# Washington State Commercial Building Energy Modeling Analysis

Prepared for the Washington State Energy Code Technical Advisory Group (TAG)

**Prepared on behalf of:**

California Statewide Utility Codes and Standards Team

**Prepared by:**

Neil Bulger, A2 Efficiency
Shilpa Surana, Kristen Driskell, 2050 Partners
August 28, 2023

This report was prepared on behalf of the California Statewide Codes and Standards Program that is funded, in part, by California utility customers under the auspices of the California Public Utilities Commission.

# WA EPCA Commercial Building Energy Modeling Analysis

Date: 08/28/2023

## Executive Summary of Energy Analysis

### Overview

The 2021 Washington State Energy Code – Commercial (WSEC-C) is currently under review and revision to explore the integration of gas-based systems in buildings while maintaining the required level of efficiency standards. The Energy Code Technical Advisory Group has sought support from the California Investor-Owned Utilities (CA IOUs) Code and Standards team to evaluate a series of building energy models to aid in the development of a set of energy efficiency credits based on a proposed enhancement to the prescriptive code. The CA IOUs have been advocates for multiple improvements to both the International Energy Conservation Code (IECC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 90.1. These efforts aim to enhance national energy efficiency and contribute to potential advancements in California's future building standards. While this collaboration is focused on aiding the Washington state energy code, many elements within the proposal offer possibilities for similar applications in the IECC, ASHRAE 90.1, and future California state building code and reach code advancements.

The following memo outlines the approach and assumptions used in the development of typical building energy modeling results for the 2021 Washington State Energy Code – Commercial (WSEC-C) Energy Policy Conservation Act (EPCA) compliant prescriptive pathway for a natural gas and all electric system. Modeling assumptions [1]utilized in developing a series of energy models and the results of the simulation in two climate zones in Washington State are included below.

## Energy Modeling Framework

Energy modeling of prototypical buildings were used to evaluate the energy use with two different fuel options for space heating and water heating, one based on all electric sources and one based on natural gas sources. Models were developed from a set of pre-existing EnergyPlus models developed for 2018 WSEC-C code evaluations. Models were modified to generate the different heating components necessary to create the different fuel options. Due to time constraints in analysis, no additional efficiency modifications were made to these prototype models to represent the 2021 code provisions. The models are detailed enough to establish the difference in site energy use across major building types between natural gas heating technologies and electric heat pump equipment. The modeled results and additional efficiency credits developed in this analysis only represent the starting point for a code change proposal which was developed outside of this report and includes several modifications when utilizing these results.

Models were evaluated in two ASHRAE Climate Zones, 4C and 5B in Washington State utilizing Seattle and Spokane weather files. Six building prototypes were developed to determine site energy use and efficiency credit differences.

[1] Detailed modeling assumptions and link to modeling files are available upon request.

## Additional Energy Credits

Credits are based on site energy difference from a gas-based system to an all-electric system for space and domestic hot water heating. These credits would be included in the 2021 code language revisions proposed for WSEC-C[2]. Based on the models available, the final construction group 'All Other' was estimated based on averaging all other building types as a reasonable estimate of efficiency differences.

| Model Mapping to Construction Group | *Hotel Small* | *MF Apartment Midrise* | *Office Medium* | *School Primary* | *Retail Stand Alone* | *Avg* |
|---|---|---|---|---|---|---|

| **Additional Credits** | **Group R-1** | **Group R-2** | **Group B** | **Group E** | **Group M** | **All Other** |
|---|---|---|---|---|---|---|
| Space Heating | 7 | 24 | 101 | 38 | 111 | 56 |
| Domestic Hot Water | 198 | 204 | 27 | 17 | 79 | 105 |
| ***Total*** | ***205*** | ***228*** | ***128*** | ***55*** | ***190*** | ***161*** |

Construction weighted to be 75% in CZ4C, 25% in CZ5B

| Space Heating Credits | | | |
|---|---|---|---|
| Building Prototype | **CZ4C** | **CZ5B** | Weighted Average (Rounded) |
| Office Medium | 93 | 126 | 101 |
| MF Apartment Midrise | 17 | 45 | 24 |
| School Primary | 33 | 54 | 38 |
| Warehouse | 134 | 200 | 151 |
| Retail Stand Alone | 98 | 149 | 111 |
| Hotel Small | 6 | 11 | 7 |

| Domestic HW Credits | | | |
|---|---|---|---|
| Building Prototype | **CZ4C** | **CZ5B** | Weighted Average (Rounded) |
| Office Medium | 28 | 25 | 27 |
| MF Apartment Midrise | 219 | 159 | 204 |
| School Primary | 20 | 10 | 17 |
| Warehouse | 28 | 17 | 26 |
| Retail Stand Alone | 83 | 66 | 79 |
| Hotel Small | 196 | 202 | 198 |

[2] https://sbcc.wa.gov/sites/default/files/2023-05/2021_WSEC_C_2ndPrint_0518023.pdf

# Energy Analysis in Support of WA Compliance Pathway Development

8/28/2023
A2 Efficiency

The following energy analysis was developed for support of multiple heating fuel pathways for the WA 2021 code. The project was in support of identifying opportunities for further enhancements to energy codes both federal and state in other jurisdictions where similar challenges to advancing cost effective, low emission systems will be needed.

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# Energy Modeling Inputs

## Systems Map for Space Heating and Domestic Hot Water Systems

The following systems were utilized in each prototype for space heating and water heating in the following all electric and gas system models:

| | Electric Systems | | Gas Systems | |
|---|---|---|---|---|
| Building Prototype | Space Heating | DHW Heating | Space Heating | DHW Heating |
| Office Medium | DOAS + Fan Coil Air to Water Heat Pump | HPWH central* | DOAS + Fan Coil Boiler central | Gas WH central |
| Apartment Midrise | DOAS + Unitary HP, Split System | HPWH central* | DOAS + Unitary AC with Furnace | Gas WH unitized |
| School Primary | DOAS + Unitary HP, Single Packaged | HPWH central* | DOAS + Unitary AC with Furnace | Gas WH unitized |
| Warehouse | DOAS + Unitary HP, Single Packaged | HPWH unitary* | DOAS + Unitary AC with Furnace | Gas WH unitary |
| Retail Stand Alone | DOAS + Unitary HP, Single Packaged | HPWH unitary * | DOAS + Unitary AC with Furnace | Gas WH unitary |
| Hotel Small | DOAS + Unitary HP Split System in common PTAC AC-Elec guest rooms | HPWH central* | DOAS + Unitary AC with Furnace in common PTAC AC-Elec guest rooms | Gas WH central |

**all HPWH system included an electric resistance element located in a swing tank for central systems and in the primary tank for unitary systems for peak demand instances.*

## Domestic Hot Water System Efficiency Assumptions

Efficiency values for each heat pump unit were derived from minimum efficiency criteria tables as outlined in Section C403 of the 2021 WSEC-Commercial provisions. For all heat pump models, the heat pumps were configured along with a heating element in the secondary swing tank to provide heat. For centralized systems, electric resistance was included in the secondary swing-tank, which provided heating for the recirculation loop and pipe losses in the buildings.

Heat Pump Water Heater (HPWH) efficiency was determined to be two different values:

| DHW System | Efficiency |
|---|---|
| HPWH unitized (stand alone without a pump) | UEF >=2.24 (WA 2021)<br>COP = 2.24 (assumed) |
| HPWH central | COP 2.31 for CZ4c<br>COP 1.63 for CZ5b |

1. COP 2.31 Table 403.3.2(15) Heat Pump and Heat Recovery Chiller Minimum Efficiency; Air Source, 47F, 140F Supply Water
2. COP 1.63 Table 403.3.2(15) Heat Pump and Heat Recovery Chiller Minimum Efficiency; Air Source, 17F, 140F Supply Water
3. For smaller systems (such as unitary),Table C404.2 requires at the most a UEF of >= 2.24.

Key information on sizing of each system in each building prototype is included in the following table. Pipe losses for each HPWH system are accounted for as “Parasitic losses”, shown for the swing tank object, with the same value for On and Off in the simulated model as shown in the table below.

The following are key assumptions for sizing each heat pump water heater in the all electric systems. In EnergyPlus, heat pump water heaters are defined by multiple objects with several parameters requiring manual sizing.

| EnergyPlus Object | Attribute | Unit | Medium Office | Hotel, DHW | Hotel, Laundry | Apartment, Midrise | Retail Standalone | School, Primary | Warehouse |
|---|---|---|---|---|---|---|---|---|---|
| HPWH Sched | Supply | F | 139.1 | 139.1 | 139.1 | 139.1 | 139.1 | 139.1 | 139.1 |
| WaterHeater:Stratified | Tanks Size | gal | 465 | 465 | 465 | 465 | 40 | 250 | 20 |
| | Heat Capacity 1 | Watts | 2,951 | 9,901 | 7,116 | 6,243 | 1,040 | 5,800 | 443 |
| | Off Cycle Parasitic | Watts | 472 | 1584 | 1139 | 999 | 166 | 928 | 71 |
| | On Cycle Parasitic | Watts | 472 | 1584 | 1139 | 999 | 166 | 928 | 71 |
| Coil:WaterHeating:Air ToWater HeatPump:Pumped | Heating Capacity | Btu/h | 20,135 | 67,564 | 48,559 | 42,600 | 7,096 | 39,579 | 3,026 |
| DHW Temperature Change | | Delta-F | 86.1 | 86.1 | 86.1 | 86.1 | 86.9 | 86.9 | 86.9 |
| Peak Heating Load | =500*gpm*delta-t | Btu/h | 20,135 | 67,564 | 48,559 | 42,600 | 7,096 | 39,579 | 3,026 |
| | Sizing Factor | % | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| | | Btu/h | 28,188.8 | 94,590.0 | 67,982.2 | 59,640.1 | 9,934.8 | 55,410.7 | 4,236.7 |
| | Heating Capacity | Watts | 5,311 | 17,822 | 12,809 | 11,237 | 1,872 | 10,440 | 798 |
| | Efficiency (CZ4c)1 | $COP_{47}$ | 2.31 | 2.31 | 2.31 | 2.31 | n/a | 2.31 | n/a |
| | Efficiency (CZ5b)2 | $COP_{17}$ | 1.63 | 1.63 | 1.63 | 1.63 | n/a | 1.63 | n/a |
| | Efficiency (Unitary)3 | UEF | n/a | n/a | n/a | n/a | 2.24 | n/a | 2.24 |
| | Pump Power | Btu/h | 512 | 512 | 512 | 512 | 0 | 512 | 0 |
| Circulation Pump | Included | Y/N | yes | yes | yes | yes | no | yes | no |
| Fan:SystemModel | Pressure | inH2O | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 | 0.401 |
| WaterUse:Equipment | Peak Flow rate | gal/min | 0.06 | 3.70E-02 | | | | | |
| Number of Water Uses | # | | 15.00 | 77 | | | | | |
| Total Flow Peak | Peak Flow rate | gal/min | 0.85 | 2.85 | 2.05 | 1.80 | 0.30 | 1.67 | 0.13 |
| **Calculated Parameters** | | | | | | | | | |
| HP Power | Compressor | Watts | 2,555 | 8,572 | 6,161 | 5,405 | 928 | 5,022 | 396 |
| Ratio Swing Tank Elec Total | | % | 54% | 54% | 54% | 54% | 53% | 54% | 53% |
| Capacity of HP to Load Peak | | % | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| Parasitic Load to Capacity | | % | 16% | 16% | 16% | 16% | 16% | 16% | 16% |
| Tank Size to Flow | size/flow | hrs | 9.12 | 2.72 | 3.78 | 4.31 | 2.23 | 2.49 | 2.61 |

1. Table 403.3.2(15) Heat Pump and Heat Recovery Chiller Minimum Efficiency; Air Source, 47F, 140F Supply Water
2. Table 403.3.2(15) Heat Pump and Heat Recovery Chiller Minimum Efficiency; Air Source, 17F, 140F Supply Water

## Model Enhancements for Indirect Assumptions

For select models, the assumptions to building usage was enhanced to better represent anticipated building use patterns which directly impact building heating and hot water use. Values were modified based on identified sources of information and informed by evaluating the resultant end use for space heating and domestic hot water compared with measured building data showing end uses.

*By Building, note each building and if no changes, note (same as DOE / PNNL assumptions from 2018 WA code evaluation).*

***Office Medium***

HVAC system changed from WSHP to be Four-Pipe-Fan-Coils with either AWHP or Boiler so the natural gas systems is 100% gas or 100% electric. WSHP with boiler represents a hybrid system with higher efficiencies.

- Office envelope assumptions were also updated in all models to better represent heating loads.
    - Changes in air leakage coefficients for wind speed, temperature
    - Changes to window U-factors to account for thermal bridging of frames
- Office internal gains were modified to better represent lower internal gains requiring more heating:
    - Reduced elevator power
    - Reduced equipment in office power density
    - Reduced occupancy schedule value peaks
    - Reduced lighting schedule value peaks
- Office domestic hot water flow rate at peak was reduced to better match expected office heating EUI. Target EUI for office water use based on CA Title 24 flow rates and schedules.

***School Primary***

No changes

***Apartment Midrise***

No changes

***Warehouse***

No changes

***Retail***

No changes

***Hotel***

No changes

# Appendix 1: Energy Modeling Results

## Office Medium

| | | office-medium CZ4C | CZ4C | | | office-medium CZ5B | CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 13.3 | 13.3 | 0% | 0.0 | 13.3 | 13.3 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 3.0 | 3.0 | 0% | 0.0 | 3.0 | 3.0 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 1.2 | 1.2 | 0% | 0.0 | 1.2 | 1.2 | 0% | 0.0 |
| Fans | *kBtu/sf* | 1.6 | 1.5 | 8% | -0.1 | 2.0 | 1.6 | 17% | -0.3 |
| Pumps | *kBtu/sf* | 0.4 | 0.4 | -14% | 0.1 | 0.43 | 0.52 | -21% | 0.1 |
| Cooling | *kBtu/sf* | 6.2 | 6.1 | 1% | -0.1 | 6.4 | 6.4 | 1% | 0.0 |
| Space Heat, Gas | *kBtu/sf* | 4.3 | 0.0 | 100% | -4.3 | 8.9 | 0.0 | 100% | -8.9 |
| Space Heat, Elec | *kBtu/sf* | 0.0 | 1.4 | 0% | 1.4 | 0.0 | 4.3 | 0% | 4.3 |
| DHW, Gas | *kBtu/sf* | 1.2 | 0.0 | 100% | -1.2 | 1.2 | 0.0 | 100% | -1.2 |
| DHW, Elec | *kBtu/sf* | 0.0 | 0.5 | 0% | 0.5 | 0.0 | 0.6 | 0% | 0.6 |
| BACK CHECK EUI | | *31.1* | *27.4* | 12% | -3.8 | *36.4* | *30.9* | 15% | -5.5 |
| **TOTAL** | ***kBtu/sf*** | **31.1** | **27.4** | **12%** | **-3.8** | **36.4** | **30.9** | **15%** | **-5.5** |

| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | *kBtu/sf* | 13.3 | 13.3 | | | 13.3 | 13.3 | | |
| Lighting | *kBtu/sf* | 4.2 | 4.2 | | | 4.2 | 4.2 | | |
| Space Heating | *kBtu/sf* | 4.3 | 1.4 | 9.3% | 93 | 8.9 | 4.3 | 12.6% | 126 |
| DHW (+ HVAC) | *kBtu/sf* | 9.4 | 8.5 | 2.8% | 28 | 10.0 | 9.1 | 2.5% | 25 |
| | | 31.12 | 27.36 | | | 36.38 | 30.85 | | |
| | | | 12.1% | | | | 15.2% | | |

## Apartment-Midrise

| | | multifamily-midrise CZ4C | CZ4C | | | multifamily-midrise CZ5B | CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 13.5 | 13.5 | 0% | 0.0 | 13.5 | 13.5 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 3.6 | 3.6 | 0% | 0.0 | 3.6 | 3.6 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 0.7 | 0.7 | 0% | 0.0 | 0.7 | 0.7 | 0% | 0.0 |
| Fans | *kBtu/sf* | 2.2 | 2.2 | -1% | 0.0 | 2.4 | 2.8 | -13% | 0.3 |
| Pumps* | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Cooling | *kBtu/sf* | 2.5 | 2.2 | 13% | -0.3 | 2.8 | 2.5 | 10% | -0.3 |
| Space Heat, Gas | *kBtu/sf* | 1.3 | 0.0 | 100% | -1.3 | 4.3 | 0.0 | 100% | -4.3 |
| Space Heat, Elec | *kBtu/sf* | 0.0 | 0.6 | 0% | 0.6 | 0.0 | 2.3 | 0% | 2.3 |
| DHW, Gas | *kBtu/sf* | 15.8 | 0.0 | 100% | -15.8 | 15.8 | 0.0 | 100% | -15.8 |
| DHW, Elec | *kBtu/sf* | 0.0 | 7.4 | 0% | 7.4 | 0.0 | 8.9 | 0% | 8.9 |
| BACK CHECK EUI | | *39.6* | *30.3* | 24% | -9.3 | *43.1* | *34.3* | 20% | -8.8 |
| **TOTAL** | ***kBtu/sf*** | **39.6** | **30.2** | **24%** | **-9.3** | **43.1** | **34.3** | **20%** | **-8.8** |
| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
| Equipment | *kBtu/sf* | 13.5 | 13.5 | | | 13.5 | 13.5 | | |
| Lighting | *kBtu/sf* | 4.3 | 4.3 | | | 4.3 | 4.3 | | |
| Space Heating | *kBtu/sf* | 1.3 | 0.6 | 1.7% | 17 | 4.3 | 2.3 | 4.5% | 45 |
| DHW (+ HVAC) | *kBtu/sf* | 20.5 | 11.8 | 21.9% | 219 | 21.0 | 14.2 | 15.9% | 159 |
| | | 39.59 | 30.25 | | | 43.11 | 34.29 | | |
| | | | 23.6% | | | | 20.5% | | |

**Note: Pumps are less than 0.01 EUI and not shown here with the resolution of these results*

## School-Primary

| | | **school-primary** CZ4C | CZ4C | | | **school-primary** CZ5B | CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 19.3 | 19.3 | 0% | 0.0 | 19.3 | 19.3 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.2 | 0.2 | 0% | 0.0 | 0.2 | 0.2 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.8 | 0.8 | 0% | 0.0 | 0.8 | 0.8 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 3.2 | 3.2 | 0% | 0.0 | 3.2 | 3.2 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 0.4 | 0.4 | 0% | 0.0 | 0.4 | 0.4 | 0% | 0.0 |
| Fans | *kBtu/sf* | 3.4 | 3.5 | -1% | 0.0 | 3.8 | 4.0 | -6% | 0.2 |
| Pumps* | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Cooling | *kBtu/sf* | 1.6 | 1.6 | 0% | 0.0 | 2.4 | 2.3 | 0% | 0.0 |
| Space Heat, Gas | *kBtu/sf* | 1.6 | 0.0 | 100% | -1.6 | 3.6 | 0.0 | 100% | -3.6 |
| Space Heat, Elec | *kBtu/sf* | 0.0 | 0.5 | -7199% | 0.5 | 0.0 | 1.7 | -10329% | 1.7 |
| DHW, Gas | *kBtu/sf* | 2.2 | 0.0 | 100% | -2.2 | 2.2 | 0.0 | 100% | -2.2 |
| DHW, Elec | *kBtu/sf* | 0.0 | 1.5 | 0% | 1.5 | 0.0 | 1.7 | 0% | 1.7 |
| BACK CHECK EUI | | *32.8* | *31.1* | 5% | -1.7 | *35.9* | *33.7* | 6% | -2.3 |
| **TOTAL** | ***kBtu/sf*** | **32.8** | **31.1** | **5%** | **-1.7** | **35.9** | **33.7** | **6%** | **-2.3** |

| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | *kBtu/sf* | 20.3 | 20.3 | | | 20.3 | 20.3 | | |
| Lighting | *kBtu/sf* | 3.6 | 3.6 | | | 3.6 | 3.6 | | |
| Space Heating | *kBtu/sf* | 1.6 | 0.5 | 3.3% | 33 | 3.7 | 1.7 | 5.4% | 54 |
| DHW (+ HVAC) | *kBtu/sf* | 7.2 | 6.6 | 2.0% | 20 | 8.3 | 8.0 | 1.0% | 10 |
| | | 32.78 | 31.06 | | | 35.93 | 33.66 | | |
| | | | 5.3% | | | | 6.3% | | |

**Note: Pumps are less than 0.01 EUI and not shown here with the resolution of these results*

## Retail Stand Alone

| | | retail-standalone CZ4C | CZ4C | | | retail-standalone CZ5B | CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 7.5 | 7.5 | 0% | 0.0 | 7.5 | 7.5 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 8.6 | 8.6 | 0% | 0.0 | 8.7 | 8.7 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 1.6 | 1.6 | 0% | 0.0 | 1.6 | 1.6 | 0% | 0.0 |
| Fans | *kBtu/sf* | 3.3 | 3.3 | -1% | 0.0 | 3.6 | 3.8 | -6% | 0.2 |
| Pumps | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Cooling | *kBtu/sf* | 1.4 | 1.4 | -1% | 0.0 | 2.0 | 2.0 | -1% | 0.0 |
| Space Heat, Gas | *kBtu/sf* | 4.6 | 0.0 | 100% | -4.6 | 9.7 | 0.0 | 100% | -9.7 |
| Space Heat, Elec | *kBtu/sf* | 0.0 | 1.6 | 0% | 1.6 | 0.0 | 4.2 | 0% | 4.2 |
| DHW, Gas | *kBtu/sf* | 3.6 | 0.0 | 100% | -3.6 | 3.6 | 0.0 | 100% | -3.6 |
| DHW, Elec | *kBtu/sf* | 0.0 | 1.0 | 0% | 1.0 | 0.0 | 1.0 | 0% | 1.0 |
| BACK CHECK EUI | | *30.7* | *25.1* | 18% | -5.6 | *36.7* | *28.8* | 22% | -7.9 |
| **TOTAL** | ***kBtu/sf*** | **30.6** | **25.1** | **18%** | **-5.6** | **36.7** | **28.8** | **22%** | **-7.9** |

| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | *kBtu/sf* | 7.5 | 7.5 | | | 7.5 | 7.5 | | |
| Lighting | *kBtu/sf* | 10.3 | 10.3 | | | 10.3 | 10.3 | | |
| Space Heating | *kBtu/sf* | 4.6 | 1.6 | 9.8% | 98 | 9.7 | 4.2 | 14.9% | 149 |
| DHW (+ HVAC) | *kBtu/sf* | 8.3 | 5.7 | 8.3% | 83 | 9.2 | 6.8 | 6.6% | 66 |
| | | 30.65 | 25.09 | | | 36.69 | 28.80 | | |
| | | | 18.1% | | | | 21.5% | | |

## Warehouse

| | | warehouse CZ4C | CZ4C | | | warehouse CZ5B | CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 2.5 | 2.5 | 0% | 0.0 | 2.5 | 2.5 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 1.9 | 1.9 | 0% | 0.0 | 1.9 | 1.9 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 1.2 | 1.2 | 0% | 0.0 | 1.2 | 1.2 | 0% | 0.0 |
| Fans | *kBtu/sf* | 0.4 | 0.4 | -2% | 0.0 | 0.5 | 0.6 | -11% | 0.1 |
| Pumps | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Cooling | *kBtu/sf* | 0.1 | 0.1 | -11% | 0.0 | 0.1 | 0.1 | -5% | 0.0 |
| Space Heat, Gas | *kBtu/sf* | 2.2 | 0.0 | 100% | -2.2 | 7.6 | 0.0 | 100% | -7.6 |
| Space Heat, Elec | *kBtu/sf* | 0.0 | 1.0 | 0% | 1.0 | 0.0 | 4.7 | 0% | 4.7 |
| DHW, Gas | *kBtu/sf* | 0.5 | 0.0 | 100% | -0.5 | 0.5 | 0.0 | 100% | -0.5 |
| DHW, Elec | *kBtu/sf* | 0.0 | 0.2 | 0% | 0.2 | 0.0 | 0.2 | 0% | 0.2 |
| BACK CHECK EUI | | *8.8* | *7.4* | 16% | -1.4 | *14.4* | *11.3* | 22% | -3.1 |
| **TOTAL** | ***kBtu/sf*** | **8.8** | **7.4** | **16%** | **-1.4** | **14.4** | **11.3** | **22%** | **-3.1** |

| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | *kBtu/sf* | 2.5 | 2.5 | | | 2.5 | 2.5 | | |
| Lighting | *kBtu/sf* | 3.1 | 3.1 | | | 3.1 | 3.1 | | |
| Space Heating | *kBtu/sf* | 2.2 | 1.0 | 13.4% | 134 | 7.6 | 4.7 | 20.0% | 200 |
| DHW (+ HVAC) | *kBtu/sf* | 1.0 | 0.7 | 2.8% | 28 | 1.2 | 0.9 | 1.7% | 17 |
| | | 8.81 | 7.38 | | | 14.38 | 11.25 | | |
| | | | 16.3% | | | | 21.8% | | |

## Hotel Small

| | | Hotel Small CZ4C | Hotel Small CZ4C | | | Hotel Small CZ5B | Hotel Small CZ5B | | |
|---|---|---|---|---|---|---|---|---|---|
| | | gas | hp | Site Savings (%) | Site Savings EUI | gas | hp | Site Savings (%) | Site Savings EUI |
| Equipment Int. | *kBtu/sf* | 22.2 | 22.2 | 0% | 0.0 | 22.2 | 22.2 | 0% | 0.0 |
| Equipment Ext. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Equipment Refrig. | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Lighting Int. | *kBtu/sf* | 3.6 | 3.6 | 0% | 0.0 | 3.6 | 3.6 | 0% | 0.0 |
| Lighting Ext. | *kBtu/sf* | 0.9 | 0.9 | 0% | 0.0 | 0.9 | 0.9 | 0% | 0.0 |
| Fans | *kBtu/sf* | 6.4 | 6.4 | 0% | 0.0 | 7.3 | 7.3 | 0% | 0.0 |
| Pumps | *kBtu/sf* | 0.0 | 0.0 | 0% | 0.0 | 0.0 | 0.0 | 0% | 0.0 |
| Cooling | *kBtu/sf* | 5.7 | 5.5 | 4% | -0.2 | 5.6 | 5.3 | 5% | -0.3 |
| Space Heat, Gas | *kBtu/sf* | 0.6 | 0.0 | 100% | -0.6 | 1.3 | 0.0 | 100% | -1.3 |
| Space Heat, Elec | *kBtu/sf* | 0.8 | 1.0 | -25% | 0.2 | 2.1 | 2.7 | -30% | 0.6 |
| DHW, Gas | *kBtu/sf* | 22.0 | 0.0 | 100% | -22.0 | 22.0 | 0.0 | 100% | -22.0 |
| DHW, Elec | *kBtu/sf* | 0.0 | 10.0 | 0% | 10.0 | 0.0 | 9.1 | 0% | 9.1 |
| BACK CHECK EUI | | *62.3* | *49.7* | 20% | -12.6 | *65.1* | *51.2* | 21% | -13.9 |
| **TOTAL** | ***kBtu/sf*** | **62.3** | **49.7** | **20%** | **-12.6** | **65.1** | **51.2** | **21%** | **-13.9** |

| | | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits | Site Energy: Gas | Site Energy: Elec | Energy Savings (% site) | Additional Credits |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | *kBtu/sf* | 22.2 | 22.2 | | | 22.2 | 22.2 | | |
| Lighting | *kBtu/sf* | 4.6 | 4.6 | | | 4.5 | 4.5 | | |
| Space Heating | *kBtu/sf* | 1.3 | 1.0 | 0.6% | 6 | 3.4 | 2.7 | 1.1% | 11 |
| DHW (+ HVAC) | *kBtu/sf* | 34.2 | 21.9 | 19.6% | 196 | 34.9 | 21.7 | 20.2% | 202 |
| | | 62.27 | 49.69 | | | 65.08 | 51.20 | | |
| | | | 20.2% | | | | 21.3% | | |

# Appendix 2: Energy Modeling Key Inputs for Efficiency

MODEL EFFICIENCY INPUTS

## Office Medium

| **Office Medium** | | **Office Medium** | |
|---|---|---|---|
| Electric Heating | | Gas Heating | |
| Scenario | | Scenario | |
| *Space Heating* | | *Space Heating* | |
| *Central Heat Pump and HR Chillers* | | Central Boiler | |
| Table C403.3.2(15) | | Table 403.3.2(6) | |
| Air Source HP, OA DB 47F (CZ4C) | | Boiler, hot water | |
| | | Capacity Range, | |
| Medium HW, 120 F | | BTU/h | 300,000 to 2,500,000 Btu/h |
| Capacity Range, BTU/h | any | Efficiency, Et | 84% |
| Model Compressor, | | | |
| COP | 2.77 | Efficiency Modeled | 84% |
| Air Source HP, OA DB 17F (CZ5B) | | | |
| Medium HW, 120 F | | | |
| Model Compressor, | | | |
| COP | 1.95 | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Central HPWH | | Central Boiler | |
| Model Compressor, | 2.31 or 1.63 | | |
| COP | by CZ | Modeled Efficiency | 80% |

## Apartment Midrise

| **Apartment Midrise** | | **Apartment Midrise** | |
|---|---|---|---|
| Electric Heating Scenario | | Gas Heating Scenario | |
| *Space Heating,* | | *Space Heating,* | |
| *apartments only shown* | | *apartments only shown* | |
| | | Air Cooled Unitary with | |
| *Air Cooled Unitary Heat Pumps* | | Furnace | |
| Table 403.3.2(2) | | Table 403.3.2(5) | |
| Capacity Range, BTU/h | <65000 | Capacity Range, BTU/h | any |
| Split System, three phase | | Warm Air Duct Furnace | |
| Efficiency, HSPF | 7.5 | Efficiency, Ec | 80% |
| Model Compressor, COP | 3.69 | Modeled Efficiency | 80% |
| *COP_heat = -0.0296 x HSPF^2 + 0.7134 x HSPF* | | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Central HPWH | | In-Unit Gas | |
| | 2.31 or 1.63 | | |
| Model System, COP | by CZ | Modeled Efficiency | 80% |

## School Primary

| **School Primary** | | **School Primary** | |
|---|---|---|---|
| Electric Heating Scenario | | Gas Heating Scenario | |
| *Space Heating* | | *Space Heating* | |
| | | Air Cooled Unitary with | |
| *Air Cooled Unitary Heat Pumps* | | Furnace | |
| Table 403.3.2(2) | | Table 403.3.2(5) | |
| Capacity Range, BTU/h | <65000 | Capacity Range, BTU/h | any |
| Single Packaged, three phase | | Warm Air Duct Furnace | |
| Efficiency, HSPF | 6.7 | Efficiency, Ec | 80% |
| Model Compressor, COP | 3.45 | Modeled Efficiency | 80% |
| *COP_heat = -0.0296 x HSPF^2 + 0.7134 x HSPF* | | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Central HPWH | | *Gas Stand Alone Unit* | |

| | | | |
|---|---|---|---|
| Model System, COP | 2.31 or 1.63 by CZ | Modeled Efficiency | 80% |

Warehouse

| **Warehouse** | | **Warehouse** | |
|---|---|---|---|
| Electric Heating Scenario | | Gas Heating Scenario | |
| *Space Heating* | | *Space Heating* | |
| | | Air Cooled Unitary with | |
| *Air Cooled Unitary Heat Pumps* | | Furnace | |
| Table 403.3.2(2) | | Table 403.3.2(5) | |
| Capacity Range, BTU/h | <65000 | Capacity Range, BTU/h | any |
| Single Packaged, three phase | | Warm Air Duct Furnace | |
| Efficiency, HSPF | 6.7 | Efficiency, Ec | 80% |
| Model Compressor, COP | 3.45 | Modeled Efficiency | 80% |
| *COP_heat = -0.0296 x HSPF^2 + 0.7134 x HSPF* | | | |
| | | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Unitized HPWH | | Unitized gas water heater | |
| Model System, COP | 2.24 | Modeled Efficiency | 80% |

Retail Stand Alone

| **Retail** | | **Retail** | |
|---|---|---|---|
| Electric Heating Scenario | | Gas Heating Scenario | |
| *Space Heating* | | *Space Heating* | |
| | | Air Cooled Unitary with | |
| *Air Cooled Unitary Heat Pumps* | | Furnace | |
| Table 403.3.2(2) | | Table 403.3.2(5) | |
| Capacity Range, BTU/h | <65000 | Capacity Range, BTU/h | any |
| Single Packaged, three phase | | Warm Air Duct Furnace | |
| Efficiency, HSPF | 6.7 | Efficiency, Ec | 80% |
| Model Compressor, COP | 3.45 | Modeled Efficiency | 80% |
| *COP_heat = -0.0296 x HSPF^2 + 0.7134 x HSPF* | | | |
| | | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Unitized HPWH | | Unitized gas water heater | |
| Model System, COP | 2.24 | Modeled Efficiency | 80% |

Hotel Small

| **Hotel Motel (Small)** | | **Hotel Motel (Small)** | |
|---|---|---|---|
| Electric Heating Scenario | | Gas Heating Scenario | |
| *Space Heating* | | *Space Heating* | |
| | | Air Cooled Unitary with | |
| *Air Cooled Unitary Heat Pumps* | | Furnace | |
| Table 403.3.2(2) | | Table 403.3.2(5) | |
| Capacity Range, BTU/h | <65000 | Capacity Range, BTU/h | any |
| Single Packaged, three phase | | Warm Air Duct Furnace | |
| Efficiency, HSPF | 6.7 | Efficiency, Ec | 80% |
| Model Compressor, COP | 3.45 | Modeled Efficiency | 80% |
| *COP_heat = -0.0296 x HSPF^2 + 0.7134 x HSPF* | | | |
| | | | |
| *Domestic Hot Water* | | *Domestic Hot Water* | |
| Central HPWH | | Central Gas | |
| Model System, COP | 2.31 or 1.63 by CZ | Modeled Efficiency | 80% |