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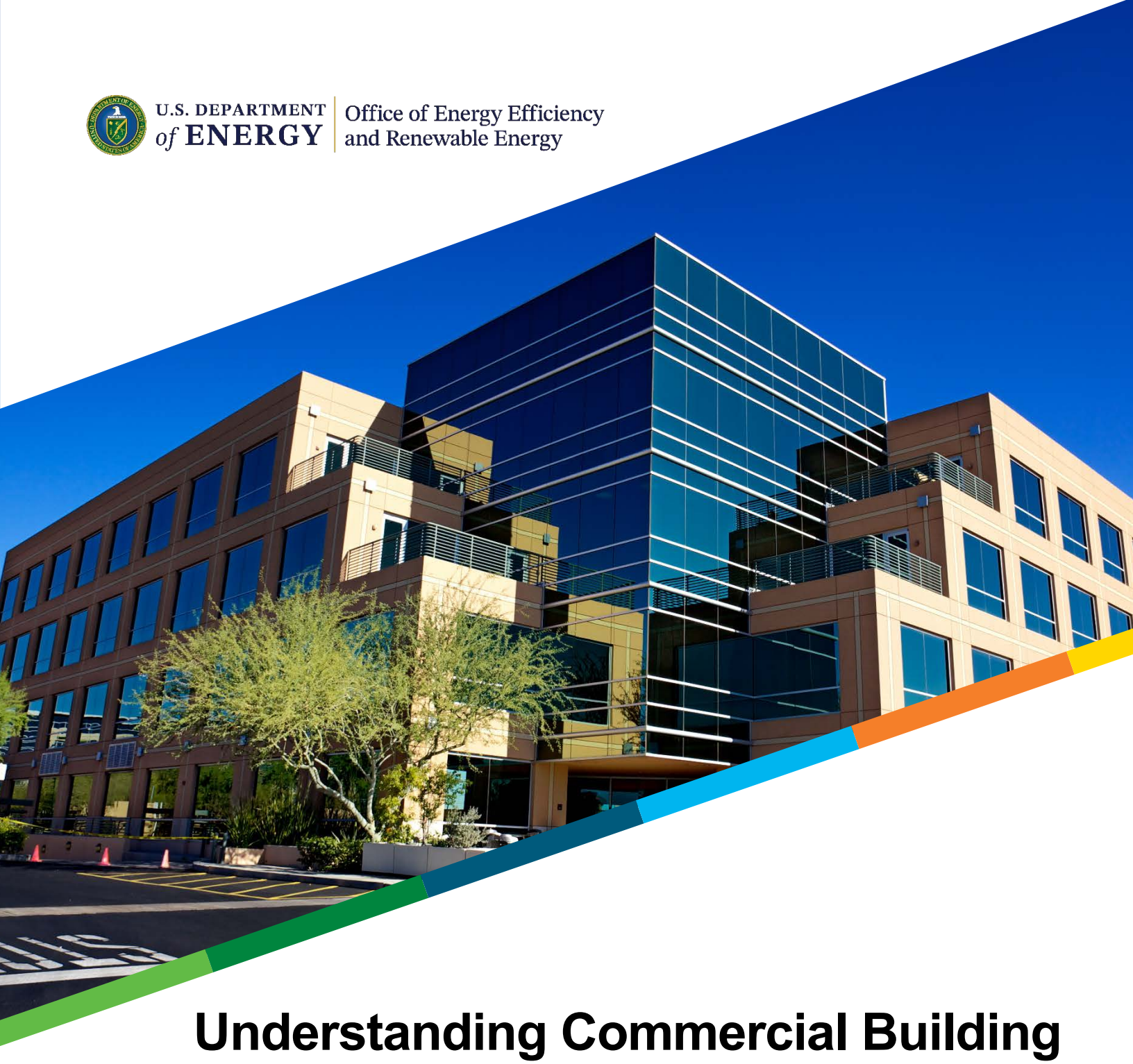

# Understanding Commercial Building Energy Use in the Greater Memphis Area:

## Building Stock Segmentation for Retrofit Planning

**May 2025**

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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 Greater Memphis 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.

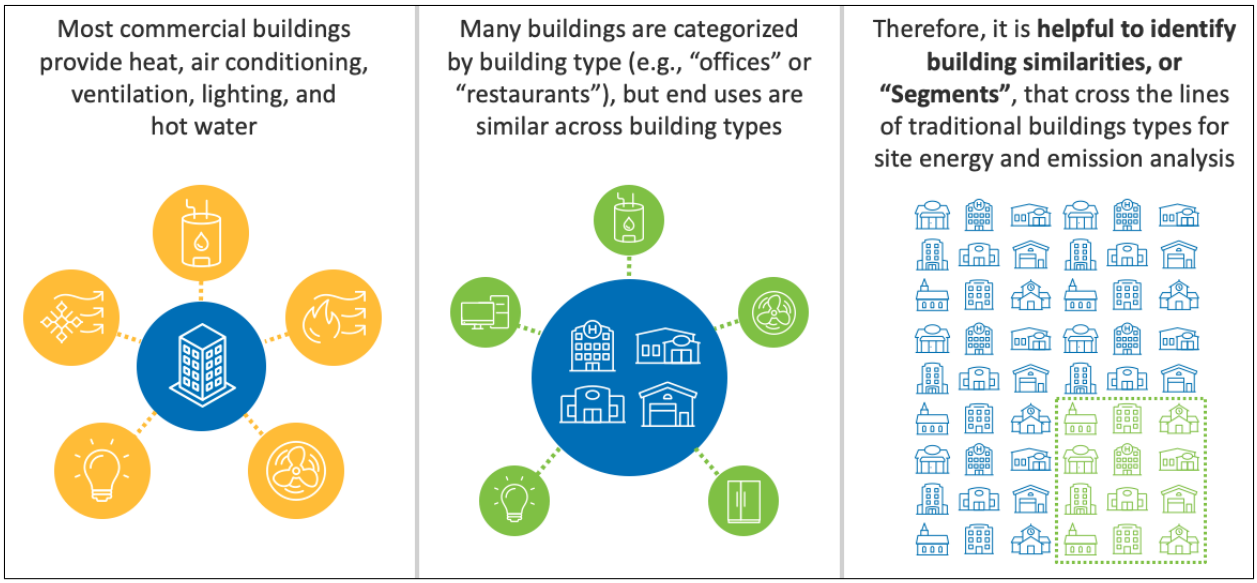



Figure 1. Segmentation Analysis

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<br>• Heating and cooling outside air drives the HVAC energy consumption<br>• Leased space will cause split incentive challenges for approximately 50% of the segment |
| Rooftop Units, Food Service | • Common Examples: freestanding restaurants<br>• Many small, high energy intensity buildings<br>• Heating and cooling outside air drives the HVAC energy consumption<br>• High ventilation because of cooking air exhaust hoods<br>• High service water heating needs, including high temperature water for dish-washing<br>• High process loads for cooking, primarily natural gas |
| Rooftop Units, Strip Malls with Some Food-Service | • Common Examples: strip malls with restaurants<br>• Many small, high energy intensity buildings<br>• Heating and cooling outside air drives the HVAC energy consumption<br>• High ventilation because of cooking air exhaust hoods in restaurant portions<br>• High service water heating needs, including high temperature water for dish-washing<br>• High process loads for cooking, primarily natural gas<br>• 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<br>• Majority are heated with electric resistance |
| Zone-by-Zone Units, Lodging | • Common Examples: motels and hotels, typically part of large chains<br>• Majority are heated with electric resistance<br>• 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.)<br>• Commonly called central forced air in the residential context<br>• Typically do not have mechanical ventilation |
| Packaged Multi-zone Systems | • Common Examples: small to medium offices and schools<br>• Natural gas heating coils |
| Hydronically Heated Multi-zone Systems | • Common Examples: large buildings with boilers (schools, large offices, health-care facilities)<br>• Heating and cooling outside air drives the HVAC energy consumption<br>• Typically complex custom-engineered HVAC systems<br>• Split incentive less likely to be a barrier in institutional or healthcare, but still an issue in large offices<br>• 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<br>• 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<br>• Understand retrofit solutions to address energy efficiency and affordability for your building stock's top four segments<br>• Know how to apply retrofit solutions for each segment<br>• 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)<br>• 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 Greater Memphis 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<br>Quick Service Restaurant |
| | Mercantile | Retail Strip Mall<br>Retail Standalone |
| | Office | Small Office<br>Medium Office<br>Large Office |
| | Education | Primary School<br>Secondary School |
| | Healthcare | Outpatient<br>Hospital |
| | Lodging | Small Hotel<br>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 Greater Memphis 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.

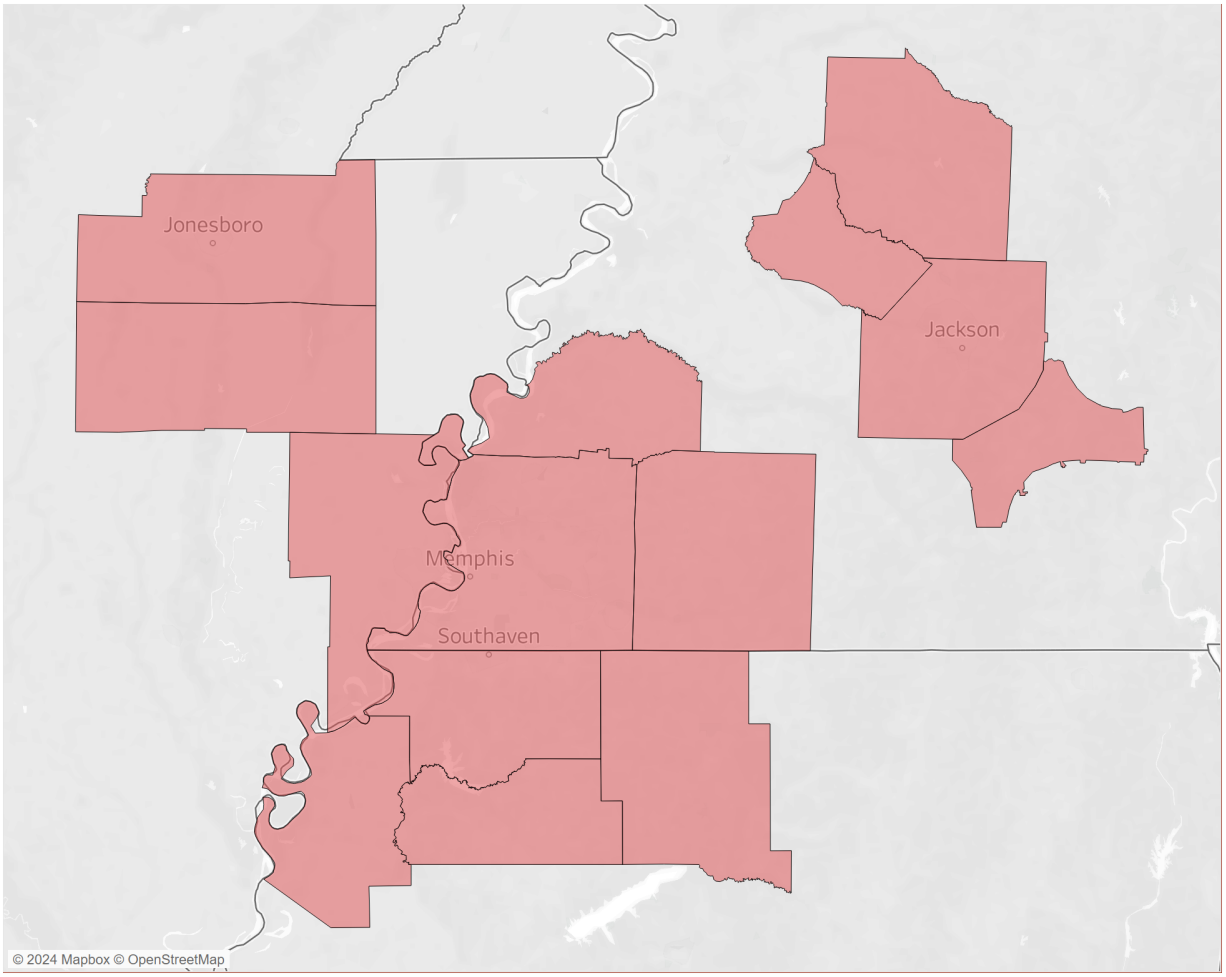



Figure 2. Map showing the cluster of counties and county equivalents covered in this report (See Appendix A for a list of the counties and county equivalents)

# 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 77% of your building stock's site energy consumption is Electricity, with 38% of the Electricity consumption accounted to HVAC. In addition, 87% of your building stock's emissions are attributable to emissions from Electricity use, with 43% 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, Healthcare, Office, and Warehouse and Storage buildings. Most of the emissions from energy use from HVAC in the building stock are attributed to buildings with Multizone Systems, particularly in Education, Healthcare, Office, and Warehouse and Storage 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.

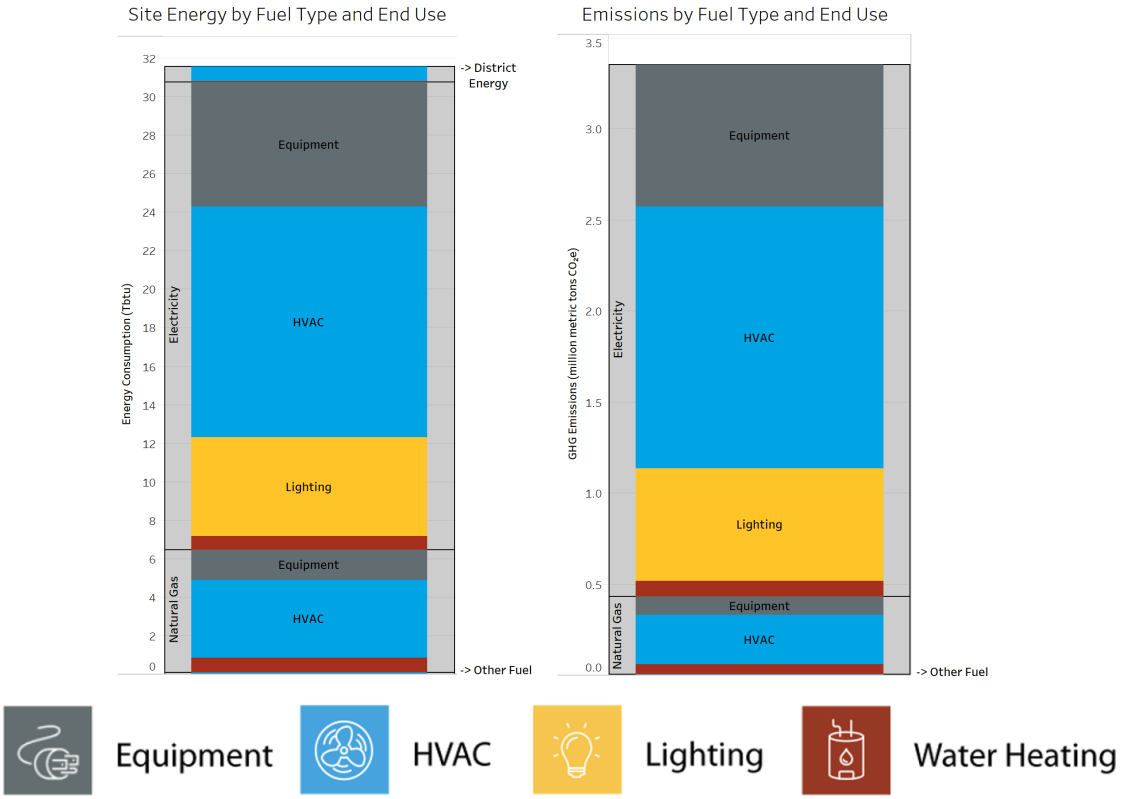



Figure 3. Site Energy and Emissions by Fuel Type and End Use (See Tables 5 and 6 in Appendix C for data in tabular format)

## 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 70% of the site energy consumed and 70% of the emissions from energy use by your building stock.

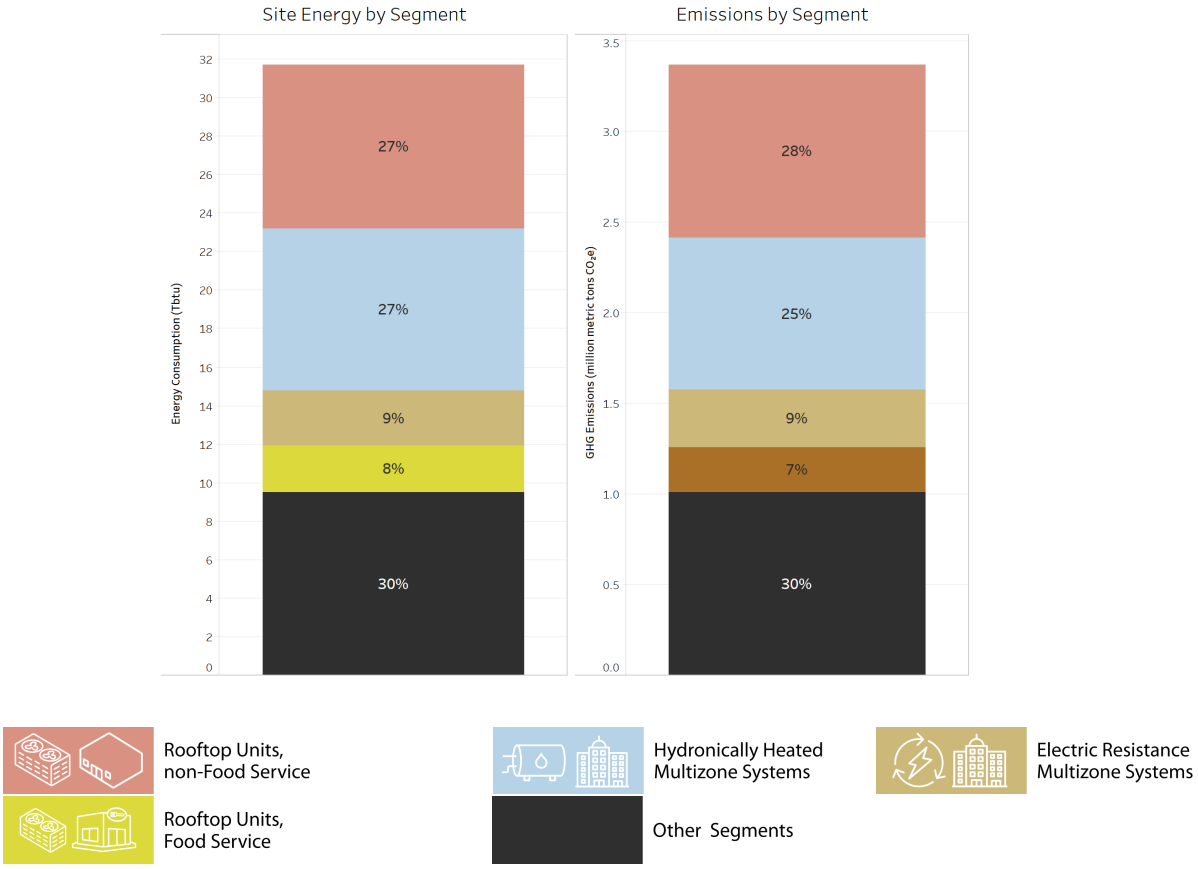



Figure 4. Top Four Segments (See Tables 7 and 8 in Appendix C for data in tabular format)

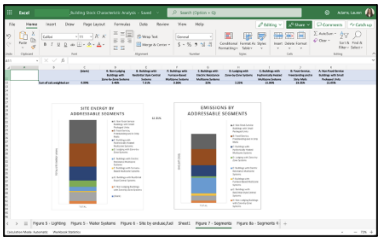
Effective retrofit solutions for your top four segments can be broken down by end use. The Xs in Table 4 represent retrofit solutions that apply to the segments of your building stock that consume the most site energy and generate the most emissions. For instance, buildings that have Rooftop Units, non-Food 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

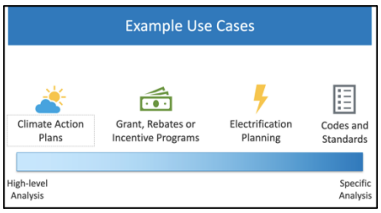
| End Use | Effective Retrofit Solutions | Rooftop Units, non-Food Service | Hydronically Heated Multizone Systems | Electric Resistance Multizone Systems | Rooftop Units, Food Service |
|---|---|---|---|---|---|
| HVAC | Packaged Heat Pumps | X | | | X |
| | Rooftop ERV + Split System | X | | | |
| | 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 |
| | Residential-Style HPWH | X | | | |
| | Dishwashing and Laundry Equipment Efficiency | | | | 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, Healthcare, Office, and Warehouse and Storage 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, Healthcare, Office, and Warehouse and Storage buildings.

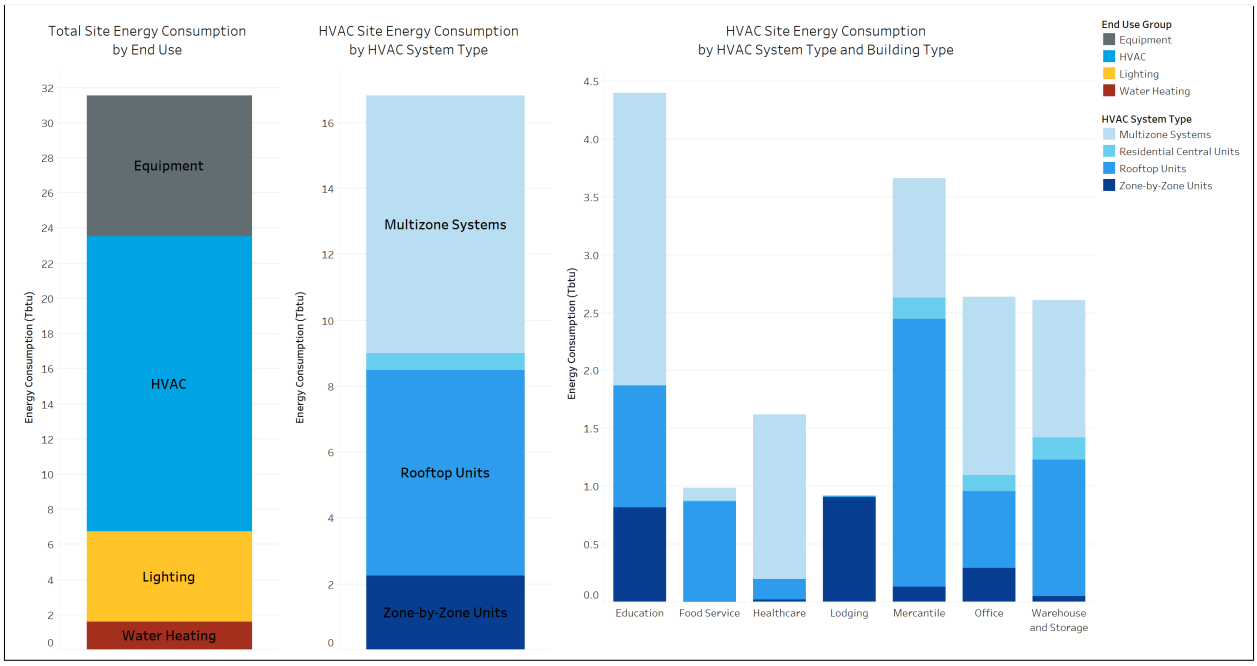



Figure 5. HVAC: Site Energy Consumption (TBtu) (See Table 9 in Appendix C for data in tabular format)

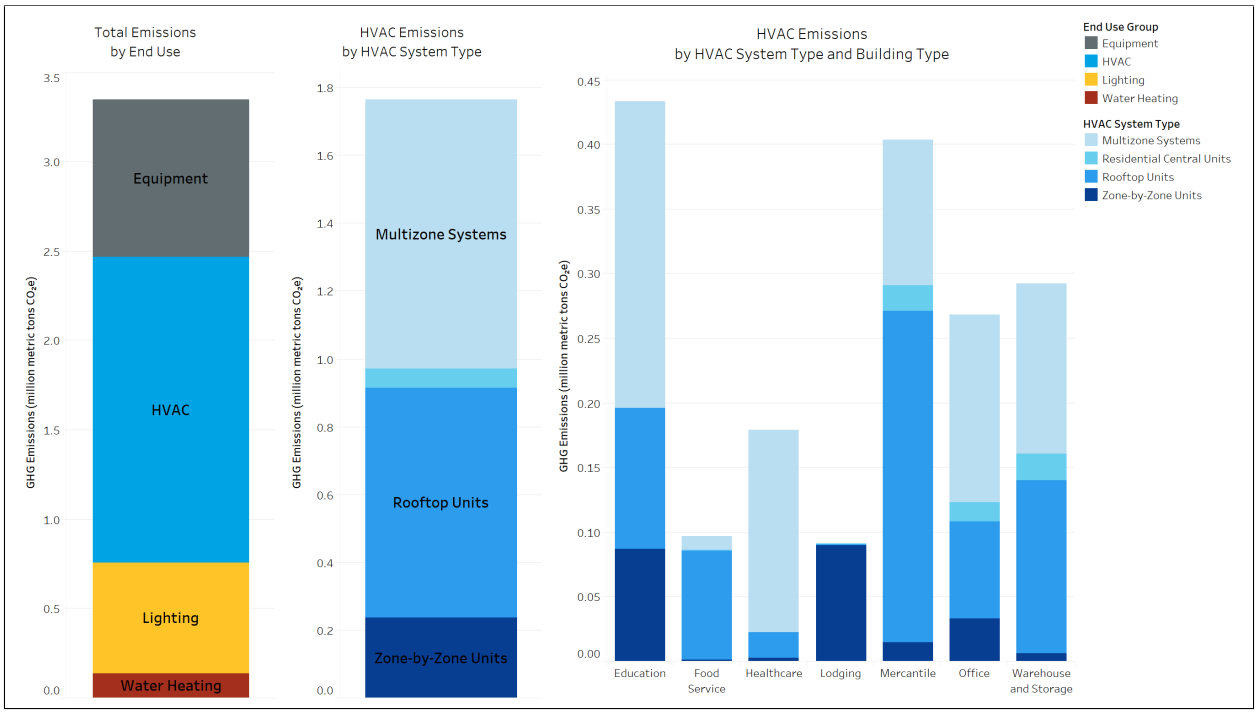



Figure 6. HVAC: Emissions (million metric tons $CO_2e$) (See Table 10 in Appendix C for data in tabular format)

## 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.

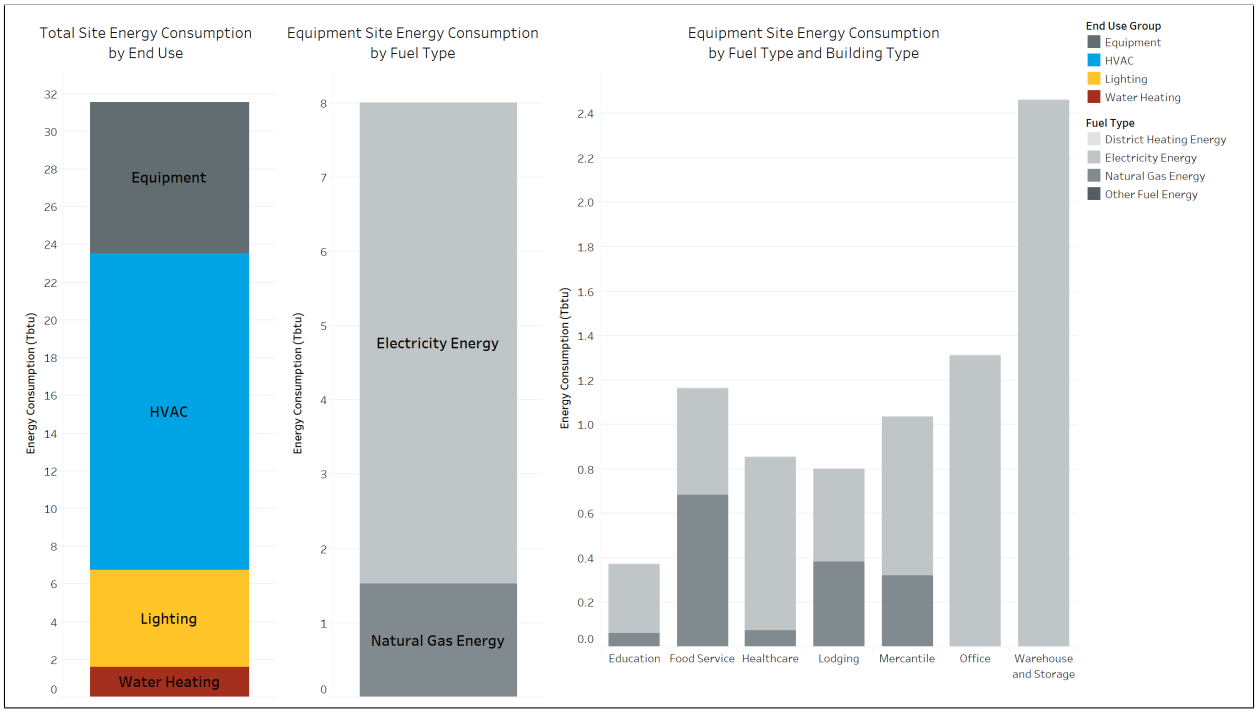



Figure 7. Equipment: Site Energy Consumption (TBtu) (See Table 11 in Appendix C for data in tabular format)

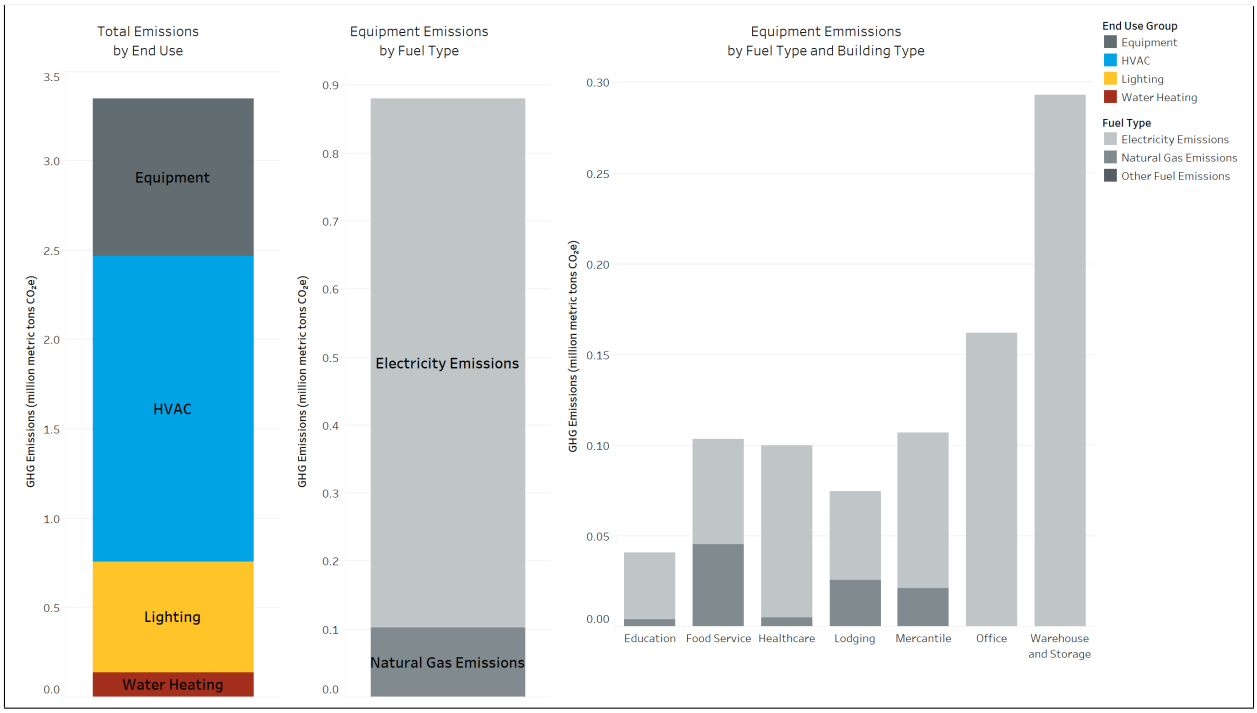



Figure 8. Equipment: Emissions (million metric tons $CO_2e$) (See Table 12 in Appendix C for data in tabular format)

## 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 T12 bulbs, particularly in Education, 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 T12 bulbs, particularly in Education, Mercantile, and Warehouse and Storage buildings.

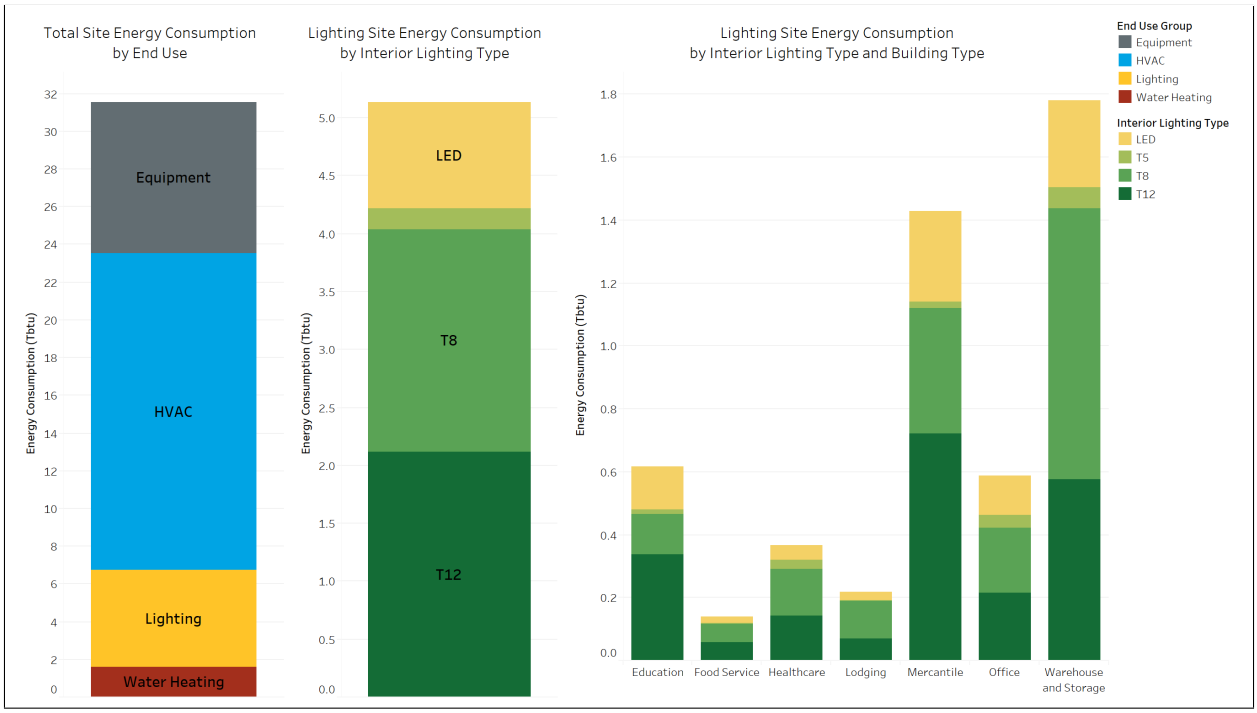



Figure 9. Interior and Exterior Lighting by Interior Lighting Type: Site Energy Consumption (TBtu) (See Table 13 in Appendix C for data in tabular format)

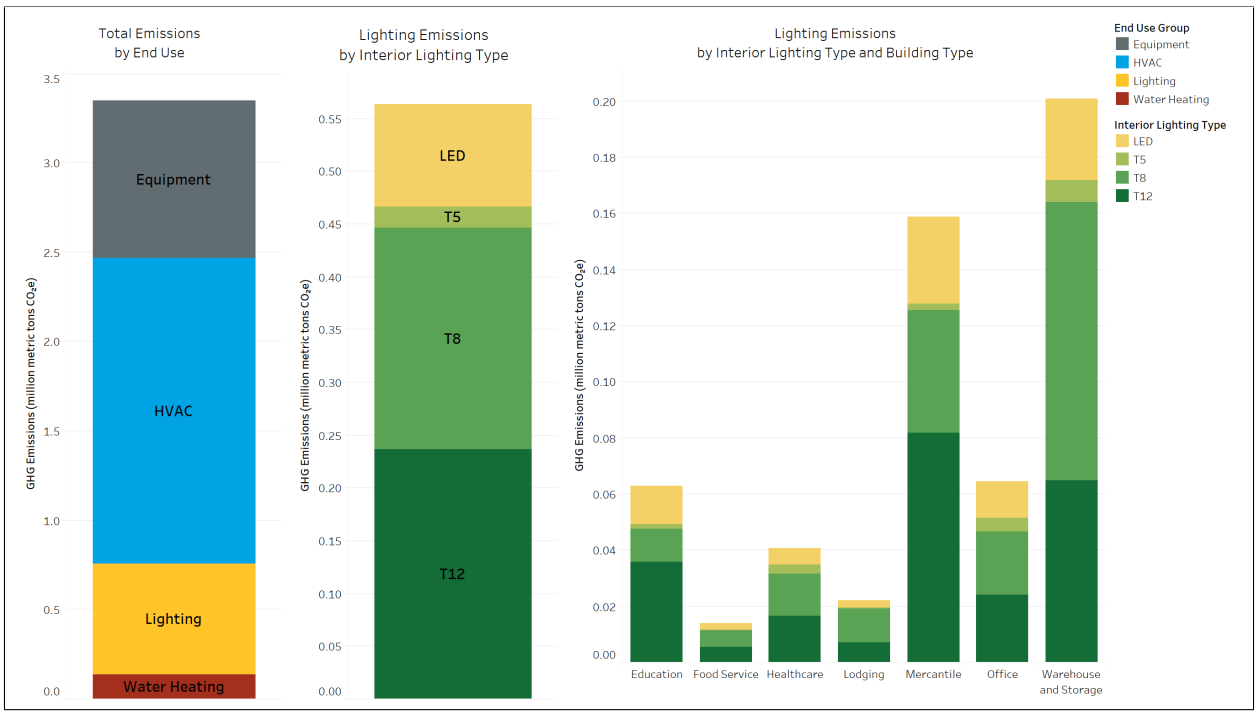



Figure 10. Interior and Exterior Lighting by Interior Lighting Type: Emissions (million metric tons $CO_2e$) (See Table 14 in Appendix C for data in tabular format)

## 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 Education, Food Service, Lodging, 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 Education, Food Service, Lodging, and Mercantile buildings.

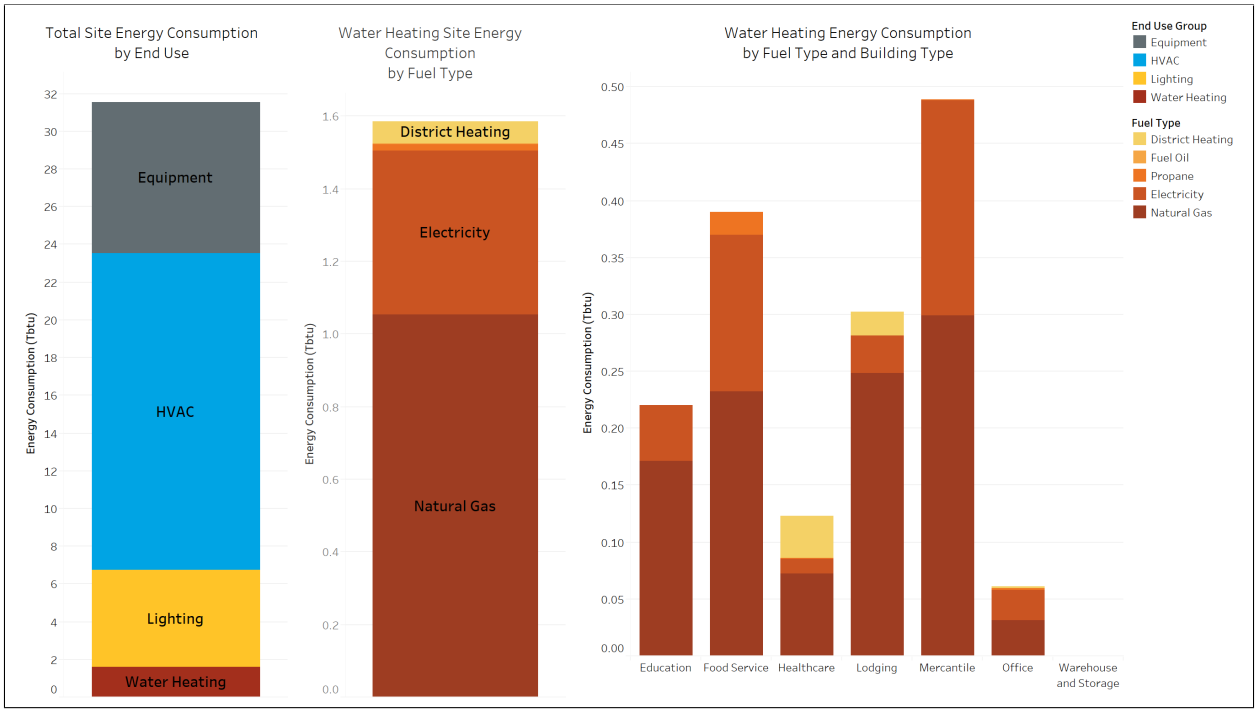



Figure 11. Water Heating: Site Energy Consumption (TBtu) (See Table 15 in Appendix C for data in tabular format)

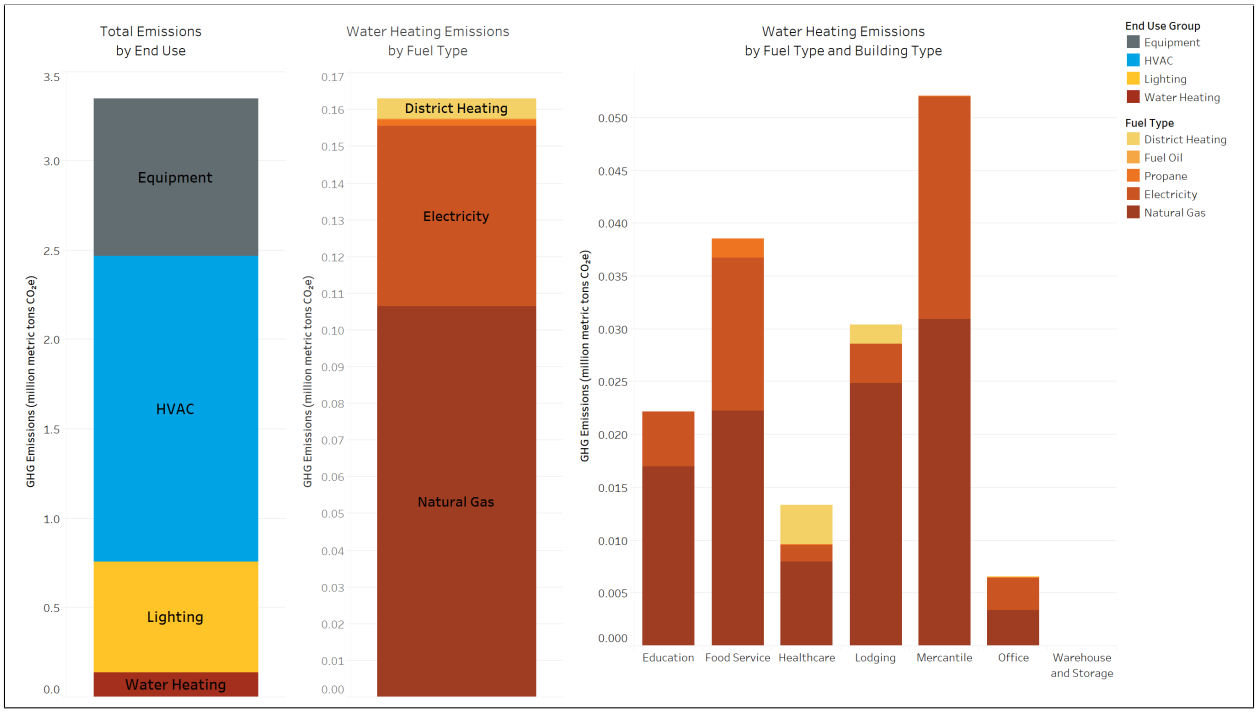



Figure 12. Water Heating: Emissions (million metric tons $CO_2e$) (See Table 16 in Appendix C for data in tabular format)

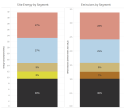
# 5 Results by Building Type for Your Top Four Segments

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 Rooftop Units, non-Food Service



Buildings with Rooftop Units, non-Food Service consume 27% of your building stock's site energy and generate 28% of the emissions associated with energy consumption. Within the segment, Education, Mercantile, Office and Warehouse and Storage buildings consume 96% of your building stock's site energy and Education, Mercantile, Office and Warehouse and Storage buildings generate 96% of the emissions associated with energy consumption.

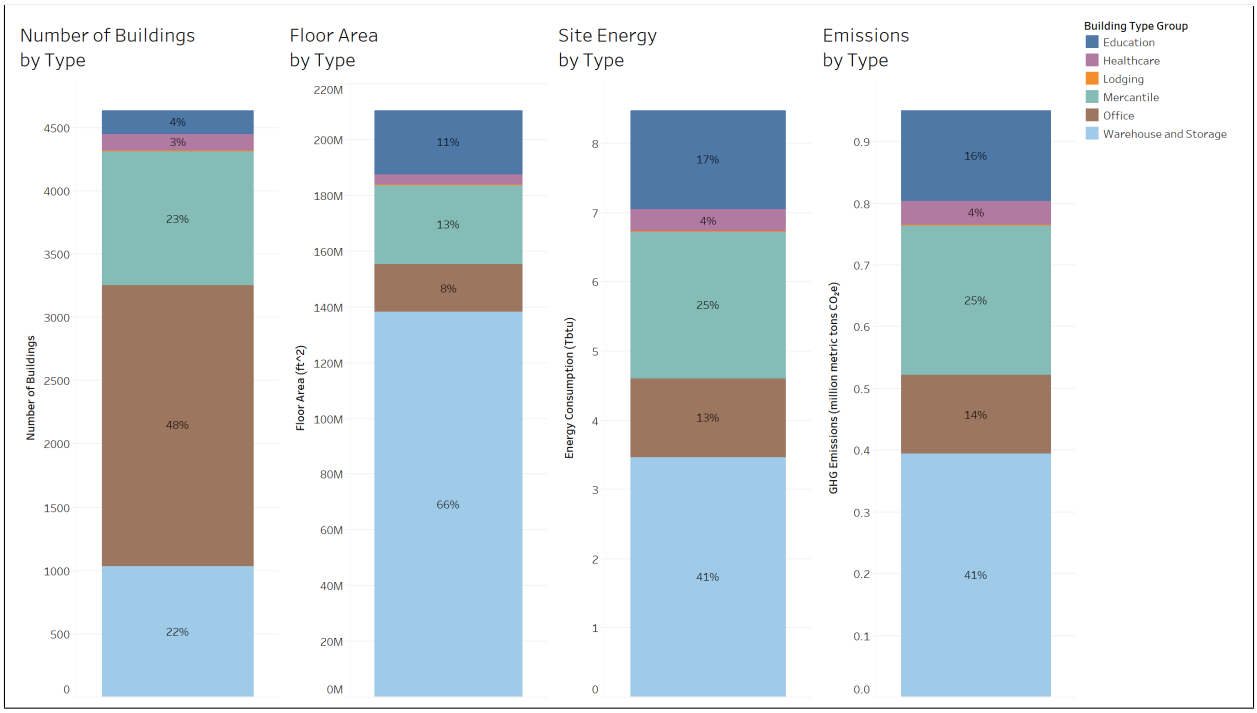
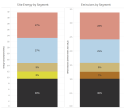



Figure 13. Rooftop Units, non-Food Service (See Table 17 in Appendix C for data in tabular format)

## 5.2 Hydronically Heated Multizone Systems





Buildings with Hydronically Heated Multizone Systems consume 27% of your building stock's site energy and generate 25% of the emissions associated with energy consumption. Within the segment, Education, Healthcare, Office and Warehouse and Storage buildings consume 93% of your building stock's site energy and Education, Healthcare, Office and Warehouse and Storage buildings generate 93% of the emissions associated with energy consumption.

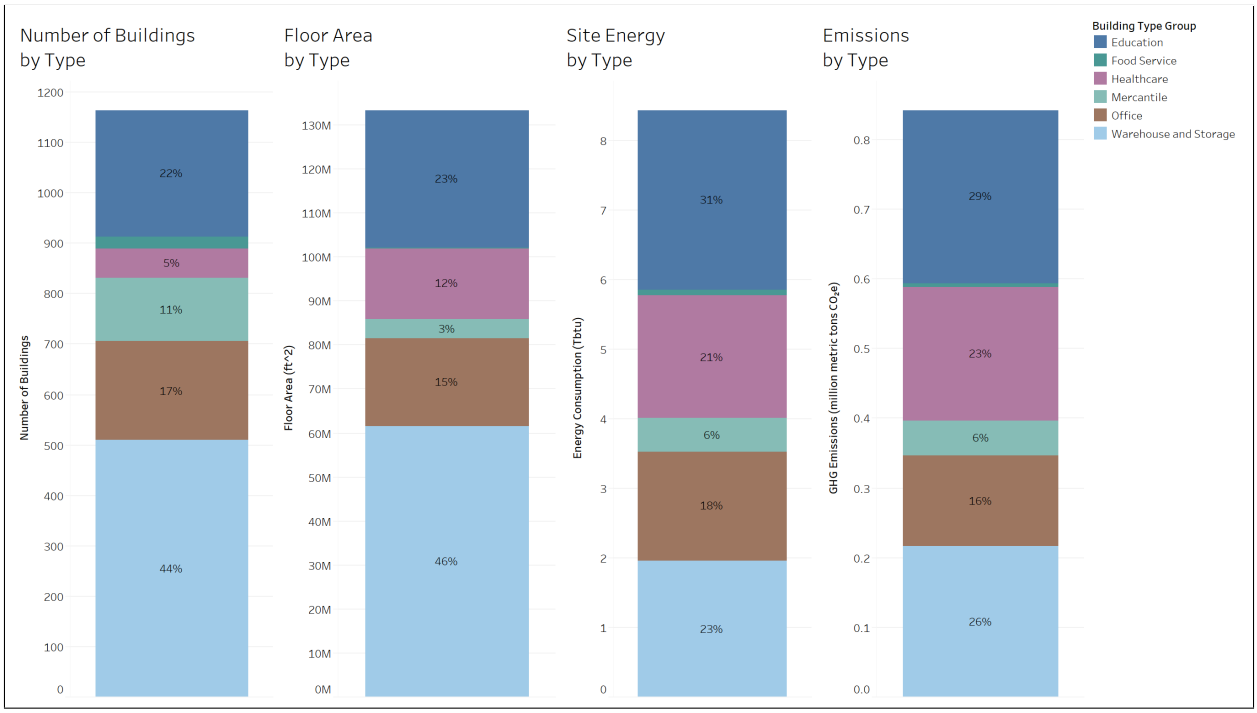
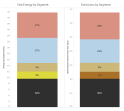



Figure 14. Hydronically Heated Multizone Systems (See Table 18 in Appendix C for data in tabular format)

## 5.3 Electric Resistance Multizone Systems



Buildings with Electric Resistance Multizone Systems consume 9% of your building stock's site energy and generate 9% of the emissions associated with energy consumption. Within the segment, Education, Healthcare, Mercantile and Office buildings consume 89% of your building stock's site energy and Healthcare, Mercantile and Office buildings generate 80% of the emissions associated with energy consumption.

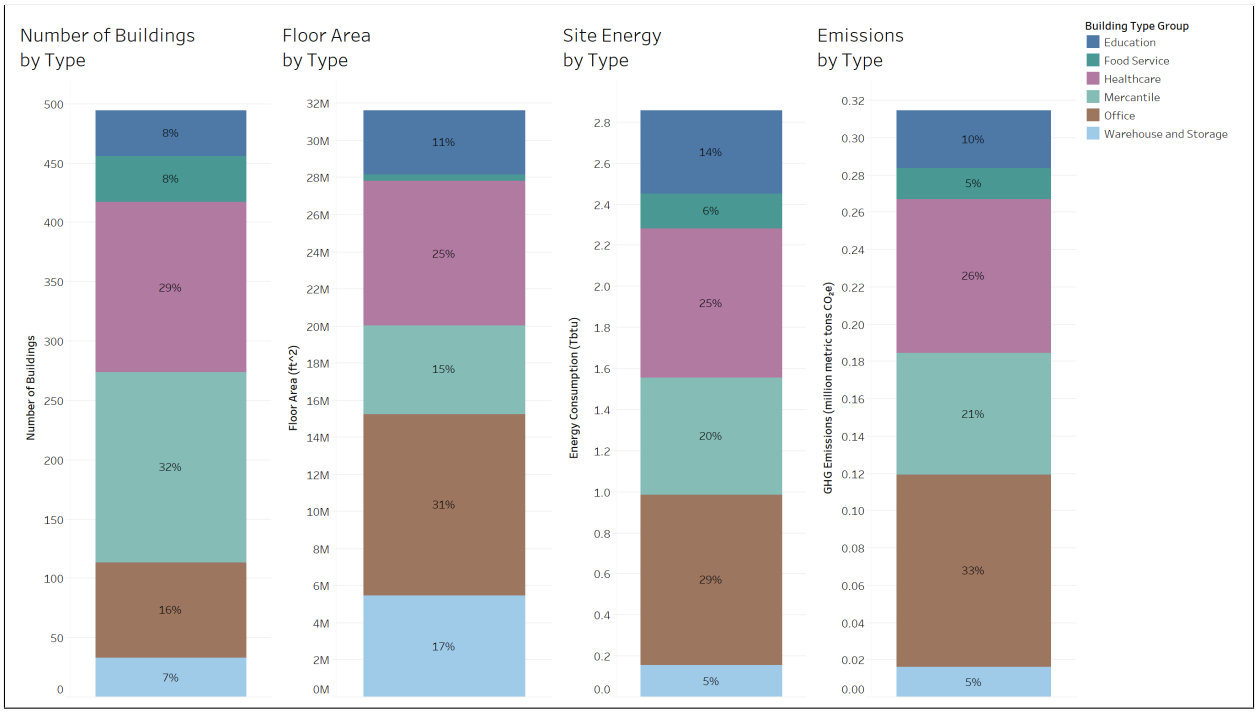
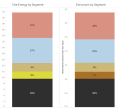



Figure 15. Electric Resistance Multizone Systems (See Table 19 in Appendix C for data in tabular format)

## 5.4 Rooftop Units, Food Service





Buildings with Rooftop Units, Food Service consume 8% of your building stock's site energy and generate 7% 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.

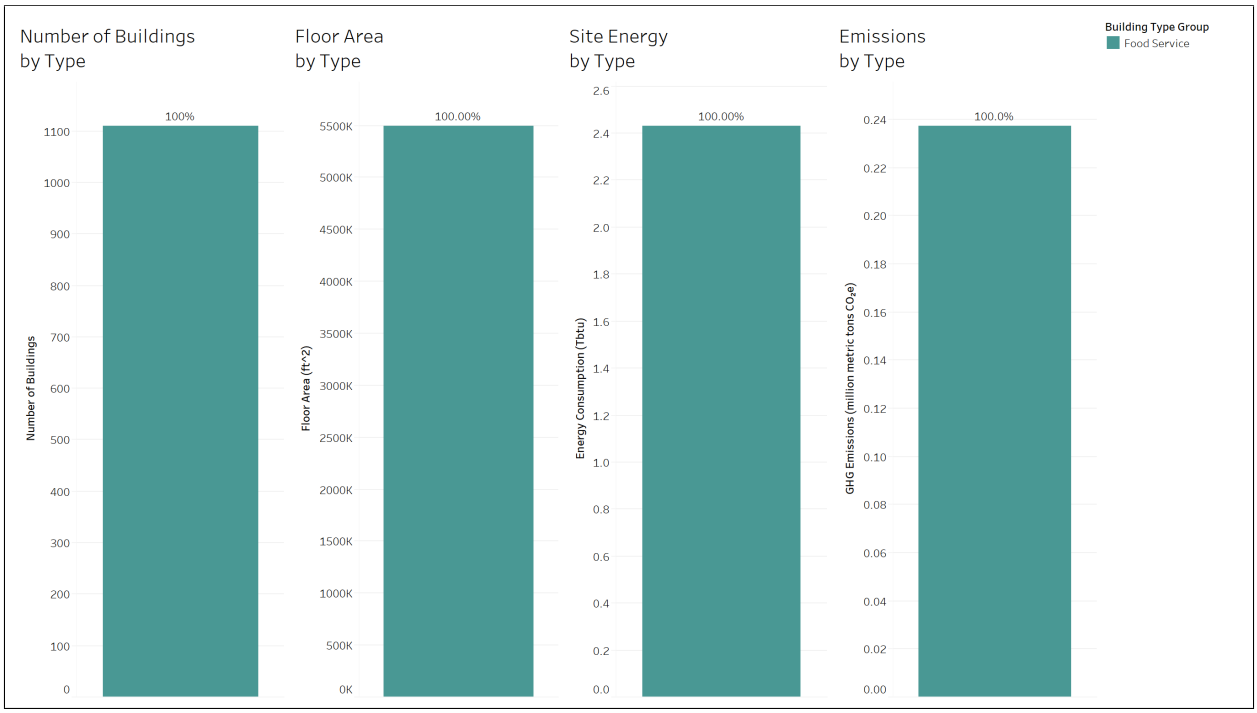



Figure 16. Rooftop Units, Food Service (See Table 20 in Appendix C for data in tabular format)

# 6 Conclusion

In conclusion, 77% of your building stock's site energy consumption is Electricity, with 38% 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, Healthcare, Office, and Warehouse and Storage buildings. Your building stock's segment with the most site energy consumed is Rooftop Units, non-Food Service. Potentially effective efficiency solutions you can implement for your building stock include replacing Rooftop Units with Packaged Heat Pumps, or Rooftop ERV + Split Systems. These solutions should be considered primarily for Education, Mercantile, Office and Warehouse and Storage buildings.

In addition, 87% of your building stock's emissions are attributable to emissions from Electricity use, with 43% 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, Healthcare, Office, and Warehouse and Storage buildings. Your building stock's segment with the most emissions from energy use is Rooftop Units, non-Food Service. Potentially effective retrofit solutions you can implement for your building stock include replacing Rooftop Units with Packaged Heat Pumps, or Rooftop ERV + Split Systems. These solutions 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:

**Arkansas** Craighead, Crittenden, Poinsett.

**Mississippi** DeSoto, Marshall, Tate, Tunica.

**Tennessee** Chester, Crockett, Fayette, Gibson, Madison, Shelby, Tipton.

# 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:

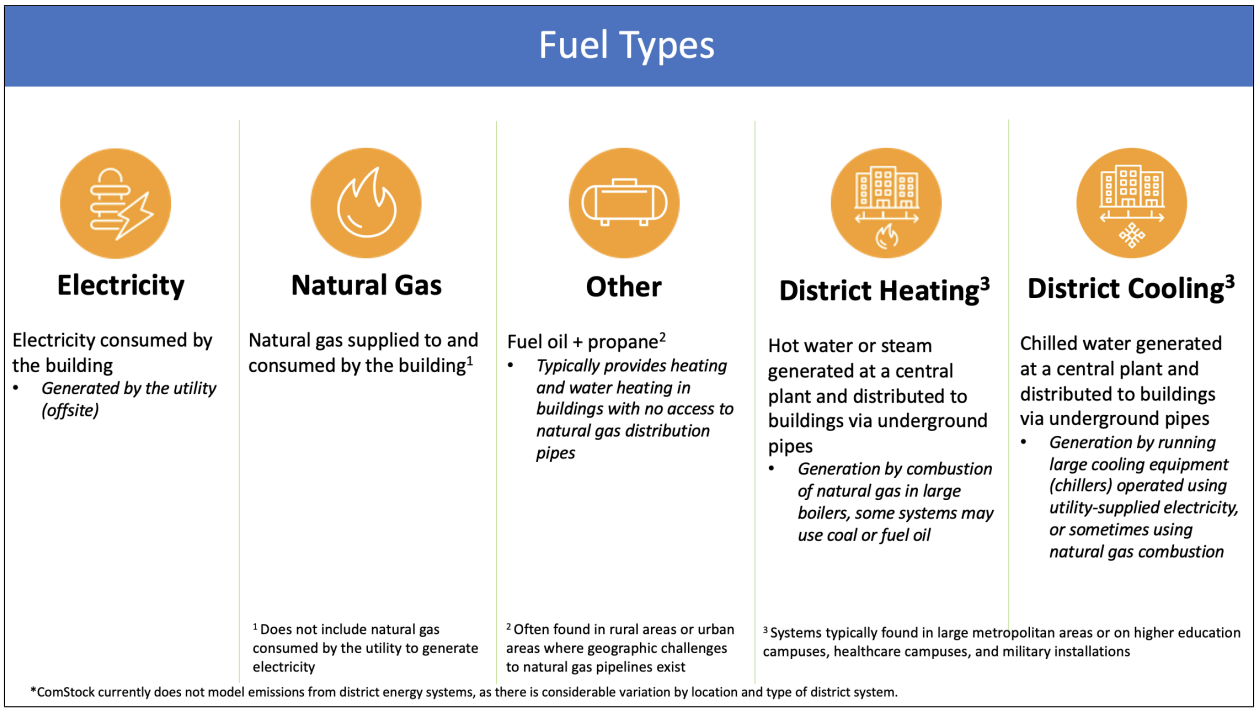



Figure 17. Fuel Types

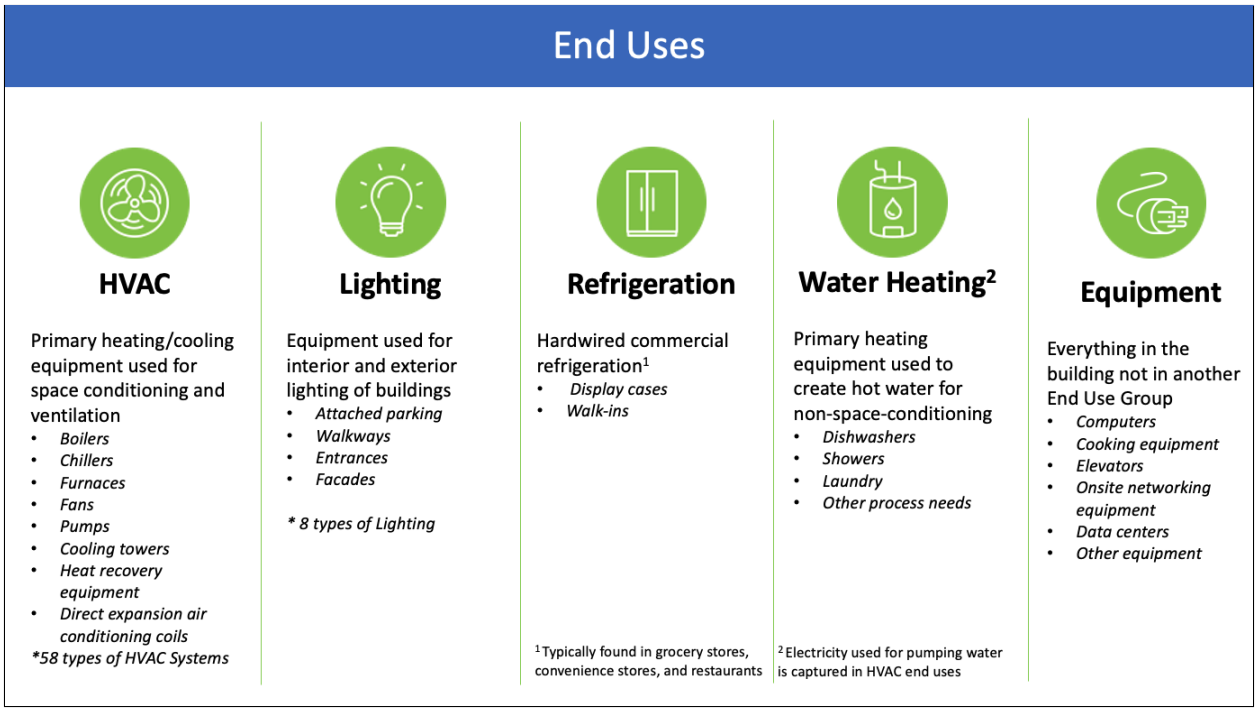



Figure 18. End Uses

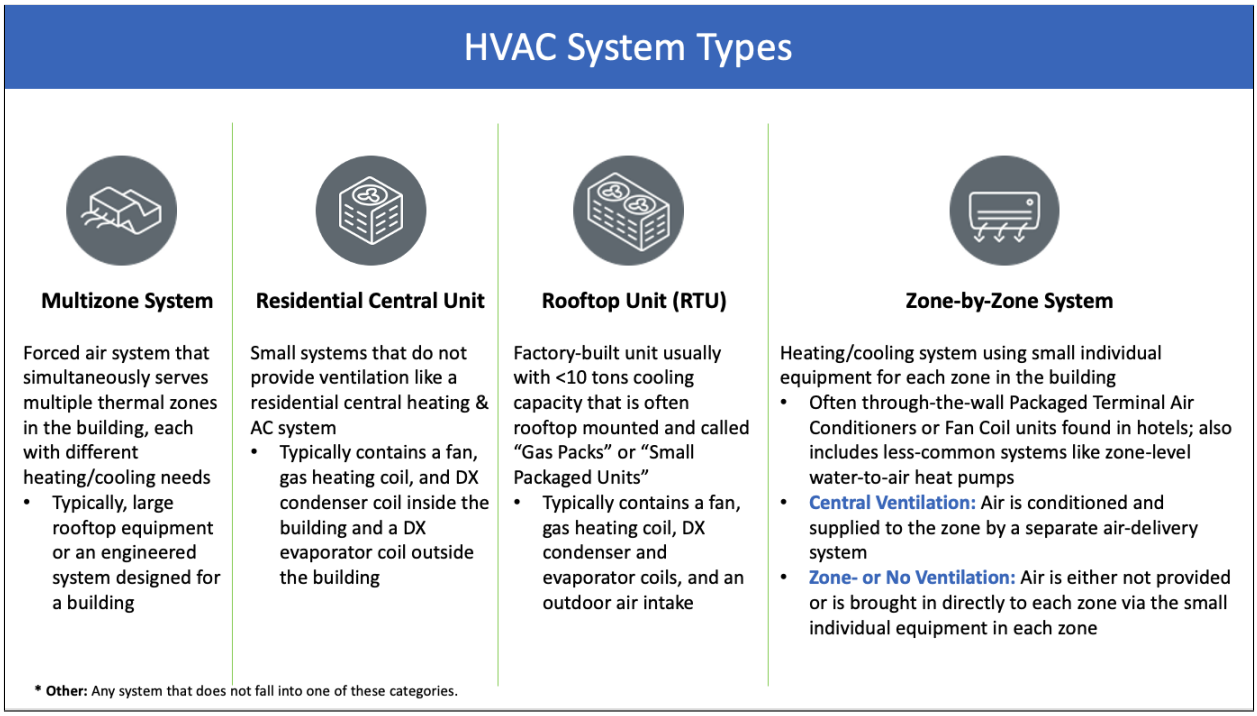



Figure 19. HVAC System Types

| 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 | 0.738 |
| District Energy - Water Heating | 0.0587 |
| Electricity - Equipment | 6.49 |
| Electricity - HVAC | 12 |
| Electricity - Lighting | 5.14 |
| Electricity - Water Heating | 0.728 |
| Natural Gas - Equipment | 1.52 |
| Natural Gas - HVAC | 4.05 |
| Natural Gas - Water Heating | 0.777 |
| Other Fuel - HVAC | 0.0684 |
| Other Fuel - Water Heating | 0.0212 |

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

| Fuel Type - End Use | Emissions (million metric tons $CO_2e$) |
|---|---|
| Electricity - Equipment | 0.779 |
| Electricity - HVAC | 1.44 |
| Electricity - Lighting | 0.616 |
| Electricity - Water Heating | 0.0867 |
| Natural Gas - Equipment | 0.102 |
| Natural Gas - HVAC | 0.271 |
| Natural Gas - Water Heating | 0.0519 |
| Other Fuel - HVAC | 0.00552 |
| Other Fuel - Water Heating | 0.00171 |

Table 7. Site Energy by Segment (Figure 4)

| Segment | Site Energy (TBtu) |
|---|---|
| Rooftop Units, non-Food Service | 8.48 |
| Hydronically Heated Multizone Systems | 8.43 |
| Electric Resistance Multizone Systems | 2.86 |
| Rooftop Units, Food Service | 2.43 |
| Zone-by-Zone Units, non-Lodging | 2.25 |
| Zone-by-Zone Units, Lodging | 2.22 |
| Rooftop Units, Strip Malls with Some Food-Service | 1.92 |
| Packaged Multizone Systems | 1.71 |
| Residential Central Units | 1.4 |

Table 8. Emissions by Segment (Figure 4)

| Segment | Emissions (million metric tons $CO_2e$) |
|---|---|
| Rooftop Units, non-Food Service | 0.951 |
| Hydronically Heated Multizone Systems | 0.842 |
| Electric Resistance Multizone Systems | 0.315 |
| Zone-by-Zone Units, non-Lodging | 0.249 |
| Rooftop Units, Food Service | 0.237 |
| Zone-by-Zone Units, Lodging | 0.222 |
| Rooftop Units, Strip Malls with Some Food-Service | 0.203 |
| Packaged Multizone Systems | 0.197 |
| Residential Central Units | 0.151 |

## 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 | 2.53 | 0.114 | 1.42 | 0 | 1.03 | 1.54 | 1.19 |
| Residential Central Units | 0 | 0.00593 | 0 | 0.0103 | 0.184 | 0.139 | 0.192 |
| Rooftop Units | 1.05 | 0.858 | 0.174 | 0.00364 | 2.31 | 0.662 | 1.18 |
| Zone-by-Zone Units | 0.816 | 0.0109 | 0.0257 | 0.907 | 0.132 | 0.296 | 0.054 |

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 | 0.237 | 0.0109 | 0.156 | 0 | 0.113 | 0.145 | 0.132 |
| Residential Central Units | 0 | 0.000649 | 0 | 0.00097 | 0.0197 | 0.015 | 0.0207 |
| Rooftop Units | 0.109 | 0.0844 | 0.0201 | 0.000426 | 0.256 | 0.0747 | 0.133 |
| Zone-by-Zone Units | 0.0874 | 0.00118 | 0.00292 | 0.0899 | 0.0149 | 0.0335 | 0.0064 |

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 | 0.311 | 0.484 | 0.783 | 0.419 | 0.717 | 1.31 | 2.46 |
| Natural Gas | 0.0632 | 0.682 | 0.0748 | 0.384 | 0.32 | 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 | 0.0365 | 0.0576 | 0.0952 | 0.0492 | 0.0855 | 0.162 | 0.293 |
| Natural Gas | 0.00422 | 0.0456 | 0.005 | 0.0257 | 0.0214 | 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 | 0.136 | 0.0221 | 0.0475 | 0.0255 | 0.288 | 0.123 | 0.276 |
| T12 | 0.337 | 0.0567 | 0.143 | 0.0691 | 0.72 | 0.216 | 0.576 |
| T5 | 0.0154 | 0.0026 | 0.0299 | 0.00191 | 0.0202 | 0.0427 | 0.0678 |
| T8 | 0.128 | 0.0597 | 0.147 | 0.12 | 0.4 | 0.205 | 0.861 |

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 | 0.0136 | 0.00214 | 0.0057 | 0.00261 | 0.0311 | 0.0131 | 0.0291 |
| T12 | 0.036 | 0.0057 | 0.0166 | 0.00732 | 0.0817 | 0.024 | 0.065 |
| T5 | 0.00164 | 0.000287 | 0.00314 | 0.000185 | 0.00209 | 0.00507 | 0.00786 |
| T8 | 0.0117 | 0.00583 | 0.0152 | 0.0119 | 0.0439 | 0.0225 | 0.0989 |

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 | 0.0363 | 0.0205 | 0 | 0.00192 | 0 |
| Electricity | 0.0493 | 0.138 | 0.0139 | 0.0332 | 0.189 | 0.0269 | 0 |
| Fuel Oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas | 0.171 | 0.232 | 0.0724 | 0.248 | 0.299 | 0.0314 | 0 |
| Propane | 0 | 0.0201 | 0.000237 | 0 | 0 | 0.000864 | 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 | 0.00369 | 0.00179 | 0 | 0.000125 | 0 |
| Electricity | 0.00524 | 0.0144 | 0.00162 | 0.00373 | 0.0211 | 0.003 | 0 |
| Fuel Oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas | 0.0169 | 0.0223 | 0.00799 | 0.0249 | 0.0309 | 0.00339 | 0 |
| Propane | 0 | 0.00183 | 2.39e-05 | 0 | 0 | 0.0001 | 0 |

## 0.3 Results by Building Type for Your Top Four Segments

Table 17. Rooftop Units, non-Food Service (Figure 13)

| Building Type Group | Percentage of Number of Buildings | Percentage of Floor Area | Percentage of Site Energy | Percentage of Emissions |
|---|---|---|---|---|
| Education | 0.0404 | 0.11 | 0.168 | 0.155 |
| Healthcare | 0.0283 | 0.0173 | 0.0382 | 0.0393 |
| Lodging | 0.000756 | 0.000624 | 0.00133 | 0.00138 |
| Mercantile | 0.229 | 0.134 | 0.25 | 0.254 |
| Office | 0.478 | 0.0825 | 0.134 | 0.135 |
| Warehouse and Storage | 0.223 | 0.656 | 0.409 | 0.414 |

Table 18. Hydronically Heated Multizone Systems (Figure 14)

| Building Type Group | Percentage of Number of Buildings | Percentage of Floor Area | Percentage of Site Energy | Percentage of Emissions |
|---|---|---|---|---|
| Education | 0.216 | 0.233 | 0.306 | 0.294 |
| Food Service | 0.0198 | 0.00124 | 0.00843 | 0.00768 |
| Healthcare | 0.0492 | 0.12 | 0.21 | 0.227 |
| Mercantile | 0.108 | 0.0331 | 0.0572 | 0.0583 |
| Office | 0.17 | 0.15 | 0.185 | 0.156 |
| Warehouse and Storage | 0.438 | 0.462 | 0.233 | 0.257 |

Table 19. Electric Resistance Multizone Systems (Figure 15)

| Building Type Group | Percentage of Number of Buildings | Percentage of Floor Area | Percentage of Site Energy | Percentage of Emissions |
|---|---|---|---|---|
| Education | 0.0777 | 0.109 | 0.142 | 0.0989 |
| Food Service | 0.0778 | 0.0105 | 0.0597 | 0.0521 |
| Healthcare | 0.291 | 0.247 | 0.254 | 0.263 |
| Mercantile | 0.323 | 0.15 | 0.198 | 0.207 |
| Office | 0.163 | 0.309 | 0.291 | 0.327 |
| Warehouse and Storage | 0.0674 | 0.173 | 0.0547 | 0.0522 |

Table 20. Rooftop Units, Food Service (Figure 16)

| 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 |

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