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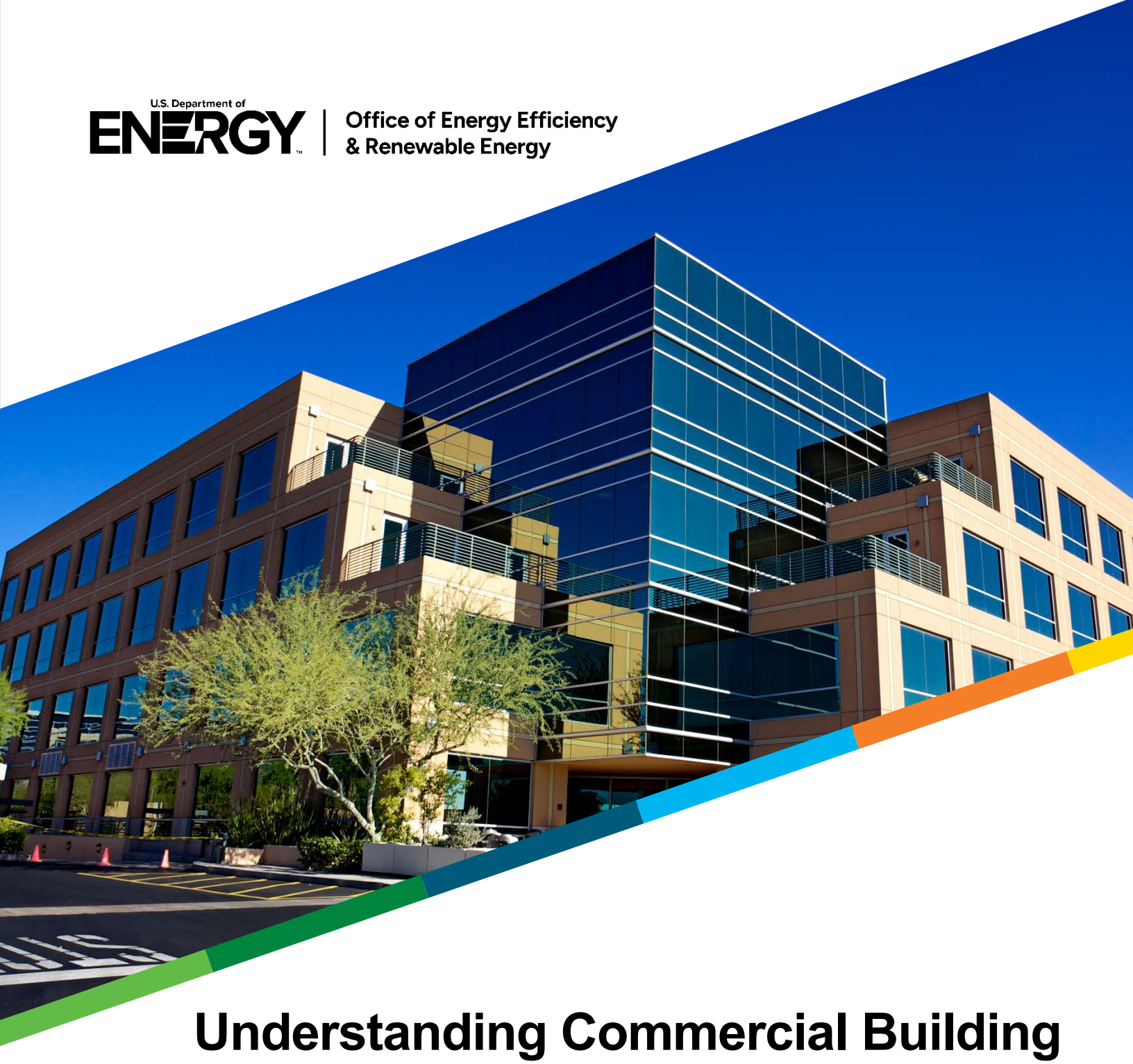

Understanding Commercial Building Energy Use in the Columbus-Dayton-Cincinnati-Lexington Area:

Building Stock Segmentation for Retrofit Planning

January 2025

Disclaimer

Authors

The authors of this report are:

Lauren Adams, National Renewable Energy Laboratory (NREL)

Ry Horsey, NREL

Andrew Parker, NREL

Lauren Klun, NREL

Chris CaraDonna, NREL

Matthew Dahlhausen, NREL

Wenyi Kuang, NREL

Marlena Praprost, NREL

Eric Ringold, NREL

Amy Van Sant, NREL

The technical managers of this report are:

Hayes Jones, U.S. Department of Energy

Sam Petty, U.S. Department of Energy

Billierae Engelman, U.S. Department of Energy

Sydney Applegate, U.S. Department of Energy

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Contributors:

Jessica Price, City of Madison, WI

Ross MacWhinney, Environmental Sustainability and Resiliency, New York City Mayor's Office of Management and Budget

Crystal Egelkamp, Colorado Energy Office

Andrew Held, Department of Energy and Environment, Washington DC

Maggie Kelley Riggins, Southeast Energy Efficiency Alliance

Chris Burgess and Michelle Thorsell, Midwest Energy Exchange Alliance

Cornelia Wu, Northeast Energy Efficiency Partnerships

Building Performance Standards (BPS) Laboratory Team: Joshua Kace, Haley Tong and Travis Walter, Lawrence Berkeley National Laboratory (LBNL); Isabel Langlois and Nicholas Long, NREL; Andrea Mengual, Pacific Northwest National Laboratory (PNNL)

Brendan Hall, Caterina Hatcher and Cindy Jacobs, U.S. Environmental Protection Agency (EPA)

Harry Bergmann, U.S. Department of Energy

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List of Acronyms

BPS	Building Performance Standards
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERV	energy recovery ventilator
HPWH	heat pump water heater
LBNL	Lawrence Berkeley National Laboratory
NREL	National Renewable Energy Laboratory
PNNL	Pacific Northwest National Laboratory

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1 Overview

This report is part of the second phase of a series of publications focusing on approximately 100 different local geographies, or "clusters." Each report provides characteristic features and energy data for commercial buildings in a specific area to help policy makers at the city, county, and state level better understand building energy use and emissions. This report breaks down the energy consumption and emissions of the building stock in the Columbus-Dayton-Cincinnati-Lexington Area counties, as shown in Figure 2, by building type, building size, end use, energy consumption, emissions, and segment.

The source of the data in this report is the public release of *"ComStock End Use Savings Shape 2023 Release 2 Baseline Dataset - 2018 Weather"* 2023. **The data and estimated values communicated in this report represent energy use from 2018; they are not present-day values.**

At the time of this publication, with the abovementioned data source, ComStock underestimates annual natural gas use by roughly 20% relative to CBECS 2018. Emissions from site natural gas use are likewise underestimated. Consider this underestimation when using ComStock to make emissions reduction decisions.

Electricity emissions totals in the figures below use eGRID 2021 subregion emission factors, which are calculated based on the emissions associated with electricity generation in the year 2021 in each subregion. Electricity emission factors (pounds of CO_2e per kWh of electricity) are decreasing year-over-year as new low-emissions generation comes online, and projections show that this trend will continue in the future (Gagnon, Cowiestoll, and Schwarz 2023). Estimates of future electricity emission reductions using historical electricity emissions factors will likely overestimate realized emission reductions as a result. Using a weighted average of projected annual electricity emission factors corresponding to the useful life of an intervention or a change in the building stock is a preferred method.

Commercial building energy data are provided by the U.S. Energy Information Administration (EIA) for the nine U.S. census divisions, each of which covers multiple states (CBECS 2018). The EIA provides similar residential building data by state (RECS 2020). However, city, county, and state policymakers often need finer resolution to understand the building stock and guide decision-making. This report presents commercial building energy data for the counties shown in Figure 2. The energy data in this report are broken down by building type, building size, end use and segment.

For reference documentation please see Parker, Horsey, Dahlhausen, Praprost, CaraDonna, LeBar, and Klun 2023.

1.1 What Types of Questions Can This Report Help Me Answer for My City, County, or Region?

- How many buildings exist, by type and size?

- Which buildings are responsible for the most emissions today, by type and size?
- How many buildings or what fraction of emissions are covered by a building size threshold?
- What end uses (e.g., HVAC, Equipment, Lighting or Water Heating) and segments (see Table 1) have the highest energy consumption and emissions for each building type?
- What technology solutions can be adopted to address energy efficiency and affordability?

1.2 What Types of Questions Will This Report Not Help Me Answer?

- What will the building stock, energy use, and emissions look like in 2030, 2040, or 2050?
- What metric and target levels are best for building energy policy?
- How should a policy acknowledge variation in use within a given building type?
- How will zoning and development changes impact building energy use?

1.3 What Building Stock Segments Are Covered?

The United States commercial building stock can be divided into nine segments common across jurisdictional boundaries that are based on common retrofit solutions. These nine segments are primarily based on HVAC System Types (see Appendix B for an explanation of each HVAC System Type).

Most commercial buildings have heating, air conditioning, ventilation, lighting and hot water, all which utilize various fuel types (see Appendix B for fuel type definitions). Historically, many buildings have been categorized by their building type (e.g., “offices” or “restaurants”), but end uses, such as HVAC, lighting, water heating and equipment (see Appendix B for a description and example of each end use) are similar across all building types. Therefore, it is helpful to identify building similarities, or “segments”, that cross the boundaries of traditional building types for analyzing energy consumption and emissions.

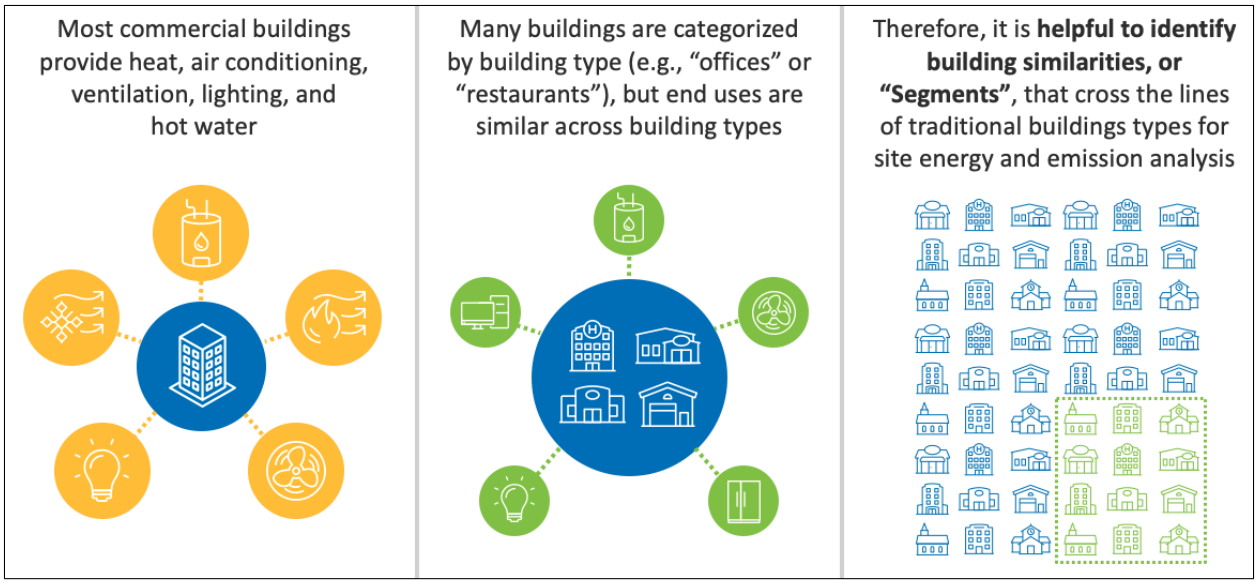


Figure 1. Segmentation Analysis

These nine segments are described in Table 1:

Table 1. Segment Descriptions

Segment	Description
Rooftop Units, non-Food Service	• Common Examples: 1 to 2 story strip malls, retail buildings, warehouses, offices • Heating and cooling outside air drives the HVAC energy consumption • Leased space will cause split incentive challenges for approximately 50% of the segment
Rooftop Units, Food Service	• Common Examples: freestanding restaurants • Many small, high energy intensity buildings • Heating and cooling outside air drives the HVAC energy consumption • High ventilation because of cooking air exhaust hoods • High service water heating needs, including high temperature water for dish-washing • High process loads for cooking, primarily natural gas
Rooftop Units, Strip Malls with Some Food-Service	• Common Examples: strip malls with restaurants • Many small, high energy intensity buildings • Heating and cooling outside air drives the HVAC energy consumption • High ventilation because of cooking air exhaust hoods in restaurant portions • High service water heating needs, including high temperature water for dish-washing • High process loads for cooking, primarily natural gas • Leased space will cause split incentive challenges for most of the segment, but cooking and dishwashing equipment may be tenant supplied
Zone-by-Zone Units, non-Lodging	• Common Examples: small buildings of varying type • Majority are heated with electric resistance
Zone-by-Zone Units, Lodging	• Common Examples: motels and hotels, typically part of large chains • Majority are heated with electric resistance • Significant service water heating demand for showering and sometimes laundry
Residential Central Units	• Common Examples: small buildings converted from residential uses (small offices such as accountant, lawyer, etc.) • Commonly called central forced air in the residential context • Typically do not have mechanical ventilation
Packaged Multi-zone Systems	• Common Examples: small to medium offices and schools • Natural gas heating coils
Hydronically Heated Multi-zone Systems	• Common Examples: large buildings with boilers (schools, large offices, health-care facilities) • Heating and cooling outside air drives the HVAC energy consumption • Typically complex custom-engineered HVAC systems • Split incentive less likely to be a barrier in institutional or healthcare, but still an issue in large offices • More likely to be served by a district heating or cooling system
Electric Resis-tance Multizone Systems	• Common Examples: medium to large offices and healthcare facilities • Often use electric reheat or electric resistance heat in the perimeter zones for construction cost reasons

1.4 What Audience Is This Report For?

Below is a guideline on how the data and findings outlined within this document pertain to you based on the type of stakeholder you are:

Table 2. User Guideline

Stakeholder	How data and findings pertain to you:
City Manager / Sustainability Manager	• Learn about the composition of your building stock in more detail • Understand retrofit solutions to address energy efficiency and affordability for your building stock's top four segments • Know how to apply retrofit solutions for each segment • Assist in identifying technical solutions that can be promoted alongside state/federal tax credit and utility incentive programs
Building Codes	• Understand how much of your building stock will be affected by the applicable requirements if BPS or fuel switching code requirements are considered
City Facilities Manager or Public Works	• Understand the technology packages that can be impactful for the subset of buildings owned by your jurisdiction (e.g. offices, schools) • Know what additional retrofit solutions can be utilized for your building stock to enhance your tracked buildings and allow a deeper dive into city-owned buildings

1.5 How to Best Utilize These Insights?

Step 1: Refer to the first report in this publication series "Understanding Building Energy Use in the Columbus-Dayton-Cincinnati-Lexington Area: Basic Building Stock Characterization" to better understand your building stock by building type, building size, site energy and emissions external to end use and segmentation analysis, as presented in this report.

Step 2: Identify key building segments for your building stock or an applicable retrofit program and understand how buildings are similar to each other from the perspective of how energy is consumed

- Segments are based on similarities of installed HVAC system types
- Different from traditional perspectives, which categorizes buildings based on their use case (e.g., "Office" or "Restaurant")

Step 3: Consider the common retrofit solutions for your key building segment(s)

- Understand the amount of site energy consumed and/or emissions from energy use you will be addressing if you apply a particular retrofit solution for the buildings within your segment(s)

Step 4: Develop next steps with the provided "Resources for Actionable Next Steps" section:

- Use the Building Stock Characteristic and Segmentation Analysis 2023 Microsoft Excel template to review these insights, and more, for your custom geography
- Read Introduction to ComStock 2023 for example use cases on how the provided analysis can be utilized for your building stock

1.6 How Were the Geographic Clusters Developed?

Clusters are formed on a county basis and depend on building type, age, and climate. Adjacent counties with similar commercial densities, types, and age distributions form a cluster. Clusters form regional groups if they belong to the same American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Std. 169) climate zone. See Horsey, Rozenfeld, and Bergmann 2023 for more detail on the clustering method.

1.7 What Building Types Are Covered?

This report includes the commercial buildings listed in Table 3. The commercial building types considered in this analysis represent two-thirds of annual commercial building site energy consumption across the entire United States.

This report excludes several building types not currently included in the underlying data. The omitted building types with the highest national energy use include colleges, laboratories, grocery stores, entertainment venues, recreation centers, religious buildings, and vehicle repair shops. Some of these may be added in the future. Information on omitted building types, such as counts, energy use, and floor area can be found in CBECS 2018.

Table 3. Building Stock Building Types Covered in This Document

Sector	Building Type Group	Building Type
Commercial	Food Service	Full Service Restaurant Quick Service Restaurant
	Mercantile	Retail Strip Mall Retail Standalone
	Office	Small Office Medium Office Large Office
	Education	Primary School Secondary School
	Healthcare	Outpatient Hospital
	Lodging	Small Hotel Large Hotel
	Warehouse and Storage	Warehouse

1.8 Vintage

The analysis in this report is not segmented by vintage (year constructed). The data do not support the common perception that older commercial buildings have a higher energy use per square foot. For example, commercial buildings constructed between 2000 and 2018 have roughly 10% higher energy use per square foot than buildings constructed before 2000. There do not appear to be other vintage-related energy use per square foot trends in the data (EIA 2022).

2 Geographies Covered in This Report

Figure 2 shows the map of the buildings covered in this report for the Columbus-Dayton-Cincinnati-Lexington Area. The building stock within these counties have their own unique outcomes with similar site energy consumption and emissions from energy use. See Appendix A for a list of the counties and county equivalents included in the map.

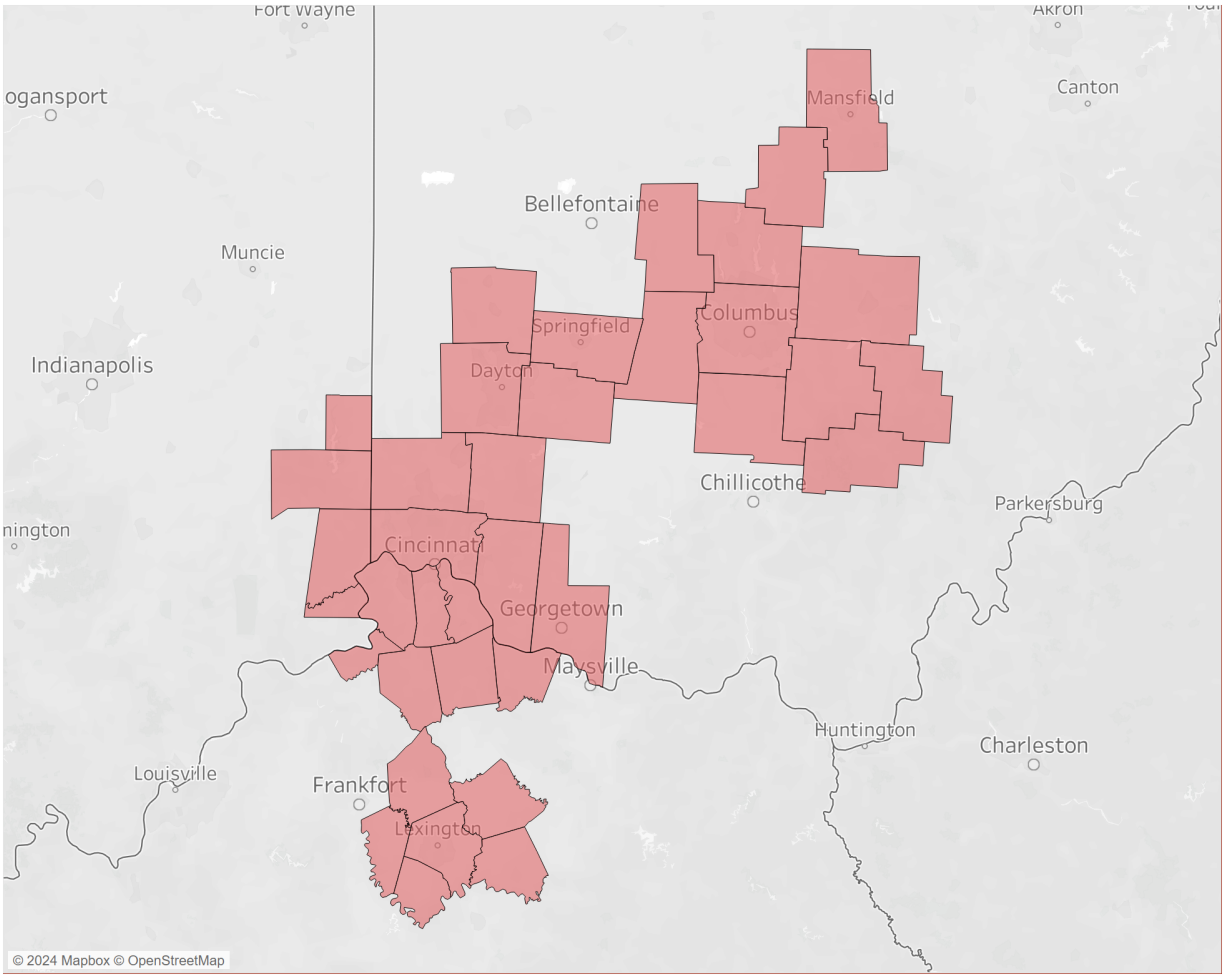


Figure 2. Map showing the cluster of counties and county equivalents covered in this report (See Appendix A for a list of the counties and county equivalents)

3 Results Summary

3.1 Site Energy and Emissions (Direct + Indirect)

Figure 3 summarizes the site energy and emissions from energy use by fuel type and end use for your building stock (see Appendix B for descriptions and examples of fuel types and end uses). In this figure we see that 65% of your building stock's site energy consumption is Electricity, with 29% of the Electricity consumption accounted to HVAC. In addition, 80% of your building stock's emissions are attributable to emissions from Electricity use, with 35% of the Electricity consumption accounted to HVAC.

Emissions include both direct and indirect greenhouse gas emissions. Direct emissions are from on-site fossil fuel combustion, and indirect emissions are from regional electricity generation. Direct emissions include both combustion and pre-combustion emissions (e.g., methane leakage for natural gas) and are based on RESNET/ANSI/ICC Standard 301 2018. Indirect emissions are calculated using subregion data from the EPA for 2021 (eGRID 2021). As mentioned above, electricity emissions factors (pounds of CO_2e per kWh of electricity) are decreasing year-over-year as new low-emissions generation comes online, and projections show this trend continuing in the future (Gagnon, Cowiestoll, and Schwarz 2023). Estimates of future electricity emissions reductions using historical electricity emissions factors will likely overstate realized emission reductions as a result. Using a weighted average of projected yearly electricity emissions factors corresponding with the useful life of an intervention or change in the building stock is a preferred method. Figure 3 does not include emissions for direct systems because ComStock currently does not model emissions from district systems as there is considerable variation by location and type of district system.

When considering end uses and building types, most of the site energy from HVAC in the building stock is attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings. Most of the emissions from energy use from HVAC in the building stock are attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings.

Building energy use and emissions from energy use depend on the total floor area, not the number of buildings. This is because lighting, heating, cooling, and ventilation scale with floor area.

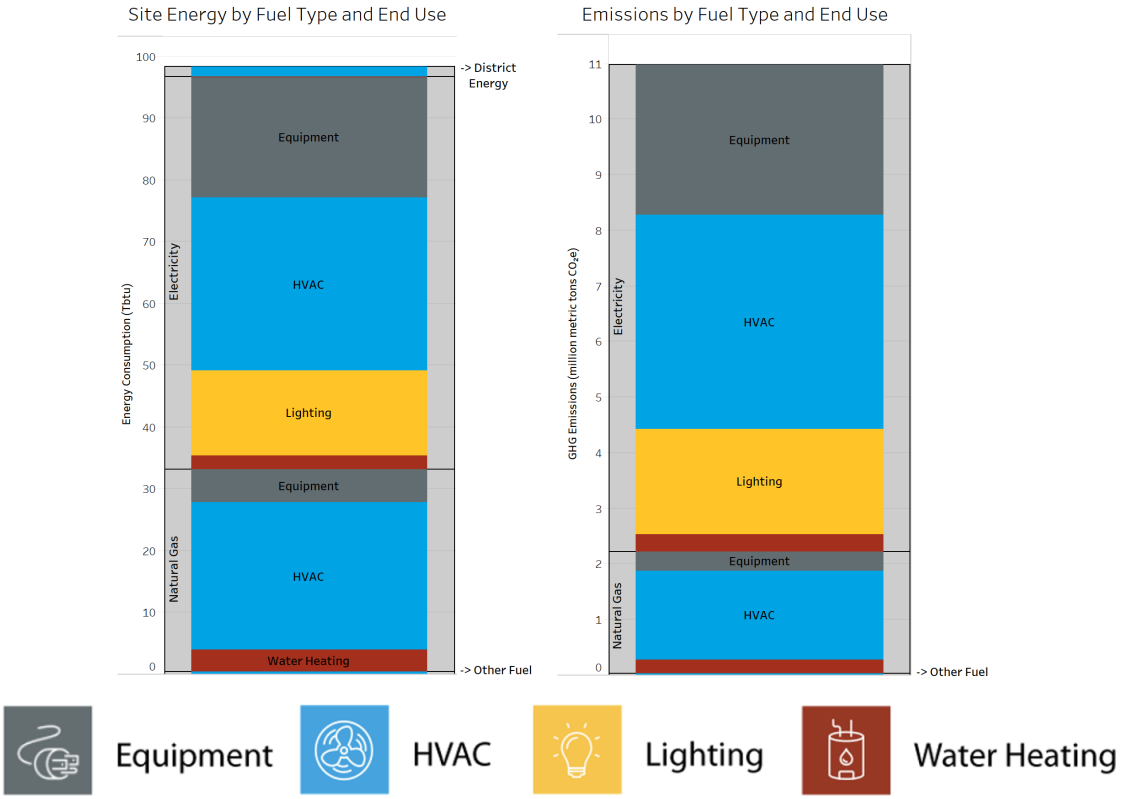


Figure 3. Site Energy and Emissions by Fuel Type and End Use (See Tables 5 and 6 in Appendix C for data in tabular format)

3.2 Segments with Similar Retrofit Solutions

The United States commercial building stock can be divided into nine segments across common jurisdictional boundaries that have similar retrofit solutions. A description of these nine segments, along with examples of building types within each segment, can be found in Table 1.

Figure 4 shows that the top four segments make up 72% of the site energy consumed and 71% of the emissions from energy use by your building stock.

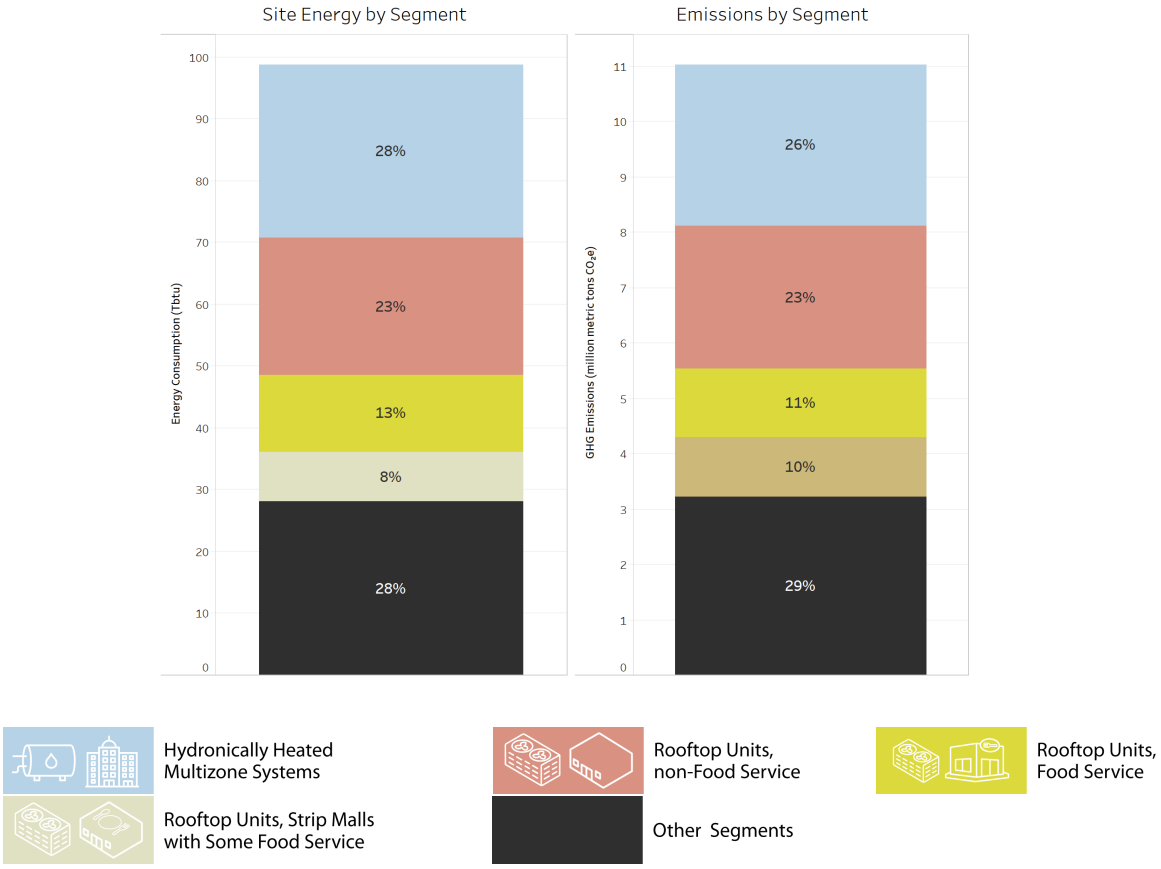


Figure 4. Top Four Segments (See Tables 7 and 8 in Appendix C for data in tabular format)

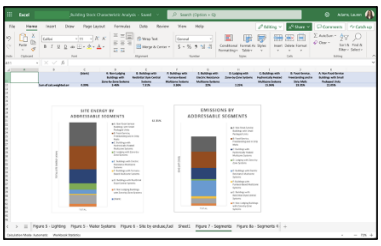
Effective retrofit solutions for your top four segments can be broken down by end use. The Xs in Table 4 represent retrofit solutions that apply to the segments of your building stock that consume the most site energy and generate the most emissions. For instance, buildings that have Rooftop Units, non-Food Service could be retrofitted by installing Packaged Heat Pumps or Rooftop energy recovery ventilator (ERV) + Split System HVAC Systems instead (see Appendix B for an explanation of each HVAC System Type). In addition, many buildings across all segments could save energy by installing LED lighting. Please refer to Appendix B for additional notes about each retrofit solution.

Table 4. Retrofit Solutions

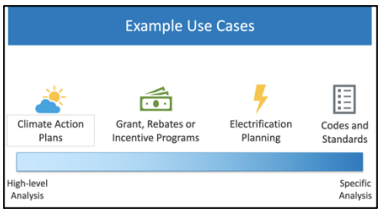
End Use	Effective Retrofit Solutions	Hydronically Heated Multizone Systems	Rooftop Units, non-Food Service	Rooftop Units, Food Service	Rooftop Units, Strip Malls with Some Food Service
HVAC	Packaged Heat Pumps		X	X	X
	Rooftop ERV + Split System		X		X
	Heat Pump Chillers + Potentially Needed Fossil Supplement	X			
Lighting	LED Lighting	X	X	X	X
Water Heating	Higher-Capacity heat pump water heaters (HPWHs) with Recirculation	X		X	X
	Residential-Style HPWH		X		X
	Dishwashing and Laundry Equipment Efficiency			X	X

3.3 Resources for Actionable Next Steps

The following resources available on ComStock's website can support you with actionable next steps to implement retrofit solutions for your building stock:



1. Interact with the Building Stock Characteristic and Segmentation Analysis 2023 Microsoft Excel template to review these insights, and more, for your custom geography
   - Dive into your data deeper (e.g., filter by county, building type and/or climate zone)
   - Utilize data fields that can be applied to your own additional analysis (e.g., cooling tons, insulation values, window surface area)
   - Guidance is provided to support suitable use of the ComStock Dataset



2. Read through the Introduction to ComStock 2023 presentation to understand how the provided analysis can be utilized for your building stock
    - Includes use case examples demonstrating ComStock's data in action
    - Describes how ComStock's analysis can be used for:
        - Climate action plans;
        - Grant, rebates or incentive programs;
        - Electrification planning; and
        - Codes and standards.

4 Building Site End Use Results

In this report series, “end use” is defined as the equipment that directly consumes energy in a building such as heating, cooling and ventilation, lighting, water heating, or other interior equipment (e.g., computers, cooking equipment, etc.). Refrigeration is excluded from this report since ComStock does not have recommendations for the end use currently. The relative importance of each end use varies by building type. For example, lighting represents a greater fraction of the energy consumption in mercantile buildings than in warehouses. Restaurants are considered energy intensive because of their high cooking and water heating needs.

The following figures show building stock characteristics by end use and building type. The far-left chart in each figure shows end uses for the whole building stock. The two right charts dive into the end use group itself. Tables in Appendix B provide these data in a tabular format.

4.1 HVAC

HVAC here refers to primary heating and cooling equipment used for space conditioning and ventilation such as: boilers, chillers, furnaces, fans, pumps, cooling towers, heat recovery equipment, and direct expansion air conditioning coils.

For your location, most of the site energy from HVAC Systems in the building stock is attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings. Most of the emissions from energy use from HVAC Systems in the building stock are attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings.

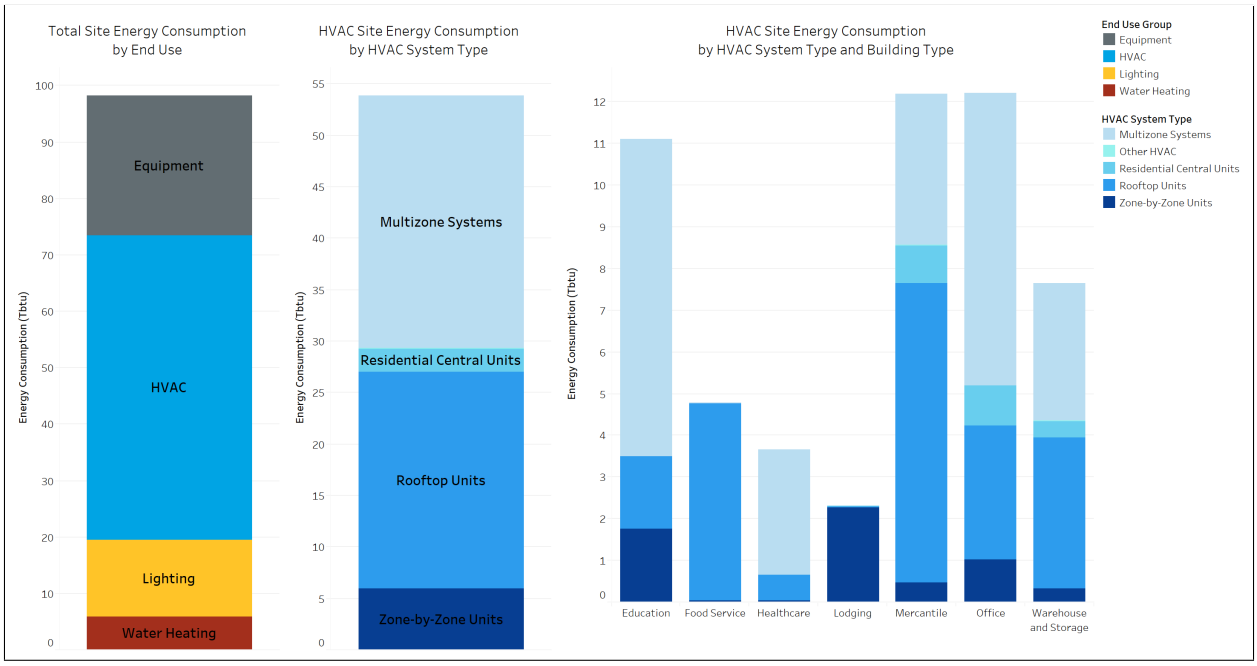


Figure 5. HVAC: Site Energy Consumption (TBtu) (See Table 9 in Appendix C for data in tabular format)

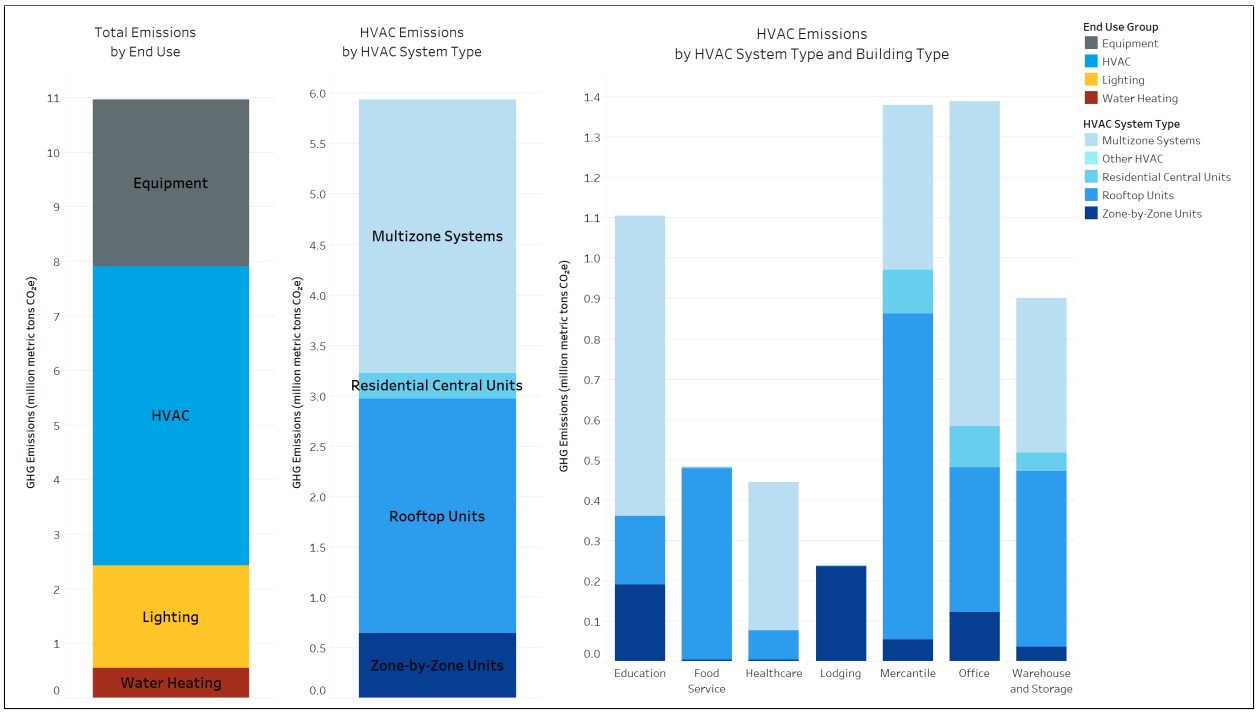


Figure 6. HVAC: Emissions (million metric tons CO_2e) (See Table 10 in Appendix C for data in tabular format)

4.2 Equipment

Equipment can be defined as everything in the building that is not in another end use group, such as: computers, cooking equipment, elevators, on-site networking equipment, data centers, etc.

For your location, most of the site energy from Equipment in the building stock is attributed to Electricity, particularly in Office and Warehouse and Storage buildings. Most of the emissions from energy use from Equipment in the building stock are attributed to Electricity, particularly in Office and Warehouse and Storage buildings.

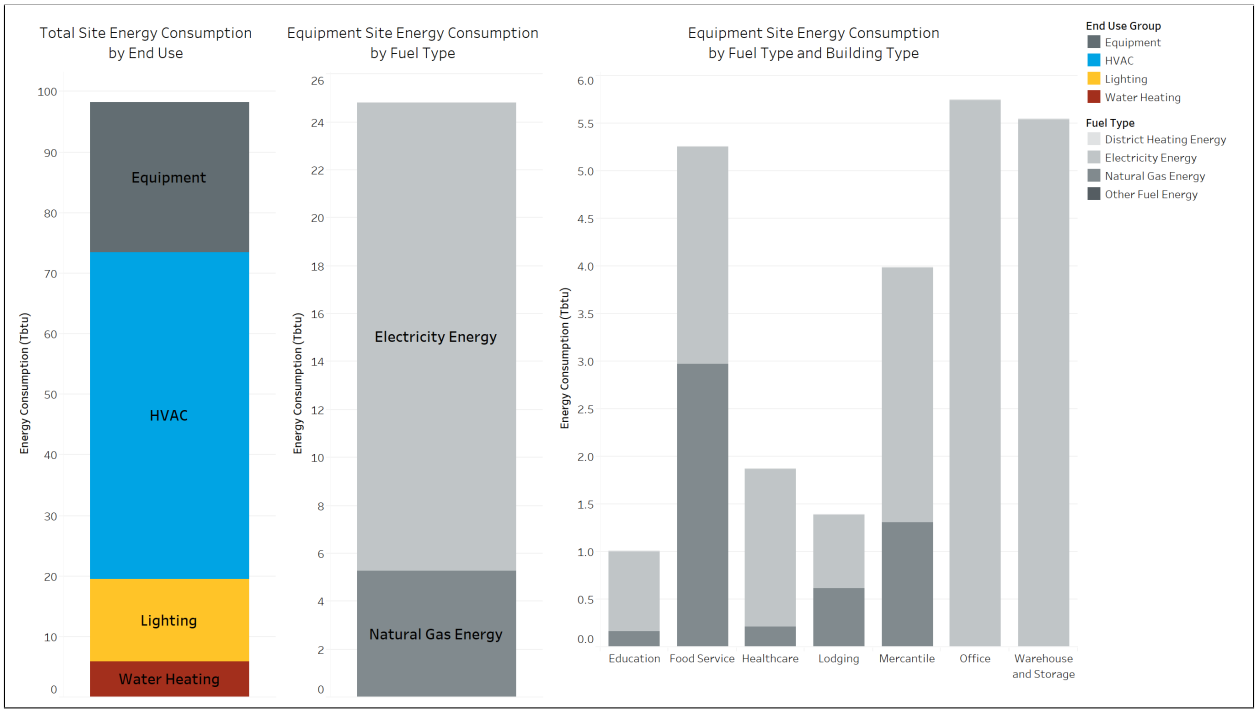


Figure 7. Equipment: Site Energy Consumption (TBtu) (See Table 11 in Appendix C for data in tabular format)

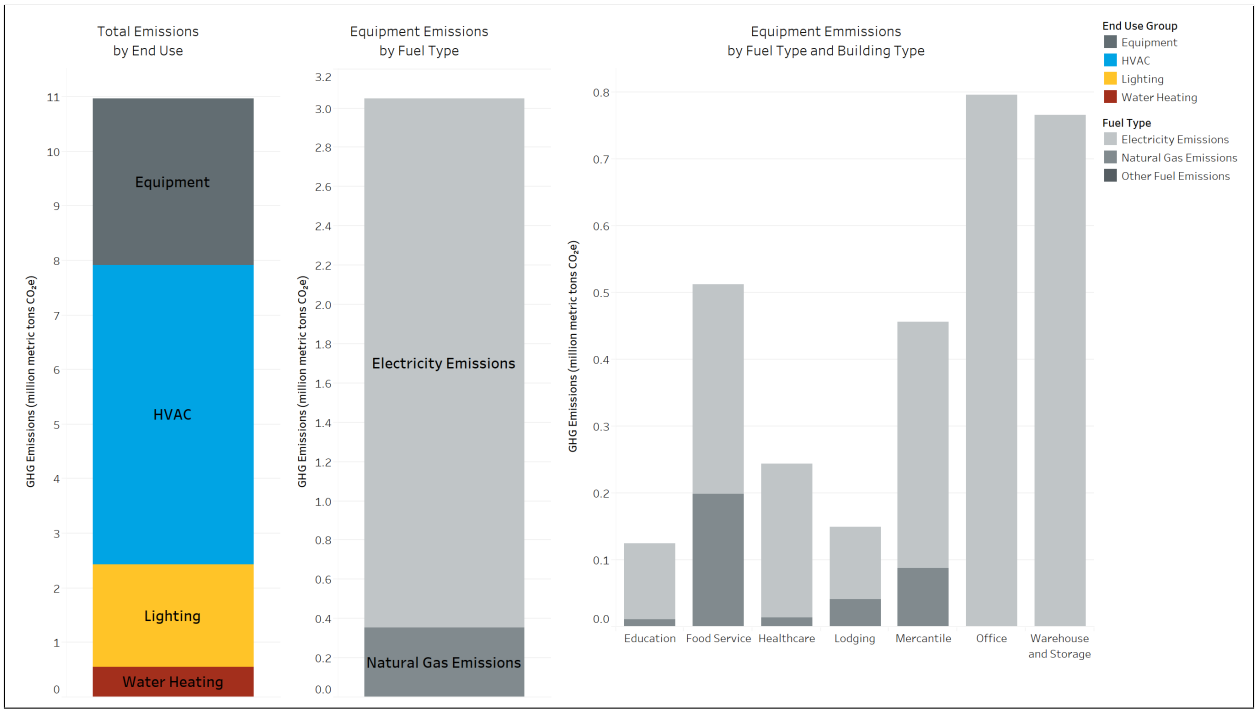


Figure 8. Equipment: Emissions (million metric tons CO_2e) (See Table 12 in Appendix C for data in tabular format)

4.3 Lighting

Lighting is defined as the components used for interior and exterior lighting of buildings. This includes interior space lighting, attached parking, walkways, entrances, and façade lighting.

In Figures 9 and 10, total lighting energy is broken out by interior lighting technology. The estimates for lighting in this report represent the 2018 building stock and ComStock does not believe the values shown represent the building stock at the time this report is released. For instance, it is likely that more LED lighting is represented in your location's building stock today. Please refer to Parker, Horsey, Dahlhausen, Praprost, CaraDonna, LeBar, and Klun 2023 for additional details on the interior lighting type definitions.

For your location, most of the site energy from Lighting Systems in the building stock is attributed to buildings with T8 bulbs, particularly in Mercantile and Warehouse and Storage buildings. Most of the emissions from energy use from Lighting Systems in the building stock are attributed to buildings with T8 bulbs, particularly in Mercantile and Warehouse and Storage buildings.

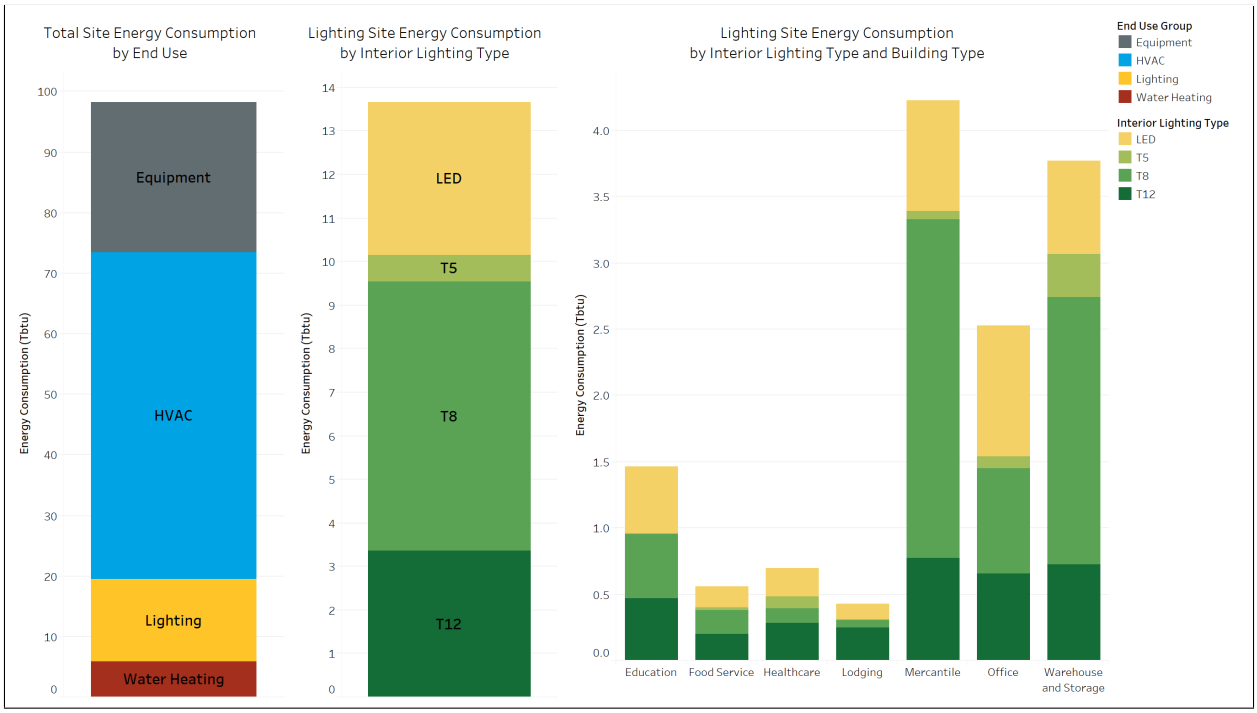


Figure 9. Interior and Exterior Lighting by Interior Lighting Type: Site Energy Consumption (TBtu) (See Table 13 in Appendix C for data in tabular format)

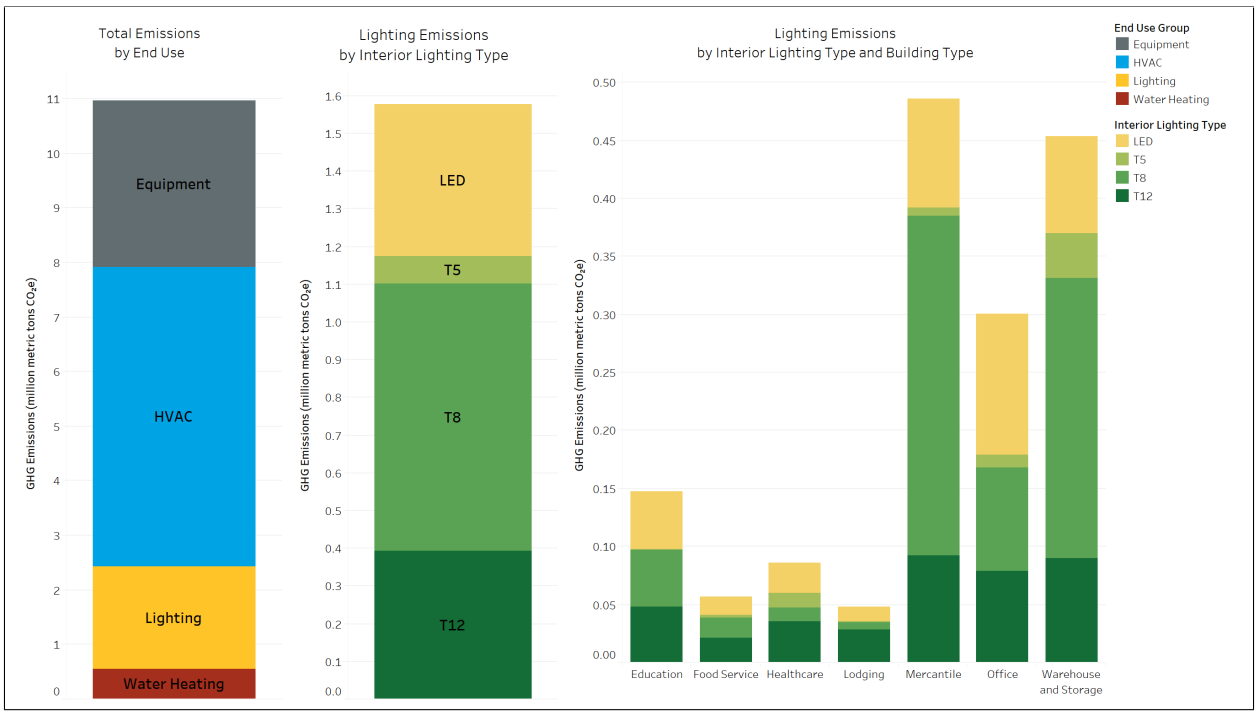


Figure 10. Interior and Exterior Lighting by Interior Lighting Type: Emissions (million metric tons CO_2e) (See Table 14 in Appendix C for data in tabular format)

4.4 Water Systems

Service water heating (SWH) includes all water heating usage other than space heating and process requirements, i.e., primary heating equipment used to create hot water for non-space-conditioning. This includes general water heating for uses such as sink faucets and showers, but also building-type-specific uses like commercial dish washing and laundry.

For your location, most of the site energy from Water Heating Systems in the building stock is attributed to Natural Gas, particularly in Food Service and Mercantile buildings. Most of the emissions from energy use from Water Heating Systems in the building stock are attributed to Natural Gas, particularly in Food Service and Mercantile buildings.

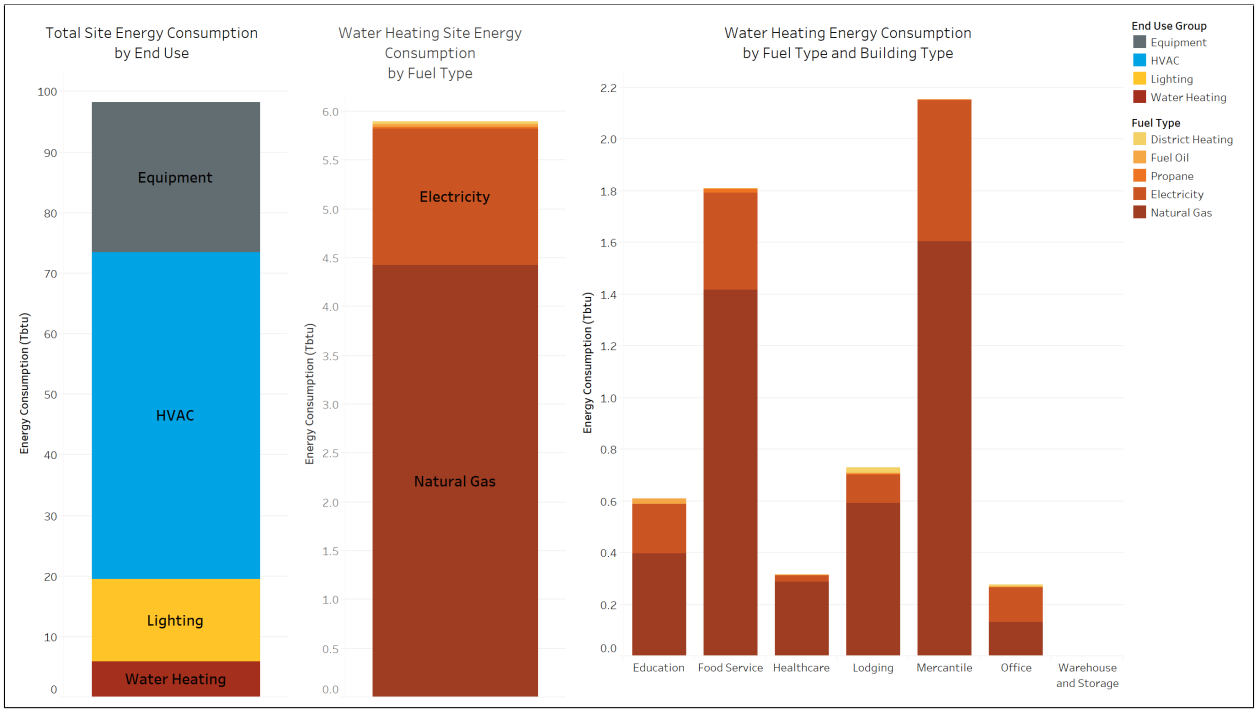


Figure 11. Water Heating: Site Energy Consumption (TBtu) (See Table 15 in Appendix C for data in tabular format)

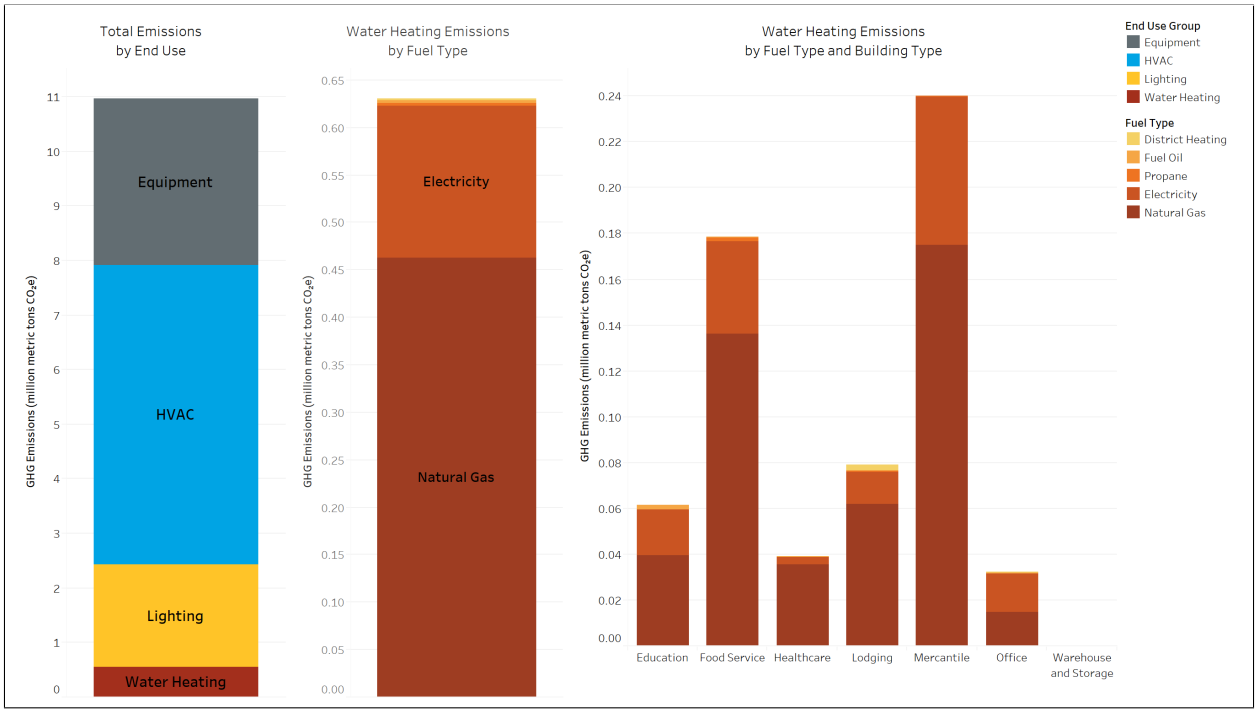


Figure 12. Water Heating: Emissions (million metric tons CO_2e) (See Table 16 in Appendix C for data in tabular format)

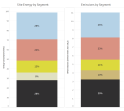
5 Results by Building Type for Your Top Four Segments

The following subsections provide insights for your top four segments. Within each segment is a summary of the:

- Number of Buildings by Building Type;
- Floor Area by Building Type;
- Site Energy by Building Type; and
- Emissions by Building Type.

The existing building types within each segment can help you determine where to apply the appropriate retrofit solution(s), as shown in Table 4, to provide the largest impact for your building stock.

5.1 Hydronically Heated Multizone Systems



Buildings with Hydronically Heated Multizone Systems consume 28% of your building stock's site energy and generate 26% of the emissions associated with energy consumption. Within the segment, Education, Mercantile, Office and Warehouse and Storage buildings consume 91% of your building stock's site energy and Education, Mercantile, Office and Warehouse and Storage buildings generate 90% of the emissions associated with energy consumption.

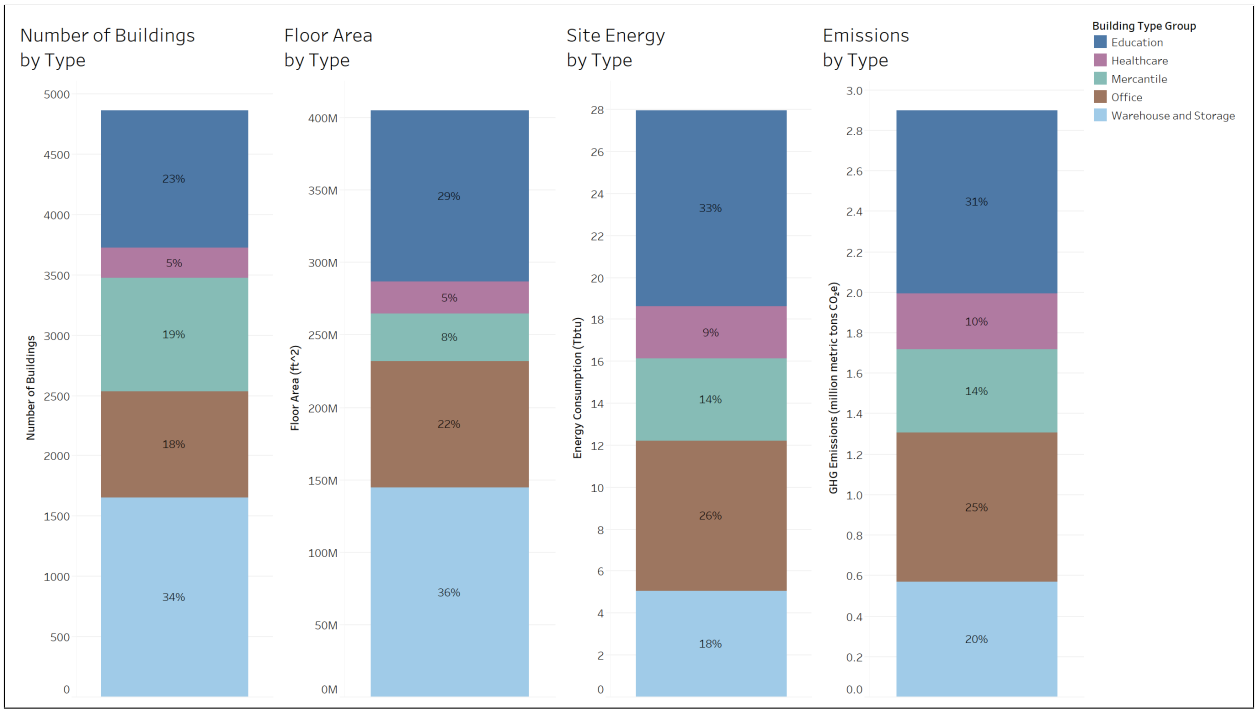
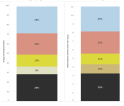


Figure 13. Hydronically Heated Multizone Systems (See Table 17 in Appendix C for data in tabular format)

5.2 Rooftop Units, non-Food Service



Buildings with Rooftop Units, non-Food Service consume 23% of your building stock's site energy and generate 23% of the emissions associated with energy consumption. Within the segment, Education, Mercantile, Office and Warehouse and Storage buildings consume 95% of your building stock's site energy and Mercantile, Office and Warehouse and Storage buildings generate 86% of the emissions associated with energy consumption.

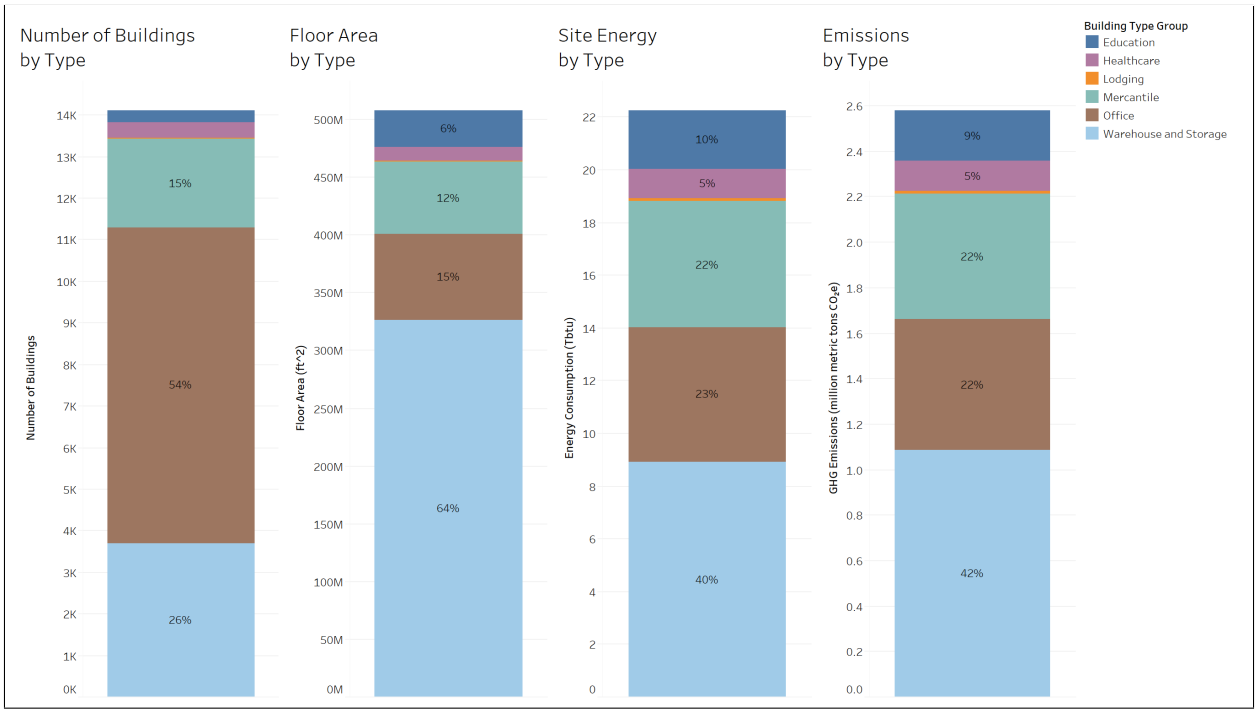
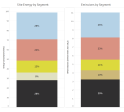


Figure 14. Rooftop Units, non-Food Service (See Table 18 in Appendix C for data in tabular format)

5.3 Rooftop Units, Food Service



Buildings with Rooftop Units, Food Service consume 13% of your building stock's site energy and generate 11% of the emissions associated with energy consumption. Within the segment, Food Service buildings consume 100% of your building stock's site energy and Food Service buildings generate 100% of the emissions associated with energy consumption.

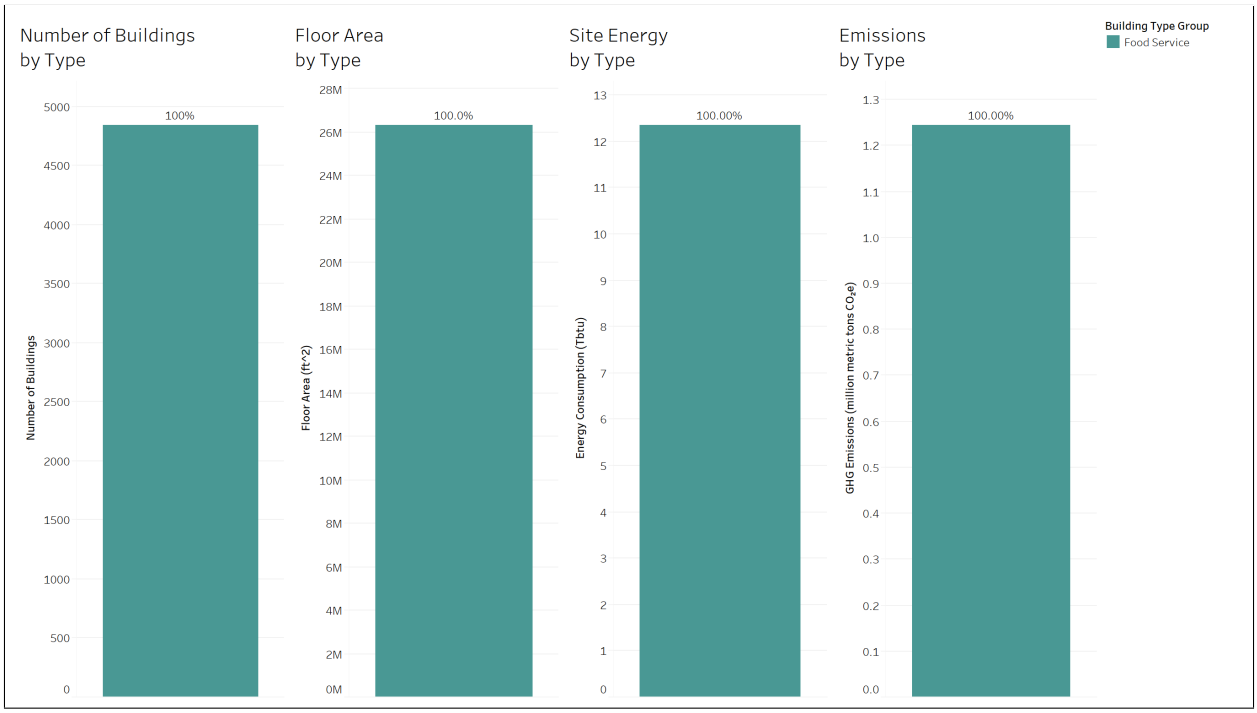
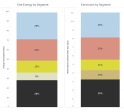


Figure 15. Rooftop Units, Food Service (See Table 19 in Appendix C for data in tabular format)

5.4 Rooftop Units, Strip Malls with Some Food Service



Buildings with Rooftop Units, Strip Malls with Some Food Service consume 8% of your building stock's site energy and generate 8% of the emissions associated with energy consumption. Within the segment, Mercantile buildings consume 100% of your building stock's site energy and Mercantile buildings generate 100% of the emissions associated with energy consumption.

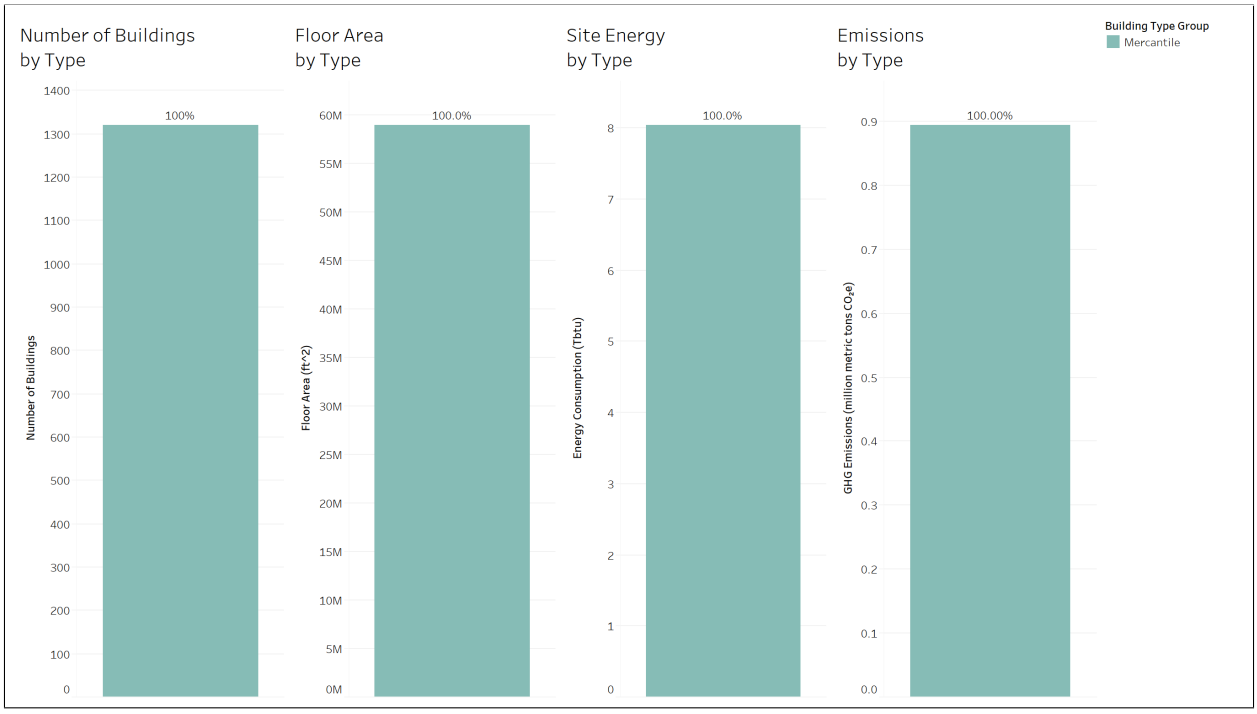


Figure 16. Rooftop Units, Strip Malls with Some Food Service (See Table 20 in Appendix C for data in tabular format)

6 Conclusion

In conclusion, 65% of your building stock's site energy consumption is Electricity, with 29% of the Electricity consumption accounted to HVAC. Most of the site energy consumed by HVAC is attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings. Your building stock's segment with the most site energy consumed is Hydronically Heated Multizone Systems. A potentially effective efficiency solution you can implement for your building stock is replacing Hydronically Heated Multizone Systems with Rooftop Heat Pump Chillers + Potentially Needed Fossil Supplement. This solution should be considered primarily for Education, Mercantile, Office and Warehouse and Storage buildings.

In addition, 80% of your building stock's emissions are attributable to emissions from Electricity use, with 35% of the Electricity consumption accounted to HVAC. Most of the emissions from energy use from HVAC are attributed to buildings with Multizone Systems, particularly in Education, Mercantile, and Office buildings. Your building stock's segment with the most emissions from energy use is Hydronically Heated Multizone Systems. A potentially effective retrofit solution you can implement for your building stock is replacing Hydronically Heated Multizone Systems with Rooftop Heat Pump Chillers + Potentially Needed Fossil Supplement. This solution should be considered primarily for Education, Mercantile, Office and Warehouse and Storage buildings.

Potentially effective efficiency and retrofit solutions for Equipment are listed below. Please refer to the *Advanced Energy Design Guides* 2022 for additional Equipment retrofit strategies.

- Replacing equipment with energy efficient models (ENERGY STAR®), especially equipment that has reached end-of-life.
- Replacing gas-powered equipment, such as commercial cooking and laundry equipment, with electric models.
- Installing control technologies, such as smart outlets or advanced power strips, to automatically turn off non-critical equipment when the building is unoccupied. Educate occupants to ensure they know how to interact with the technologies.
- Enabling low-power or sleep settings on equipment, especially computers and printers.
- Consolidating redundant equipment and removing obsolete equipment that is energized but not being used.

Additional effective efficiency and retrofit solutions to address lighting and water heating systems can be found in Table 4 for each of your building stock's top four segments.

A Counties and County Equivalents Covered in this Report

The following counties (or equivalents thereof) are included in this analysis:

Indiana Dearborn, Franklin, Ohio, Union.

Kentucky Boone, Bourbon, Bracken, Campbell, Clark, Fayette, Gallatin, Grant, Jessamine, Kenton, Pendleton, Scott, Woodford.

Ohio Brown, Butler, Clark, Clermont, Delaware, Fairfield, Franklin, Greene, Hamilton, Hocking, Licking, Madison, Miami, Montgomery, Morrow, Perry, Pickaway, Richland, Union, Warren.

B Background Information

The following figures include examples and definitions for the Fuel Types, End Uses, HVAC System Types and Retrofit Solution Notes referred to throughout this report:

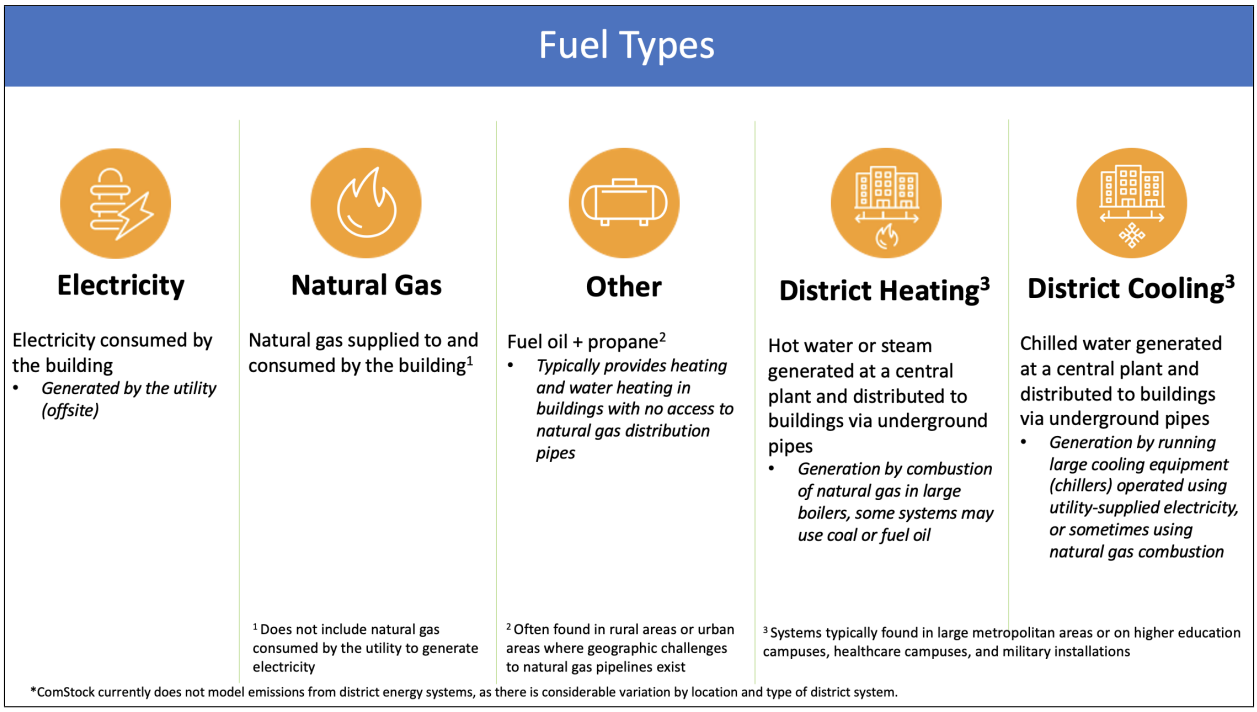


Figure 17. Fuel Types

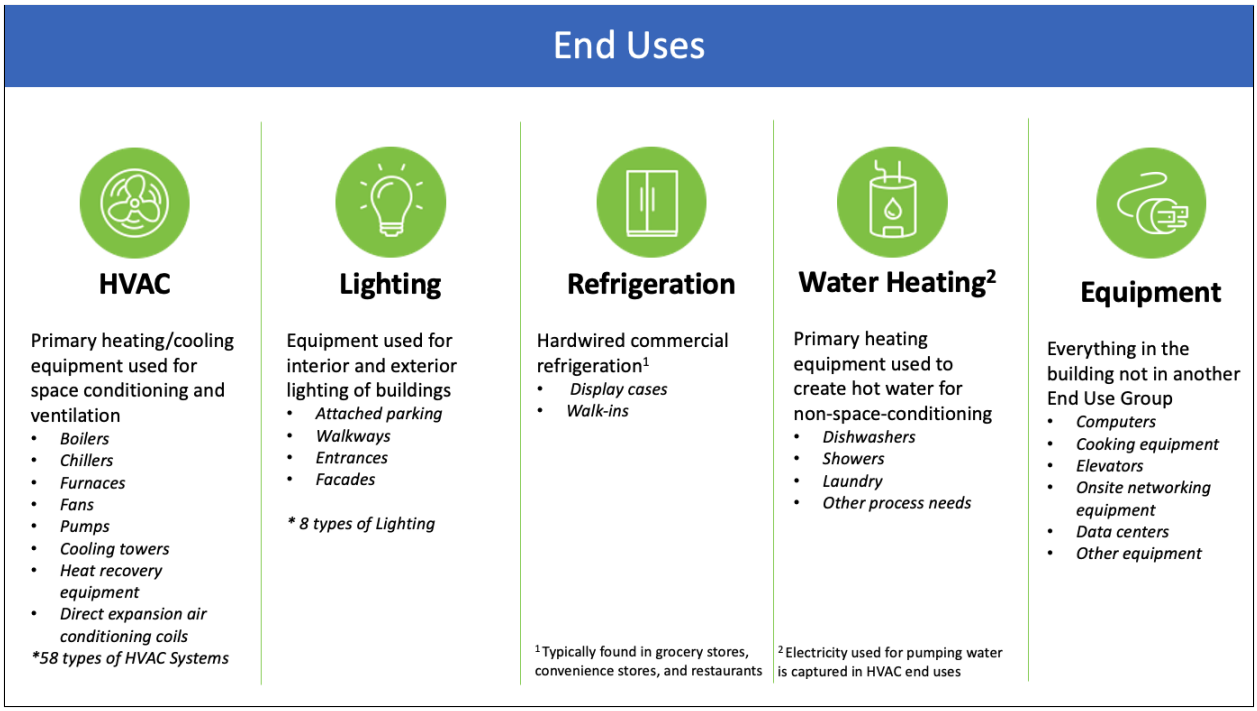


Figure 18. End Uses

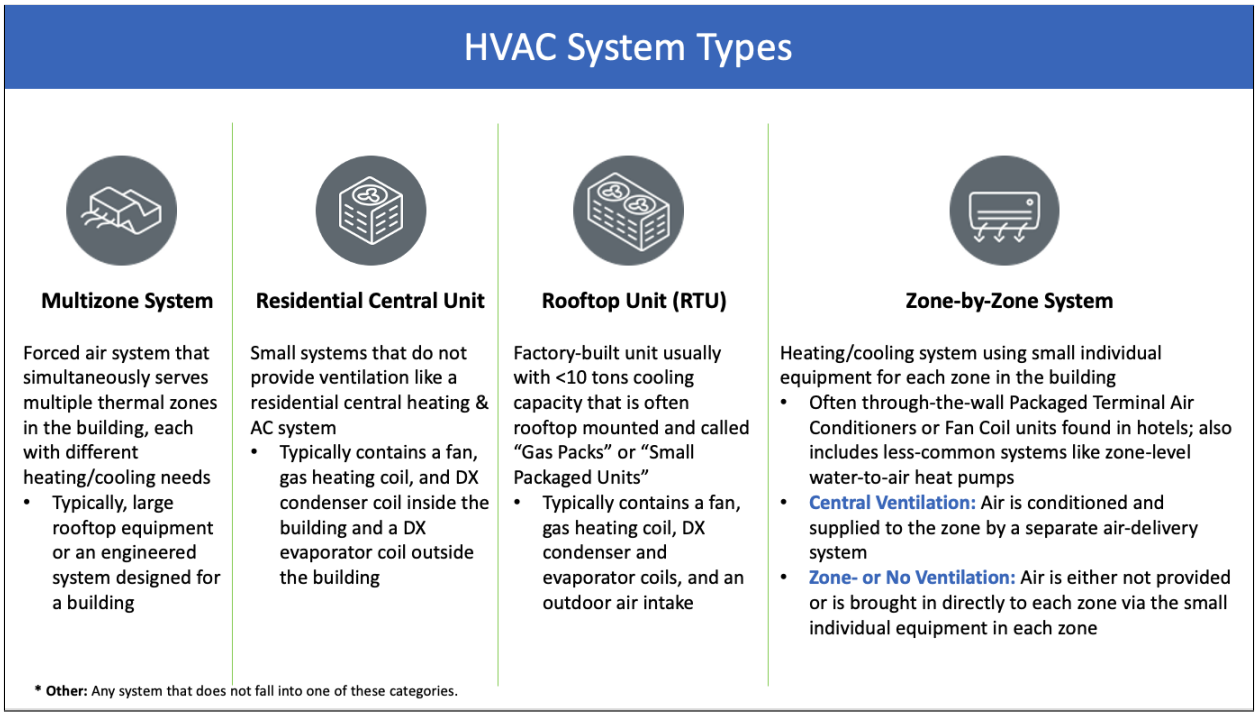


Figure 19. HVAC System Types

Effective Retrofit Solutions by End Use		Notes
HVAC	Packaged Heat Pumps	Many existing buildings in this climate already use this technology, but higher efficiency options will improve heating and cooling savings.
	Rooftop Ventilator + Split System	Less common but gaining adoption in US engineering & HVAC installation market and widely demonstrated.
	Heat Pump Chillers + Potentially Needed Fossil Supplement	Engineered systems currently designed and operating with hot water temperatures higher than HPWHs can today. Will require detailed engineering and convincing engineers that heat pump chillers plus innovative design is a reliable design.
Lighting	LED Lighting	Widely available for most applications.
Water Heating	Higher-capacity HPWHs with Recirculation	Engineered system combining one or more heat pump water heaters plus potentially electric resistance elements to reach temperatures above what HPWHs can reach.
	Residential-style HPWH	Service water heating mostly for hand washing.
	Dishwashing and Laundry Equipment Efficiency	Significant potential in switching to dishwashing and laundry equipment that uses less hot water, making HPWHs more feasible.

Figure 20. Retrofit Solution Notes

C Tables of Figure Values

The following tables summarize the figures shown throughout the report.

0.1 Results Summary

Table 5. Site Energy by Fuel Type and End Use (Figure 3)

Fuel Type - End Use	Site Energy (TBtu)
District Energy - HVAC	1.53
District Energy - Water Heating	0.0261
Electricity - Equipment	19.6
Electricity - HVAC	28.1
Electricity - Lighting	13.7
Electricity - Water Heating	2.27
Natural Gas - Equipment	5.27
Natural Gas - HVAC	23.9
Natural Gas - Water Heating	3.55
Other Fuel - HVAC	0.367
Other Fuel - Water Heating	0.0465

Table 6. Emissions by Fuel Type and End Use (Figure 3)

Fuel Type - End Use	Emissions (million metric tons CO_2e)
Electricity - Equipment	2.7
Electricity - HVAC	3.85
Electricity - Lighting	1.88
Electricity - Water Heating	0.312
Natural Gas - Equipment	0.352
Natural Gas - HVAC	1.6
Natural Gas - Water Heating	0.237
Other Fuel - HVAC	0.0321
Other Fuel - Water Heating	0.00396

Table 7. Site Energy by Segment (Figure 4)

Segment	Site Energy (TBtu)
Hydronically Heated Multizone Systems	28
Rooftop Units, non-Food Service	22.3
Rooftop Units, Food Service	12.3
Rooftop Units, Strip Malls with Some Food-Service	8.04
Electric Resistance Multizone Systems	7.85
Zone-by-Zone Units, non-Lodging	6.44
Residential Central Units	5.04
Zone-by-Zone Units, Lodging	4.78
Packaged Multizone Systems	3.91
Other	0.0801

Table 8. Emissions by Segment (Figure 4)

Segment	Emissions (million metric tons CO_2e)
Hydronically Heated Multizone Systems	2.9
Rooftop Units, non-Food Service	2.58
Rooftop Units, Food Service	1.24
Electric Resistance Multizone Systems	1.07
Rooftop Units, Strip Malls with Some Food-Service	0.894
Zone-by-Zone Units, non-Lodging	0.734
Residential Central Units	0.581
Zone-by-Zone Units, Lodging	0.509
Packaged Multizone Systems	0.501
Other	0.0111

0.2 Building Site End Use Results

Table 9. HVAC Site Energy Consumption by HVAC System Type and Building Type (site energy is in TBtu) (Figure 5)

HVAC System Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
Multizone Systems	7.61	0.00784	3.01	0	3.61	7.01	3.29
Other HVAC	0	0	0	0	0.00921	0	0.0137
Residential Central Units	0	0.0261	0	0.0068	0.927	0.961	0.397
Rooftop Units	1.73	4.72	0.613	0.0251	7.17	3.21	3.62
Zone-by-Zone Units	1.77	0.0335	0.0386	2.28	0.472	1.03	0.332

Table 10. HVAC Emissions by HVAC System Type and Building Type (emissions is in million metric tons CO_2e) (Figure 6)

HVAC System Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
Multizone Systems	0.744	0.000779	0.368	0	0.406	0.807	0.38
Other HVAC	0	0	0	0	0.00129	0	0.00189
Residential Central Units	0	0.00301	0	0.000697	0.111	0.103	0.0455
Rooftop Units	0.17	0.475	0.0728	0.00323	0.808	0.358	0.436
Zone-by-Zone Units	0.19	0.00369	0.00492	0.235	0.0544	0.122	0.037

Table 11. Equipment Site Energy Consumption by Fuel Type and Building Type (site energy is in TBtu) (Figure 7)

Fuel Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
District Heating	0	0	0	0	0	0	0
Electricity	0.841	2.29	1.67	0.787	2.68	5.75	5.55
Natural Gas	0.166	2.98	0.209	0.612	1.31	0	0
Other Fuel	0	0	0	0	0	0	0

Table 12. Equipment Emissions by Fuel Type and Building Type (emissions is in million metric tons CO_2e) (Figure 8)

Fuel Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
Electricity	0.114	0.314	0.23	0.108	0.369	0.796	0.766
Natural Gas	0.0111	0.199	0.014	0.0409	0.0874	0	0
Other Fuel	0	0	0	0	0	0	0

Table 13. Interior and Exterior Lighting Site Energy Consumption by Interior Lighting Type and Building Type (site energy is in TBtu) (Figure 9)

Interior Lighting Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
LED	0.498	0.153	0.211	0.118	0.838	0.991	0.707
T12	0.466	0.201	0.286	0.252	0.773	0.654	0.726
T5	0.0113	0.0232	0.0936	0.00909	0.0643	0.0881	0.32
T8	0.485	0.179	0.105	0.0507	2.55	0.797	2.02

Table 14. Interior and Exterior Lighting Emissions by Interior Lighting Type and Building Type (emissions is in million metric tons CO_2e) (Figure 10)

Interior Lighting Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
LED	0.0498	0.0156	0.0258	0.0123	0.0943	0.122	0.0836
T12	0.0478	0.021	0.0353	0.0285	0.0923	0.0788	0.0898
T5	0.00105	0.0022	0.0125	0.00104	0.0072	0.0111	0.0389
T8	0.0492	0.0179	0.0121	0.0061	0.292	0.0892	0.242

Table 15. Water Heating Site Energy Consumption by Fuel Type and Building Type (site energy is in TBtu) (Figure 11)

Fuel Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
District Heating	0	0	0	0.022	0	0.00404	0
Electricity	0.191	0.374	0.0276	0.113	0.547	0.139	0
Fuel Oil	0.0193	0.00152	0.00038	0.00369	0	0.000664	0
Natural Gas	0.398	1.42	0.287	0.59	1.61	0.13	0
Propane	0	0.0175	0.000315	0.00252	0	0.000551	0

Table 16. Water Heating Emissions by Fuel Type and Building Type (emissions is in million metric tons CO_2e) (Figure 12)

Fuel Type	Education	Food Service	Healthcare	Lodging	Mercantile	Office	Warehouse and Storage
District Heating	0	0	0	0.00213	0	0.000341	0
Electricity	0.0199	0.0405	0.00351	0.0143	0.065	0.0171	0
Fuel Oil	0.00222	0.000139	4.37e-05	0.00044	0	7.51e-05	0
Natural Gas	0.0395	0.136	0.0357	0.0618	0.175	0.0147	0
Propane	0	0.00172	4.03e-05	0.000306	0	6.08e-05	0

0.3 Results by Building Type for Your Top Four Segments

Table 17. Hydronically Heated Multizone Systems (Figure 13)

Building Type Group	Percentage of Number of Buildings	Percentage of Floor Area	Percentage of Site Energy	Percentage of Emissions
Education	0.234	0.291	0.334	0.311
Healthcare	0.0517	0.0549	0.0895	0.0964
Mercantile	0.193	0.0812	0.14	0.141
Office	0.181	0.215	0.256	0.254
Warehouse and Storage	0.34	0.357	0.18	0.197

Table 18. Rooftop Units, non-Food Service (Figure 14)

Building Type Group	Percentage of Number of Buildings	Percentage of Floor Area	Percentage of Site Energy	Percentage of Emissions
Education	0.0203	0.0616	0.1	0.0859
Healthcare	0.0264	0.0247	0.0502	0.0516
Lodging	0.00174	0.00166	0.0034	0.00377
Mercantile	0.152	0.123	0.217	0.215
Office	0.537	0.146	0.228	0.223
Warehouse and Storage	0.263	0.643	0.402	0.421

Table 19. Rooftop Units, Food Service (Figure 15)

Building Type Group	Percentage of Number of Buildings	Percentage of Floor Area	Percentage of Site Energy	Percentage of Emissions
Food Service	1	1	1	1

Table 20. Rooftop Units, Strip Malls with Some Food Service (Figure 16)

Building Type Group	Percentage of Number of Buildings	Percentage of Floor Area	Percentage of Site Energy	Percentage of Emissions
Mercantile	1	1	1	1

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