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Gas High Efficiency DOAS Energy Savings Analysis

Prepared For NEEA:
Adam Gage, Senior Product Manager

Prepared By:
Neil Bulger, Founder & Principal
Michael Sawford, Senior Consultant

A2 Efficiency
1709 Bryden Lane
Santa Rosa, CA 95404

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
EMAIL
info@neea.org

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Acknowledgements

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1. Introduction

1.1 Background

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit organization that works in collaboration with utilities and stakeholders across the Northwest to accelerate the adoption of energy-efficient products, services, and practices for long-term energy savings. NEEA's HVAC Products group is interested in finding strategies to help save heating from natural gas in commercial and residential dwelling buildings when utilizing Dedicated Outdoor Air Systems (DOAS) and high efficiency gas boilers and associated components. The group observed large HVAC savings in the Very High Efficiency DOAS program with regard to electrical savings and is interested in understanding the possible magnitude of savings in a Gas High Efficiency DOAS (GHE DOAS) configuration.

1.2 Purpose and Objectives

The purpose of this project is to leverage energy analysis of building energy use to estimate the energy savings potential from GHE DOAS configurations in which the primary heating system for HVAC is a natural gas solution. Such applications may open opportunities as well into larger HVAC systems in which hot water boilers and chillers are used. The analysis will investigate the savings potential in a sample set of commercial and residential dwelling buildings with a series of standard HVAC configurations in the Northwest region.

From this purpose, the project team developed the following objectives:

1. Evaluate the energy use and savings of GHE DOAS in commercial and residential dwelling buildings.
2. Identify how climate and building type impact energy savings potential.
3. Evaluate the energy use and savings potential of new and existing buildings with GHE DOAS.

1.3 Study Approach

The study approach and design were developed by A2 Efficiency, working closely with NEEA and Energy 350 to develop and scope. The study utilizes building energy analyses of annual energy use, evaluating different configurations for energy use and energy savings among each. The approach to the project was as follows:

1. Define a set of parameters to study for market-wide impact assessment in the Northwest, including climate zones, building types, HVAC systems, and standard baseline HVAC systems for comparison.
2. Define HVAC configurations, component and system efficiency criteria.
3. Enhance building prototypes for parametric processing with different climates, constructions, and HVAC systems.
4. Develop an initial set of HVAC systems and savings for the primary set of comparisons of a GHE DOAS configuration potential, referred to in this report as Wave 1 Analysis.
5. Review results, compile, and issue for use by NEEA.
6. Develop an additional set of HVAC system configurations to generate a data table of annual energy use, referred to as Wave 2, for future use and comparison with standard construction baselines.

7. Review all results, compile, and issue to NEEA for market assessment.
8. Develop final analysis results documentation, modeling inputs, outputs, and key assumptions.

2. Methods

To assess the potential energy savings of the GHE DOAS system, the team utilized building energy modeling, leveraging existing building prototypes and standard systems created for past energy assessments with NEEA across multiple climate regions. The analysis evaluated a GHE DOAS system in a series of building types, each with a defined standard HVAC system and a GHE DOAS system. The analysis approach leverages a parametric energy modeling workflow in which HVAC systems are applied as templates to each building assigned in each climate region, allowing for a level of automation and an error checking process.

The energy savings were determined by selecting a single baseline system type and GHE DOAS system type for each specific building use and form factor. This allowed for simplification and HVAC energy to be evaluated on both an energy usage basis (per building area) and on a relative HVAC energy savings percentage. This analysis is referred to as Wave 1 in the energy assessment.

An additional set of system configurations, constructed as the Wave 2 analysis, were determined to be valuable for future market understandings and comparisons to potential building sites and building usage types. This additional set of energy analysis results is evaluated on an energy usage intensity basis; it is not compared with a standard baseline and serves as a database of information only. Appendix A outlines both Wave 1 and Wave 2 systems. Appendix B contains Wave 2 energy usage intensity results without discussion.

2.1 Building Energy Modeling Simulation

Models were built in EnergyPlus, based in version 24.2, in the parametric energy modeling platform Modelkit. Modelkit enabled the batch model development of HVAC systems applied to each building. Outputs of the model will be standardized to provide annual information for reporting purposes. As needed, hourly outputs will be generated to serve as part of the quality assurance and quality control process.

A series of HVAC templates for each system were leveraged from past NEEA projects as well as created from scratch for new configurations needed for hydronic HVAC systems. The analysis primarily focused on evaluation of larger hydronic HVAC systems in which natural gas boilers are typically utilized along with a few smaller buildings that utilized gas furnaces. This approach required the creation of a series of new HVAC system configurations, such as fan coils and chilled beams, which were then applied to the different building prototypes to assess differences in energy use.

With each template, efficiency parameters for the specific attributes of the GHE DOAS system and standard system were then added to enable packages to be easily evaluated.

2.2 Building Types and Weather Data

Ten prototype buildings were selected based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 2022 U.S. Department of Energy (U.S. DOE) prototypes. These buildings form the basis of the new construction building vintage. The research team developed a custom small school model based on the primary school DOE prototype and reused a custom-developed single-story office building made for previous NEEA modeling efforts.

Table 1: Building Prototypes Selected

Table	Short Name	Stories	GHE DOAS System Conditioned Floor Area (sf)	Total Conditioned Floor Area (sf)	Window to Wall Ratio (WWR) (%)
Single-Story Office	SS Off	1	17,878	17,878	33%
Medium Office	Med Off	3	53,633	53,633	33%
Large Office	Lrg Off	12	455,604	455,604	38%
Small School	Sm Sch	1	46,160	55,203	34%
Primary School	Pri Sch	1	60,628	73,966	35%
Secondary School	Sec Sch	2	147,480	210,907	35%
Small Hotel	Sm Htl	4	40,100	40,100	11%
Large Hotel	Lrg Htl	6	122,132	122,132	27%
Midrise Apartment	Mid Apt	4	30,400	30,400	20%
Highrise Apartment	Hi Apt	10	75,999	75,999	30%

The ASHRAE 90.1 2022 DOE prototype buildings were used as the base for the new construction vintage. To simplify the analysis and to also focus comparisons on the HVAC system changes, the envelopes for each prototype building do not vary by climate zone. This allows direct comparison of results from buildings modeled in climate zones 4C and 5B for the impact of the system selection only. The 2004 building envelope properties were taken from the ASHRAE commercial reference building prototypes and used to model the existing building construction vintage. Assuming some envelope updates may have occurred for very old existing buildings, the 2004 material data represent buildings that use an envelope that is 20 years old, which is more representative for a default existing building. Appendix D delineates the assumptions used for envelope parameters for both existing and new buildings. The envelope properties used in the modeling came from climate zone 4C from each prototype building.

Table 2: Construction Vintages Selected

Vintages	Material Data
New Construction	2022 90.1 U.S. DOE Prototypes
Existing Construction	2004 U.S. DOE Reference Prototypes

Two climate zones were selected to represent the Northwest climates using ASHRAE climate zones 4C and 5B. Recently published TMYx weather files from 2009–2023 observed weather data were selected. This weather file set is commonly used to represent current period weather conditions.

Table 3: Climate Zones Selected

Climate Zone	Location	Weather File
4C	Seattle, WA	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMYx.2009-2023.epw
5B	Bend, OR	USA_OR_Bend.Muni.AP.720638_TMYx.2009-2023.epw

2.3 HVAC Systems Configurations and Efficiency Criteria

HVAC systems were developed based on standard engineering practices, energy codes and standards, and documented assumptions. System efficiencies were based on GHE DOAS criteria as well as standard assumptions about new construction and existing construction component efficiencies. The analysis seeks to capture key features of energy efficiency of a GHE DOAS configuration, included in the following table.

Table 4: HVAC System Efficiency Aspects Considered

Efficiency Aspect	Description
HVAC Configuration	How ventilation, heating and cooling are supplied to a building, either mixed air systems or dedicated outdoor air systems
Boiler Type	Classifies the boiler as condensing (high efficiency) or non-condensing (standard efficiency)
Boiler Rated Efficiency	The maximum tested thermal efficiency of a boiler under standardized conditions
Boiler Efficiency by Temperature	Represents how actual efficiency varies with water temperatures with lower return temperatures improving condensing performance
Boiler Turn Down Limit	The modulation range of the boiler (e.g., 5:1), indicates how low it can ramp down from its maximum output while maintaining efficiency
Boiler Staging Controls	Controls that sequence multiple boilers on or off to match heating demand efficiently, based on logic such as lead-lag or load sharing
Ventilation Heat Recovery	The effectiveness of HVAC heat recovery (HRV) systems to reclaim heat or cooling from exhaust air
Pump Efficiency	Motor and hydraulic efficiency of pumps and their configurations
Supply Air Temperature	Strategies used to regulate the temperature control of supply air that impacts HRV and the heating quality

The analysis focused on applying a standard baseline system and a GHE DOAS system to each building type and vintage based on what the research team observed as typical practice. In both systems, the heating system was natural gas. The general system types included as the high efficiency cases (Eff) were dedicated outdoor air systems with either four-pipe fan coil (FPFC) or active chilled beam (CHB) systems.

For smaller buildings in Wave 1, a single zone rooftop unit system was used, applying one per thermal zone in the prototype building model. The medium-size buildings, primary school and medium office, used a packaged variable air volume (PVAV) system with air-source direct expansion cooling (DX-cooling) and boiler reheat. The larger buildings, secondary school and large office, used a typical VAV system with a chiller and boiler plant. For the hotel and apartment buildings, the existing vintages use exhaust ventilation systems while the new construction models use balanced ventilation.

Table 5 below summarizes the Wave 1 simulated systems for each prototype. Systems were selected by NEEA in development of the project for what was understood to be the most typical configuration anticipated for the building type of a natural gas hydronic-based system. These system selections were refined through the analysis process by the research team at A2 Efficiency. Additional information detailing each system is provided in Section 3 and Appendix C.

Table 5: HVAC Systems vs. Building Type Evaluated

HVAC System Types	HVAC System	Sm Sch	Pri Sch	Sec Sch	SS Off	Med Off	Lrg Off	Sm Htl	Lrg Htl	Med Apt	Hi Apt
Wave 1	Short Name	Baseline (Base) and High Efficiency Case (Eff)									
a. SZ RTU* Furnace	SZ RTU	Base			Base						
b. PVAV Reheat Boiler	PVAV		Base			Base					
c. VAV Reheat Boiler (Chiller)	VAV			Base			Base				
d. HE DOAS-HRV FPFC, Chiller, Boiler	DOAS-FPFC	Eff	Eff	Eff	Eff	Eff	Eff	Eff	Eff	Eff	Eff
e. HE DOAS-HRV Chilled Beam, Chiller, Boiler	DOAS-CHB	Eff	Eff	Eff	Eff	Eff	Eff				
f. Exhaust Ventilation, FPFC_Nat-Gas Boiler (existing vintage)	EXH-FPFC							Base	Base	Base	Base
g. Balanced Ventilation, FPFC_Nat-Gas Boiler (new construction vintage)	BAL-FPFC							Base	Base	Base	Base

*RTU = Rooftop unit

A total of 120 simulations were performed for the savings estimates comprising the 30 building-system combinations indicated in Table 5 above (across 10 building prototypes and seven system types) simulated with two vintages and in two climate zones.

The details of each HVAC aspect for the standard baseline efficiency configuration were based primarily on prescriptive code requirements in ASHRAE 90.1 2022 when selecting types of boilers, operating temperatures, and efficiency levels. Existing buildings were selected assuming equipment would be replaced. Operating controls of the water temperature were simplified and maintained at constant setpoints in all cases, relying on the change in temperature to represent the overall improvement in efficiency. This is true in the assumptions of the GHE DOAS configuration as well as the standard configurations. Major assumptions for the standard baseline cases and the GHE DOAS configurations related to the gas heating system are shown in the table below.

Table 6: Wave 1 GHE DOAS Attributes Evaluated

Attribute	Existing Building Standard Configuration	New Building Standard Configuration	GHE DOAS Configuration
HVAC Configuration	Non-Res: Mixed Air Systems; RTU with Furnaces, VAV with Boilers Res: Exhaust Driven Ventilation	Non-Res: Mixed Air Systems; RTU with Furnaces, VAV with Boilers Res: Balanced Ventilation	Non-Res and Res: Dedicated Outdoor Air*; Fan Coils or Chilled Beams with Boiler
Boiler Type	Non-Condensing (All Capacities)	Non-Condensing <1MMBTU Condensing 1>MMBTU	Condensing
Rated Efficiency Boiler/Furnace	80% / 81%	80% Non-Condensing 90% Condensing	94%
Boiler Efficiency by Temperature	Return Water: 160° F	Return Water: Non-Condensing 160° F Condensing 120° F	Return Water: 106° F
Boiler Turn Down Limit	3:1 Per Boiler	3:1 Per Boiler	5:1 Per Boiler
Boiler Staging Controls	Sequential Loading	Sequential Loading	Sequential Loading
Ventilation Heat Recovery	None	None	HRV, 82% Effectiveness
Pump Efficiency	CEE Tier 1	CEE Tier 1	CEE Tier 2
Supply Air Temperature	Fixed, 55F	Seasonal Reset, 55°–65°F	Seasonal Reset, 55°–65° F

*Note: All dwelling unit buildings assumed a central DOAS, balancing ventilation, with an HRV.

2.4 Result Outputs and Processing

Results were compiled in a spreadsheet database. Visualizations of annual results were plotted through Tableau for quality control purposes.

2.5 Quality Assurance and Quality Control (QA/QC)

To ensure accurate use of the modeling framework and modeling estimates, a QA and QC process was implemented, as outlined below.

2.5.1 Prototype Enhancements (Quality Assurance)

- The first step was to create the new system-building prototype pairs using the modeling framework and compare the baseline system against the original ASHRAE 90.1 2022 DOE prototype buildings for overall and end use breakdowns, ensuring changes observed were in line with expectations.
- The analysis of the original DOE prototype buildings and generated baselines showed a favorable comparison. It was determined that the modeling framework was accurately rebuilding the models with the new system configurations.
- An additional step was taken to compare the overall energy use intensity (EUI) and end use breakdowns to real new construction EUI data. From that standpoint, the project team noted that the ASHRAE 90.1 2022 DOE prototype predictions for overall EUI were very low

compared to new construction real building data, and the generated results for our new model runs also showed low EUIs.

- Due to the very low predictions of the models, a series of calibration steps were performed.
    - The calibration steps to align the overall EUI prediction and HVAC end uses to real new construction building data first included removing efficiency complexities found in the ASHRAE 90.1 2022 prototype buildings that were designed to reproduce the exact requirements of the ASHRAE 90.1 standard in the model.
- To further calibrate the overall energy use with example data points from real buildings in the region, steps were taken with each of the 30 building prototype and system pairs. Changes included the following:
    - Increased ventilation density in schools and offices by building type based on the following research and professional experience for average building ventilation rates due to the diversity of use types in each building raising the average ventilation needs. While ventilation minimum requirements are based on ASHRAE Standard 62.1, the exact space type and density is left to each building to determine for the peak usage cases. Office building prototypes, for example, utilized ventilation levels for open office areas only, yet may often include a mix of highly dense spaces such as conference rooms and lobbies, greatly increasing ventilation needs. To properly estimate absolute energy savings potential, the research team raised the average ventilation rates for the following buildings to reflect a more realistic estimate of operations:

Table 7: Ventilation Input Densities Selected

Model	Original Prototype Ventilation Density (cfm/sf)	Target Ventilation Density (cfm/sf)
Small K-12 School	0.24	0.35
Primary School	0.26	0.35
Secondary School	0.25	0.35
Single Story Office	0.08	0.20
Medium Office	0.08	0.20
Large Office	0.08	0.20

    - Original ventilation density values are sourced from each prototype by space, where space type and occupancy density were assumed by the U.S. DOE and then evaluated for ventilation minimum requirements with ASHRAE 62.1. Certain buildings are more developed than others, yet not all files available reflect current best practices. In a 2018 publication (Im, P., & New, J. 2018) by U.S. DOE for updates to the small office prototype, with 8% of the area dedicated to conference rooms, the ventilation was calculated for four different vintages of the standards and found that buildings in 2004 utilized 0.18 cfm/sf for which buildings under ASHRAE 90. 2013 would utilize 0.11 cfm/sf. If the same building had included 16% of the area as meeting or conference rooms, these values would have been 0.13 cfm/sf and 0.25 cfm/sf with drastically different outcomes for energy use.
    - The large office prototype assumes a surface-to-floor area ratio (SAR) of 0.37, consistent with buildings of 40–60 stories (Goel et al. 2014). Literature on tall

buildings indicates that such SAR values (0.35–0.50) are typical for this height range (Oldfield et al. 2009). In contrast, mid-rise buildings of 10–20 stories often exhibit higher SAR values (0.65–0.90), reflecting greater envelope exposure per unit floor area (Oldfield 2009; Yeang 1999). To better align with the characteristics of existing mid-rise office buildings in the Pacific Northwest, the prototype SAR was adjusted from 0.37 to 0.65, and insulation levels were recalculated based on equivalent heat loss (Heat loss = Insulation (U) * Area (A) * Change in Temperature (delta-T)).

Table 8: Surface to Area Ratio Adjustment

Model	Prototype Model SAR	Refined Model SAR
Large Office	0.37	0.65

- Thermostat setbacks in two of the school models for setback temperature at night were adjusted to be more conservative, maintaining a setback of 65° F at night versus the original assumption of 60° F.

2.5.2 Measure Effectiveness Evaluation (Quality Control)

To explain the savings predictions from baseline to the GHE DOAS efficiency cases, a series of step runs were made incrementally, adding efficiency components from the GHE DOAS specification one at a time to understand the impact of each. These runs were all performed with the DOAS-FPFC system in new construction in climate zone 4C for each prototype building.

For each building prototype model, the following comparisons were made. The step numbers below are accurate for all models except the large office, which used an additional step.

- Standard (non-condensing) boiler vs. HE (condensing) boiler (Step 1 vs. Step 2)
- No HRV vs. standard HRV (Step 1 vs. Step 3)
- No HRV vs. HE-HRV (Step 1 vs. Step 4)
- Standard boiler, no HRV vs. HE-boiler, HE-HRV (Step 1 vs. Step 5)

The following table summarizes the step assumptions for typical step runs and the unique large office step runs.

Table 9: Efficiency Step Runs Developed

Step numbering for All Prototypes and Large Office	Prototype Configuration (typical step runs, medium office used as example)	Large Office (used unique step number)
Baseline case—new construction	PVAV, non-condensing boiler, no HRV	VAV, condensing boiler, no HRV
Step 0 (large models only with condensing boiler, baseline–Step 0 comparison)	(not applicable)	condensing boiler, no HRV
Step 1 (always non-condensing boiler)	non-condensing boiler, no HRV	non-condensing boiler, no HRV
Step 2 (boiler efficiency upgrade)	HE boiler, no HRV	non-condensing boiler, basic HRV (70%)
Step 3 (standard HRV upgrade)	non-condensing boiler, basic HRV (70%)	non-condensing boiler, HE HRV (82%)
Step 4 (HE-HRV upgrade)	non-condensing boiler, HE HRV (82%)	HE boiler, no HRV
Step 5 (HE-boiler and HE-HRV upgrades—equal to HE case)	HE boiler, HE HRV (82%)	HE boiler, basic HRV (70%)
Step 6	(n/a)	HE boiler, HE HRV (82%)

3. Modeled Systems by Building Type

Each prototype building selected was configured to automatically accept different HVAC systems to be evaluated with baseline and efficiency case configurations. Select prototypes utilized multiple efficiency cases for additional data to be used as needed for future comparisons. Existing and new construction configurations were developed with each prototype. The HVAC system configuration, as well as starting efficiency assumptions and zoning to system assignments, were developed for each case.

3.1 HVAC System Configurations

A ruleset was developed for each system to work with the intended set of prototype buildings. This ruleset allows the modeling framework to take parameters and switch among the different system types and included components to dynamically allow for repeatable and consistent application of the systems and subcomponents.

Below are two example configurations of the systems used in the analysis and the component energy attribution. The first example included is the packaged variable air volume (PVAV) system used as the baseline in the medium office and school buildings, and the second example system configuration is for the DOAS four-pipe fan coil system (DOAS-FPFC) used in all building prototypes as a high efficiency case.

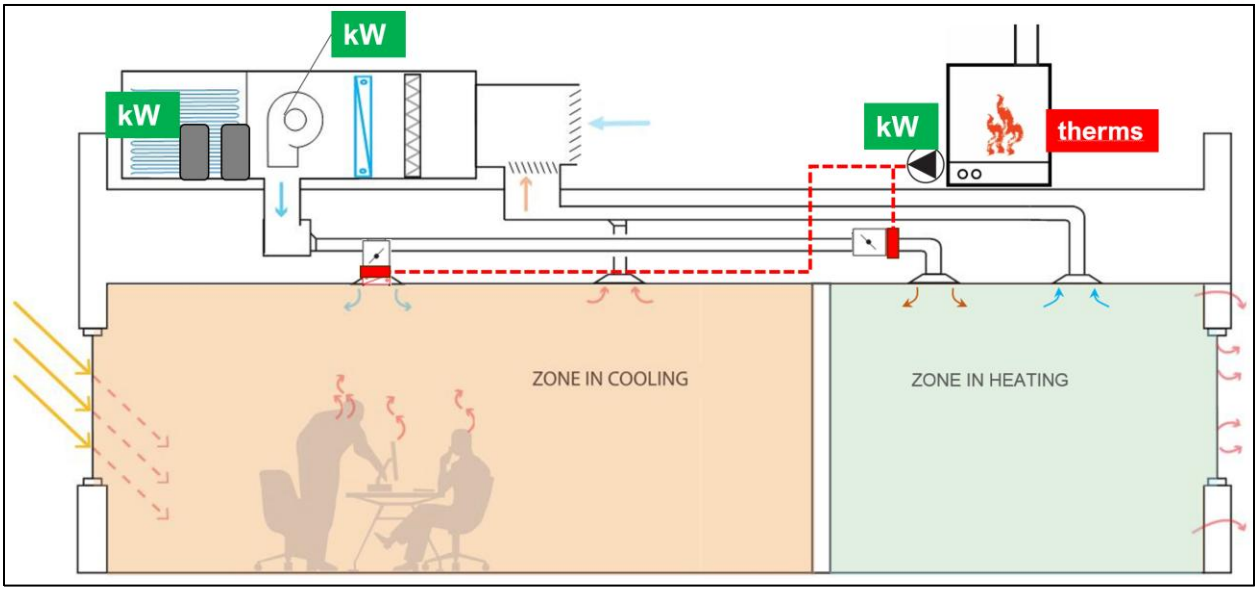

Figure 1: Packaged VAV with Gas Boiler and Reheat

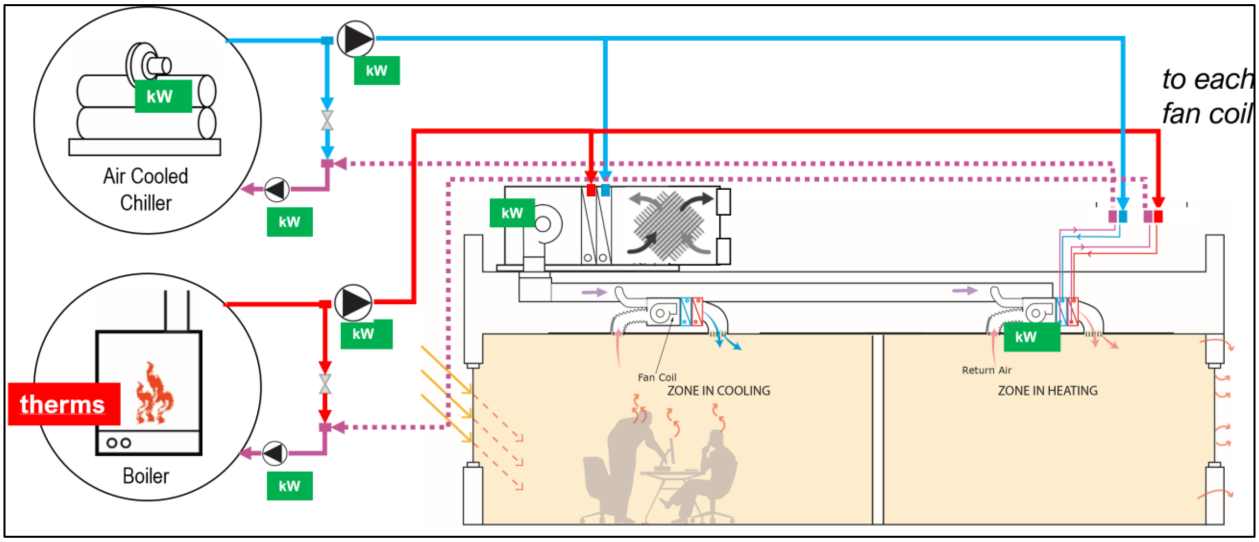

Figure 2: DOAS with Four-Pipe Fan Coils, Central Chiller Plant, and Hot Water Boiler Plant

Inputs for the boiler and DOAS unit used to generate the results are shown below. Note, the image above is a simplified representation of the ventilation ducting configuration with the purpose of showing how central cold and hot water are sent to equipment. In the model and in practice, ventilation air would be delivered downstream of the fan coil into the supply or through separate diffusers to enable decoupled ventilation. Additional tables of HVAC system assumptions are included for each component in Appendix C.

Table 10: HVAC Input Assumptions for Heating Hot Water (HHW) Boilers

Attributes (rows)	Units	Standard, Existing Building	Standard, New Building	High Efficiency, New Building	Very High Efficiency (GHE DOAS)
Boiler Type	-	Gas Fired	Gas Fired	Condensing	Condensing
Boiler Rated Efficiency	%	80%	80%	90%	94%
Boiler Turn-Down Ratio	-	3-to-1 turndown	3-to-1 turndown	3-to-1 turndown	5-to-1 turndown
Hot Water Setpoint Control	-	Constant	Constant	Constant	Constant
Leaving Water Temp	°F	180	180	160	120
Return Water Temp	°F	160	160	120	106
Delta-T	ΔF	20	20	40	14

Table 11: HVAC Input Assumptions for DOAS Units

Efficiency Criteria	Units	GHE DOAS, with FPFC	GHE DOAS, Chilled Beams	GHE DOAS, WSHP
Sensible Eff	%	82%	82%	82%
Latent Eff	%	0%	0%	0%
Ventilation Standard	-	ASHRAE 62.1	ASHRAE 62.1	ASHRAE 62.1
Primary Air Induction Min Rate	cfm/sf	n/a	0.30	0.30
DOAS Fan System	W/cfm	4.3	4.8	4.8
DX CLG SAT (F)	°F	60	60	60
DX HTG SAT (F)	°F	65	65	65
Ventilation Sizing (ASHRAE 62.1)		100%		
SAT Setpoint		60° F	60° F	60° F
SAT Control Configuration		Constant	Constant	Constant
DOAS Cooling Coil		Water Coil	Water Coil	No Coil
DOAS Heating Coil		Water Coil	Water Coil	No Coil
Fan Pressure Supply	inches	2.6	2.9	2.9
Fan Pressure Exhaust	inches	1.7	1.9	1.9
Fan Efficiency	%	60%	60%	60%
Fan Motor Efficiency	%	93%	93%	93%
Fan Overall Efficiency	W/cfm	0.90	1.01	1.01
Fan Pressure Supply	PA	642	717	717
Fan Pressure Exhaust	PA	428	478	478

Further details by HVAC component are included in Appendix C.

4. Analysis Results

The analysis found a range of potential HVAC savings for GHE DOAS configurations compared with standard systems in each building type with the magnitude of savings changing by climate, building vintage, and the building usage patterns and intensities themselves. Across the buildings, HVAC site energy savings for a GHE DOAS system compared to the standard baseline system ranges from 23% to 56% when averaged across climate, building vintage, and GHE DOAS configurations. Figure 3 below provides a summary of HVAC savings for two HVAC configurations evaluated, fan coils and active chilled beams, with fan coils showing the greater energy savings across all buildings. Active chilled beams were selected for the capability of handling both cooling and heating loads and based on known field sites by the NEEA team with such technologies in the Northwest.

While active chilled beams as an HVAC distribution system can be efficient, modeling assumed these systems require increased ventilation beyond a standard system to enable the beams to actively induce room air flow when there was a call in each zone for heating or cooling. The model accounted for a variable speed chilled beam configuration, which allowed the active flow of air to rise and fall with thermal loads. Overall, this functionality increased the portion of outdoor air in the chilled beam configurations compared with the baseline configuration, using more heating energy in particular and resulting in lower overall energy savings.

Figure 3: HVAC Percent Savings of GHE DOAS

The information was organized into a detailed database of energy usage and savings assessments for NEEA to build upon and incorporate into higher-level market assessments.

4.1 HVAC Energy Savings Intensity

Samples of the data produced for the HVAC energy end uses for each building in EUI (per floor area) are shown below for each building. The charts show the end uses of HVAC for each system simulated along with the corresponding baseline or standard for that building assumed, shown on the left side of each set of results. Results are shown for each building vintage, new or existing, and each climate zone.

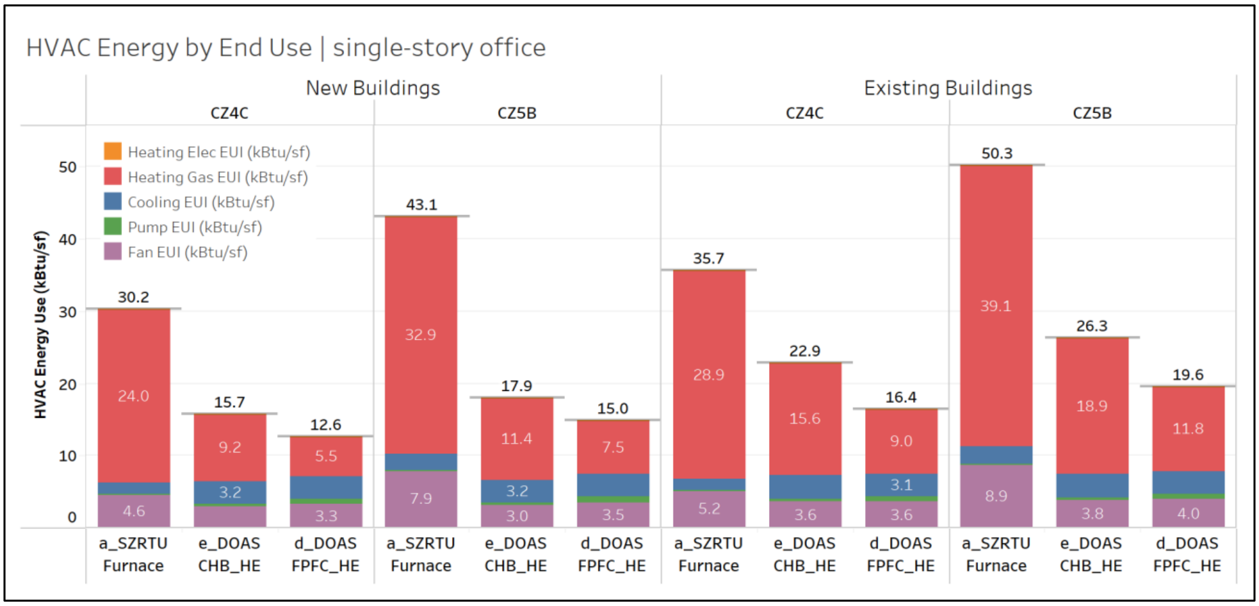

Figure 4: HVAC by End Use for Single Story Offices of GHE DOAS Configurations

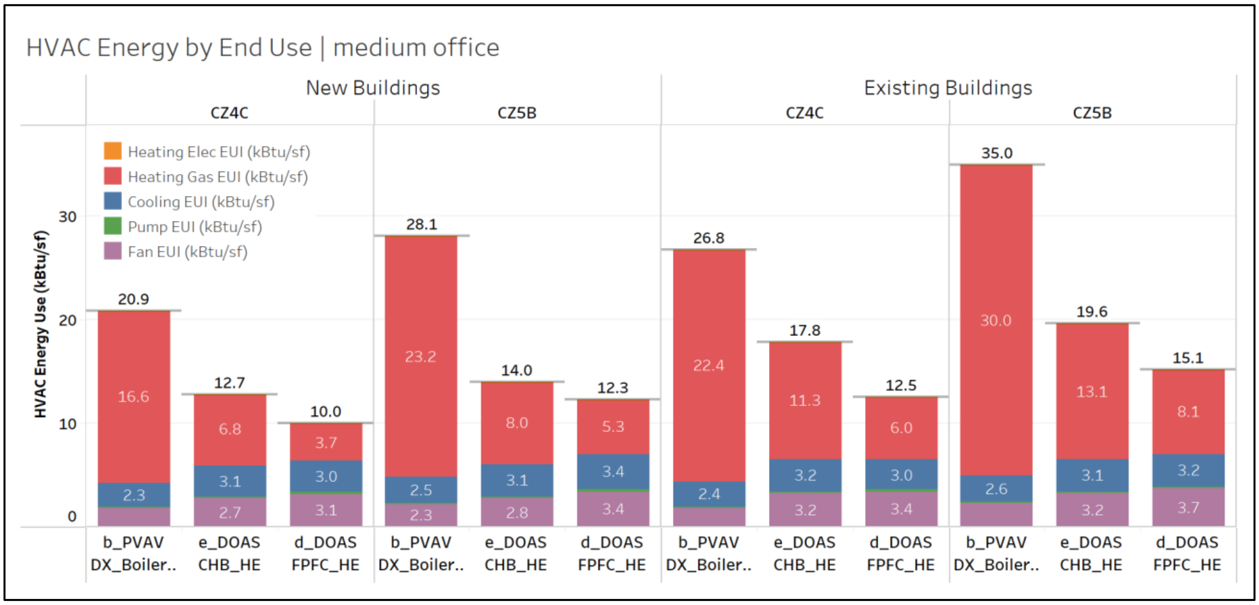

Figure 5: HVAC by End Use for Medium Offices of GHE DOAS Configurations

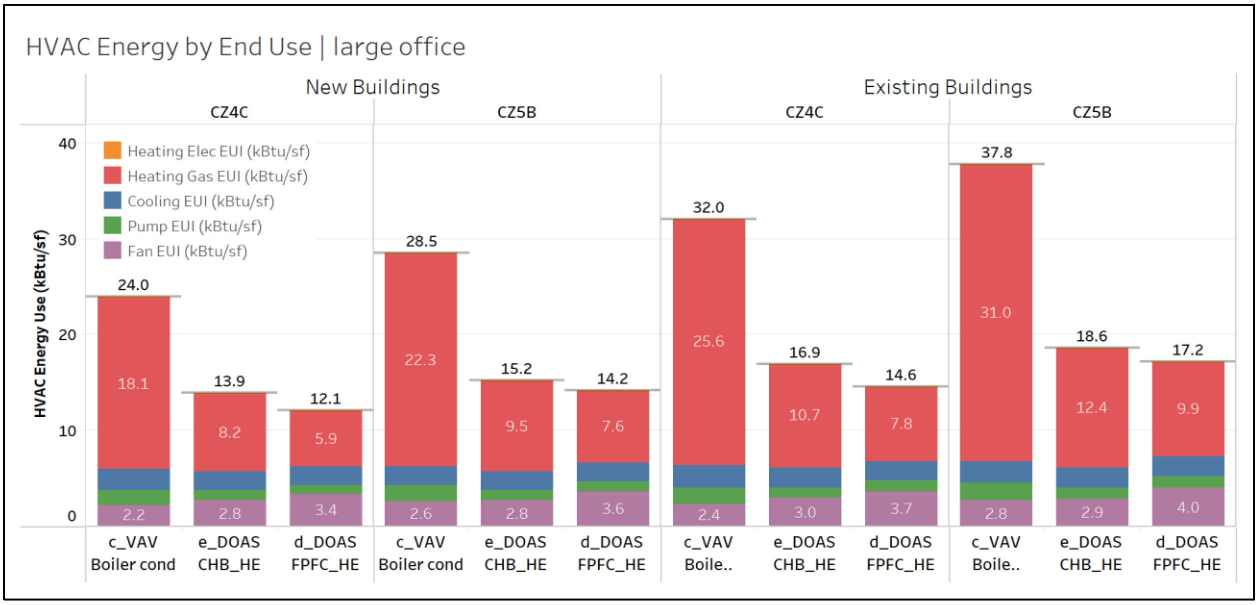

Figure 6: HVAC by End Use for Large Offices of GHE DOAS Configurations

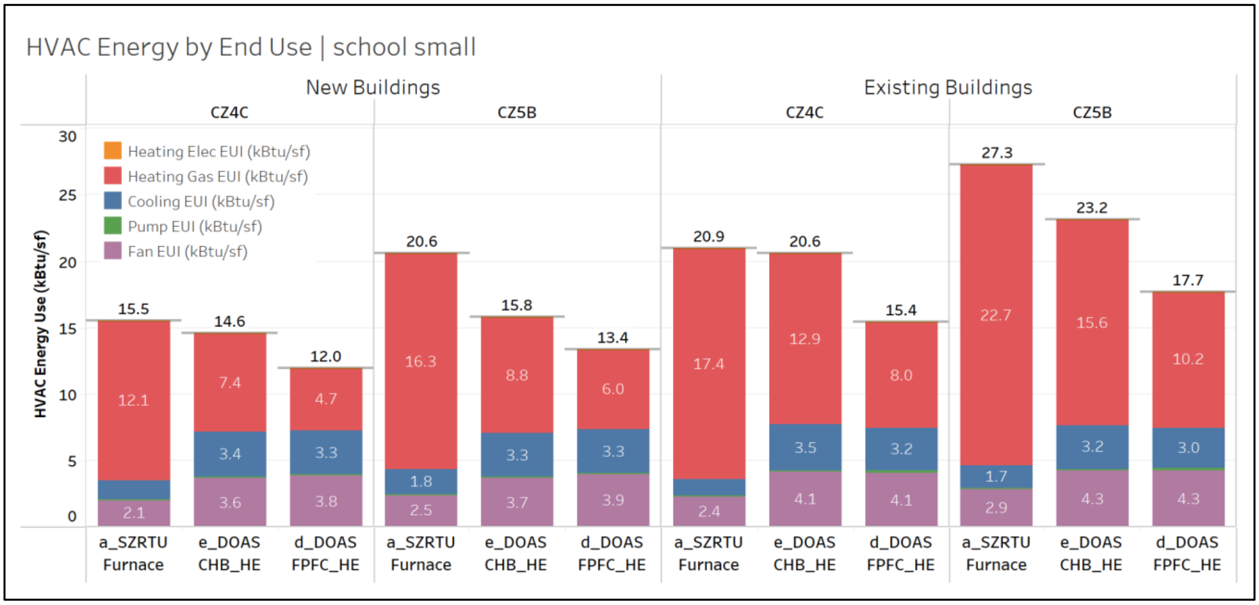

Figure 7: HVAC by End Use for Small Schools of GHE DOAS Configurations

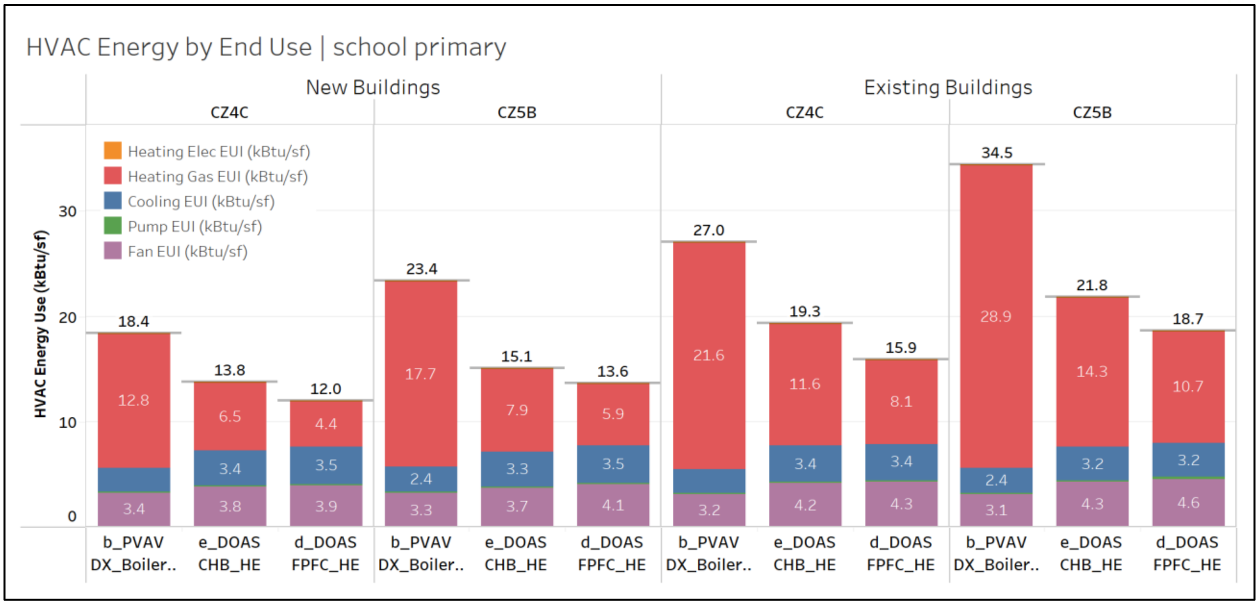

Figure 8: HVAC by End Use for Primary Schools (Medium) of GHE DOAS Configurations

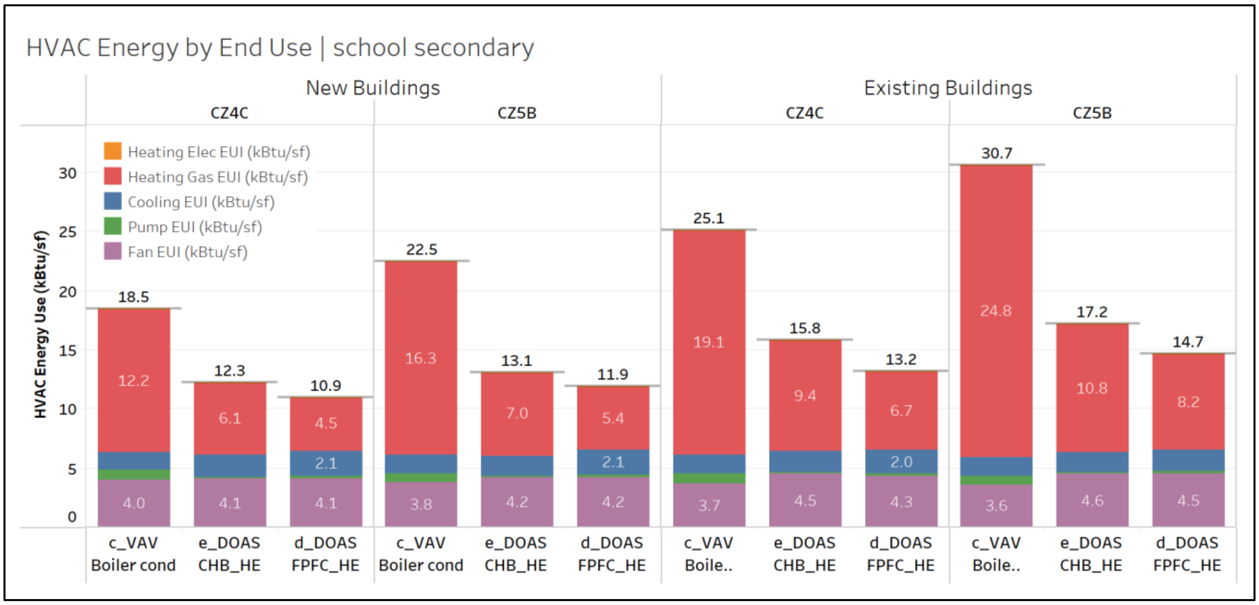

Figure 9: HVAC by End Use for Secondary Schools (Large) of GHE DOAS Configurations

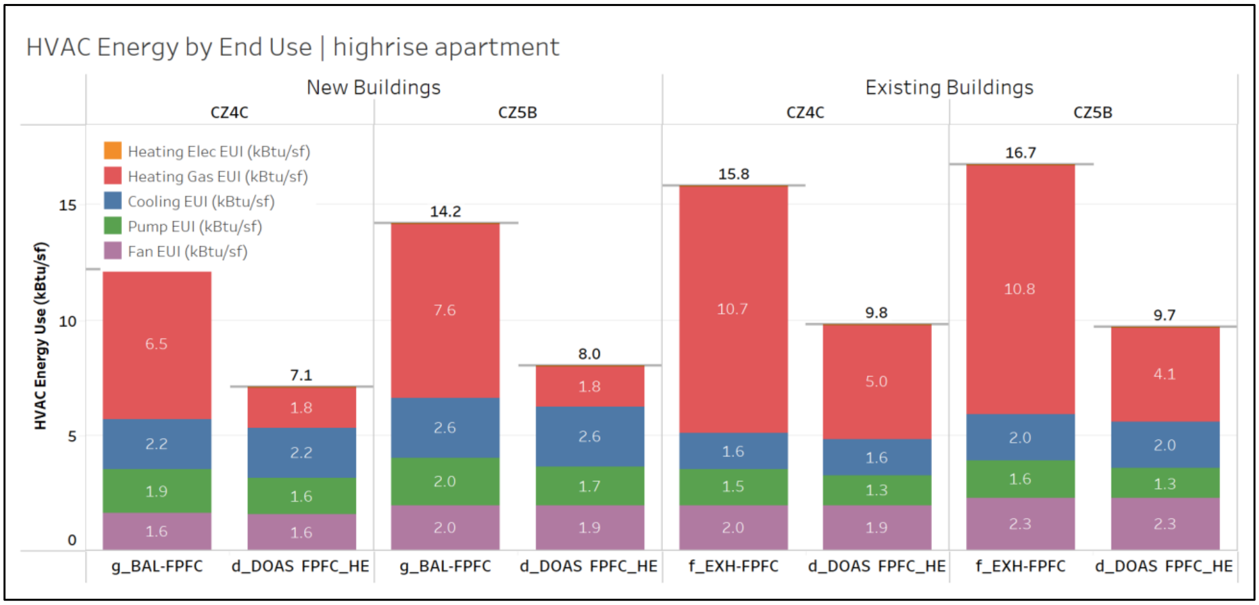

Figure 10: HVAC by End Use for Highrise Apartments of GHE DOAS Configurations

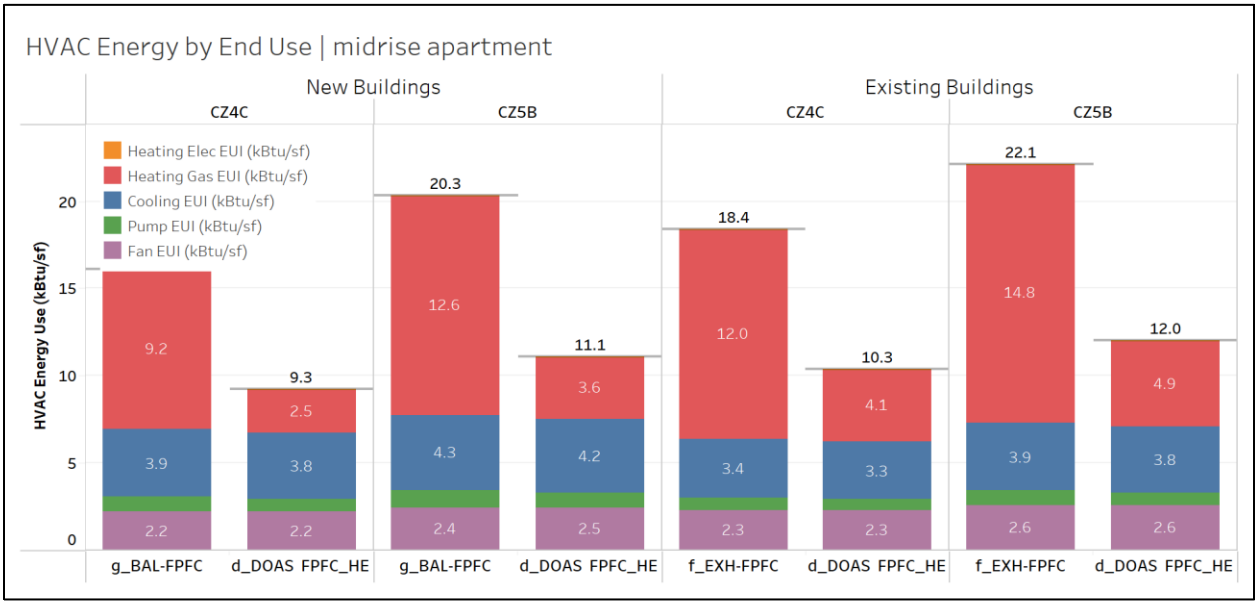

Figure 11: HVAC by End Use for Midrise Apartments of GHE DOAS Configurations

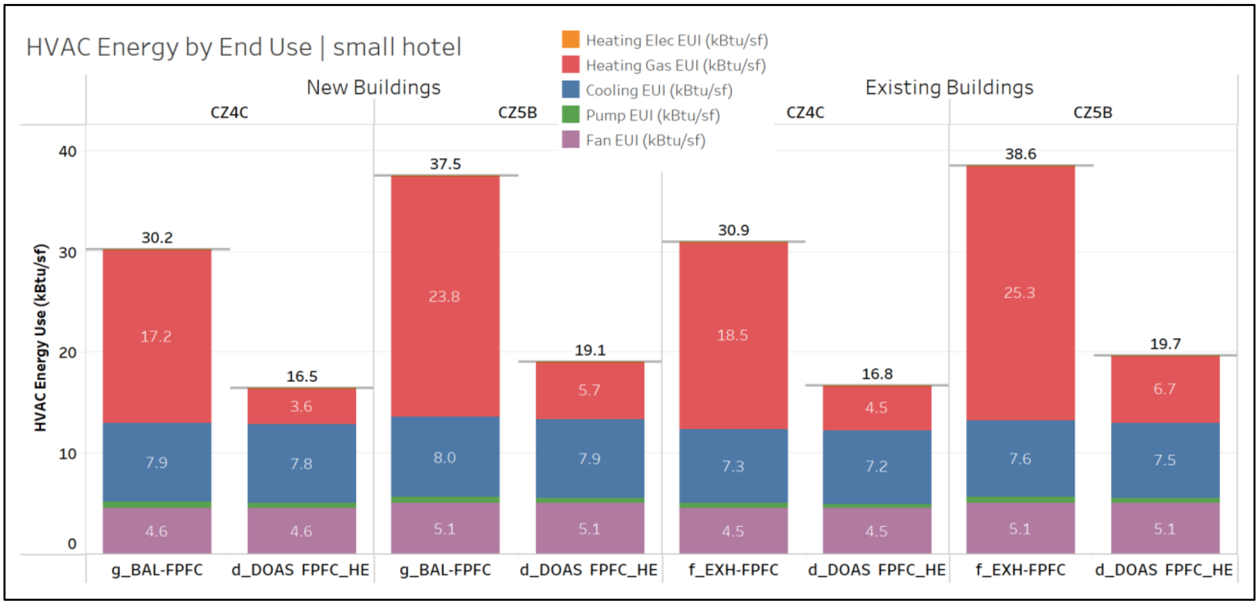

Figure 12: HVAC by End Use for Small Hotels of GHE DOAS Configurations

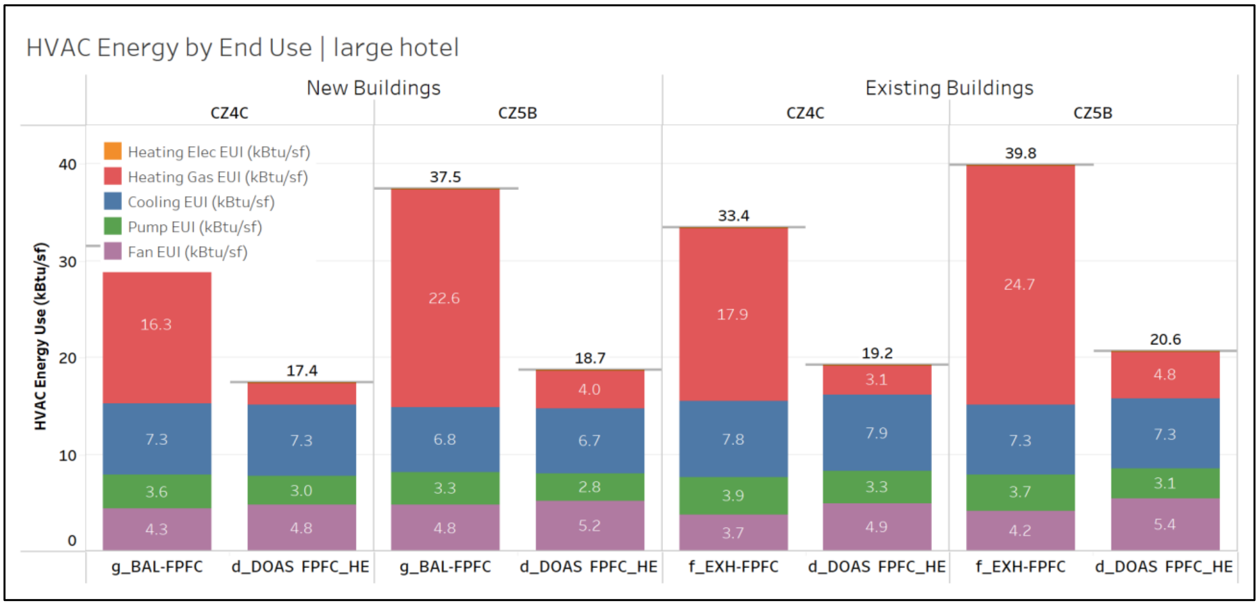

Figure 13: HVAC by End Use for Large Hotels of GHE DOAS Configurations

5. Conclusions & Recommendations

Average savings for the configurations of GHE DOAS were found to be 45% HVAC energy savings with some building and system configurations saving up to 65% HVAC energy and others only 4% HVAC energy. Small schools were on the low side, where the standard configuration for gas furnaces is a rooftop unit (RTU), specifically in the milder climate 4C and in new construction buildings with lower thermal loads. Where the system was compared more directly with a standard configuration HVAC system with a hydronic boiler, such as a packaged VAV system, the savings were closer to the average of 45%.

While this analysis provides an estimated potential, the configurations of GHE DOAS combined several high efficiency measures working together to achieve deep energy savings. To further drive the understanding of energy use and savings potential, the team developed the following recommendations for consideration:

1. Evaluate heating demands by sampling new or recently constructed non-residential buildings in the Northwest to better calibrate energy use intensity and potential savings.
2. Evaluate savings available from partial upgrades to ventilation or boiler systems, including condensing boilers or modulating boiler systems based on heating demand.

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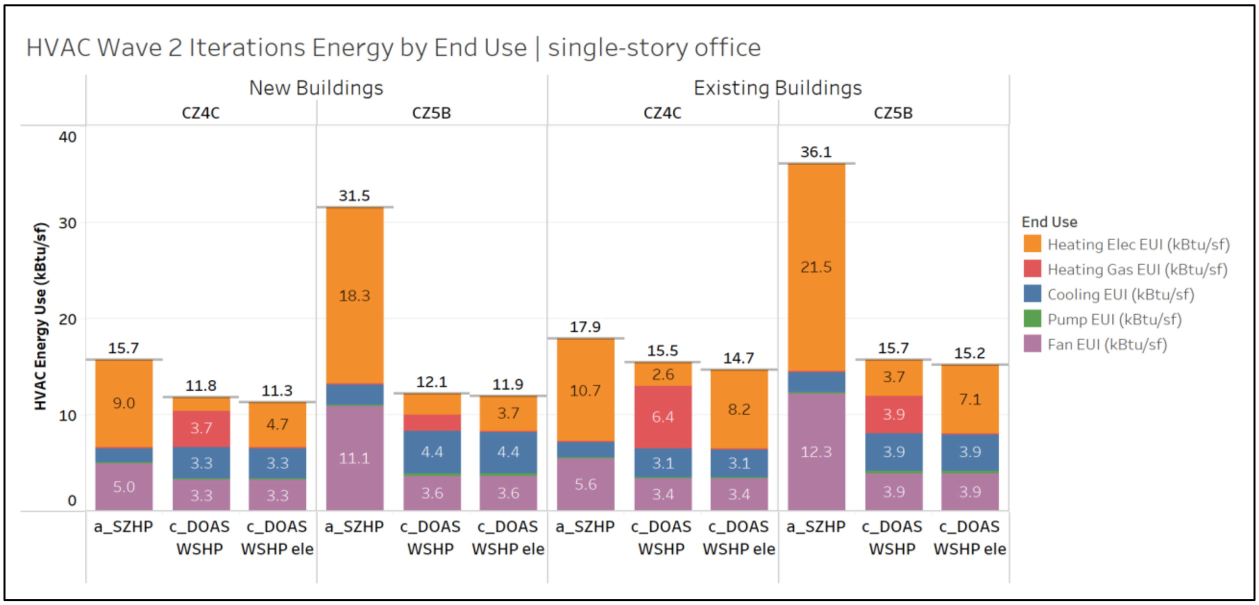
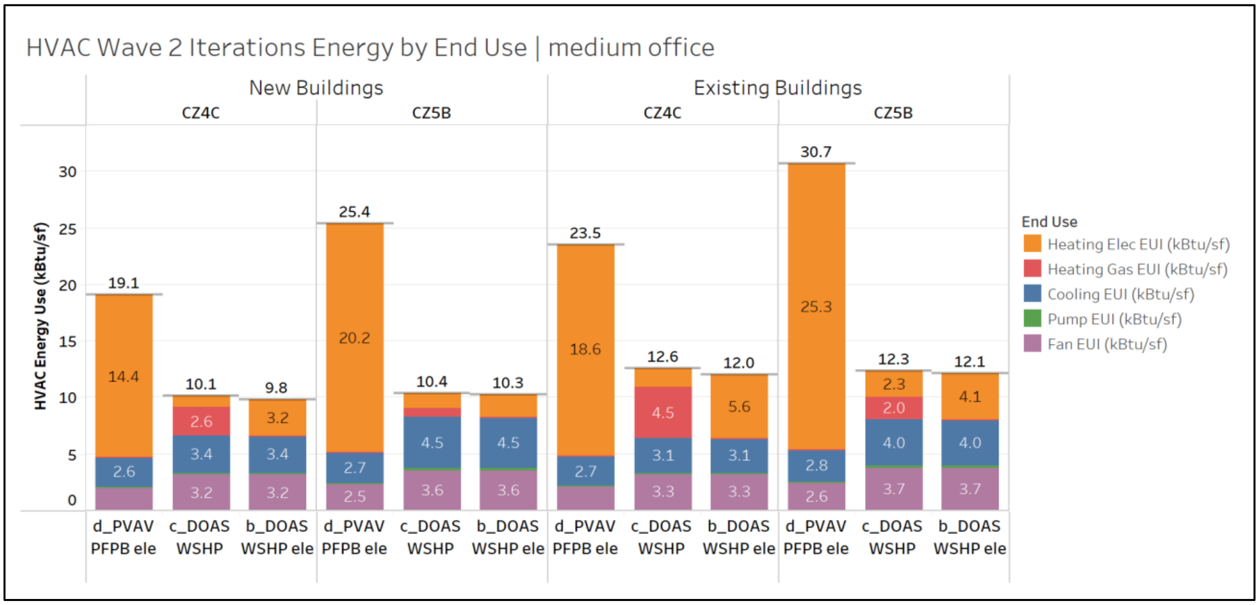
Appendix A: Wave 1 and 2 Systems

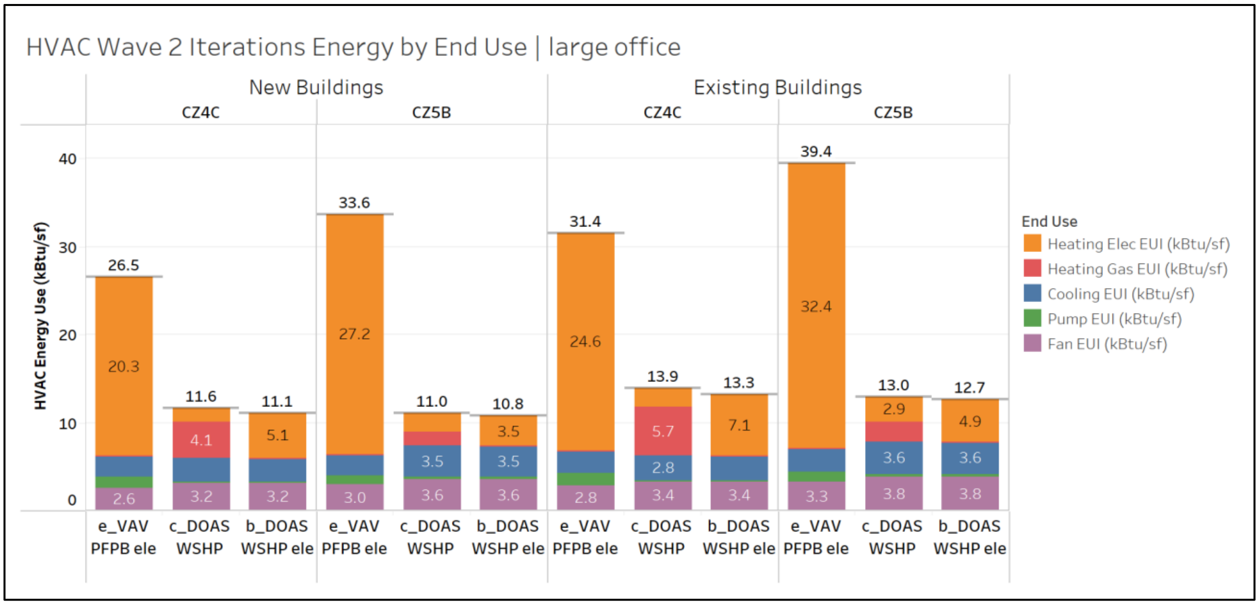
HVAC System Type	HVAC System Short Name	Case Type
WAVE 1		
a. SZ RTU Furnace	SZ RTU	Baseline-Gas
b. PVAV Reheat Boiler	PVAV	Baseline-Gas
c. VAV Reheat Boiler (Chiller)	VAV	Baseline-Gas
d. HE DOAS-HRV FPFC, Chiller, Boiler	DOAS-FPFC	GHE DOAS
e. HE DOAS-HRV Chilled Beam, Chiller, Boiler	DOAS-CHB	GHE DOAS
f. Exhaust Ventilation, FPFC_Nat-Gas Boiler	EXH-FPFC	Baseline-Gas, existing bld
g. Balanced Ventilation, FPFC_Nat-Gas Boiler	BAL-FPFC	Baseline-Gas, new bld
WAVE 2		
a. SZ HP_Electric	SZ HP-RTU_e	Baseline-Elec
b. DOAS-HRV WSHP_Elec Boiler	DOAS-WSHP_e	HE DOAS
c. DOAS-HRV WSHP_Nat-Gas Boiler	DOAS-WSHP_gas	GHE DOAS
d. PVAV – PFPB with Electric Heat, DX	PVAV-PFPB_e	Baseline-Elec
e. VAV - PFPB with Electric Heat, CHW	VAV-PFPB_e	Baseline-Elec
f. Exhaust Ventilation WSHP_Nat-Gas Boiler	EXH-WSHP_gas	Baseline-Gas, existing bld
g. Balanced Ventilation WSHP_Nat-Gas Boiler	BAL-WSHP_gas	Baseline-Gas, new bld
h. Exhaust Ventilation WSHP_Elec Boiler	EXH-WSHP_e	Baseline-Elec, existing bld
i. Balanced Ventilation WSHP_Elec Boiler	BAL-WSHP_e	Baseline- Elec, new bld

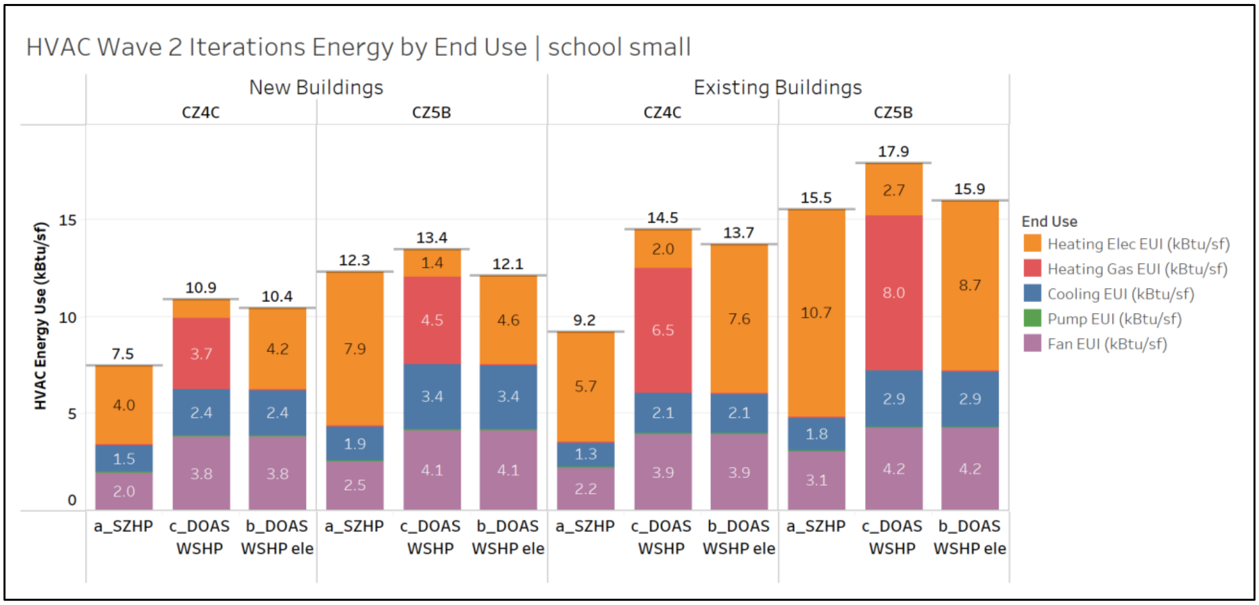
Appendix B: Wave 2 Results

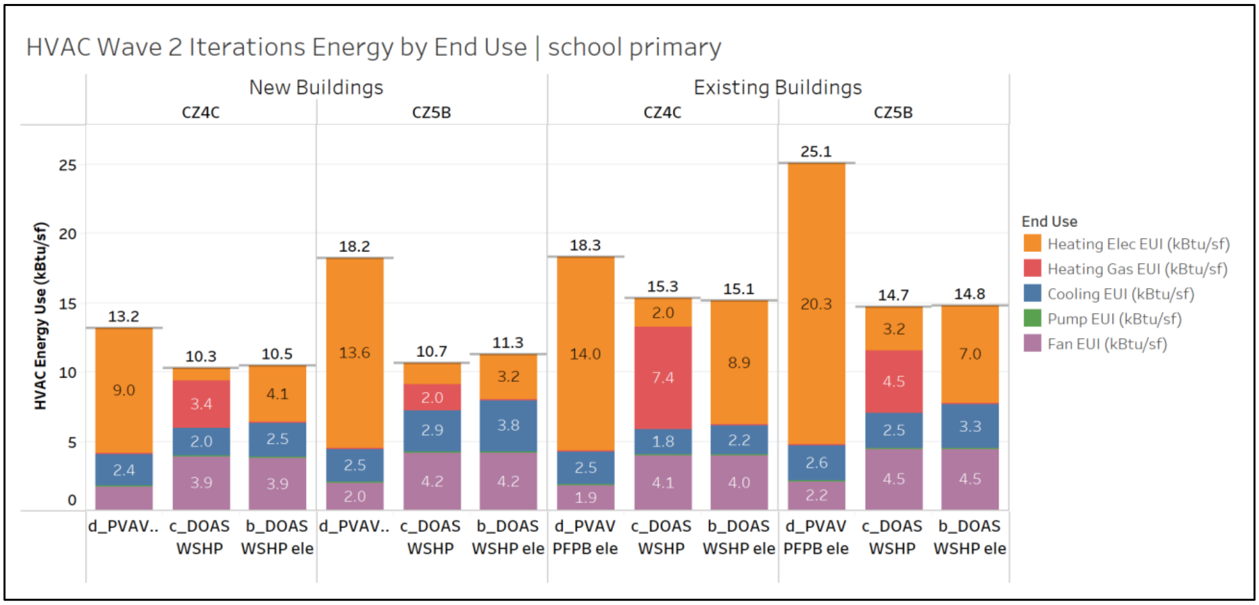
Results of the Wave 2 iterations of water source heat pumps (WSHP) and configurations with both electric and natural gas heating systems are included below for reference.

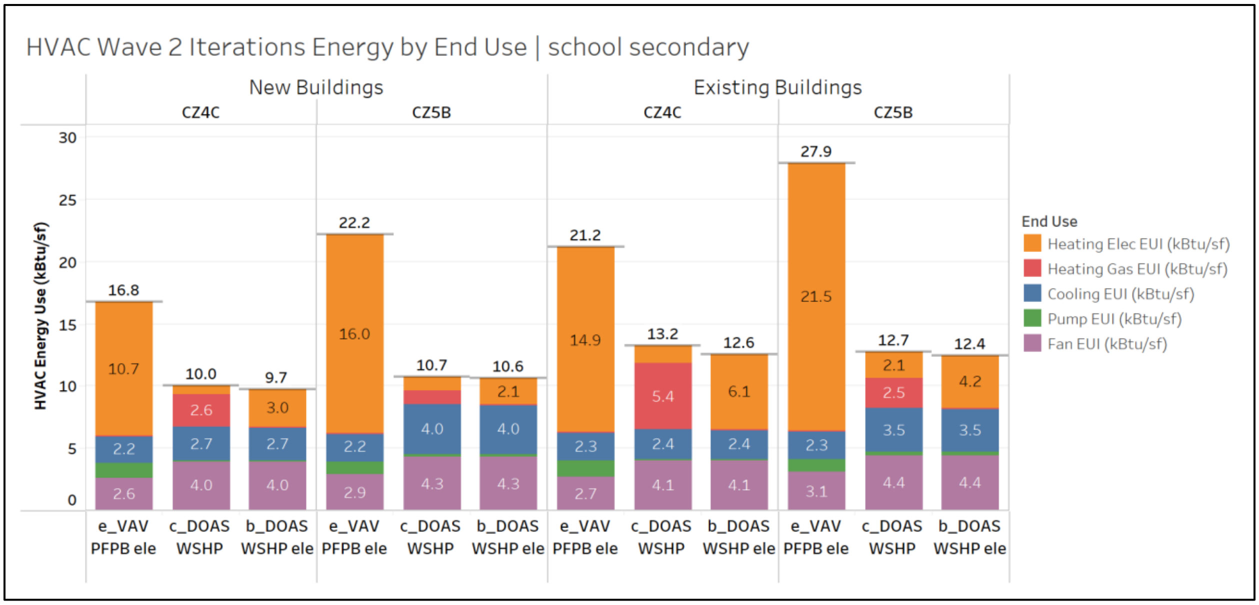


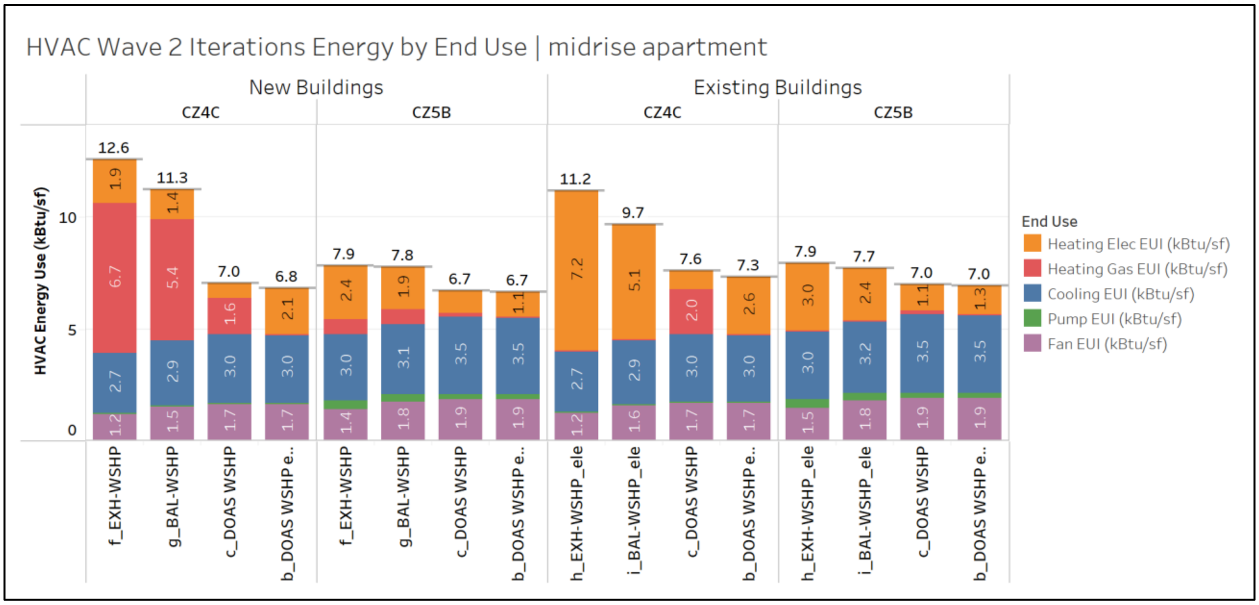


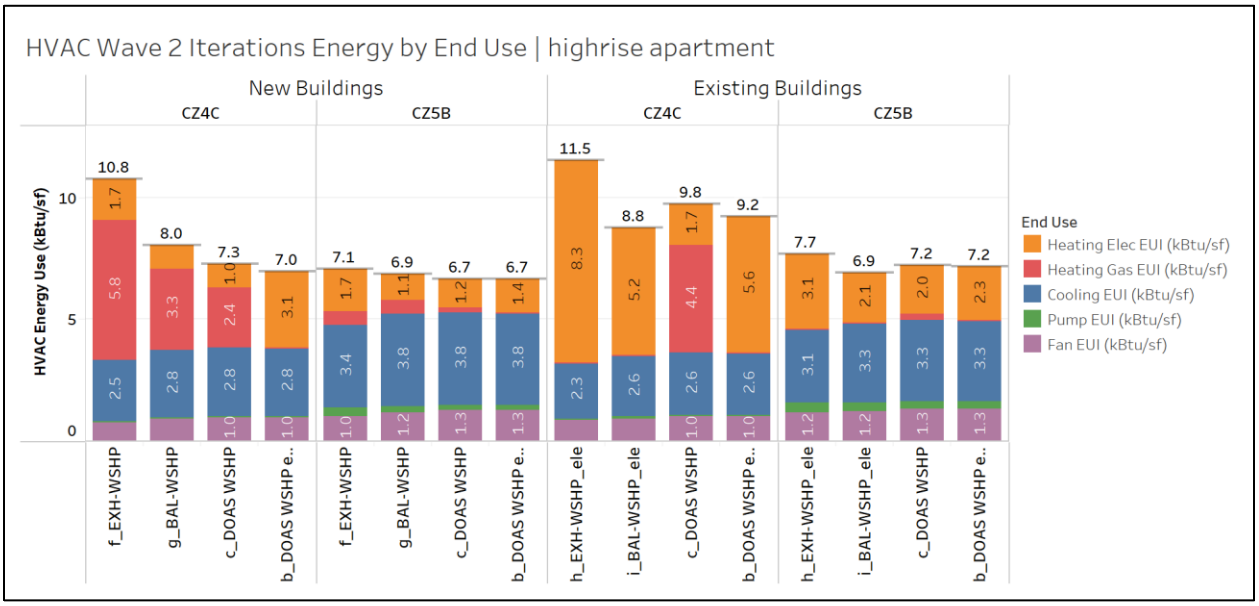

HVAC Wave 2 Iterations Energy by End Use | large office
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
e_VAV PFPB ele
c_DOAS WSHP
b_DOAS WSHP ele
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)

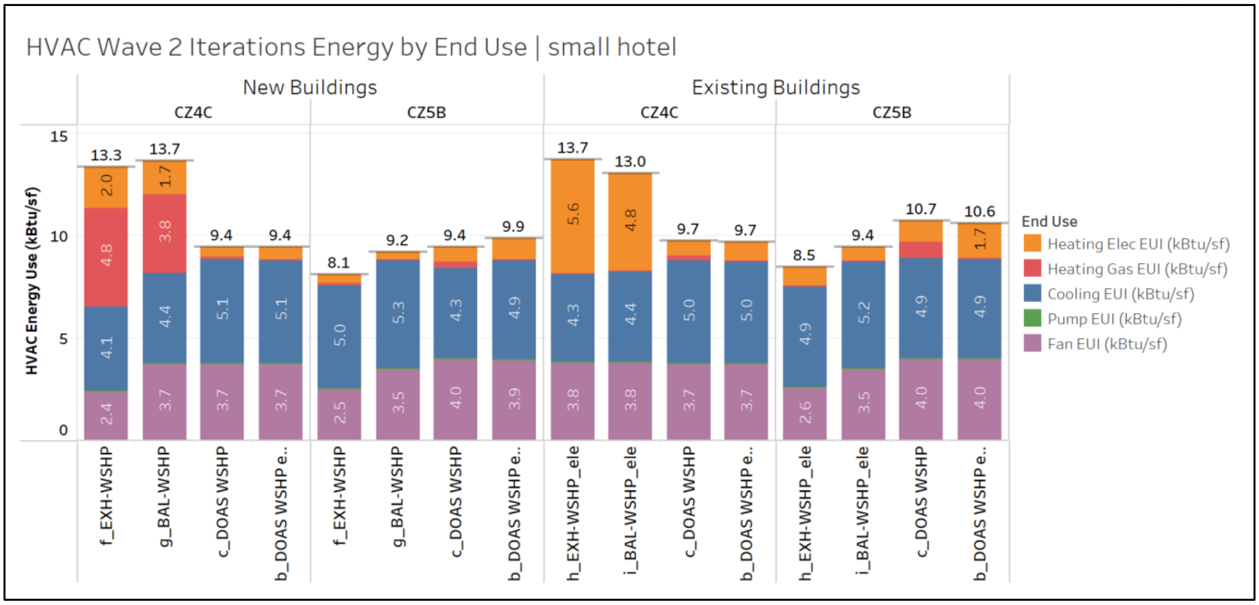

HVAC Wave 2 Iterations Energy by End Use | school small
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
a_SZHP
c_DOAS WSHP
b_DOAS WSHP ele
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)

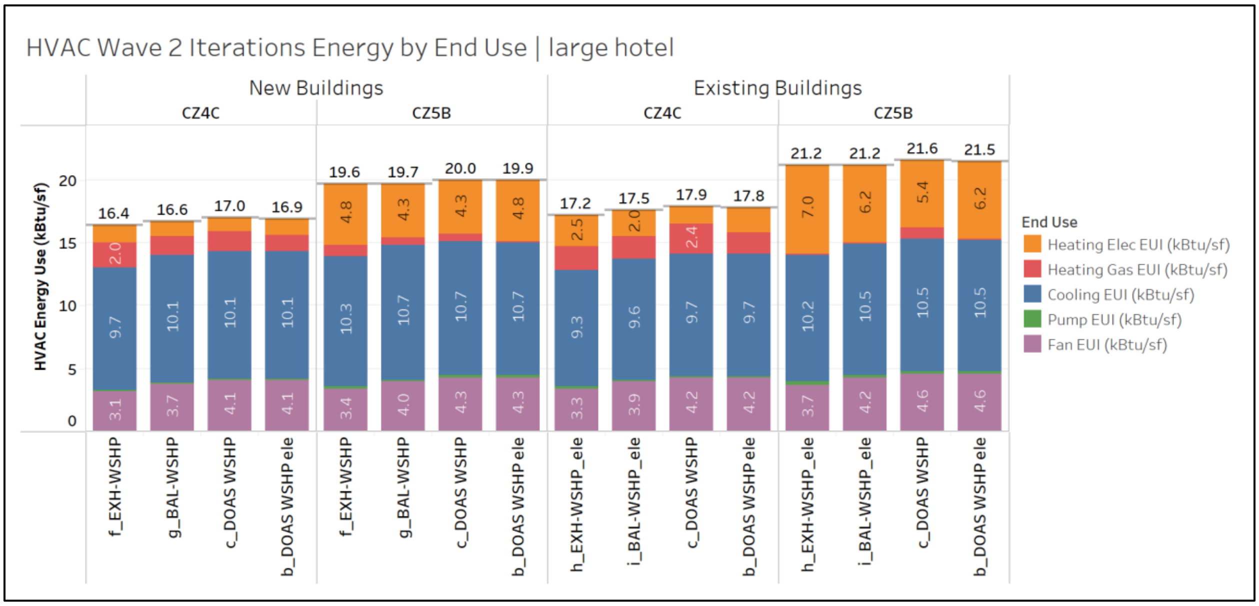

HVAC Wave 2 Iterations Energy by End Use | school primary
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
d_PVAV..
c_DOAS WSHP
b_DOAS WSHP ele
d_PVAV PFPB ele
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)


HVAC Wave 2 Iterations Energy by End Use | school secondary
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
e_VAV PFPB ele
c_DOAS WSHP
b_DOAS WSHP ele
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)


HVAC Wave 2 Iterations Energy by End Use | midrise apartment
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)
f_EXH-WSHP
g_BAL-WSHP
c_DOAS WSHP
b_DOAS WSHP e..
h_EXH-WSHP_ele
i_BAL-WSHP_ele


HVAC Wave 2 Iterations Energy by End Use | highrise apartment
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)
f_EXH-WSHP
g_BAL-WSHP
c_DOAS WSHP
b_DOAS WSHP e..
h_EXH-WSHP_ele
i_BAL-WSHP_ele


HVAC Wave 2 Iterations Energy by End Use | small hotel
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)
f_EXH-WSHP
g_BAL-WSHP
c_DOAS WSHP
b_DOAS WSHP e..
h_EXH-WSHP_ele
i_BAL-WSHP_ele


HVAC Wave 2 Iterations Energy by End Use | large hotel
New Buildings
Existing Buildings
CZ4C
CZ5B
HVAC Energy Use (kBtu/sf)
End Use
Heating Elec EUI (kBtu/sf)
Heating Gas EUI (kBtu/sf)
Cooling EUI (kBtu/sf)
Pump EUI (kBtu/sf)
Fan EUI (kBtu/sf)
f_EXH-WSHP
g_BAL-WSHP
c_DOAS WSHP
b_DOAS WSHP ele
h_EXH-WSHP_ele
i_BAL-WSHP_ele

Appendix C: Additional HVAC System Input Assumptions

DX Cooling Coil

Attributes (rows)	Units	Small SZ RTU	Small SZHP	Large PVAV
Capacity Range	-	>65kBtu	>65kBtu	>135 kBtu
Rated Efficiency	EER	11.2	11.2	11.0
Modeled Efficiency	COP_nf	3.84	3.84	3.83

SZ RTU / HP

Attributes (rows)	Units	All Configurations
Economizer		yes
Fan Speed Control		2 speed
Fan Pressure	inches	3.2
Fan Efficiency	%	60%
Fan Motor Efficiency	%	85.50%

Chillers

Attributes (rows)	Units	Standard, Air Cooled	Standard, Water Cooled
Chiller Type	-	Scroll	Centrifugal
Capacity Range	tons	20–200 tons	201–500 tons
CHW Leaving Temperature	°F	42	42
CHW Delta-T	ΔF	12	12
Chiller Peak Eff	kW/ton	1.19	0.61
Chiller Efficiency Part Load	COP	2.96	5.76

Cooling Tower

Attributes (rows)	Units	Standard
Cooling Tower Type		Cross Flow
Fan Efficiency	hp/gpm	60
Cooling Tower LWT	°F	80
Cooling Tower EWT	°F	90
Cooling Tower Approach	ΔF	10

Zone VAV, Reheat

Attributes (rows)	Units	Reheat Box
VAV Box Sizing (delta-T)	ΔF	20
VAV Minimum Turn-Down	%	30%

Zone Fan Coil Unit

Attributes	Units	Value
Fan Pressure Total Static	inches	1.5
Fan Ventilation Configuration		Decoupled
Fan Control		3 Speed
Fan Efficiency	%	60%
Fan Motor Efficiency	%	90%

WSHP Units

Attributes	Units	Value
WtoA WSHP >17k < 135k Btu	EER	13
EER to COP Capacity Avg	Btu	85,000
Efficiency in Cooling	COP	4.5
WtoA WSHP Water Src	ISCOP	4.8
ISCOP to COP Estimate	%	90%
Efficiency in Heating	COP	4.3
Fan Ventilation Configuration		Decoupled
Fan Pressure Total Static	inches	1.5
Fan Control		3 Speed
Fan Efficiency	%	60%
Fan Motor Efficiency	%	90%

All Pumps for CHW, HHW, CW

		CEE Tier 3	CEE Tier 2	CEE Tier 1
Pressure	ft	120	120	120
Pump Eff	%	78%	67%	56%
Pump Power Ratio	W/gpm	29.0	33.5	40.0
Pump Power Ratio	W/m3/s	459,402	530,334	634,251
Pump Power Ratio	W/m3/s-PA	1.28	1.48	1.77
Motor Efficiency	IE3 same	85.5%	85.5%	85.5%

Appendix D: Envelope Assumptions

	Unit	Existing Buildings	New Buildings
Parameter			
Wall Assembly		Metal Framed Wall	Metal Framed Wall
Wall 1 Insulation, U-factor	Btu/h-ft2-°F	0.124	0.111
Wall 1 Insulation, R-overall		8.06	9.01
Roof Assembly		IEAD Roof Assembly	IEAD Roof Assembly
Roof Insulation, U-factor	Btu/h-ft2-°F	0.064	0.032
Roof Insulation, R-overall		15.625	31.25
U-factor/SHGC/VT		0.569/0.392/0.304	0.372/0.359/0.394
Floor F-factor		F-0.032, F-0.018	F-0.032, F-0.018