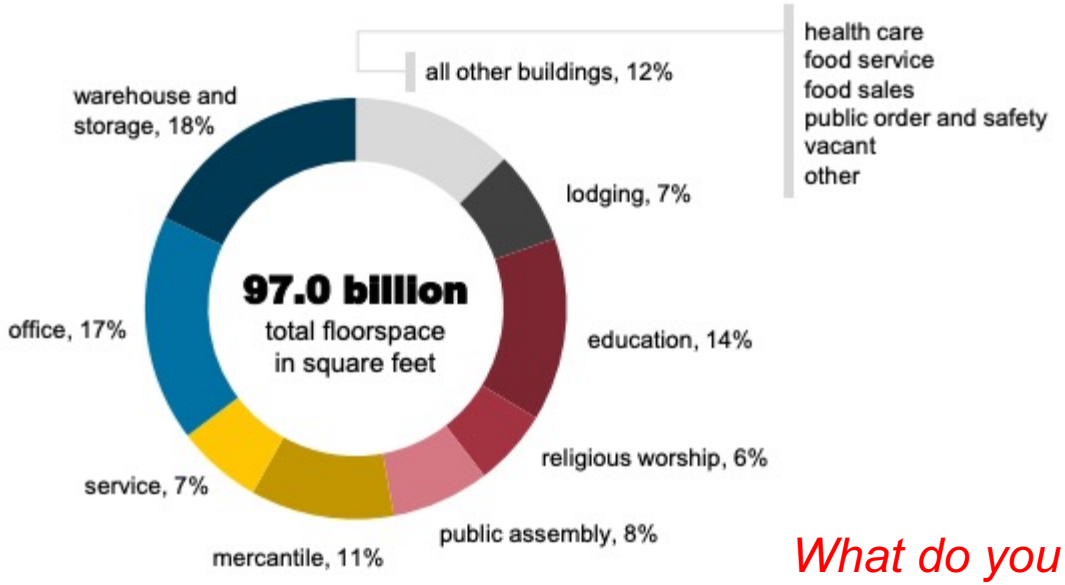
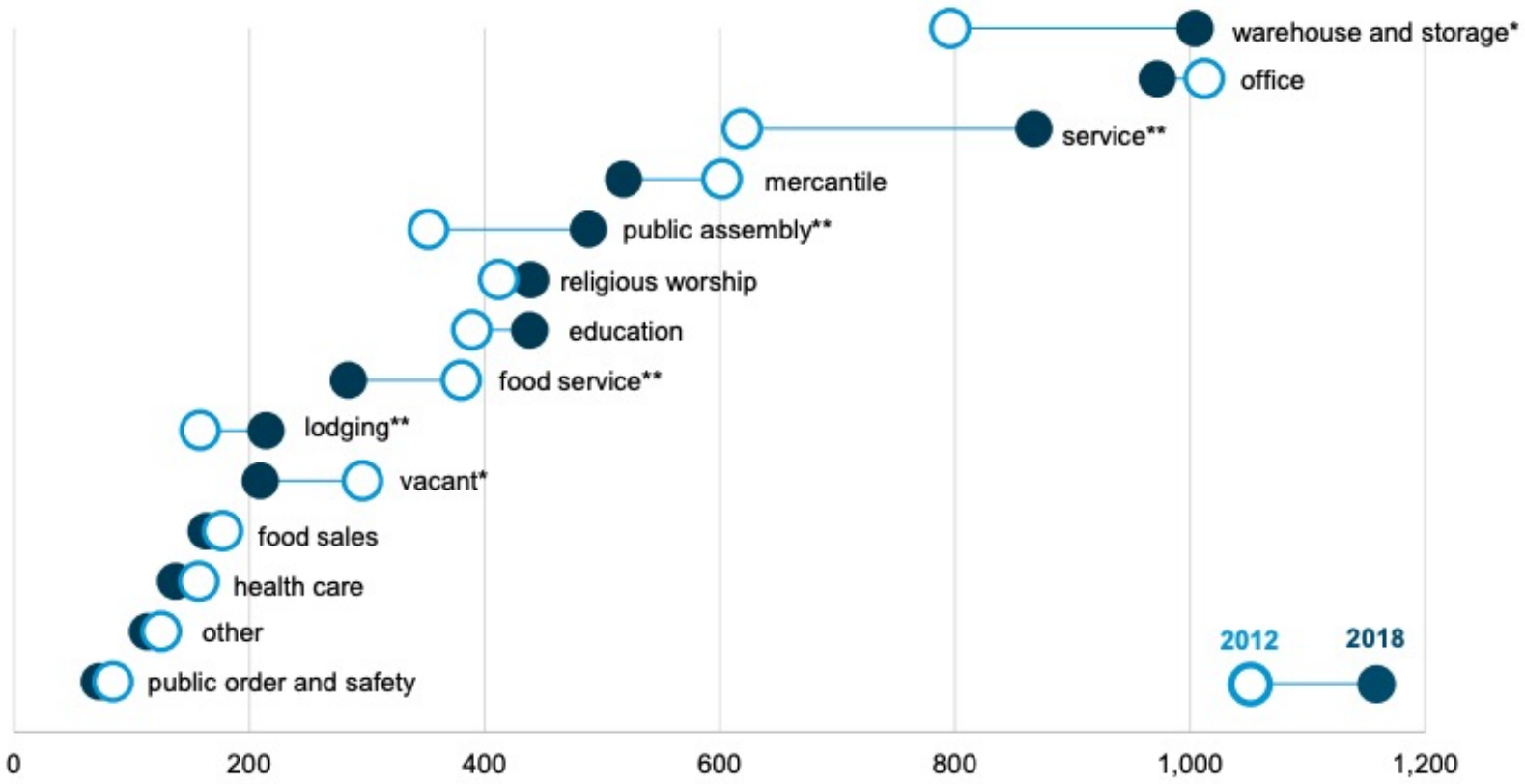




What do you see here?

CBECS

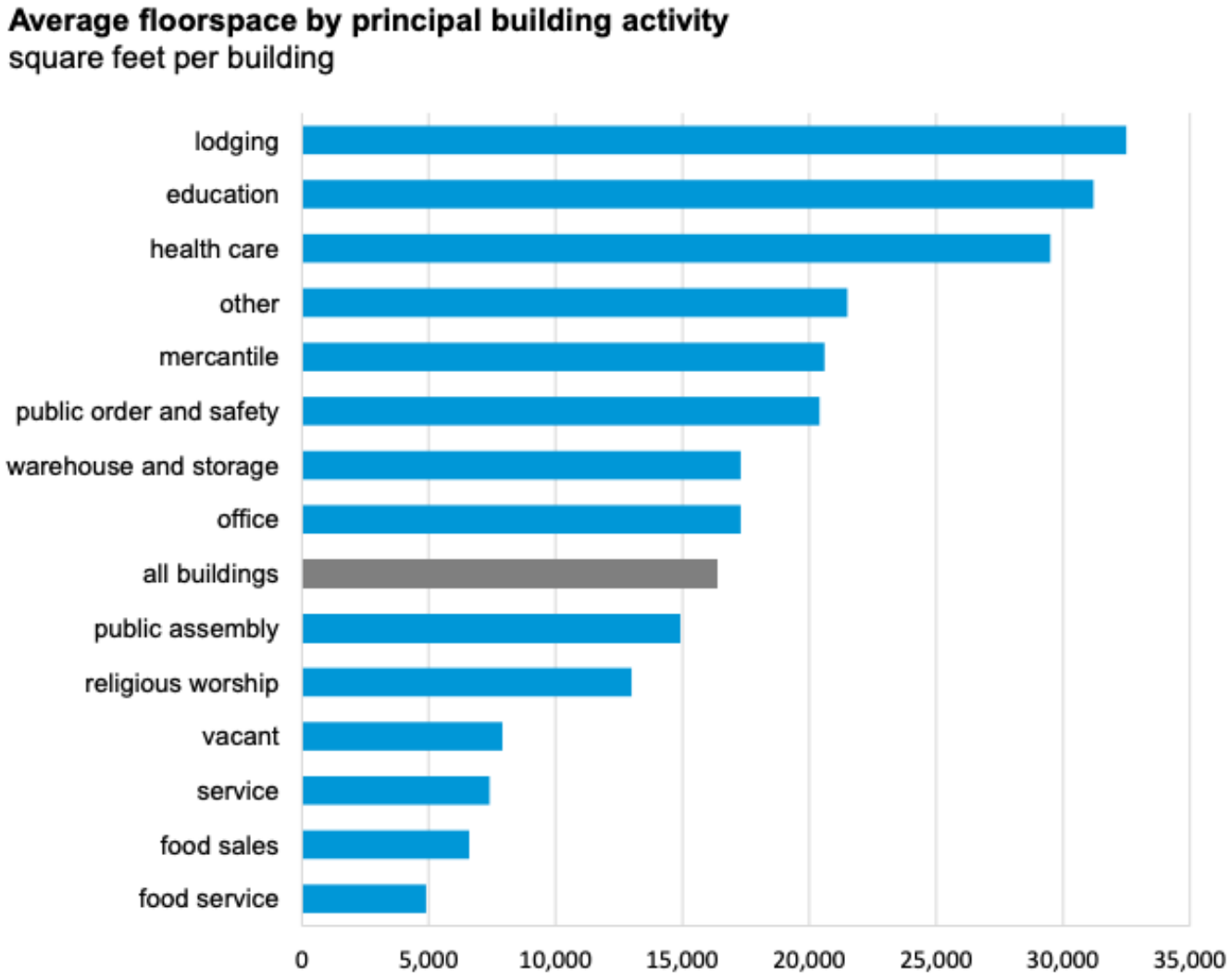
Number of commercial buildings by principal building activity
thousands



* Change is statistically significant at the 90% confidence level.
** Change is statistically significant at the 90% and 95% confidence levels.

What do you see here?

CBECS



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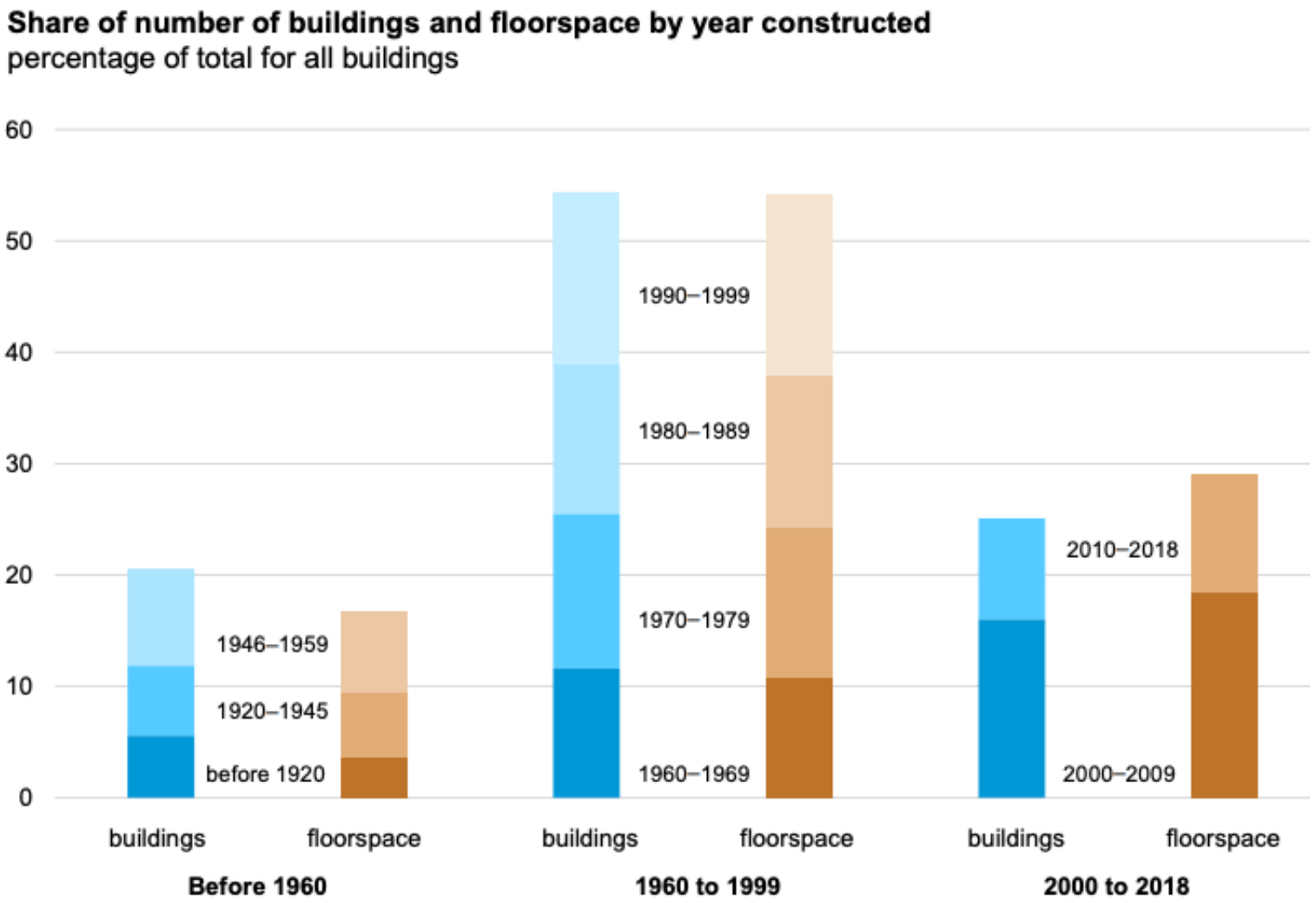

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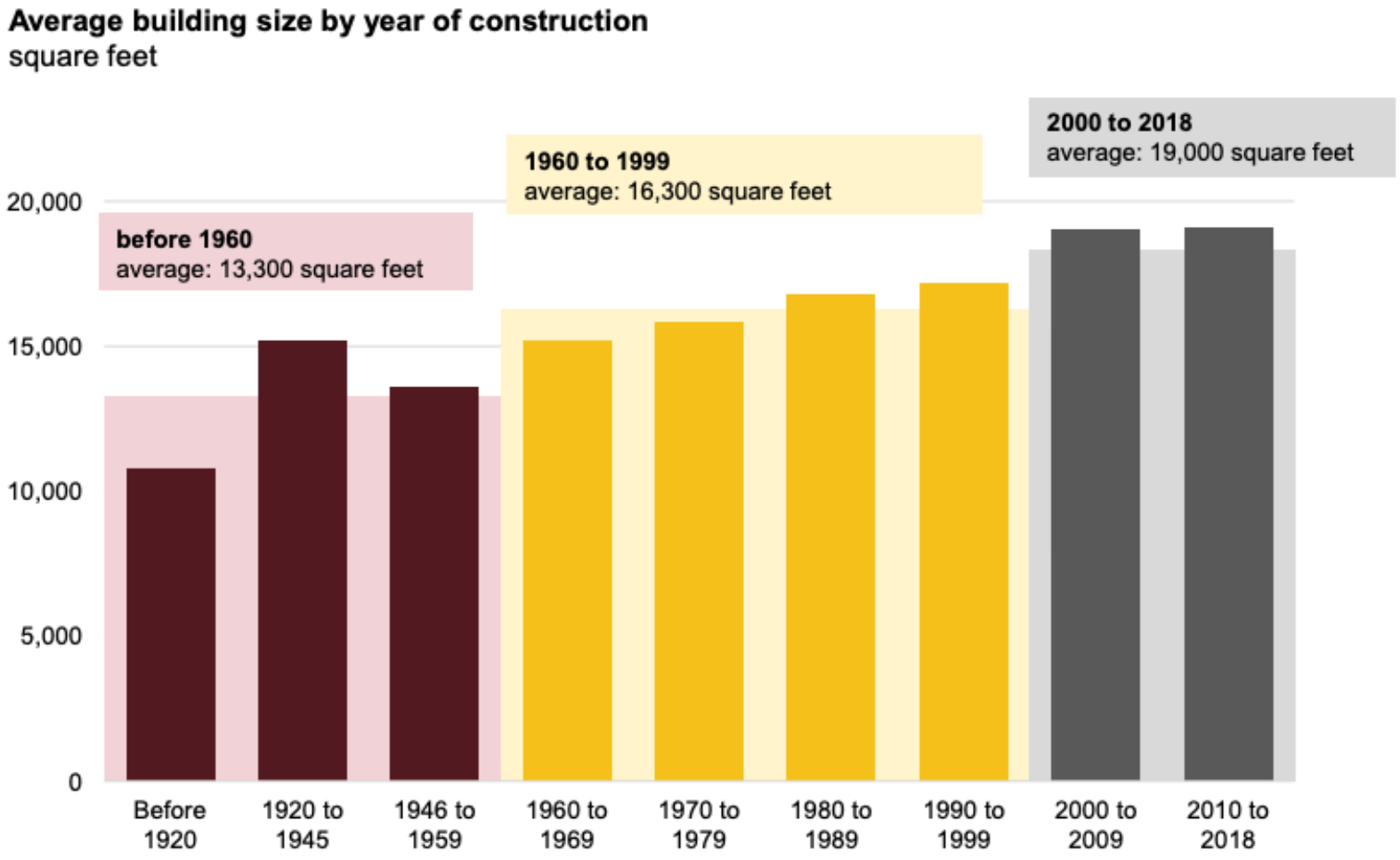


What do you see here?

CBECS

Broad Category	Primary Function	Further Breakdown (where needed)	Source EUI (kBtu/ft²)	Site EUI (kBtu/ft²)	Reference Data Source - Peer Group Comparison
Entertainment/Public Assembly	Stadium	Indoor Arena	112.0	56.2	CBECS - Public Assembly
		Race Track			
		Stadium (Closed)			
		Stadium (Open)			
		Other - Stadium			
	Other	Aquarium			
		Casino			
		Zoo			
		Other - Entertainment/Public Assembly			
		Bar/Nightclub	297.0	130.7	CBECS - Bar/Pub/Lounge
Food Sales & Service	Convenience Store	Convenience Store with Gas Station	592.6	231.4	CBECS - Food Sales
		Convenience Store without Gas Station			
	Restaurant/Bar	Bar/Nightclub	297.0	130.7	CBECS - Bar/Pub/Lounge
		Fast Food Restaurant	886.4	402.7	CBECS - Fast Food
		Restaurant	573.7	325.6	CBECS - Restaurant/Cafeteria
		Other - Restaurant/Bar			
	Supermarket/Grocery Store*		444.0	196.0	CBECS - Grocery Store/Food Market
	Wholesale Club/Supercenter*		120.0	51.4	CBECS - Retail Store
	Other	Food Sales	592.6	231.4	CBECS - Food Sales
		Food Service	527.7	270.3	CBECS - Food Service

CBECS

U.S. National Median Reference Values for All Portfolio Manager Property Types

Broad Category	Primary Function	Further Breakdown (where needed)	Source EUI (kBtu/ft²)	Site EUI (kBtu/ft²)	Reference Data Source - Peer Group Comparison
Banking/Financial Services	Bank Branch *		209.9	88.3	CBECS - Bank/Financial
	Financial Office*		116.4	52.9	CBECS - Office & Bank/Financial
Education	Adult Education		110.4	52.4	CBECS - Education
	College/University		180.6	84.3	CBECS - College/University
	K-12 School*		104.4	48.5	CBECS - Elementary/Middle & High School
	Pre-school/Daycare		131.5	64.8	CBECS - Preschool
	Vocational School		110.4	52.4	CBECS - Education
	Other - Education				
Entertainment/Public Assembly	Convention Center		109.6	56.1	CBECS - Social/Meeting
	Movie Theater		112.0	56.2	CBECS - Public Assembly
	Museum				
	Performing Arts				
	Recreation	Bowling Alley	112.0	50.8	CBECS - Recreation
		Fitness Center/Health Club/Gym			
		Ice/Curling Rink			
		Roller Rink			
		Swimming Pool			
		Other - Recreation			
	Social/Meeting Hall		109.6	56.1	CBECS - Social/Meeting

CBECS

Broad Category	Primary Function	Further Breakdown (where needed)	Source EUI (kBtu/ft²)	Site EUI (kBtu/ft²)	Reference Data Source - Peer Group Comparison
Healthcare	Ambulatory Surgical Center		138.3	62.0	CBECS - Outpatient Healthcare
	Hospital	Hospital (General Medical & Surgical)*	426.9	234.3	Industry Survey
		Other/Specialty Hospital	433.9	206.7	CBECS - Inpatient Healthcare
	Medical Office*		121.7	51.2	CBECS - Medical Office
	Outpatient Rehabilitation/Physical Therapy		138.3	62.0	CBECS - Outpatient Healthcare
	Residential Care Facility		213.2	99.0	Industry Survey
	Senior Living Community*		213.2	99.0	Industry Survey
	Urgent Care/Clinic/Other Outpatient		145.8	64.5	CBECS - Clinic/Outpatient
Lodging/Residential	Barracks*		107.5	57.9	CBECS - Dormitory
	Hotel*		146.7	63.0	CBECS - Hotel & Motel/Inn
	Multifamily Housing*		118.1	59.6	Fannie Mae Industry Survey
	Prison/Incarceration		156.4	69.9	CBECS - Public Order and Safety
	Residence Hall/Dormitory*		107.5	57.9	CBECS - Dormitory
	Residential Care Facility		213.2	99.0	Industry Survey
	Senior Living Community*		213.2	99.0	Industry Survey
	Single Family Home		N/A	N/A	None Available
	Other - Lodging/Residential		143.6	63.6	CBECS - Lodging
Manufacturing/Industrial	Manufacturing/Industrial Plant		N/A	N/A	None Available
Mixed Use	Mixed Use Property		89.3	40.1	CBECS - Other
Office	Medical Office*		121.7	51.2	CBECS - Medical Office
	Office*		116.4	52.9	CBECS - Office & Bank/Financial
	Veterinary Office		145.8	64.5	CBECS - Clinic/Outpatient
Parking	Parking		N/A	N/A	None Available

CBECS

Broad Category	Primary Function	Further Breakdown (where needed)	Source EUI (kBtu/ft²)	Site EUI (kBtu/ft²)	Reference Data Source - Peer Group Comparison
Public Services	**Courthouse***		211.4	101.2	CBECS - Courthouse
	Drinking Water Treatment & Distribution *(Average EUI presented in Energy per Flow in gallons per day)*		5.90	2.27	AWWA - Water Treatment Plant
	Fire Station		124.9	63.5	CBECS - Fire Station/Police Station
	Library		143.6	71.6	CBECS - Library
	Mailing Center/Post Office		96.9	47.9	CBECS - Service
	Police Station		124.9	63.5	CBECS - Fire Station/Police Station
	Prison/Incarceration		156.4	69.9	CBECS - Public Order and Safety
	Social/Meeting Hall		109.6	56.1	CBECS - Social/Meeting
	Transportation Terminal/Station		112.0	56.2	CBECS - Public Assembly
	Wastewater Treatment Plant* *(Average EUI presented in Energy per Flow in gallons per day)*		7.51	2.89	AWWA - Wastewater Plant
	Other - Public Services		89.3	40.1	CBECS - Other
Religious Worship	**Worship Facility***		58.4	30.5	CBECS - Religious Worship
Retail	Automobile Dealership		124.1	55.0	CBECS - Retail other than Mall
	Convenience Store	Convenience Store with Gas Station	592.6	231.4	CBECS - Food Sales
		Convenience Store without Gas Station			
	Mall	Enclosed Mall	170.7	65.7	CBECS - Enclosed Mall
		Lifestyle Center	228.8	103.5	CBECS - Strip Shopping Mall
		Strip Mall			
		Other - Mall	225.3	101.6	CBECS - Enclosed Mall and Strip Shopping Mall
	Retail Store*		120.0	51.4	CBECS - Retail Store
	Supermarket/Grocery Store*		444.0	196.0	CBECS - Grocery Store/Food Market
	Wholesale Club/Supercenter*		120.0	51.4	CBECS - Retail Store

CBECS

Broad Category	Primary Function	Further Breakdown (where needed)	Source EUI (kBtu/ft²)	Site EUI (kBtu/ft²)	Reference Data Source - Peer Group Comparison
Technology/Science	**Data Center*** *(Average PUE presented in place of EUI: PUE = Total Energy / IT Energy)*		1.82	1.82	EPA - Data Center
	Laboratory		318.2	115.3	CBECS - Laboratory
	Other – Technology/Science		89.3	40.1	CBECS - Other
Services	**Data Center*** *(Average PUE presented in place of EUI: PUE = Total Energy / IT Energy)*		1.82	1.82	EPA - Data Center
	Personal Services (Health/Beauty, Dry Cleaning, etc.)		96.9	47.9	CBECS - Service
	Repair Services (Vehicle, Shoe, Locksmith, etc.)				
	Other - Services				
Utility	Drinking Water Treatment & Distribution *(Average EUI presented in Energy per Flow in gallons per day)*		5.90	2.27	AWWA - Water Treatment Plant
	Energy/Power Station		89.3	40.1	CBECS - Other
	Wastewater Treatment Plant* *(Average EUI presented in Energy per Flow in gallons per day)*		7.51	2.89	AWWA - Wastewater Plant
	Other - Utility		89.3	40.1	CBECS - Other
Warehouse/Storage	Self-Storage Facility		47.8	20.2	CBECS – Non-refrigerated Warehouse
	Warehouse/Distribution Center	**Distribution Center***	52.9	22.7	CBECS – Non-refrigerated Warehouse & Distribution Center
		Non-Refrigerated Warehouse*			
		Refrigerated Warehouse*	235.6	84.1	CBECS – Refrigerated Warehouses
Other	Other		89.3	40.1	CBECS - Other

RESIDENTIAL BUILDING ENERGY CONSUMPTION SURVEY (RECS)

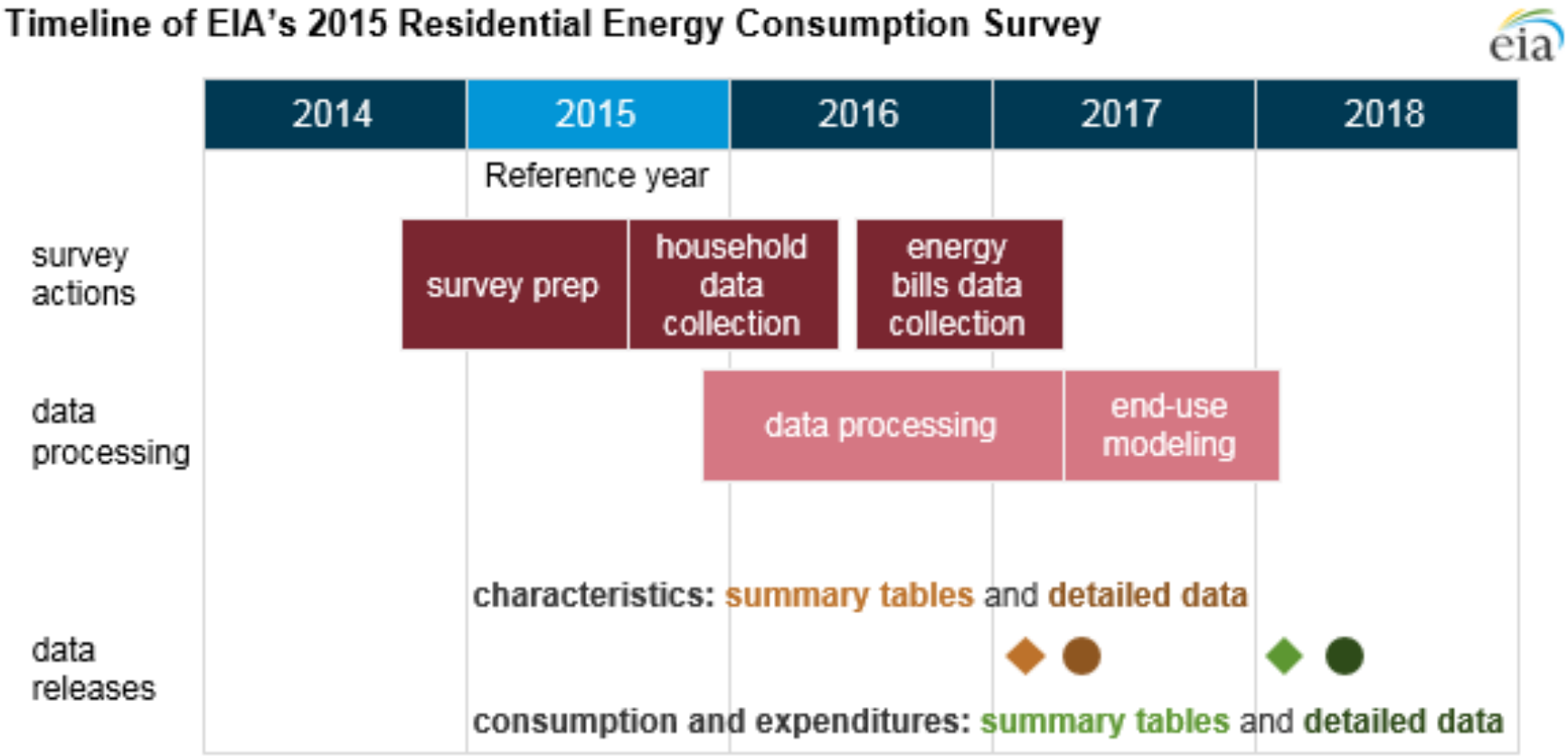
RECS

- RECS is a national sample survey of housing units:
  - ❑ Collect information on:
    - Energy characteristics on the housing unit
    - Usage patterns
    - Household demographics
  - ❑ 2015 survey cycle conducted via Web and mail forms, in addition to in-person interviews
    - The fourteenth RECS collected data
    - More than 5,600 households in housing units
    - Represent the 118.2 million housing units that are occupied as a primary residence
  - ❑ 1978, the first survey was conducted
  - ❑ 2020 is the most recent survey

https://www.eia.gov/consumption/residential/about.php

RECS

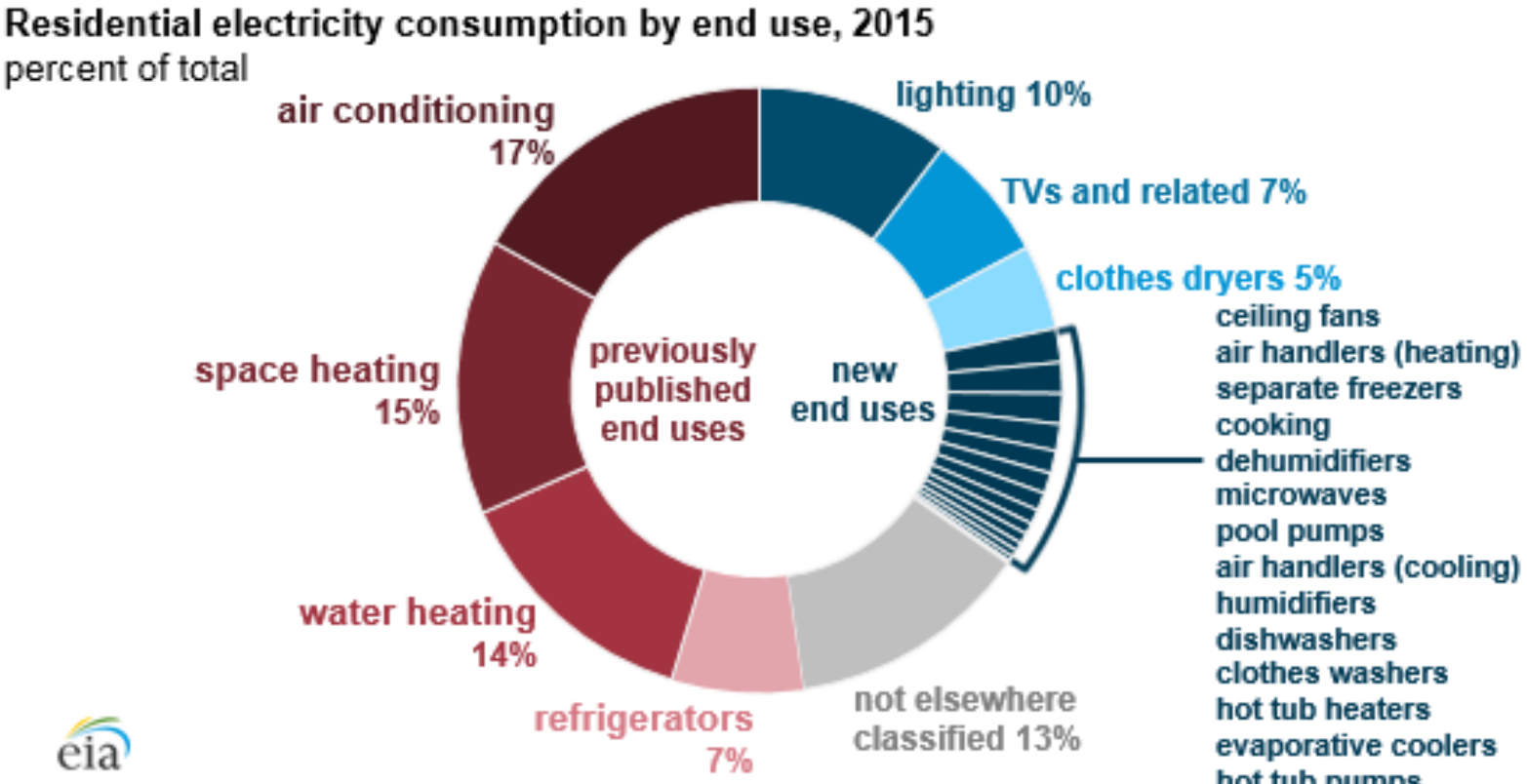
Timeline of EIA's 2015 Residential Energy Consumption Survey (RECS)



https://www.eia.gov/consumption/residential/about.php

RECS

EIA's residential energy survey now includes estimates for more than 20 new end uses



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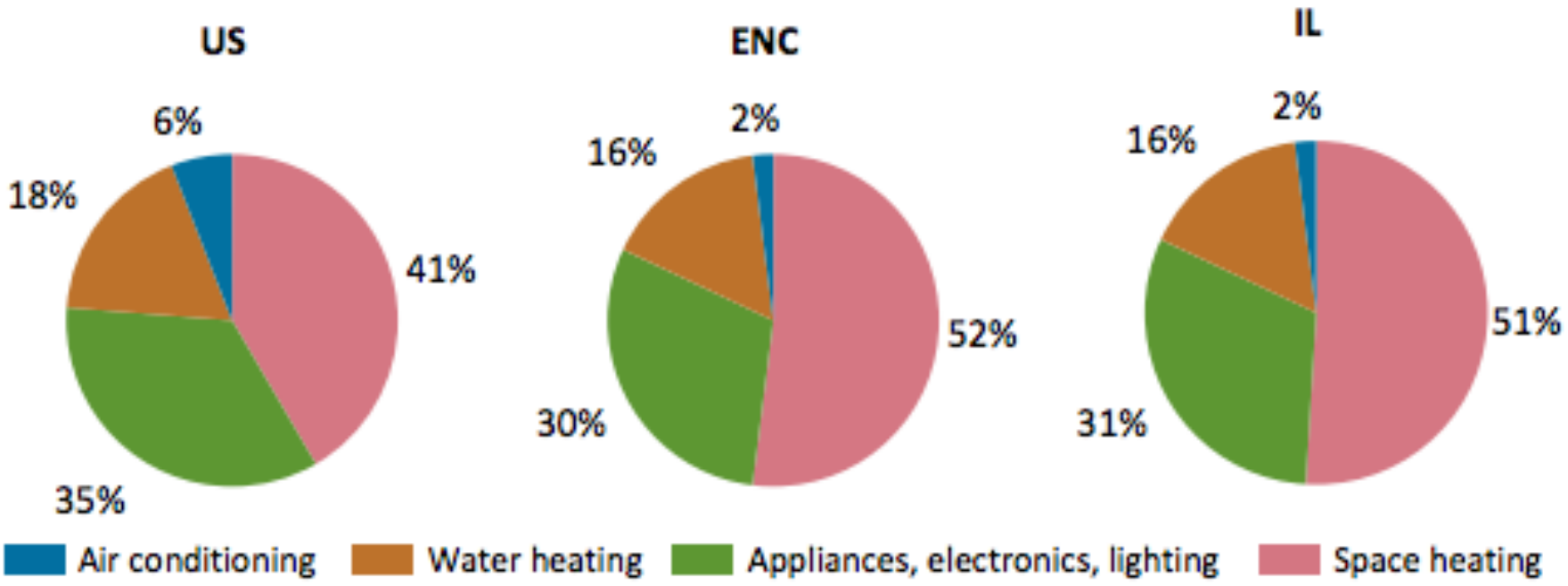
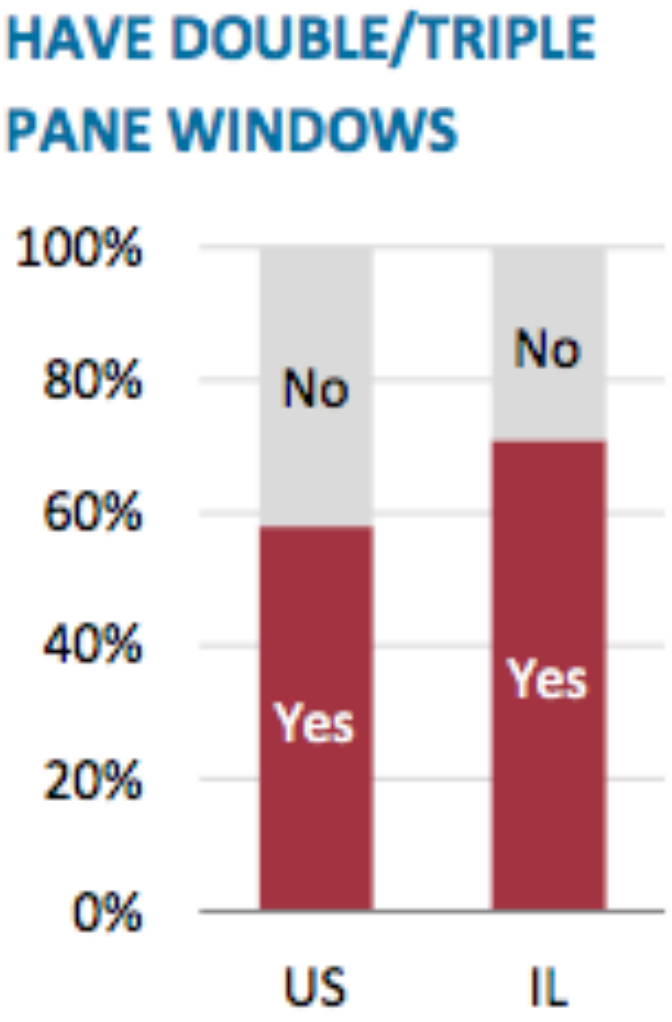
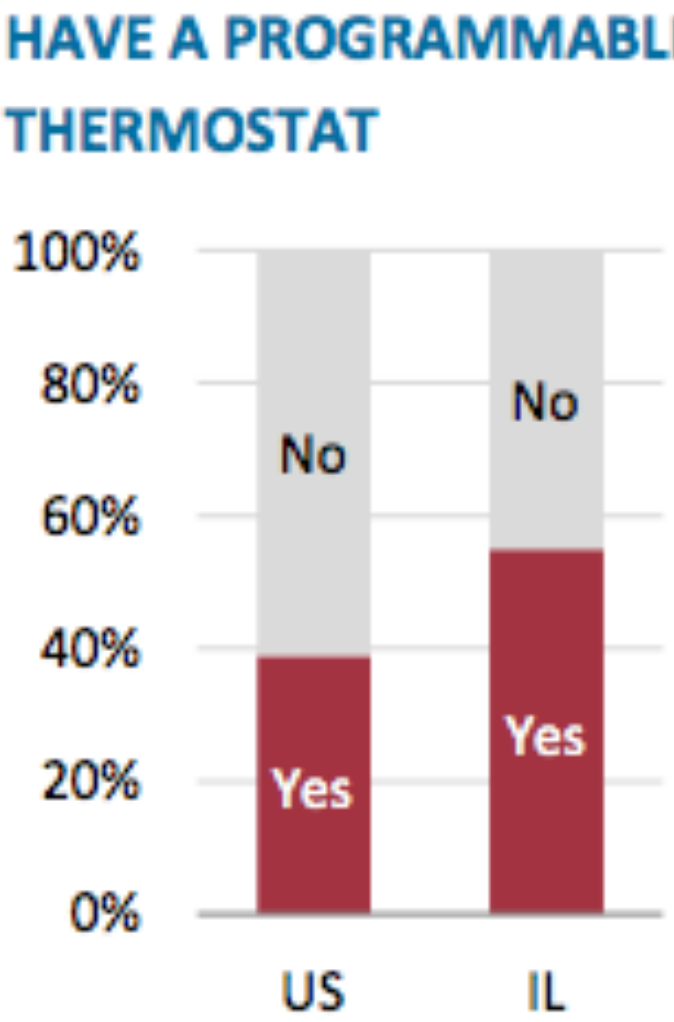
RECS



https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/IL.pdf

RECS

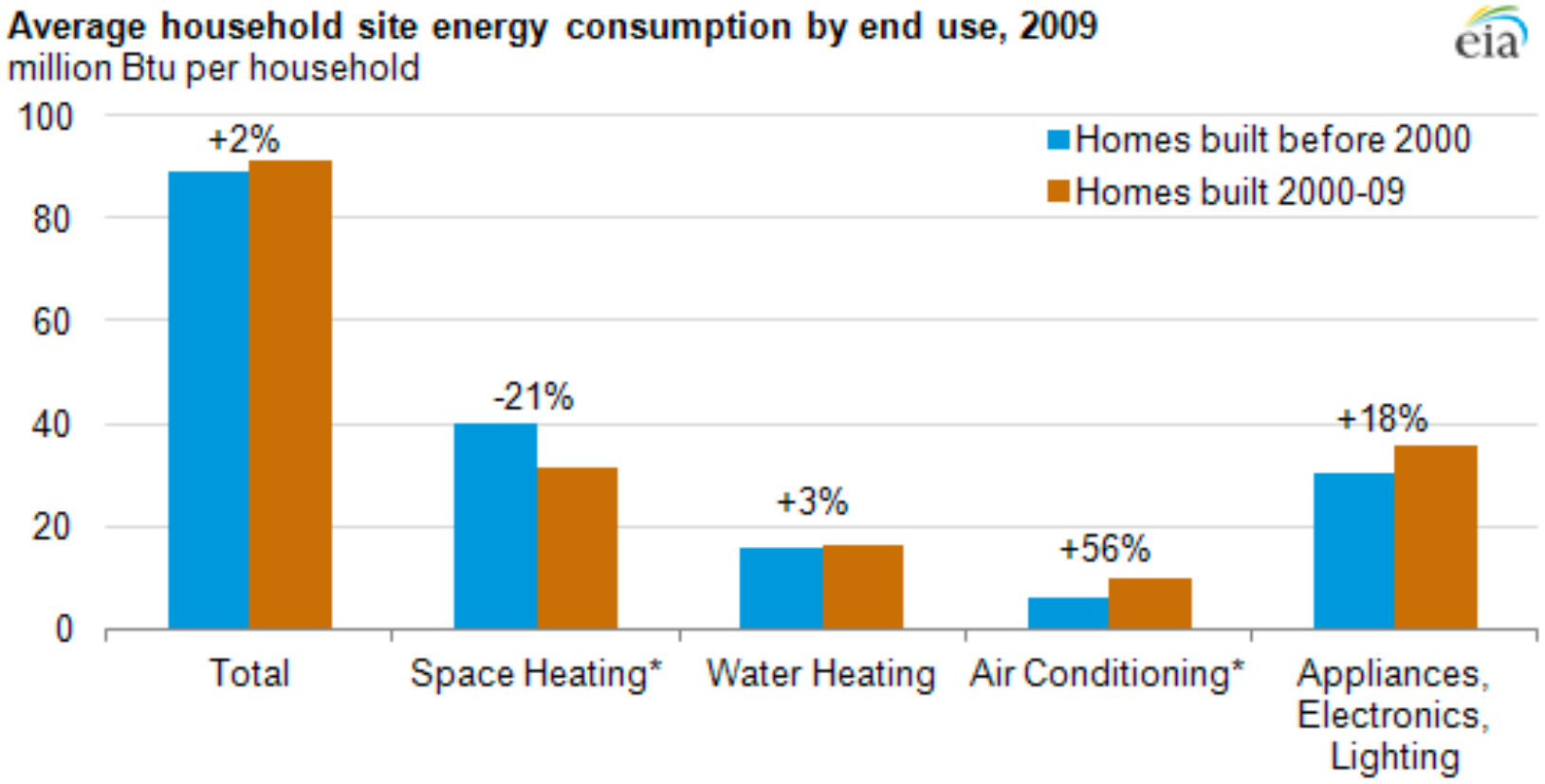




https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/IL.pdf

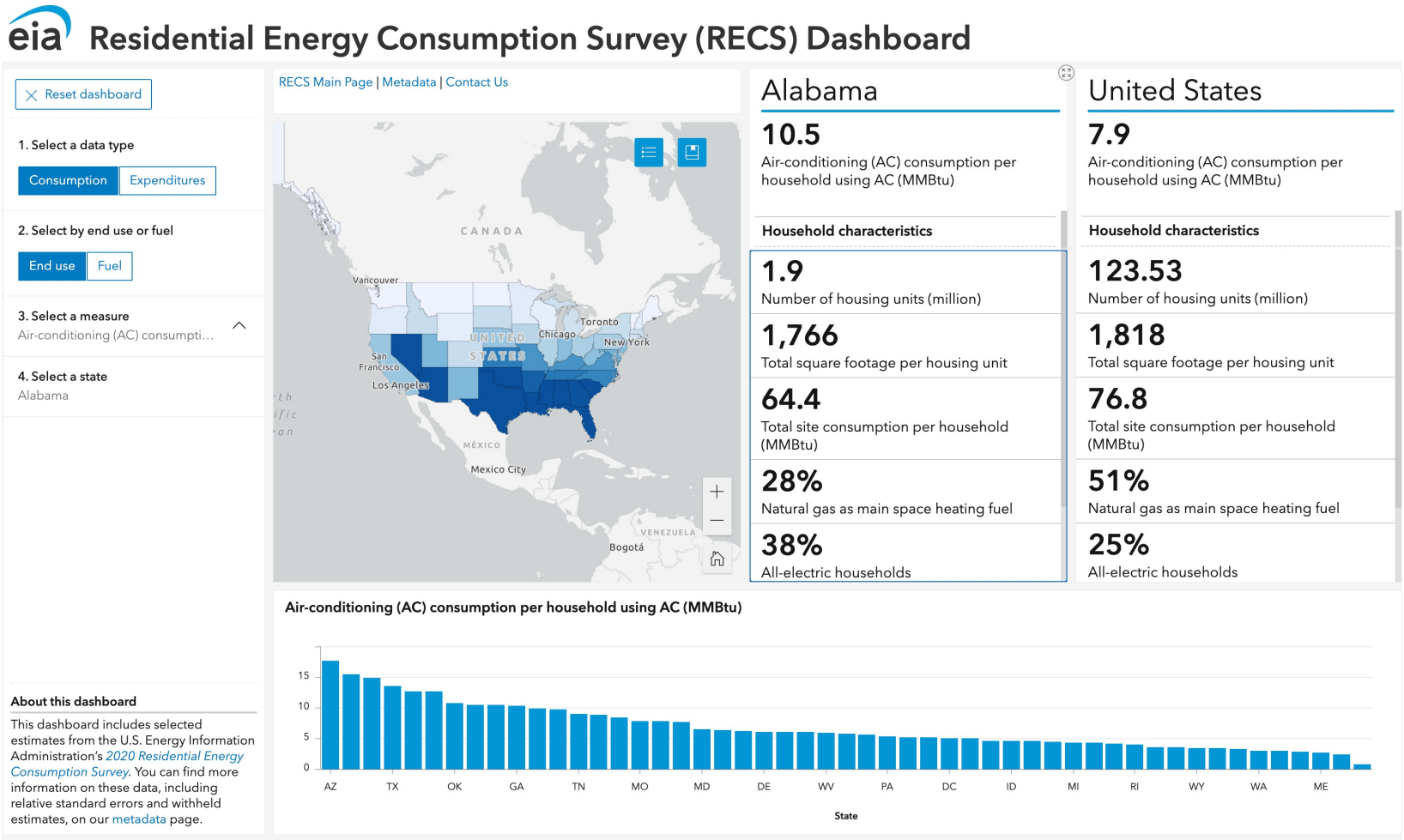
New vs. Old Buildings

- Newer U.S. homes are 30% larger but consume about as much energy as older homes



New vs. Old Buildings

- New webpage

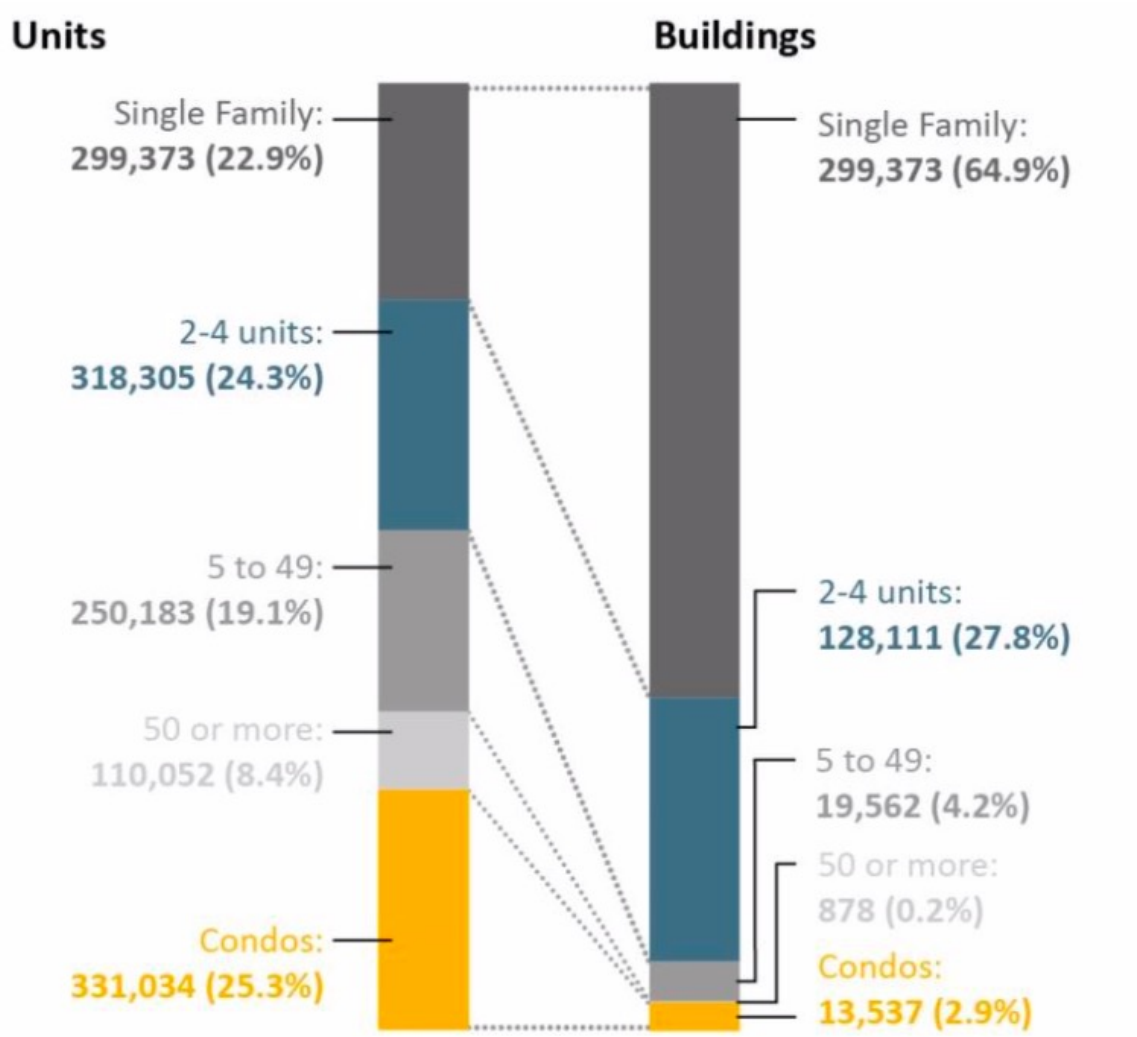


BUILDINGS IN CHICAGO

Buildings in Chicago

- Buildings in Chicago:
  - ❑ 75% of Chicagoans live in a multifamily building
  - ❑ 1.3 million housing units exist (Estimate)
    - 77% (or around 1 million units) are in multifamily buildings
    - 33% (300,000 units) of these multifamily units are condominiums (likely to be owner-occupied)
    - 67% (700,000 units) are likely to be rental units
  - ❑ Chicago's multifamily building stock is old
    - Energy intensive
    - 75% of Chicago's multifamily housing was built before 1942

Buildings in Chicago



Segmenting Chicago Multifamily Housing to Improve Energy Efficiency Programs, Elevate Energy

Buildings in Chicago

	N	EUI	Energy Star Score	Notes
Building Performance Database[vi]	689	55 (median, site, national)	n/a	5+ units
Chicago Energy Benchmarking (2016)[vii]	952	N/A	55	≥50,000 square feet
Elevate Energy Chicago Data (2007-2015)	459	111 (gas only, median, site, pre-retrofit) 94 (gas only, median, site, post-retrofit)	n/a	5+ units; Master-metered gas heated buildings
Fannie Mae National Survey (2011)[viiiix]	536	127.9 (median, source) 78.8 (median, site)	n/a	
Los Angeles (2010)[x]	104400	46.5 (median, site)		N is parcels, not buildings
Minnesota[xi]	322	58 (owner-paid heat and hot water)	n/a	
New York City (2012)[xii]	8687	121 (median, source)	n/a	≥50,000 square feet
RECS (2009)	1924	54.5 (mean, site, national) 66 (mean, site, Midwest)	n/a	5+ units
Seattle (2013)[xiii]	1565	30.3 (low-rise, median, site)	77 (low-rise, median)	≥20,000 square feet
		34.3 (mid-rise, median, site)	85 (mid-rise, median)	Energy Star Scores are preliminary
		49.0 (high-rise, median, site)	47 (high-rise, median)	

Segmenting Chicago Multifamily Housing to Improve Energy Efficiency Programs, Elevate Energy

CITY BENCHMARKING

Energy Benchmarking

Table 1
Table of benchmarking and audit legislation.

City	Legislation/ordinance	Benchmarking requirement, frequency	Benchmarking disclosure	Auditing requirement, frequency	Auditing disclosure
New York	Local laws 84, 87	Annual disclosure of total energy use and building characteristics	Public	ASHRAE Level 2 for all buildings every ten years	To City only
San Francisco	Energy Performance Ordinance	Annual disclosure of total energy use and building characteristics	Public	ASHRAE Level 1 or 2 for each building every five years	Public
Seattle	CB 116731	Annual disclosure of total energy use and building characteristics	Only to potential buyers and tenants	None	None

Table 3
Descriptive statistics for building typology. Zeroes added to ambiguous fields, in order to omit these values from the regression models.

	Variable	Mean	Std dev	Min	q25%	Median	q75%	Max
1	Area (m^2)	14,591.0	9563.8	92.9	6271.0	14,492.9	22,900.6	31,122.5
2	Floors	34.4	19.8	1.0	16.0	35.0	53.0	62.0
3	Volume (000 m^2)	2155.2	2070.4	0.4	428.2	1491.8	3291.8	7370.5
4	Buildings on lot	3.8	3.6	1.0	2.0	2.0	2.0	16.0
5	Apartment units	165.4	201.6	0.0	52.0	102.0	203.0	1744.0
6	Commercial spaces	2.6	9.1	0.0	0.0	1.0	3.0	155.0
7	Building age	1189.8	956.1	0.0	0.0	1926.0	1961.0	2009.0
8	Boiler age	15.1	15.6	0.0	0.0	11.0	26.0	64.0
9	Burner age	10.8	13.4	0.0	0.0	5.0	19.0	68.0

Hsu, Energy Policy 2014

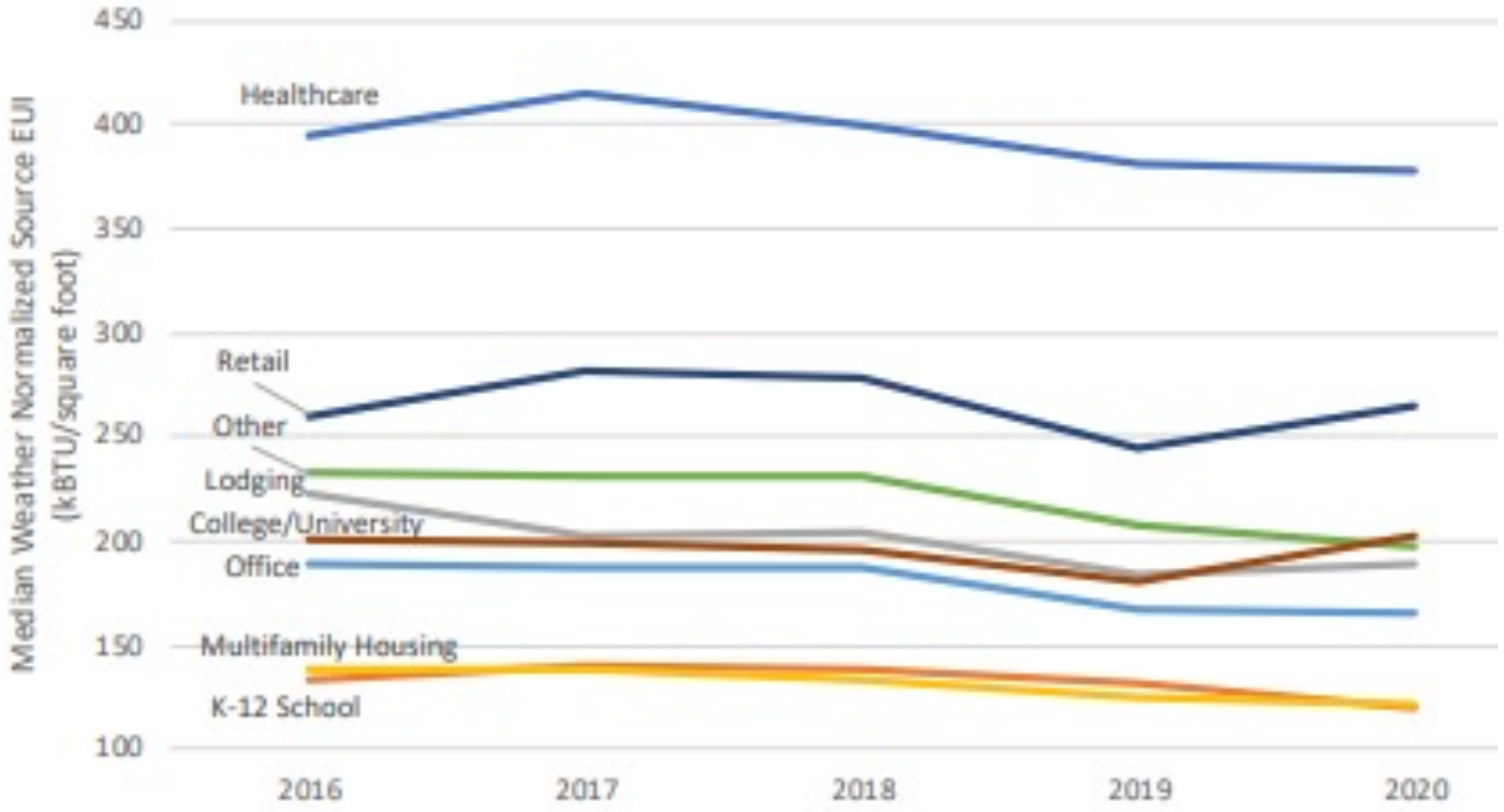
Chicago Energy Benchmarking

- Chicago energy benchmarking:
  - ❑ Cover all commercial, institutional, and residential buildings larger than 50,000 square feet
  - ❑ Requires existing municipal, commercial, and residential buildings larger than 50,000 square feet to:
    - Track whole-building energy use
    - Report to the City annually
    - Verify data accuracy every three years
  - ❑ Cover less than 1% of Chicago's buildings
  - ❑ Account for approximately 20% of total energy used by all buildings

https://data.cityofchicago.org/Environment-Sustainable-Development/Chicago-Energy-Benchmarking-Covered-Buildings/qbgc-xn9b

Chicago Energy Benchmarking

- Chicago energy benchmarking:



https://www.chicago.gov/content/dam/city/progs/env/Energy-Benchmark-Reports/2020_Chicago_Energy_Benchmarking_Report.pdf

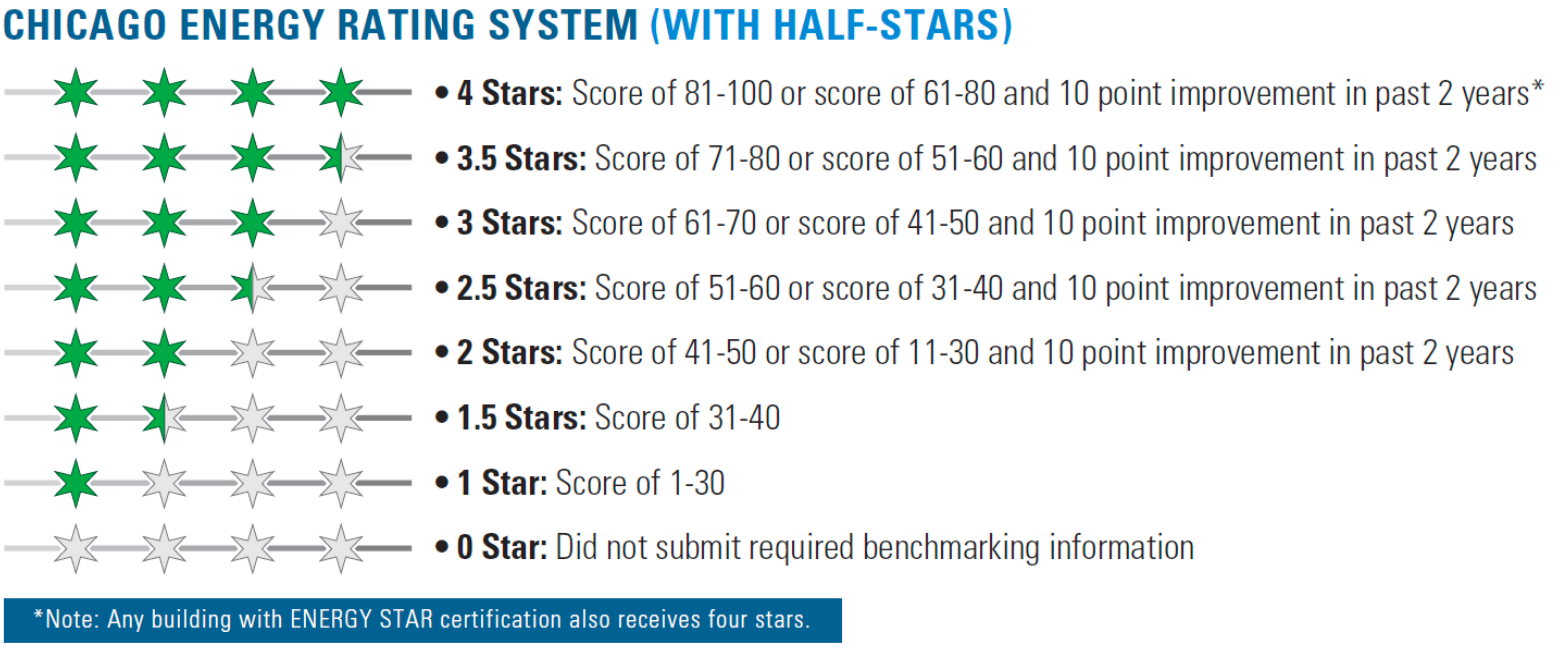
Chicago Energy Benchmarking

- Chicago City Council approved updates to the Chicago Energy Benchmarking Ordinance in 2017:

- Chicago Energy Rating System is implemented in 2019 to:
  - ❑ Improve visibility and transparency of the information reported
  - ❑ Keep existing requirements
  - ❑ Require to place a placard in the building
  - ❑ Range from zero to four based on Energy Star score
  - ❑ Make Chicago the first city to assign an energy performance rating

https://www.chicago.gov/city/en/progs/env/ChicagoEnergyRating.html

Chicago Energy Benchmarking



- Building can earn an extra star by improving its score by 10 points within the past two years

https://www.chicago.gov/city/en/progs/env/ChicagoEnergyRating.html

Chicago Energy Benchmarking

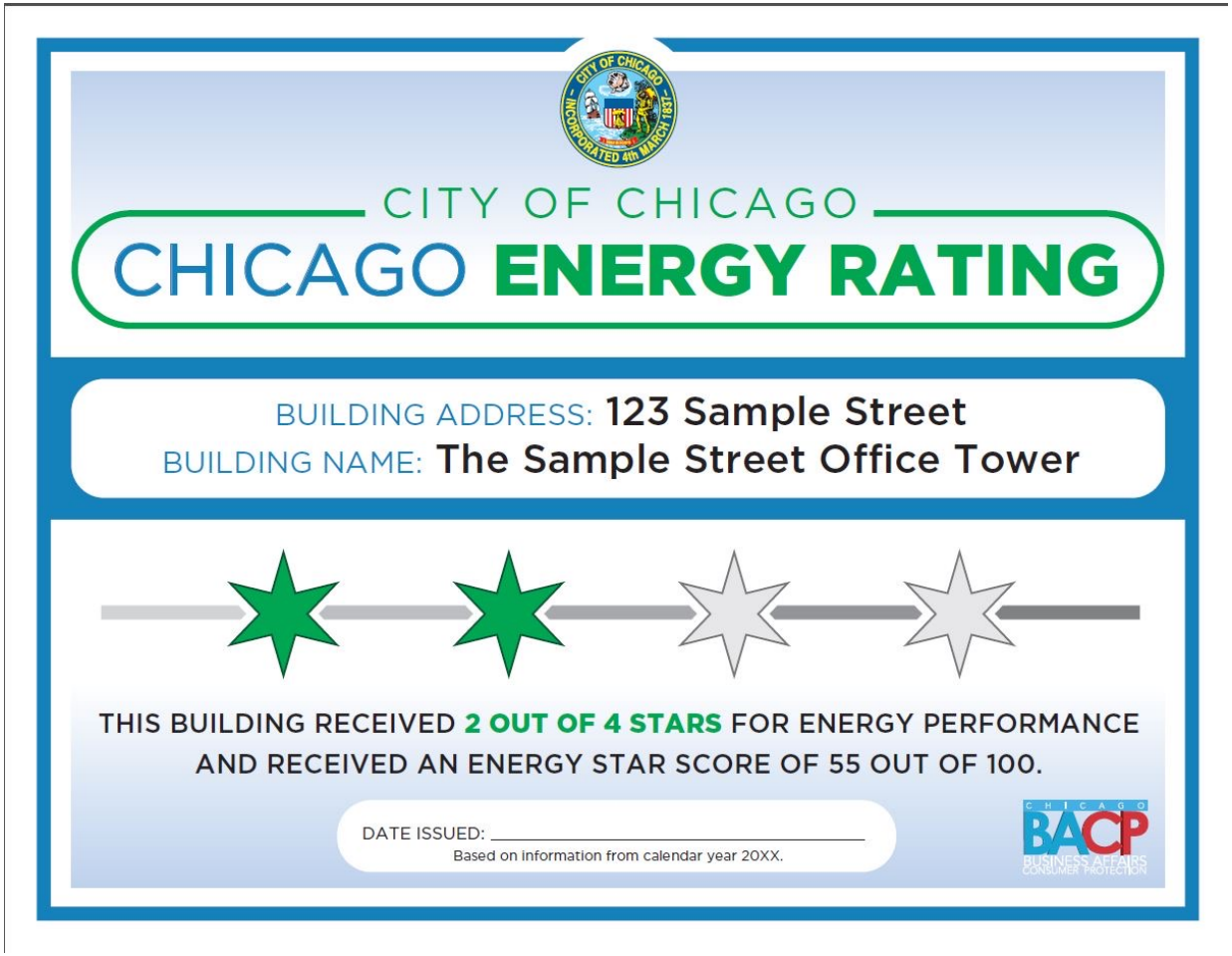
- The scale is based on:
  - ❑ 4 stars -> 1st to 25th percentile for Source EUI
  - ❑ 3 stars -> 25th to 50th percentile for Source EUI
  - ❑ 2 stars -> 50th to 75th percentile for Source EUI
  - ❑ 1 star -> Above the 75th percentile for Source EUI

  - ❑ About 15% of buildings are unable to receive 1-100 Energy Star Score (EUI comparison is used)

https://www.chicago.gov/city/en/progs/env/ChicagoEnergyRating.html

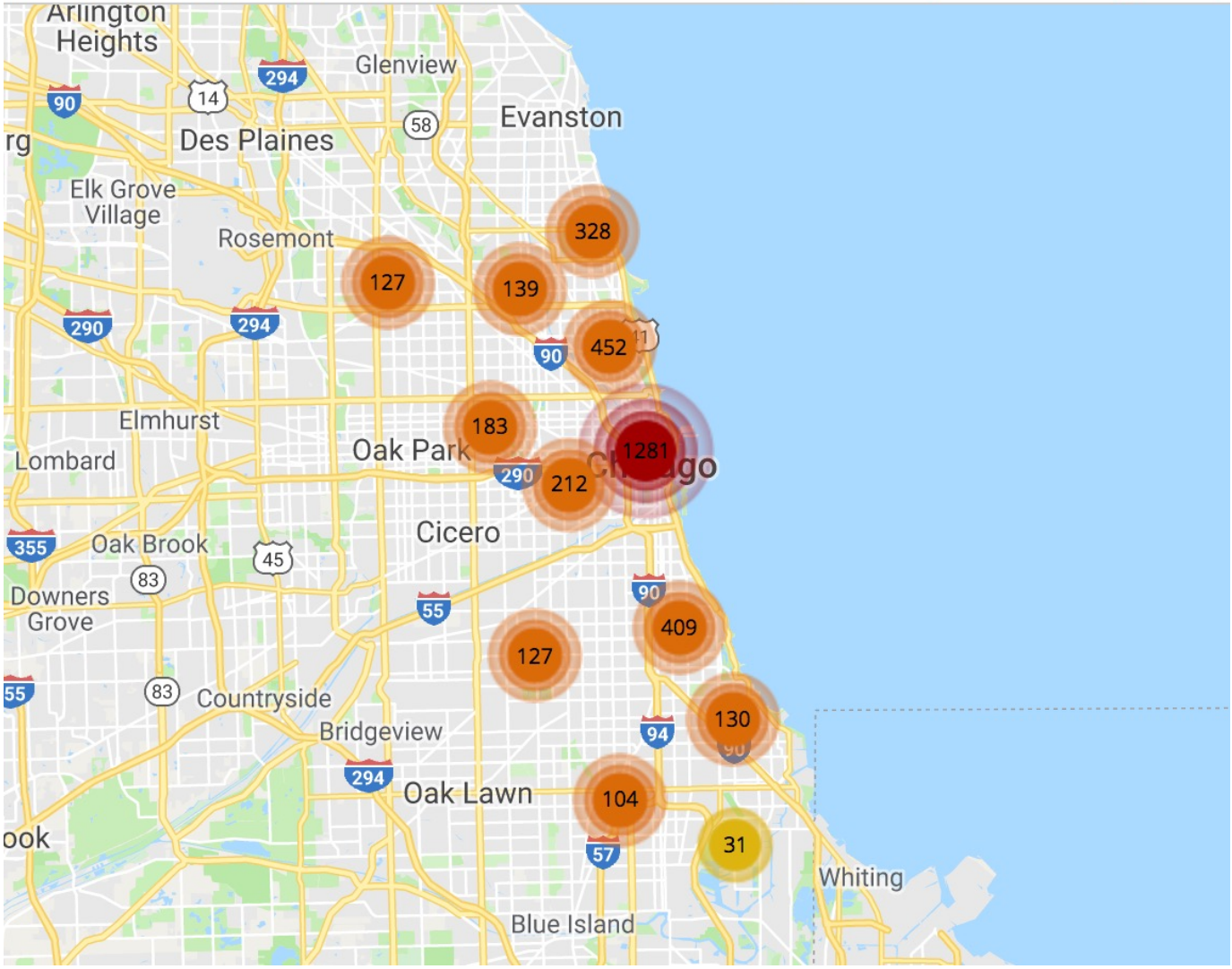
Chicago Energy Benchmarking

- A placard of 11” by 17” needs to be installed on a prominent location at the building



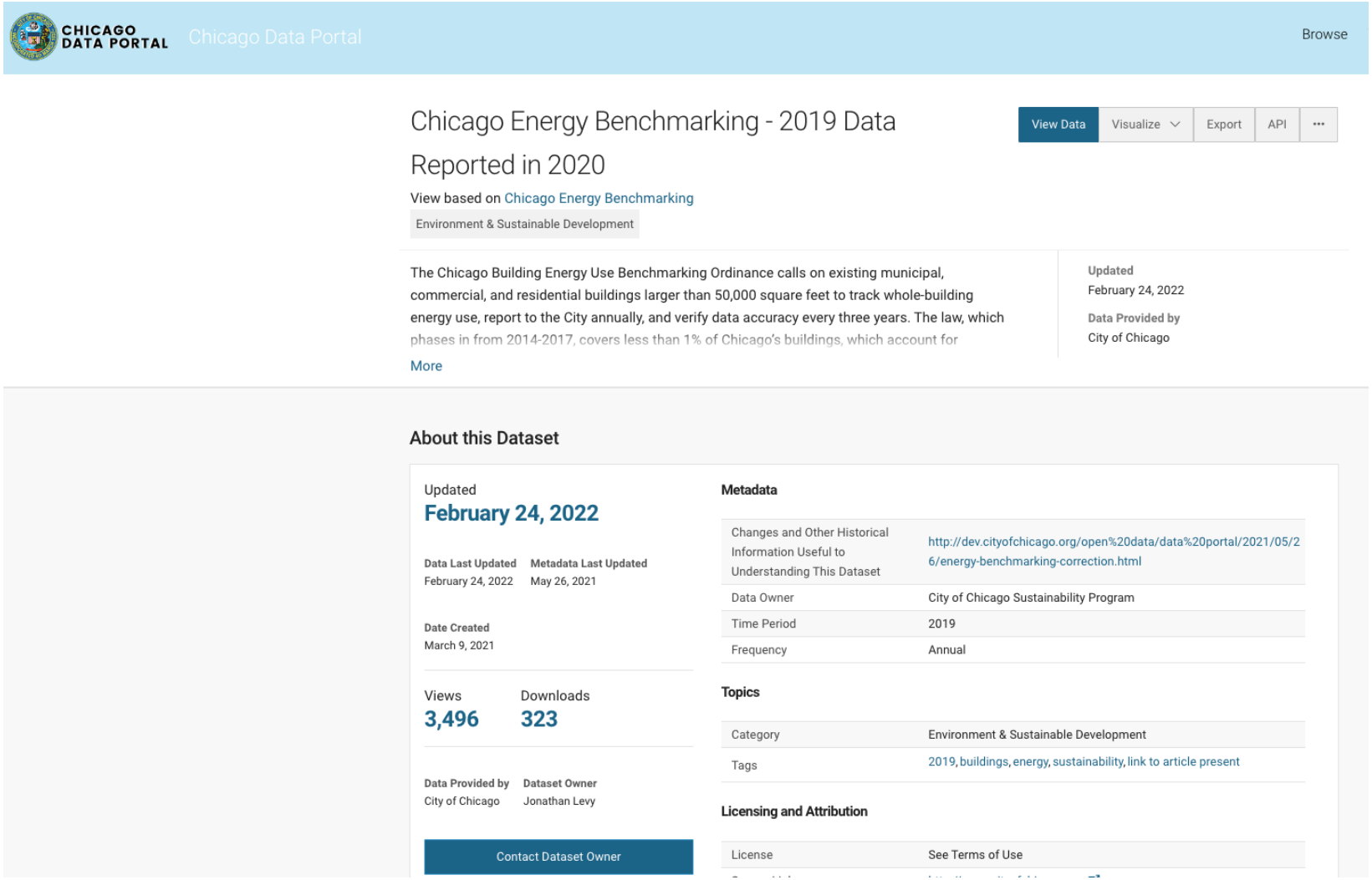
https://www.chicago.gov/city/en/progs/env/ChicagoEnergyRating.html

Chicago Benchmarking Data



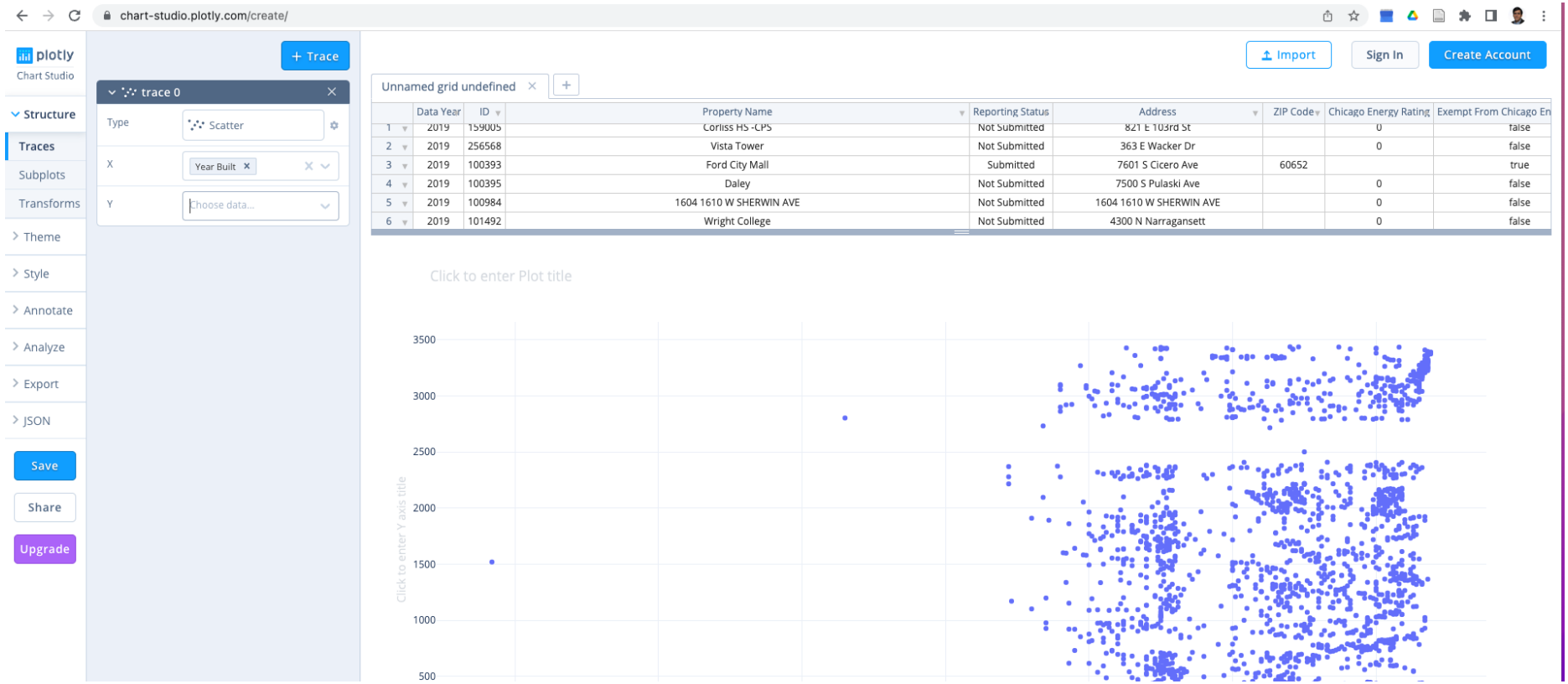
https://data.cityofchicago.org/Environment-Sustainable-Development/Chicago-Energy-Benchmarking-Covered-Buildings-Map/hpv9-sp6k

Chicago Benchmarking Data



https://data.cityofchicago.org/Environment-Sustainable-Development/Chicago-Energy-Benchmarking-2019-Data-Reported-in-/jn94-it7m

Chicago Benchmarking Data



	Data Year	ID	Property Name	Reporting Status	Address	ZIP Code	Chicago Energy Rating	Exempt From Chicago En
1	2019	159005	Corliss HS -CPS	Not Submitted	821 E 103rd St		0	false
2	2019	256568	Vista Tower	Not Submitted	363 E Wacker Dr		0	false
3	2019	100393	Ford City Mall	Submitted	7601 S Cicero Ave	60652		true
4	2019	100395	Daley	Not Submitted	7500 S Pulaski Ave		0	false
5	2019	100984	1604 1610 W SHERWIN AVE	Not Submitted	1604 1610 W SHERWIN AVE		0	false
6	2019	101492	Wright College	Not Submitted	4300 N Narragansett		0	false

https://data.cityofchicago.org/Environment-Sustainable-Development/Chicago-Energy-Benchmarking-2019-Data-Reported-in-/jn94-it7m

CLASS ACTIVITY (CAE 465/526)

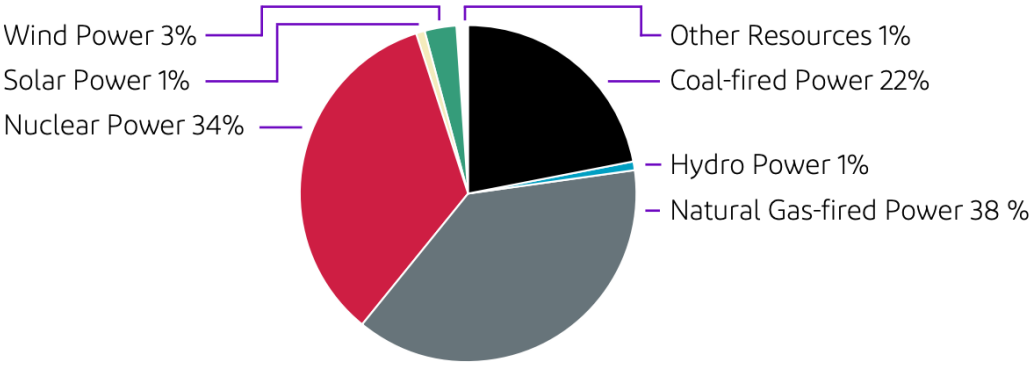
Class Activity

- What happens if we electrify all buildings right now in IL?

Class Activity

- Anything else?

Sources of Electricity for the 12 months ending December 31, 2021



Sources [1] of Electricity Supplied for the 12 Months Ending December 31, 2021	% of Total
BIOMASS POWER	0%
COAL-FIRED POWER	22%
HYDRO POWER	1%
NATURAL GAS-FIRED POWER	38%
NUCLEAR POWER	34%
OIL-FIRED POWER	0%
SOLAR POWER	1%
WIND POWER	3%
OTHER RESOURCES	1%
UNKNOWN RESOURCES PURCHASED FROM OTHER COMPANIES	0%
TOTAL	**100%**

https://www.comed.com/SiteCollectionDocuments/SafetyCommunity/Disclosure/Environmental_Disclosure_12_months_ending_12312021.pdf

CLASS ACTIVITY (IPRO)

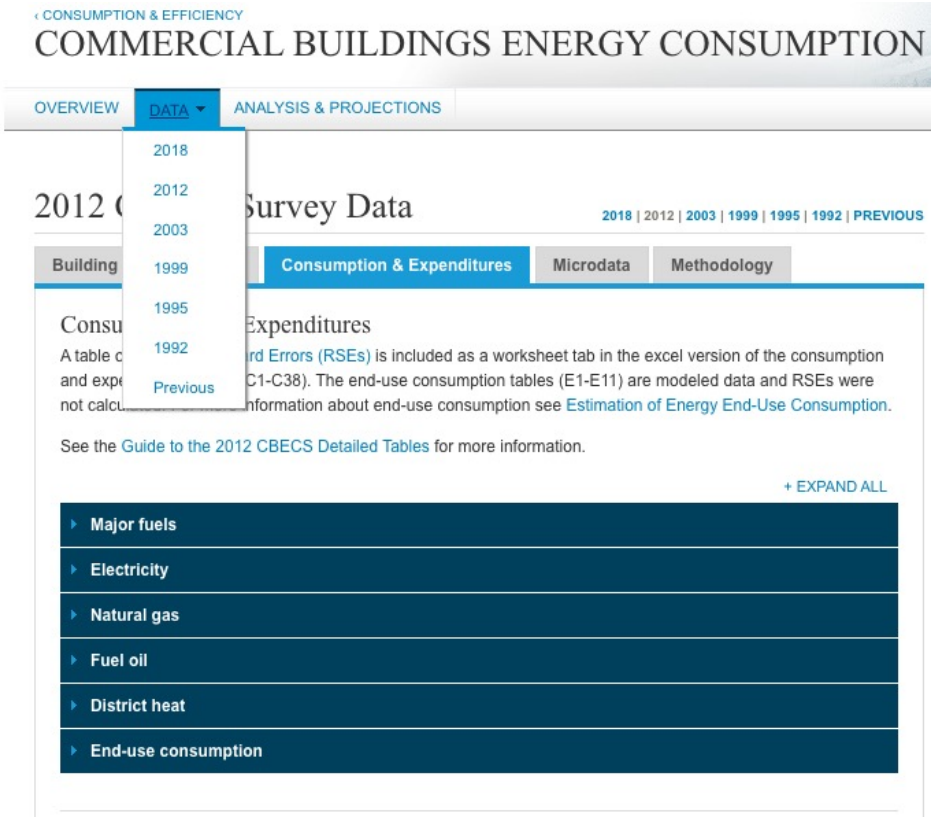
Class Activity

- Look at the options to visualize the data into a dashboard:
  - https://grafana.com/
  - https://unity.com/solutions/vr
  - https://qgis.org/en/site/

CLASS ACTIVITY (CAE 465/526)

Class Activity

- From a group of two:
  - ❑ Look at three different year consumption
  - ❑ Pick a category (e.g., electricity, major fuels, …)
  - ❑ Pick a category (e.g., Table C13, C14, …)
  - ❑ Compare the values for these three data collection years



CLASS ACTIVITY (CAE 465/526)

Class Activity

- From a group of two:
  - ❑ Calculate the percentage of heat pump installed in the past three years of data collection

CLASS ACTIVITY (CAE 465/526)

Class Activity

- From a group of two:
  - ❑ Summarize how the City of Chicago building consume energy compared to the CBECS or RECS