ComStock Measure Documentation: Ideal Thermal Air Loads

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National Renewable Energy Laboratory

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List of Acronyms

COP	coefficient of performance
DX	direct expansion
HVAC	heating, ventilating, and air conditioning
RTU	rooftop unit
VAV	variable air volume

Executive Summary

Building on a 3-year effort to calibrate and validate the U.S. Department of Energy's ResStock™ and ComStock™ models, the ComStock Standard Dataset Release produces national datasets that empower analysts working for federal, state, utility, city, and manufacturer stakeholders to answer a broad range of questions regarding their commercial building stock.

The goal of this work is to develop energy efficiency and demand flexibility end-use load shapes that cover high-impact, market-ready (or nearly market-ready) measures. "Measures" refers to various "what-if" scenarios that can be applied to buildings.

An *end-use savings shape* is the difference in energy consumption between a baseline building (or collection of buildings) and a building in which an energy efficiency or demand flexibility measure has been applied. The result is a time-series profile broken down by end use and fuel (electricity or on-site gas, propane, or fuel oil use) at each time step, as well as annual aggregates.

ComStock is a highly granular, bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual subhourly energy consumption of the commercial building stock across the United States. The baseline model intends to represent the U.S. commercial building stock as it existed in 2018. The methodology and results of the baseline model are discussed in the final technical report of the End-Use Load Profiles project and the ComStock Reference Documentation.

This report describes the modeling methodology for a single end-use savings shape measure—Ideal Thermal Air Loads—and briefly presents key results. The full public dataset can be accessed on the ComStock™ data lake or via the Data Viewer at comstock.nrel.gov. The public dataset enables users to create custom aggregations of results for their use case (e.g., filter to a specific county).

Key modeling assumptions and technology details are summarized in Table 1.

Table 1. Summary of Key Modeling Specifications

Technology Description	• This study provides hypothetical thermal heating and cooling loads for ComStock models representing the U.S. commercial building stock. This measure scenario removes all HVAC models from the baseline ComStock building model and instead uses "ideal air" to meet loads. • "Ideal air" functions like an HVAC unit that mixes zone exhaust air with the required outdoor air, then adjusts heat and moisture with 100% efficiency to provide supply air at the desired conditions. • The resulting ideal thermal loads are represented under the "district" fuel type for both heating and cooling and can be found in both annual and time-series results in the ComStock public dataset. This measure scenario does not represent any real technology or improvement, but rather, serves as a resource for thermal heating and cooling loads for buildings.

Key Performance Assumptions		• Heating and cooling loads are met by air conditioned at 100% efficiency and supplied directly to the zone. • The measure application is agnostic of the HVAC system type found in original building model. Impacts of system-specific operation, such as simultaneous heating and cooling (reheat), are not considered in this study. • Outdoor air is introduced to the ideal air supply for conditioning per design outdoor air specifications with schedules aligning to zone occupancy. • A constant cooling sensible heat ratio of 0.75 is applied. • Fan energy and its corresponding impacts to heating and cooling loads are not modeled in this study. • Active humidity control is not applied, aligning with current ComStock baseline assumptions.
Applicability		• This measure is applicable to every ComStock model, comprising 100% of the floor area modeled in ComStock. No ComStock models are excluded.
Release	2025 Release 1: 2025/comstock_amy2018_release_1/	

Note that results for impacts on metrics like greenhouse gas emissions and energy bills are not presented for this measure scenario since this study is only intended to provide thermal heating and cooling loads for ComStock models. This measure scenario should only be used as a resource to analyze building thermal loads and does not represent an actual technology study. Figure 1 shows the application of this measure on annual stock site energy between the ComStock baseline and the Ideal Thermal Air Loads scenario, where heating and cooling energy of all fuel types are converted to district heating and district cooling sources, respectively.

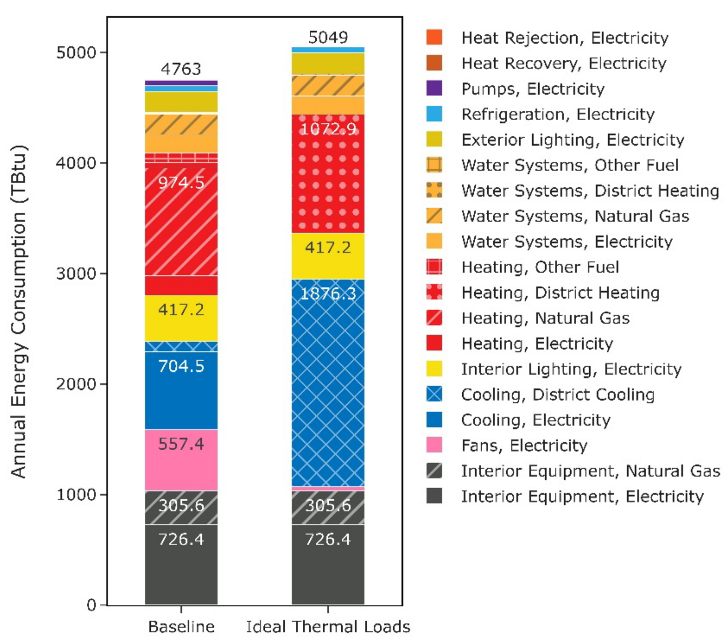

Figure 1. Comparison of annual site energy consumption between the ComStock baseline and the Ideal Thermal Air Loads scenario. Energy consumption is categorized both by fuel type and end use.

Acknowledgments

The author acknowledges the valuable guidance and input provided by Eric Bonnema and Eric Ringold.

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1 Technology Summary

The commercial building stock is a major contributor to U.S. energy consumption, grid demand, and utility bills. Equipment used for the heating, cooling, and ventilation of buildings accounts for over 50% of the total stock site energy usage [1]. There are numerous pathways to reduce energy usage, energy bill, and peak demand impacts of HVAC equipment such as improving the efficiency of the equipment meeting thermal loads, decreasing envelope losses, and incorporating thermal energy storage.

In building energy modeling, heating and cooling loads can be met with “ideal air”; that is, air conditioned at 100% efficiency to provide heating and cooling to spaces without specifying actual HVAC equipment. Zone loads, and required outdoor air ventilation, are met using theoretical air streams with infinite capacity. Simply put, the resulting loads represent the raw heating and cooling energy that must be added to or extracted from spaces to maintain thermostat setpoints. In aggregate, these form ideal thermal load profiles for buildings, ignoring the primary energy required by systems that move thermal energy into, around, and out of buildings.

Understanding building thermal loads can help further research in several areas. By leveraging ideal thermal air loads, researchers can isolate and analyze the fundamental heating and cooling demands of a building without the influence of specific HVAC system efficiencies or operational characteristics. This can help inform the development of next-generation HVAC systems that are more efficient, resilient, and capable of reducing the overall carbon footprint of the commercial building stock. This development can create pathways toward achieving energy goals, ultimately leading to more sustainable, cost-effective, and comfortable built environments.

ComStock is a highly granular, bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual subhourly energy consumption of the U.S. commercial building stock [2]. The ComStock model provides a dataset describing how and when energy is used in the building stock of today. The dataset includes several features, including building stock characterization, annual and time-series energy usage by fuel and end use, greenhouse gas emissions, and utility bills estimates. Additionally, various “what-if” scenarios add the impact of various energy efficiency and demand flexibility measure scenarios versus the ComStock baseline. ComStock data are published through public dataset releases.

This measure scenario study provides a public dataset of ideal thermal heating and cooling loads for ComStock models to serve as a resource for further research.

2 ComStock Baseline Approach

This measure scenario replaces all HVAC equipment with ideal thermal air loads objects for every model in the ComStock baseline. All other features of the baseline models (e.g., thermostat setpoints, schedules, envelope, internal loads) remain the same. Virtually all ComStock model inputs will impact the resulting ideal thermal air loads produced by this work, which are documented extensively in the ComStock Reference Documentation [2]. This includes features such as:

- Envelope type and insulation
- Schedules
- Equipment loads
- Outdoor air requirements
- Thermostat setpoints and setbacks
- Lighting type and power
- Building shape and orientation.

One notable consideration is that ComStock does not currently model active dehumidification controls with humidity limits. HVAC systems in ComStock do provide some degree of dehumidification, but only to the extent that naturally occurs to meet cooling thermostat setpoints; ComStock HVAC systems use a cooling supply air temperature of around 55°F or higher coupled with a sensible heat ratio. The Ideal Thermal Air Loads measure used in this work operates similarly to the methodology used in the ComStock baseline regarding humidity control: the simulation determines a supply air temperature, generally above 55°F, which is coupled with a constant sensible heat ratio of 0.75.

3 Modeling Approach

3.1 Applicability

The Ideal Thermal Air Loads measure is applicable to every ComStock model, or 100% of the stock floor area. No ComStock models are excluded.

3.2 Technology Details

The Ideal Thermal Air Loads measure is not a technology, per se. Rather, this measure scenario models the energy required to meet the raw heating and cooling thermal loads (based on the thermostat setpoints) with 100% efficiency. The thermostat setpoints and schedules are transferred from the baseline ComStock model in this workflow for consistency. The workflow removes all modeled HVAC equipment from the baseline model and replaces it with the EnergyPlus® "ZoneHVAC:IdealLoadsAirSystem" object in each zone as the sole conditioning equipment. The energy required to condition the air with the "ZoneHVAC:IdealLoadsAirSystem" object is metered and reported under DistrictHeatingWater and DistrictCooling.

Although the "ZoneHVAC:IdealLoadsAirSystem" object uses air as the conditioning medium, there is no fan modeled for air delivery. Therefore, the results of this measure scenario do not include fan energy, nor do they include waste fan heat that enters the supply air stream due to fan inefficiencies. Additionally, neither the ComStock baseline models nor this measure scenario model active dehumidification. In other words, the modeled HVAC equipment is not controlled to maintain any humidity specifications. Dehumidification only occurs passively as the HVAC system meets zone thermostat setpoints. The ideal air loads measure is modeled with a constant sensible heat ratio of 0.75, which will determine the fraction of energy used for sensible versus total (sensible + latent) cooling. Buildings that do actively control humidity can show increased HVAC energy consumption.

Outdoor air (ventilation) is provided to each zone based on the minimum required outdoor air flow rate for the baseline ComStock model. This flow rate is calculated using the "DesignSpecification:OutdoorAir" object assigned to the zone and is scheduled based on zone occupancy; when zone occupancy is over 5%, the zone is considered occupied and design outdoor air is provided. Note that these outdoor air schedules can deviate from the outdoor air schedules used in the ComStock baseline. This is because the ComStock baseline contains some prevalence of multizone systems, which operate based on the combined occupancy needs of all zones on the system. Additionally, the ComStock baseline intentionally includes some prevalence of HVAC systems that ventilate beyond the times when occupants are scheduled in the building.

Because all HVAC equipment in the baseline ComStock model is removed in this workflow, any existing energy efficiency HVAC features are removed as well. This includes technologies such as demand control ventilation, heat/energy recovery, and economizers. Although the "ZoneHVAC:IdealLoadsAirSystem" provides options for modeling these features, they were not utilized in this workflow so that the resulting load profiles represent raw thermal loads agnostic of HVAC system type or energy efficiency features. Similarly, other interactions found in real HVAC systems, such as reheat with a variable air volume system (VAV), do not occur with the

"ZoneHVAC:IdealLoadsAirSystem." So, a ComStock baseline model using a VAV system with high reheat loads may appear less heating intensive in this measure scenario.

A sample code snippet of the ZoneHVAC:IdealLoadsAirSystem object from an EnergyPlus input data file is show in Figure 2. The implementation for this measure study adds one ZoneHVAC:IdealLoadsAirSystem object to each thermal zone in the models. The inputs shown in this sample reflect the inputs used in the measure implementation for this study, noting that the measure implementation generalizes some fields (e.g., 'Zone Supply Air Node Name'). Some of the populated fields in this example and in the published model files in the public dataset have no impact on the simulation due to the options specified in other fields. For example, 'sensible heat recovery effectiveness' is populated but unused because 'Heat Recovery Type' is set to 'None'.

```
ZoneHVAC:IdealLoadsAirSystem,
    Zone1 Ideal Loads System, !- Name
    AlwaysOn,                 !- Availability Schedule Name
    Zone1 Ideal Loads Supply Node, !- Zone Supply Air Node Name
    Zone1 Ideal Loads Return Node, ! Zone Exhaust Air Node Name
    50,                       !- Maximum Heating Supply Air Temperature {C}
    13,                       !- Minimum Cooling Supply Air Temperature {C}
    0.0156,                   !- Maximum Heating Supply Air Humidity Ratio {kgWater/kgDryAir}
    0.0077,                   !- Minimum Cooling Supply Air Humidity Ratio {kgWater/kgDryAir}
    NoLimit,                  !- Heating Limit
    ,                         !- Maximum Heating Air Flow Rate {m3/s}
    ,                         !- Maximum Sensible Heating Capacity {W}
    NoLimit,                  !- Cooling Limit
    ,                         !- Maximum Cooling Air Flow Rate {m3/s}
    ,                         !- Maximum Total Cooling Capacity {W}
    ,                         !- Heating Availability Schedule Name
    ,                         !- Cooling Availability Schedule Name
    None,                     !- Dehumidification Control Type
    0.7,                      !- Cooling Sensible Heat Ratio
    None,                     !- Humidification Control Type
    Zone1 OA Specification, !- Design Specification Outdoor Air Object Name
    Zone1 Ideal Loads OA Inlet Node, !- Outdoor Air Inlet Node Name
    None,                     !- Demand Controlled Ventilation Type
    NoEconomizer,             !- Outdoor Air Economizer Type
    None,                     !- Heat Recovery Type
    0.70,                     !- Sensible Heat Recovery Effectiveness
    0.65;                     !- Latent Heat Recovery Effectiveness
```

Figure 2. Example EnergyPlus ideal loads air system object

3.3 Greenhouse Gas Emissions

Greenhouse gas emissions are not presented for this measure scenario since the Ideal Thermal Air Loads measure is HVAC system and fuel type agnostic. The public dataset still includes greenhouse gas emissions. However, the ideal thermal loads impacts, reported under district energy meters, are not reflected in the reported greenhouse gas emissions (ComStock does not currently include greenhouse gas estimates for district energy meters). Therefore, the reported greenhouse gas emissions for this measure scenario in the dataset do not include HVAC impacts.

3.4 Utility Bills

Utility bills are not presented for this measure scenario since the Ideal Thermal Air Loads measure is HVAC system and fuel type agnostic. The public dataset still includes utility bill impacts for natural gas, electricity, fuel oil, and propane. However, ideal thermal loads impacts are metered as district energy, which ComStock does not currently estimate bills for. Therefore, the reported utility bills for this measure scenario in the dataset do not include HVAC impacts.

3.5 Limitations and Concerns

The following limitations and concerns have been identified with this modeling study, which should be considered when using this data:

- Fan energy, and associated waste heat in the airstream, is not modeled in this study. This can increase the heating load and decrease the cooling load compared to HVAC systems that include fans. However, zone exhaust fans are not removed.

- Active humidity control is not modeled in this measure scenario. Buildings that do actively control humidity can use more energy doing so, which is not reflected in this work.

- A constant sensible heat ratio of 0.75 is used in this work. However, sensible heat ratio can vary based on equipment, run time, and conditions, which can impact results.

- Because this measure is HVAC system agnostic, interactions that occur in real HVAC systems, such as reheat, are not included in this work, nor are energy efficiency features such as heat recovery, demand control ventilation, and economizers that may be found in baseline ComStock models.

- The public dataset includes estimates for greenhouse gas emissions and utility bills, but these do not include the impact of the ideal thermal air loads. Greenhouse gas and utility bill estimates for this measure scenario will therefore only reflect non-HVAC end uses. Therefore, when comparing against the ComStock baseline, this measure scenario will likely show high savings since HVAC impacts are removed.

4 Output Variables

Table 2 includes a list of output variables that are calculated in ComStock. These variables are important in terms of understanding the differences between buildings with and without the Ideal Thermal Air Loads measure applied. These output variables can also be used for understanding the economics of the upgrade (e.g., return on investment) if cost information (e.g., material, labor, and maintenance costs for technology implementation) is available.

EnergyPlus meters the Ideal Thermal Air Loads measure under the district heating and district cooling end uses for heating and cooling loads, respectively. Therefore, the ideal thermal loads implemented in this measure scenario are reported under these fuel types, as shown in Table 2.

Table 2. Output Variables Calculated from the Measure Application

Variable Name	Description
out.district_cooling.cooling.energy_consumption..kwh	Building annual district cooling energy consumption for cooling end use. The ideal air loads measure scenario reports loads under this end use.
out.district_heating.heating.energy_consumption..kwh	Building annual district heating energy consumption for heating end use. The ideal air loads measure scenario reports loads under this end use.

5 Results

In this section, results are presented both at the stock level and for individual buildings through savings distributions. Stock-level results include the combined impact of all the analyzed buildings in ComStock, including buildings that are not applicable to this measure. Therefore, they do not necessarily represent the energy savings of a particular or average building. Stock-level results should not be interpreted as the savings that a building might realize by implementing the measure.

Total site energy savings are also presented in this section. Total site energy savings can be a useful metric, especially for quality assurance/quality control, but this metric on its own can have limitations for drawing conclusions. Further context should be considered, as site energy savings alone do not necessarily translate proportionally to savings for a particular fuel type (e.g., gas or electricity), source energy savings, and cost savings. This is especially important when a measure impacts multiple fuel types or causes decreased consumption of one fuel type and increased consumption of another. Many factors should be considered when analyzing the impact of an energy efficiency measure depending on the use case, noting that this study is theoretical for understanding building loads and does not represent a real building technology implementation.

5.1 Single Building Measure Tests

This section explores the application of the Ideal Thermal Air Loads measure scenario on a single ComStock building energy model to demonstrate performance at a manageable scale. The sample model is a 17,500 ft^2 small office located in Cody, Wyoming (climate zone 7A). The HVAC system type is packaged rooftop units (RTU) with gas furnace heating and direct expansion (DX) cooling.

Table 3 compares the sample ComStock model before and after the Ideal Thermal Air Loads scenario is applied. The end uses impacted by the change are heating, cooling, and fans; all other end uses are unaffected.

For the heating end use, energy is moved from natural gas to district heating water between the scenarios. This is because the Ideal Thermal Air Loads measure removed the gas-fired RTUs and reports the new ideal air loads under the district heating water fuel type. Also note that the heating energy for the Ideal Thermal Air Loads scenario is only about 80% of the baseline ComStock model. This is due to the baseline ComStock model using a gas furnace of ~80% efficiency, while the ideal air loads measure is 100% efficient.

For the cooling end use, energy is moved from electricity to district cooling between scenarios. Again, this is because the Ideal Thermal Air Loads measure scenario removes the DX cooling in the RTU and reports the new ideal loads under the district cooling end use. Also note that the cooling energy in the ideal air loads scenario is almost 3 times higher than the ComStock baseline. This is because the baseline model uses a DX cooling system with a coefficient of performance (COP) that ranges between 2 and 4, while the ideal air loads scenario has a constant COP of 1 (100% efficient).

Table 3. Comparison Between a Sample Model from the ComStock Baseline Versus the Same Model with the Ideal Thermal Air Loads Measure Applied

End Use/ Fuel Type	Baseline ComStock Model				Ideal Thermal Air Loads Applied			
	Electricity [kWh]	Natural Gas [kWh]	District Cooling [kWh]	District Heating Water [kWh]	Electricity [kWh]	Natural Gas [kWh]	District Cooling [kWh]	District Heating Water [kWh]
Heating	0	187583	0	0	0	0	0	148764
Cooling	8389	0	0	0	0	0	22764	0
Interior Lighting	15508	0	0	0	15508	0	0	0
Exterior Lighting	13067	0	0	0	13067	0	0	0
Interior Equipment	55578	0	0	0	55578	0	0	0
Fans	61447	0	0	0	0	0	0	0
Pumps	3	0	0	0	3	0	0	0
Water Systems	6458	0	0	0	6458	0	0	0
Total End Uses	160450	187583	0	0	90611	0	22764	148764

Energy used for the fan end use is completely removed in the Ideal Thermal Air Loads scenario. Despite the scenario using air streams for conditioning, it does so without the use of fans. Therefore, fan energy is removed, as is any impact from fan waste heat on the heating and cooling systems.

Lastly, note that the pump end use is unchanged between scenarios. This is because pumps in this model are only used for water heating, not space conditioning, and the Ideal Thermal Air Loads measure only impacts space conditioning. Other ComStock models may use pumps for space conditioning purposes, such as a chiller or boiler loop, where we expected to see a decrease in pump energy when removing the HVAC.

5.2 Stock Energy Impacts

The annual stock site energy savings by end use and fuel type are presented in Figure 3. Again, the Ideal Thermal Air Loads measure scenario does not represent an actual technology that can be implemented in a building. The results presented should only be used to understand how the measure is applied and therefore how to best utilize the results for understanding building thermal loads.

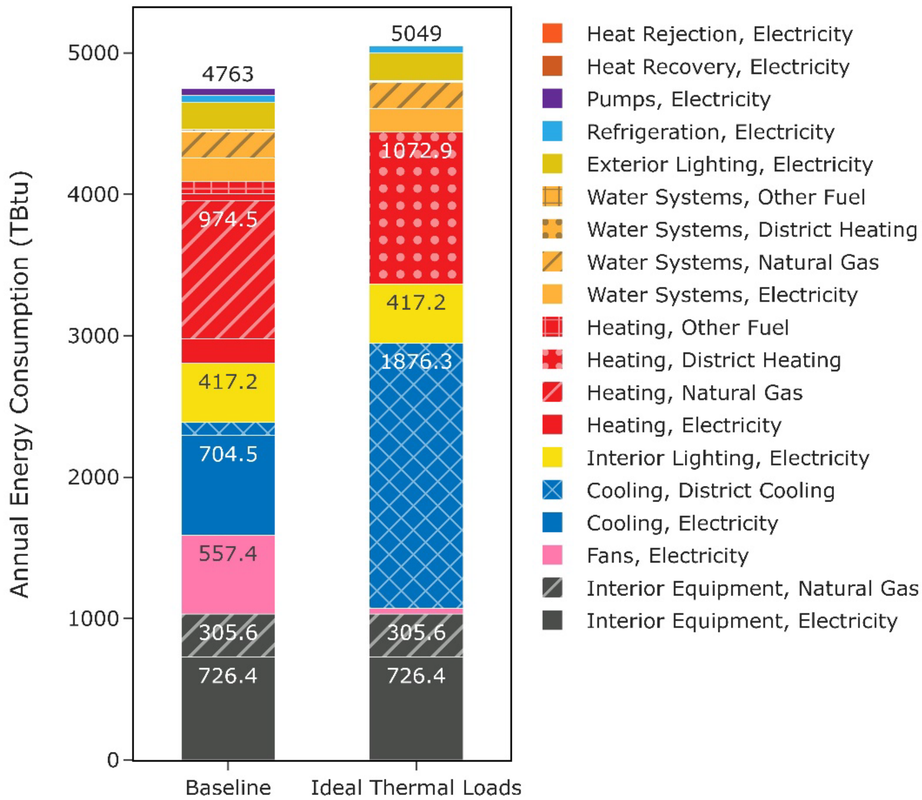

Figure 3. Comparison of annual site energy consumption between the ComStock baseline and the Ideal Thermal Air Loads scenario. Energy consumption is categorized both by fuel type and end use.

In the ComStock baseline compared to the Ideal Thermal Air Loads measure scenario, all heating energy is converted to district heating, regardless of the heating fuel type in the baseline. This is expected since the EnergyPlus ideal air loads objects are metered as district energy. The total heating energy increases slightly in the Ideal Thermal Air Loads scenario compared to the baseline. This is primarily because district energy is modeled as 100% efficient, while any gas heating found in the baseline is generally going to be modeled around 80% efficient. Additionally, the ideal air loads measure doesn't include potential system efficiency losses such as reheat in VAV systems and ensures ideal alignment between operation schedules. However, there are some features that can cause increased heating energy in some models. Energy efficiency technologies, such as heat recovery, economizers, and demand control ventilation, are not included in the Ideal Thermal Air Loads measure scenario, which can increase consumption. We chose not to include these technologies in the measure scenario to better represent the raw thermal building loads, irrespective of system-type-specific HVAC energy efficiency features.

Similarly, energy used for cooling is reported under the district cooling end use. However, one notable distinction is that the cooling end use shows much higher annual consumption in the Ideal Thermal Air Loads scenario compared to the baseline. This is because space cooling in the baseline predominately uses some kind of DX system with operational COPs generally ranging between 3 and 4. The Ideal Thermal Air Loads scenario models all cooling with 100%

efficiency, or a COP of 1, resulting in comparatively higher cooling energy consumption. But again, the results from this measure should only be used to understand building thermal loads and should not be used to compare energy consumption against the baseline ComStock model.

The fan end use is predominately eliminated in the Ideal Thermal Air Loads measure since supply and return fans are not used in this scenario. The small remaining fan energy usage shown is from zone exhaust fans, which are kept consistent between the baseline and Ideal Thermal Air Loads scenarios. Zone exhaust fans in ComStock are found in spaces such as kitchens and restrooms.

All other end uses show the same energy usage between the baseline and Ideal Thermal Air Loads measure scenario. This is expected since the systems driving energy usage in these other end uses are not impacted by the Ideal Thermal Air Loads scenario. The only exception to this is in systems where operation and efficiency are dependent on indoor air temperature, such as refrigeration. Small differences in indoor air temperature can lead to minimal changes in energy usage.

5.3 Stock Greenhouse Gas Emissions Impact

Greenhouse gas emissions are not presented for this measure scenario since this study is only intended to provide thermal heating and cooling loads for ComStock models and does not represent a real technology that can be implemented in buildings. Note that the ComStock public dataset still reports greenhouse gas emissions for this measure scenario for the non-heating and cooling end uses, but these should not be used since they don't represent an actual technology scenario.

5.4 Stock Utility Bill Impacts

Utility bill impacts are not presented for this measure scenario since this study is only intended to provide thermal heating and cooling loads for ComStock models and does not represent a real technology that can be implemented in buildings. Note that the ComStock public dataset still reports utility bill impacts for this measure scenario for the non-heating and cooling end uses, but these should not be used since they don't represent an actual technology scenario.

References

[1] EIA, "2018 COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY (CBECS)." Accessed: Nov. 13, 2022. [Online]. Available: https://www.eia.gov/consumption/commercial/

[2] A. Parker *et al.*, "ComStock Reference Documentation: Version 1," Golden, CO, 2023. Accessed: Apr. 02, 2023. [Online]. Available: https://www.nrel.gov/docs/fy23osti/83819.pdf

Appendix A.

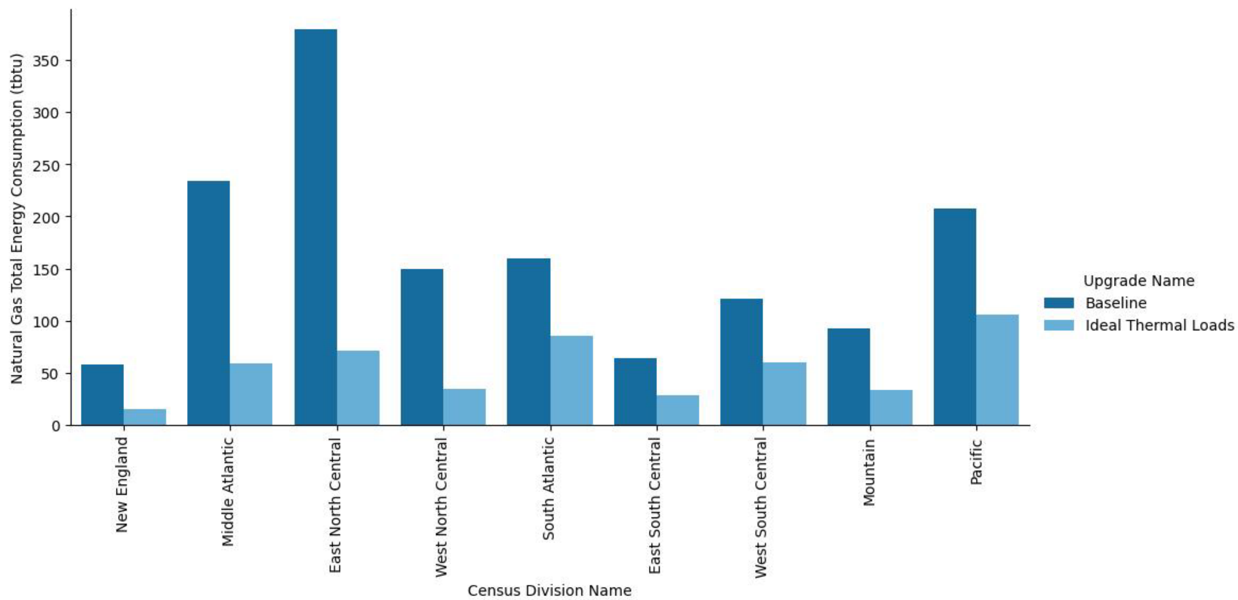

Figure A-1. Site annual natural gas consumption of the ComStock baseline and the measure scenario by census division

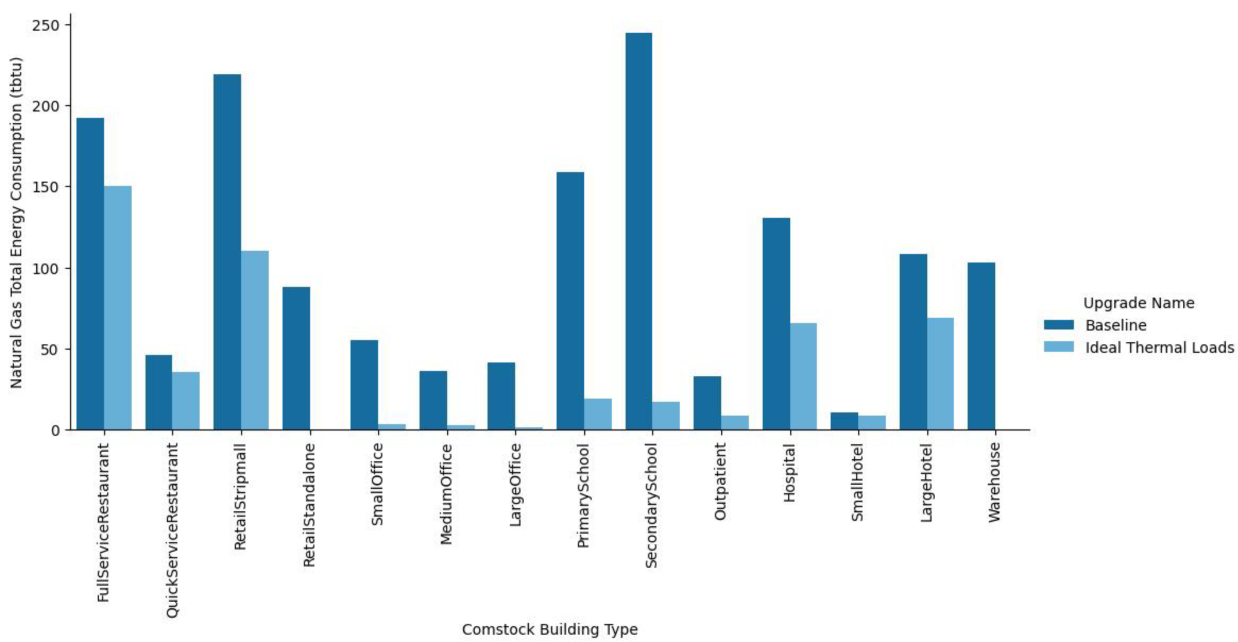

Figure A-2. Site annual natural gas consumption of the ComStock baseline and the measure scenario by building type

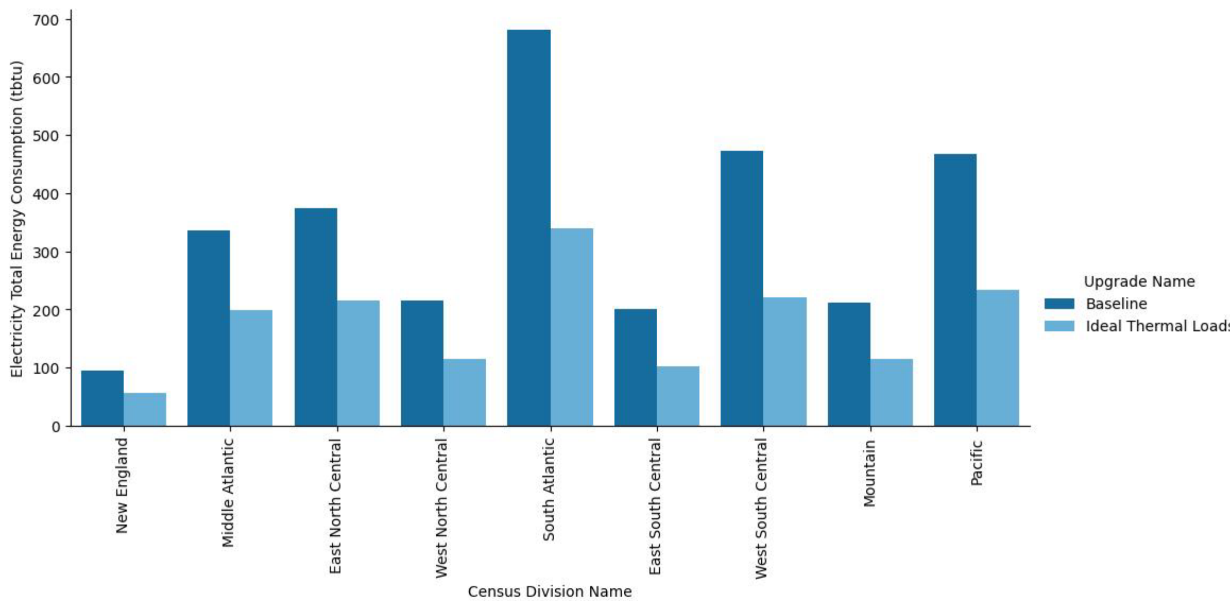

Figure A-3. Site annual electricity consumption of the ComStock baseline and the measure scenario by building type

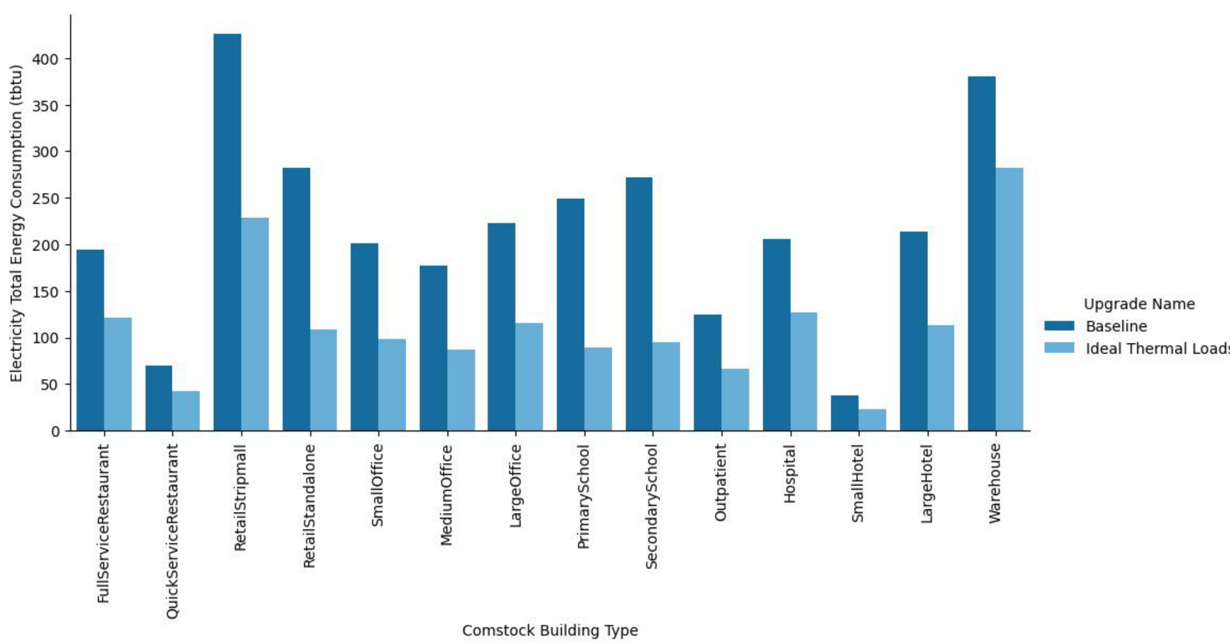

Figure A-4. Site annual electricity consumption of the ComStock baseline and the measure scenario by census division