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Energy Savings from Efficient Rooftop Units in Heating Dominated Climates

Prepared For NEEA:
Chris Wolgamott Sr. Product Manager

Prepared by:
Marcus Dimeo
Bretnie Eschenbach
Will Gorrissen
Rebecca Hovey
Angela Kora
Cory Luker
Sorochukwu Okam
Isaac Schultz
Sarah Widder

Cadeo Group
107 SE Washington Street, Suite 450
Portland, OR 97214

and

Matthew Larson

Big Ladder Software
1624 Market Street, #304
Denver, CO 80202

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

Contributors

Marcus Dimeo, Bretnie Eschenbach, Will Gorrissen, Rebecca Hovey, Angela Kora, Cory Luker, Sorochukwu Okam, Isaac Schultz, Sarah Widder, Matthew Larson (Big Ladder Software)

Please refer questions to:

Rebecca Hovey - rhovey@cadeogroup.com - (503) 905-6472

Executive Summary

This report describes the energy modeling analysis Cadeo performed to support the development of an efficient rooftop unit (RTU) initiative on behalf of NEEA and Nicor. The analysis estimated the performance impacts of five different energy efficiency measures, enumerated in Table S-1, that could be applied directly to a packaged gas-fired RTU. Cadeo modeled these measures both individually and combined into tiers to understand any interactive effects that might diminish or increase energy impacts.

Measure	Description	Tier(s)
Condensing Gas Furnace	Replace existing furnaces with condensing units	2A
Energy Recovery Ventilation	Add heat exchanger between exhaust and ventilation air steams	2B, 2B_EC
Reduced Damper Leakage	Replace baseline dampers with low leak dampers	All
Increased Enclosure Insulation	Increase RTU shell insulation	All
Efficient Cooling	Improve compressor efficiency	1_EC, 2B_EC

Table S-1. Summary of Energy Conservation Measures and the Tiers

The analysis builds on the methodology NEEA employed in previous RTU energy modeling work to support the CSA P.8 test procedure[1] development. Cadeo worked with NEEA and Nicor to select four building types that represent the most common applications of packaged rooftop units and selected five locations that represent the climate diversity in the Northwest and upper Midwest. Table S-2 details the selected building types and Table S-3 summarizes the selected climate locations.

[1] https://neea.org/resources/energy-modeling-of-commercial-gas-rooftop-units-in-support-of-csa-p-8-standard

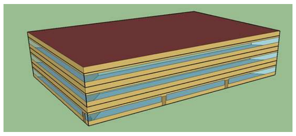
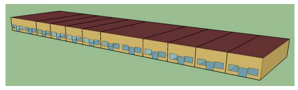
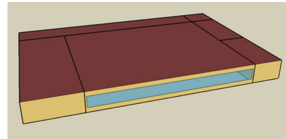
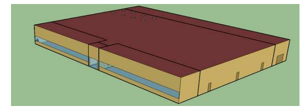
Medium Office	Strip-Mall Retail	Grocery	Stand-alone retail
			
53,600 ft^2 3 Packaged Multi Zone RTUs with Gas Heat	22,500 ft^2 with 10 Packaged Single Zone RTUs with Gas Heat	45,000 ft^2 with 6 Packaged Single Zone RTUs with Gas Heat	24,695 ft^2 with 4 Packaged Single Zone RTUs with Gas Heat

Table S-2. Summary of Modeled Building Types

Locations	Climate Zone	HDD	CDD
Seattle, WA	4C	2627	1130
Rockford, IL	5A	3719	1635
Bend, OR	5B	3633	959
Spokane, WA	5B	3715	1182
Great Falls, MT	6B	4200	1061

Table S-3. Summary of Modeled Climate Locations

The simulation results for all measures and tiers showed reduced energy use in every location and building type combination, although average savings varied by measure. Figure S-1 shows the average relative savings for each measure and tier. In all cases, the Energy Recovery Measure led to the greatest reduction in annual HVAC energy use, both alone and when combined with other measures into tiers. Condensing gas furnaces also performed well in most cases, but in one case (a medium office in Seattle, WA), the savings were less than one percent. The Efficient Cooling measure saved the least energy in all cases, due to the low cooling consumption in the simulated heating-dominated climates. These findings suggest that heat recovery and condensing gas furnaces are an important and impactful part of any program focused on decreasing RTU energy consumption in the regions studied. Conversely, the modeling found that improved compressor performance was not an important measure to include in heating-dominated climates.

Energy recovery measures saved the most, while improved compressor performance saved the least in the heating dominated climates studied.

Figure S-1: Average and Range of Savings for Each Measure and Tier

Relative savings were consistent across climates but vary across building types, indicating that different equipment efficiency measures may be appropriate for different building characteristics.

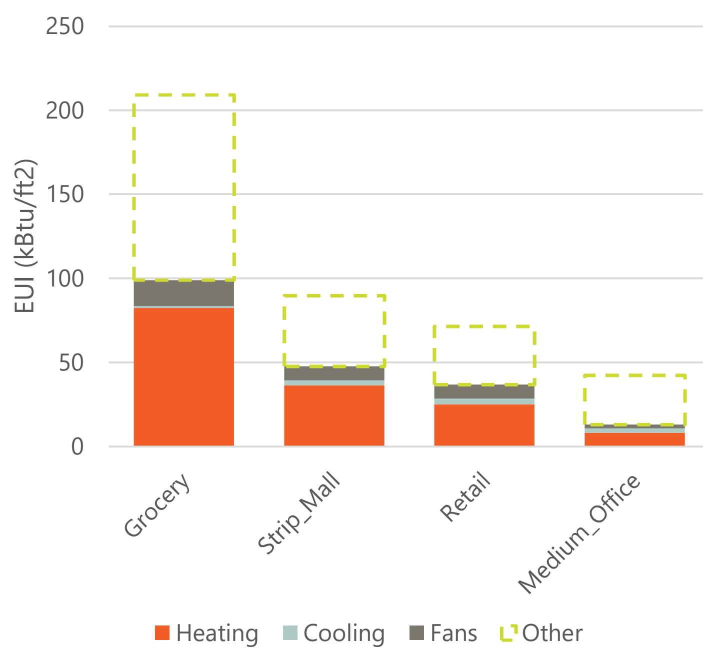


Figure S-2: Baseline Model End Use Results

Figure S-1 also shows the range of relative savings observed for each measure. This range indicates that there was significant variation between building type and location combinations. Both building type and climate location have substantial impacts on energy consumption, which thus affects the absolute magnitude of savings from each measure. When normalizing for differences in baseline buildings' HVAC loads, as in Figure S-1, the relative savings across climate zones were quite consistent, generally varying by less than one percentage point from the locations showing the most savings to the locations showing the least savings. Relative savings among building types, however, still exhibited considerable variation. Variation between building types was over 10 percentage points in some cases. These findings suggest that similar recommendations may be appropriate across heating dominated climates but that efficient equipment specifications may need to be more targeted to specific building characteristics. However, as noted previously, all the climates simulated in this analysis are heating dominated (as seen both in Table S-3 and Figure S-2), with *heating* referring, in this case, to the energy used to raise the temperature of the supply air to the required set point. Due to the gas heating focus of this analysis effort, heating is synonymous with gas use for all model results presented in this report. Understanding the applicability and impact of measures on a national basis, including in cooling-dominated regions, would require further analysis to simulate the suite of measures in additional climates. It should also be noted that the use of relative savings masks significant variation in absolute savings. While this report mostly uses relative savings to facilitate comparison between locations and across building types, it is important to note that absolute savings will also be high for buildings and locations with high baseline energy use. Absolute savings are important as they are the primary driver behind the economic viability of any measure or tier implementation.

Measures, in general, only have minor interactive effects and should be considered on their own merits for inclusion in any efficient RTU program.

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Tier level savings were, for the most part, additive with very little interaction between the measures. The model results showed some measure combinations to slightly diminish the savings of each other, such as combining a more efficient heating or cooling system with energy recovery ventilators (ERVs) or decreased shell losses, as both latter interventions serve to decrease the load. Despite this, we find that any such interactions are so minor that it is more important to apply the most appropriate and impactful measures for a given climate and application rather than consider how those measures might interact.

The savings discussed above consider total energy on a site-level basis. However, efficient gas-fired RTUs consume both gas and electricity and the analyzed measures have different impacts on gas and electricity consumption and savings. From the perspective of fuel use, the different measures can be grouped by impacts into:

1. Measures that save gas and electricity. This includes Reduced Damper Leakage and Increased Enclosure Insulation.

2. Measures that save gas but consume more electricity, which includes condensing gas burners and ERVs.
3. Measures that only save electricity, which is the case for Efficient Cooling.

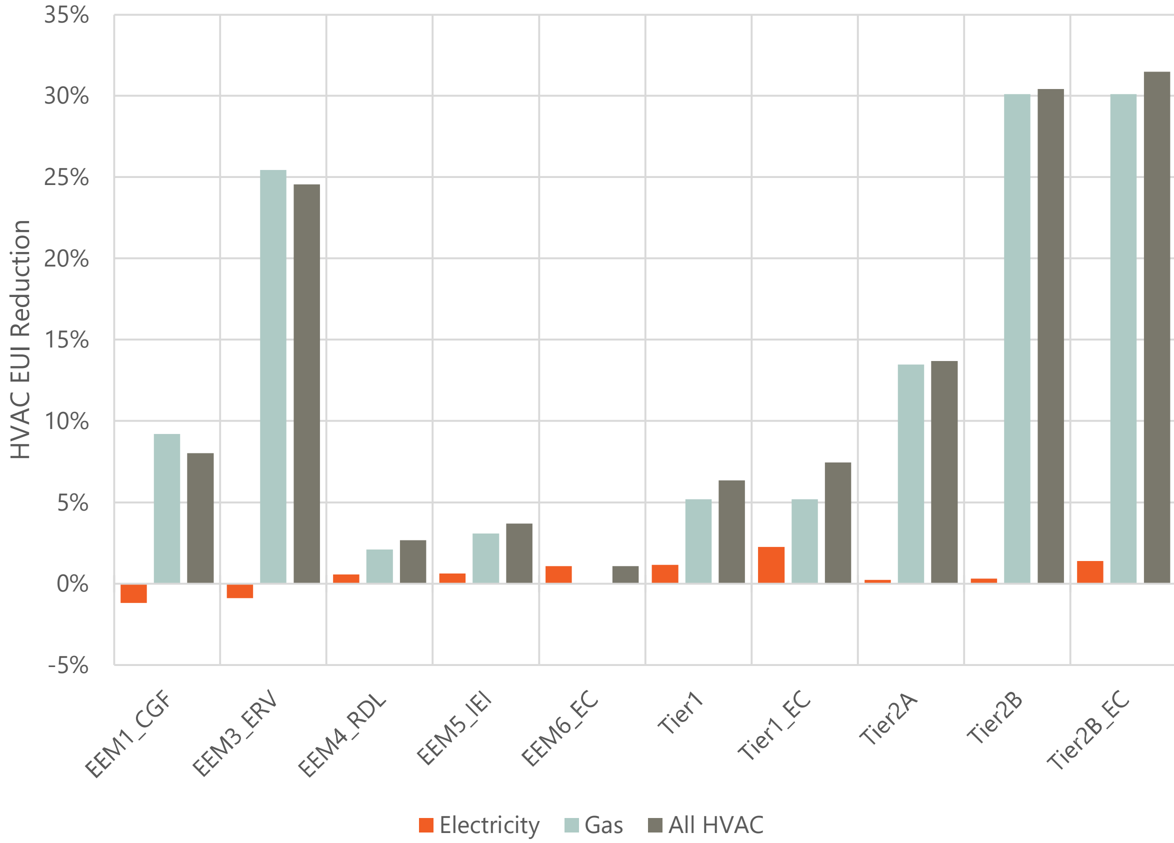

Figure S-1. Total EUI Reduction Over Baseline by Fuel Type

NEEA will have to consider these results in the context of its overall program objectives. Based on the report's key findings, there are several possible implications for program development, including the range of building characteristics (climate and dominant fuel use) to which the program could be applied and the program complexity (i.e., different pathways of program participation).

In both dimensions, NEEA and Nicor can consider more focused versus more comprehensive approaches. These two dimensions and various options form a matrix of program development opportunities, as summarized in Table S-4 Below.

	NW +Midwest Focused	National Focus
Single Pathway	1. Applies to all gas heated buildings in CZ 4C+	1. Applies to all buildings
Two Pathway	1. Applies to all buildings w/ gas > 50% of HVAC energy use in CZ 4C+ 2. Applies to all buildings w/ gas < 50% of HVAC energy use in CZ 4C+	1. Applies to all buildings w/ gas > 50% of HVAC energy use 2. Applies to all buildings w/ gas < 50% of HVAC energy use

Table S-4. Specification Development Mapping

The different implications of these possible program dimensions and the steps required to implement them will be explored in detail in this report and are summarized below in Table S-5, from low impact (1) to High impact (5). In Table S-5, *Program Complexity* reflects how many decisions a participant must make when applying the spec, *Program Long Term Viability* describes how well the spec aligns with any future trends toward building electrification, *Building Level Impact* quantifies the potential energy savings of the spec when applied at the individual building level and *Manufacturer Influence* describes the capacity of any single spec path to be applied across the RTU market.

Case	Program Complexity	Program Long Term Viability	Building Level Impact	Manufacturer Influence
Single-Path Regional	2	1	2	2
Multi-Path Regional	4	3	5	2
Single-Path National	1	4	1	5
Multi-path National	5	4	4	4

Table S-5. Program Dimension Implications

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Section 1 Introduction

This report summarizes Cadeo's energy modeling methodology and results of an investigation of efficient gas rooftop unit (RTU) energy savings in the Northwest and Midwest. The energy modeling analysis is intended to support market transformation efforts by the Northwest Energy Efficiency Alliance (NEEA) and Nicor Gas (Nicor).

This work builds upon several years of past NEEA research on efficient RTUs, including, studying condensing gas RTU in field applications, supporting revisions to the Canadian Standards Association (CSA) P.8 Commercial Warm-Air Furnace standard and test procedure, researching the gas RTU market and drafting a specification for future program use.

The current energy modeling work also builds on previous energy modeling that supported the CSA P.8 revisions. The past energy models, created in 2018 and 2019 and finalized in 2020, focused on three Canadian climate zones; two building types, Warehouse and Stand-Alone Retail; and a range of different outdoor air flow rates, from 0% to 100%.[2] The analysis examined four efficient RTU scenarios:

- Condensing gas furnace
- Energy recovery ventilators (ERVs)
- Increased RTU enclosure insulation
- Reduced outdoor air damper leakage

The analysis revealed the high impact ERVs, insulation, and damper leakage have on heating energy consumption, which existing heating efficiency metrics like Thermal Efficiency do not sufficiently capture.

1.1 Research Goals

Cadeo performed the analysis described in this report to reinforce and expand the applicability of the conclusions from the previous research efforts surrounding efficient RTUs. We wanted to better understand how ERVs, improved cabinet insulation, and dampers saved energy in both heating and cooling seasons; in more moderate climates, like the Northwest and Midwest; in additional building types; and how these measures compared to other energy efficiency options that were not considered in the previous modeling effort, like improved compressor efficiency. This latest round of research expands on the previous scopes in terms of measures, climates, and building types simulated. This analysis aims to understand how RTUs perform under the conditions they are most commonly subject to in the Northwest and parts of the Midwest.

[2] Cadeo Group, "Energy Modeling of Commercial Gas Rooftop Units in Support of CSA P.8 Standard," NEEA, May 2020, https://neea.org/resources/energy-modeling-of-commercial-gas-rooftop-units-in-support-of-csa-p-8-standard

A primary use for the results of this analysis will be the refinement of the Efficient RTU Specification, the latest (as of the publication of this report) version of which is available in appendix 6.1. This specification defines a set of RTU characteristics that NEEA hopes to encourage the adoption of across the commercial RTU sector. NEEA and Nicor will also use this analysis to inform the future efficient RTU initiative of which the draft efficient RTU specification is a critical piece. Specifically, the analysis quantifies how the different tiers of the specification perform across a wider selection of climate zones and building types than previously examined. The energy modeling will serve to understand better if the previously selected measures are still appropriate under this broader range of climatic and operational conditions. Additionally, the models include an Efficient Cooling scenario to evaluate how NEEA should incorporate measures that save cooling energy into future programs.

1.2 Research Questions

To meet NEEA and Nicor's research goals, Cadeo sought to answer the following research questions using newly developed building energy models:

- How much energy does each requirement in the draft efficient RTU specification save over a baseline RTU by requirement and by tier?
- Which of the draft requirements have the largest impact on RTU energy consumption?
- How do the current specification requirements impact RTU energy use in Northwest and Midwest climate zones and by building type?
- Are the savings from each specification requirement additive, or do interactive effects make the draft tiers less impactful?
- What are the key requirements to include in a future spec targeting annual energy performance for both heating and cooling end uses?
- On an annual basis, do the same RTU characteristics that save heating energy also save cooling energy?

1.3 Research Design

In the most general terms, the research approach was to use detailed building energy modeling to estimate the performance outcomes for different efficiency measures applied to RTUs on buildings with a range of occupancies and locations. The critical dimensions of this analysis were the climate conditions, building types, and efficiency measures that Cadeo would simulate.

1.3.1 Climate

To develop a robust understanding of how different efficiency measures, or combinations of measures, would perform across the area of study, Cadeo required a set of weather files that represent the climatic diversity across the region. These weather files specify key simulation inputs such as air temperature, humidity, wind speed, and solar radiation levels (among others), which all play a considerable role in determining the results of a simulation. The weather from a particular analysis location also defines the capacity of the HVAC equipment with design conditions based on statistical analyses of historical weather data. The analysis location and weather also define envelope performance characteristics. Energy code requirements for envelope performances vary by climate zone and Cadeo has assumed that the buildings modeled in this analysis all meet the appropriate code requirements for the modeled location (see section 2.3).

Cadeo had 96 climate representative locations available to select from within the study. Cadeo first reduced the number of options by filtering for sites with the highest quality of data (usually airports in larger towns and cities), then grouped the remaining 35 sites based on climate zone.

The team selected representative locations based on, (1) their proximity to large population centers, (2) the regional presence of a utility most likely to be an early adopter of the research outcomes, and (3) the uniqueness of the regional climate, specific to the location within the climate zone. Table 1 shows the five climate locations that the team selected based on this approach.

Locations	Climate Zone	HDD[3]	CDD
Seattle, WA	4C	2627	1130
Rockford, IL	5A	3719	1635
Bend, OR	5B	3633	959
Spokane, WA	5B	3715	1182
Great Falls, MT	6B	4200	1061

Table 1. Climate Location Properties

[3] HDD and CDD represent the time and extent to which the outdoor air temperature is above or below the point where a typical building must actively to cool or heat. These points are referred to as base temperatures and are assumed to be 18.3˚C and 10˚C, respectively, for this table.

1.3.2 Building Types

To ensure that research outcomes were broadly applicable to commercial buildings in the Northwest and Midwest regions, Cadeo used regional building characteristic data sets to determine the most common regional building types. This analysis used a variety of metrics to define "most common" including:

- Building Type with the greatest number of buildings employing RTUs
- Building Type with most floor area conditioned with RTUs
- Building Type with the greatest installed RTU Capacity

Table 2 shows the top three building types for each metric based on building population and characteristic data available in the latest CBSA data set.[4]

Number of buildings	Floor Area	Heating Capacity	Cooling Capacity
Retail/Service	Retail/Service	Retail/Service	Retail/Service
Office	Mixed Commercial	Mixed Commercial	Mixed Commercial
Grocery	Warehouse	Office	Office

Table 2. Most Common Building Types Using RTUs

Parallel to the CBSA analysis, Cadeo examined the range of available prototype and reference building energy models (see section 2.3) to identify those with characteristics most like the top three building types across all metrics. The available models aligning with the CBSA findings include three office buildings (small, medium, and large), two retail/service buildings (stand-alone and Strip Mall), one Grocery building, and one Warehouse building.

With the most appropriate prototype models identified, Cadeo consulted with the team to select a subset of models that would reflect sufficient operational and equipment type diversity and represent a cross section of the likely applications for the research outcomes. From this review, the team removed the large office building due to the use of a chiller and boiler for space conditioning, the small office due to the use of air source heat pumps, and the Warehouse due to the limited floor area that RTUs would generally condition within that building type (typically only office spaces). Figure 1 shows the prototypes that Cadeo selected through this process.

[4] The Commercial Building Stock Assessment (CBSA) is a regional study, funded by NEEA, which seeks to understand drivers of energy consumption in commercial buildings by collecting detailed information on building characteristics, installed equipment, and energy consumption for buildings throughout the Northwest. https://neea.org/data/commercial-building-stock-assessments

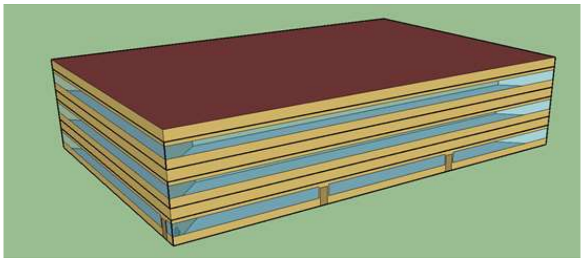
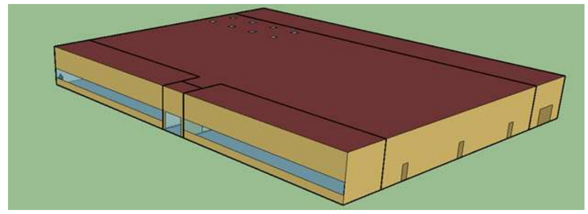
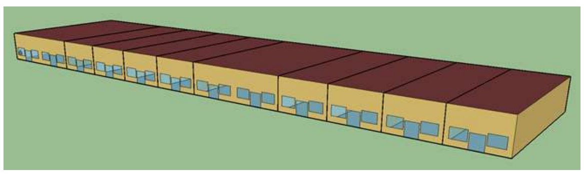
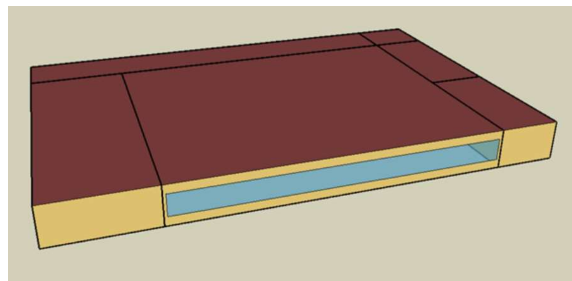
Medium Office	Stand-alone retail
	
53,600 ft^2 3 Packaged Multi Zone RTUs with Gas Heat	24,695 ft^2 with 4 Packaged Single Zone RTUs with Gas Heat
Strip-Mall Retail	**Grocery**
	
22,500 ft^2 with 10 Packaged Single Zone RTUs with Gas Heat	45,000 ft^2 with 6 Packaged Single Zone RTUs with Gas Heat

Figure 1. Selected DOE Prototype Buildings

In addition to the four building types above, Cadeo included a modified version of the Stand-Alone Retail building in the analysis to run 100% outdoor air and considered it as an additional building type in reporting. This contrasts with the prototypes listed above, where outdoor air flow rates vary based on multiple factors defined by ASHRAE 62.1 but are typically around 20% of the RTU supply air flow rate. The purpose of this inclusion was two-fold. First, the team wished to understand what the directional impacts of higher outdoor air flow rates would be for the different measures and second, to provide comparable results to previous analyses that included different outdoor air flow rate cases.

The relationship between building type and modeled energy use outcomes are complex. However, at a high level, the main drivers of different models' results fall into three main categories:

- Geometry (floor area, aspect ratio, window area)
- HVAC systems (type, zoning)
- Occupancy (internal loads, schedules)

The variability of these drivers within the selected prototype buildings is sufficient to capture the range of possible impacts for the different energy efficiency measures and packages that Cadeo modeled in this analysis.

1.3.3 Measures

The measure selection process started with Cadeo developing a list of measures that could be applied to rooftop units. From this list, the team selected measures based on their applicability to the climate zones of the Northwest and Midwest regions, the expected energy impacts, and the commercial availability of products employing the measures. Table 3 below outlines the measures selected; more detailed measure descriptions are available in section 2.4.

Measure	Measure abbreviation	Measure Description
Condensing Gas Furnace	CGF	Add condensing gas heat exchanger to RTU furnace
Energy Recovery Ventilation	ERV	Add sensible and latent heat exchanger between exhaust and ventilation air streams
Reduced Damper Leakage	RDL	Update RTU dampers to low leakage type dampers
Increased Enclosure Insulation	IEI	Add additional insulation to RTU enclosure
Efficient Cooling	EC	Increase the cooling compressor total and part load efficiencies

Table 3. Selected Measure Summary

1.3.3.1 Measure packages (Tiers)

To understand how these measures perform when applied simultaneously and to develop recommendations for the RTU specifications packages, in addition to modeling each measure individually, Cadeo also combined the above measures into packages referred to in this report as "Specification Tiers" or simply "Tiers." Table 4 describes the measure packages that were simulated as a part of this analysis:

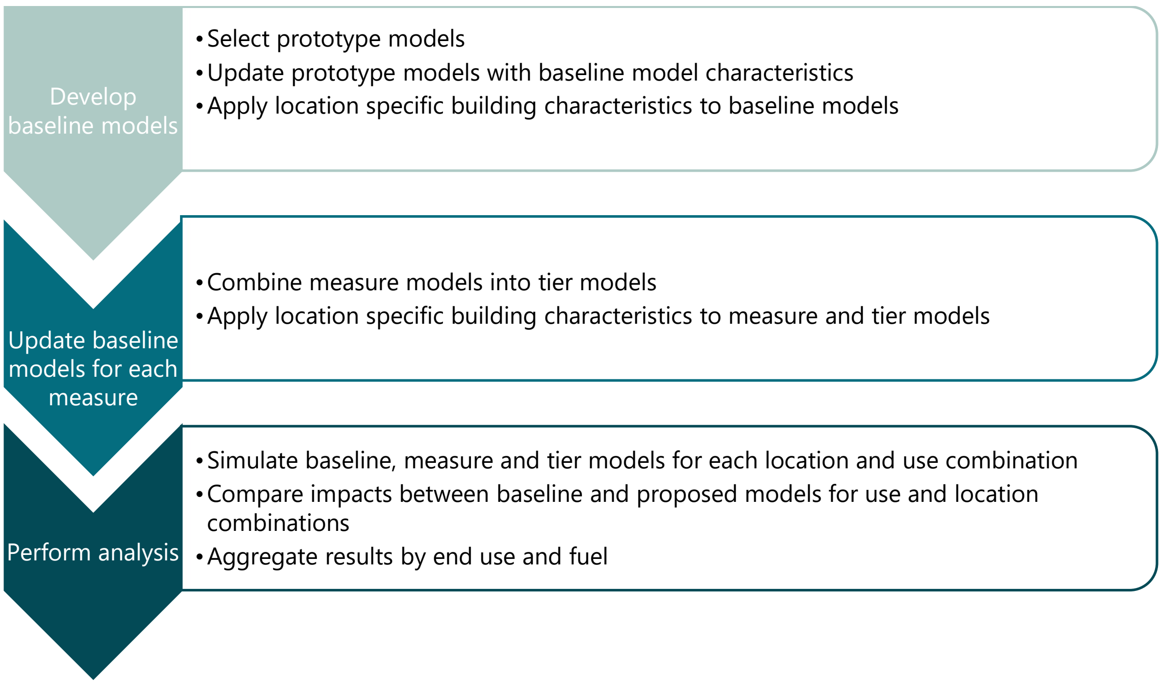
Package	Measures included
Tier 1	1. Reduced Damper Leakage 2. Increased Enclosure Insulation
Tier1 + Efficient Cooling	1. Reduced Damper Leakage 2. Increased Enclosure Insulation 3. Efficient Cooling
Tier2A	1. Reduced Damper Leakage 2. Increased Enclosure Insulation 3. Condensing Gas Furnace
Tier 2B	1. Reduced Damper Leakage 2. Increased Enclosure Insulation 3. Energy Recovery
Tier 2B + Efficient Cooling	1. Reduced Damper Leakage 2. Increased Enclosure Insulation 3. Energy Recovery 4. Efficient Cooling

Table 4. Specification Tier Summary

Section 2 Modeling Approach

2.1 Overview

Following the general approach used in previous years' analyses, the work described in this report broadly involves the steps outlined in the figure below.



2.2 Tool Selection

To perform the building energy simulation, Cadeo used the whole building energy simulation program EnergyPlus.[5] EnergyPlus is at the forefront of building energy modeling and is used widely by the energy modeling community in the United States. It is an open-source tool that is continuously maintained and supported through funding from the United States Department of Energy (US DOE) and can perform the required analyses in a manner that will provide robust and verifiable results. Using EnergyPlus also allowed the analysis team to leverage modeling work performed in a previous study, compare results for QA/QC, and build upon previous findings.

EnergyPlus is also the tool that the DOE used to develop the prototype models that are the foundation for the baseline development in this analysis. Leveraging these existing, peer-reviewed energy models allowed the modeling team to focus solely on the aspects of the buildings pertinent to the measures being examined. This allowed the team to examine a broader range of measures and building types than would otherwise be possible.

[5] https://energyplus.net/

2.3 Baseline Development

The baseline energy models represent existing buildings where the buildings' owners have replaced their original equipment with a current practice baseline RTU and have not applied any of the measures studied. To represent this, Cadeo first started with prototype buildings[6] meeting ASHRAE 90.1-2004. Cadeo selected the year 2004 as a building baseline to approximate an existing building. This is also approximately the age when the rooftop equipment has reached the end of its service life, which ASHRAE estimates for RTUs as 15 years. The ASHRAE 90.1-2004 vintage shell represents the "existing building stock" and is held constant in all model scenarios.

To develop the current practice baseline equipment, Cadeo updated the rooftop equipment in the 2004 Prototype models to reflect the performance characteristics defined by the most recent version of ASHRAE 90.1 (2019). The RTU performance characteristics that Cadeo updated in the baseline models were the HVAC equipment efficiencies defined in ASHRAE 90.1 and included the burner, compressor, and fan efficiencies. Updating the rooftop equipment to 2019 efficiencies ensures that the difference in modeled energy performance between the baseline and proposed models reflects the marginal benefit of the proposed measures against equipment that *would be* selected when the building owner went to replace their RTU equipment today. It is imperative that any follow-on cost analysis accounts for this by using the marginal (i.e., additional) cost of the efficient features rather than the whole cost of the new RTU.

Due to variation in the energy code trigger points across the region, it may not always be necessary to replace RTUs with new equipment that conforms to the latest ASHRAE 90.1 standard. Because of this, **the results presented in this report represent a minimum expected savings**. In jurisdictions that allow like-for-like replacement of commercial rooftop equipment, actual savings could be considerably higher.

Beyond updating the rooftop equipment, Cadeo made two other changes to the baseline models. These changes were required because the prototype energy models do not account for any losses at the RTU, including damper leakage and shell losses. To address this, Cadeo employed the same implementations used in the proposed models but with different values for key performance inputs. To account for baseline levels of damper leakage, Cadeo modeled baseline RTUs having dampers with the effective leakage area (ELA) equivalent to AMCA Class 3 dampers. To account for baseline shell performances, Cadeo modeled baseline RTUs with shell u-values equivalent to shells insulated to R2. Details on how Cadeo implemented these measures (including the assumed baseline performance characteristics) are available in sections 2.4.3 and 2.4.4.

[6] https://www.energycodes.gov/development/commercial/prototype_models

2.4 Measure Input Development

Simulating each measure in EnergyPlus requires developing exact and detailed specifications for each simulated RTU scenario. For example, the model input files must specify all equipment sizes, flow rates, efficiencies, and cabinet properties. The measure development approach Cadeo employed leveraged existing, peer-reviewed implementations of the different system components making up each measure. For this, Cadeo primarily relied on models developed by the Pacific Northwest National Laboratory (PNNL) and the National Renewable Energy Laboratory (NREL). Additionally, Cadeo leveraged the previous, P.8 modeling (also developed by PNNL) to inform modeling input assumptions. The following sections describe the specific simulation parameters for each measure and Tier.

2.4.1 Condensing Gas Furnaces

In this measure, the standard efficiency gas heating sections are replaced with higher efficiency condensing gas systems. In these systems, an extra stage of heat exchange cools the exhaust combustion gasses below the dewpoint to extract more energy before the gasses are exhausted to the atmosphere. This additional stage of heat extraction improves overall thermal efficiency and reduces the amount of natural gas combustion needed to meet a given space heating load.

To represent condensing gas furnaces, Cadeo updated two objects in the baseline energy models. The first object represents the heating section of the RTUs. In the baseline models, the modeled heating section thermal efficiencies are 80% to 81% (depending on the equipment capacities)[7]. Cadeo updated the thermal efficiencies to 93% to reflect a typical condensing warm air furnace efficiency.

In addition to updating the thermal efficiency, Cadeo also increased the total static pressure drop in the RTU supply fans by 0.2″ water column (50 pa). This increased pressure drop represents the average impact of airflow obstruction caused by the secondary condensing heat exchanger. The updated values of 93% thermal efficiency and 0.2″ water column are based on a survey Cadeo performed of condensing gas heat exchangers currently available on the packaged RTU market.

2.4.2 Energy Recovery

Energy recovery reduces the amount of energy needed to temper the building's incoming ventilation air. This is accomplished by placing a heat exchanger between the exhaust and intake ventilation air streams. This heat exchanger will either preheat or precool the outside air using the exhaust air stream and reduce the amount of energy required to meet the supply air temperature set point.

[7] Burner Efficiency values taken from ASHRAE 90.1-2019

The Cadeo energy modeling team added an air-to-air heat exchanger object to each of the baseline models' air systems to model the Energy Recover Measure. The modeling approach and the model object parameter inputs are based on those employed by the DOE prototype development team, which is also the same approach that Cadeo (in conjunction with PNNL) used in the previous P.8 RTU analyses. Table 5 below outlines these inputs:

Model Input	Value
Sensible Effectiveness in Heating	70%
Latent Effectiveness in Heating	60%
Sensible Effectiveness in Cooling	75%
Latent Effectiveness in Cooling	60%
Heat Exchanger Type	Rotary
Frost Control Type	Exhaust Air

Table 5. ERV Performance Characteristics

An added complexity of modeling energy recovery is that when the heat exchanger is not operating (due to economizer operation), the exhaust and ventilation air stream bypasses the energy recovery components. To model this, Cadeo again employed the method used by the DOE prototype developers, where the additional fan energy (due to the pressure drop across the heat exchanger) is assigned to the energy recovery object as electrical power required to operate the heat exchanger. With this method, when the heat exchanger is bypassed the energy use is zero. After simulation runs, the energy used is reassigned to fan energy in a post-process. Table 6 outlines the manufacturer data[8]-based assumptions used in the approach.

Input	Value
Total Static pressure drop for both air streams	1.25" water column
Total fan efficiency	60%
Non-fan energy used by ERV	0.14 Watt per ft^3/min airflow

Table 6. ERV Fan Energy Impact Parameters

Using the minimum outdoor air ventilation rate in cfm, Cadeo calculated the total power, in watts, used by the energy recovery ventilator while operating as:

$$W = (cfm \times 1.25) \div (0.6 \times 6356) \times 746 + cfm \times 0.14$$

[8] https://www.aaon.com/Documents/Technical/AAONAire_110103.pdf

2.4.3 Reduced Damper Leakage

Damper leakage occurs when the exhaust and outdoor air dampers installed on a rooftop unit are closed during hours of non-occupancy (i.e., when no ventilation air is needed) and there is a pressure differential between the interior of the RTU and the outside environment. Improving the air tightness of the dampers reduces the loss of conditioned interior air. This reduction, in turn, reduces the amount of space conditioning needed to keep a building at its interior set points.

Cadeo modeled the energy impacts of damper leakage using the effective leakage area approach from the ASHRAE Fundamentals Handbook[9] to account for wind and stack effect driven air infiltration/exfiltration. While the model object itself is straightforward to implement with only three inputs, determining the values that accurately model leakage through a damper required additional analysis.

The real-world conditions that Cadeo wished to model were those of using AMCA Class 3 dampers in the baseline energy models and Class 1 dampers in the proposed models. Table 7 gives the leak rates in cfm per ft^2 for the AMCA damper classes at different pressure differentials (measured in inches of H_20).

	Cfm/ft^2 @ 1"	cfm/ft^2 @ 4"	cfm/ft^2 @ 8"	cfm/ft^2 @ 12"
Class 1	4	8	11	14
Class 2	10	20	28	35
Class 3	40	80	112	140

Table 7. AMCA Damper Class Leakage Rates

[9] American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2009). *2009 ASHRAE handbook: Fundamentals.* Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers

To translate the AMCA damper classes into effective leakage area, the Cadeo team used the following equation[10] to solve for the required inputs:

$$\dot{m} = ELA \times C_d\sqrt{2\rho} \times (\Delta P_r)^{0.5-n}(\Delta P)^n$$

Where:

$\dot{m}$ = Air mass flow rate
ELA = Effective leakage area
P = Air Density
ΔP_r = Reference pressure difference
ΔP = Pressure different across damper
C_d = Discharge coefficient
n = Air mass flow exponent

Using EnergyPlus default values for discharge coefficient (1.0) and the reference pressure (4.0 Pa), Cadeo solved for the air mass flow exponent (n = 0.50415) that gave the same effective leakage area under all four damper leakage conditions defined within each class. Table 8 gives the resulting ELA for each damper class:

AMCA Damper Class	Effective leakage area per ft^2
Class 1	0.14 in^2
Class 2	0.36 in^2
Class 3	1.41 in^2

Table 8. AMCA Damper Class ELA

Using these values in conjunction with values from the ASHRAE Fundamentals Handbook for wind and stack coefficients (interpolated based on roof heights), Cadeo added effective leakage area objects to the baseline and proposed models representing Class 3 and Class 1 dampers, respectively. Lastly, Cadeo scheduled the damper leakage objects only to be active when the building was unoccupied, as this is the only time that the outdoor air dampers are closed and leakage through the dampers would impact energy performance.

[10] https://bigladdersoftware.com/epx/docs/9-4/input-output-reference/group-airflow-network.html#airflownetworkmultizonesurfaceeffectiveleakagearea

2.4.4 Increased Enclosure Insulation

RTUs are exposed to exterior conditions by definition, so there will always be some level of energy transfer through an RTU enclosure. This energy transfer through the RTU enclosure occurs through conduction and can be minimized by increasing the level of enclosure insulation.

The Increased Enclosure Insulation measure cannot be directly modeled using standard EnergyPlus objects. To overcome this, Cadeo employed the Energy Management System (EMS) feature of EnergyPlus. The EMS allows users to define simple programs within the energy model that can alter other model objects at different points when the simulation is running. The EMS program that Cadeo developed for this measure first tracked the air temperatures within the RTU cabinet before (mixed air temperature) and after (supply air temperature) the heating and cooling sections of the RTU. The program then uses hard entered enclosure areas based on the required equipment capacity (see Table 9) and U-values to calculate the energy transfer based on the temperature differential between the interior and exterior of the RTU and the enclosure U-value.

Equipment Type	**Mixing Box Area** (ft^2)	**Supply Section Area** (ft^2)	**Damper Area** (ft^2)
5-ton Air Cooled Packaged RTU	99.8	7.3	2.0
10-ton Air Cooled Packaged RTU	163.3	11.9	4.9
15-ton Air Cooled Packaged RTU	235.7	17.2	5.3
25-ton Air Cooled Packaged RTU	251.0	18.3	5.3

Table 9. RTU Enclosure Assumptions

The EMS program then applies the energy transfer as either a positive load (in the case of heat gain at the RTU) or a negative load (in the case of heat loss at the RTU) within the zone that the RTU serves.

2.4.5 Efficient Cooling

Cooling in package RTUs is delivered using the vapor compression cycle to meet supply air temperature set points. The overall cooling efficiency of the system is a product of its individual components, including heat exchange coils, expansion valves, and compressors. Improving the efficiency of these components allows a packaged RTU to use less energy to deliver the same amount of cooling to a space.

To model more Efficient Cooling, Cadeo needed to develop two key model inputs. The first input was the coefficient of performance (COP). The COP is the ratio of the compressor and condenser fan input power to the cooling capacity at peak load. Current equipment rating approaches (IEER, EER) include supply fan power, making it challenging to find the proper energy model input values. To overcome this, Cadeo used the DOE's *Technical Support*

Document: Energy Efficiency Program for Commercial and Industrial Equipment (TSD)[11] to find the energy use of the different elements of an RTU at different efficiency levels. The TSD breaks out compressor, condenser fan, supply fan, and controls power for 7.5-ton, 15-ton, and 30-ton packaged equipment. Using these values along with the equipment cooling capacities, Cadeo developed COPs for each efficiency level. Using Efficiency Level 1 and Efficiency Level 3 for the baseline and proposed models, respectively, Cadeo developed COPs for the different system capacities use in this analysis (see Table 10).

Equipment Type	Capacity (Tons)	Capacity (BTU/Hr)	BL COP	PROP COP
5-ton Air Cooled Packaged RTU	5	60000	3.85	3.93
10-ton Air Cooled Packaged RTU	10	120000	3.67	3.91
15-ton Air Cooled Packaged RTU	15	180000	3.52	3.85
25-ton Air Cooled Packaged RTU	25	300000	3.31	3.59

Table 10. RTU Cooling Efficiency Assumptions

The second type of input that EnergyPlus uses to simulate cooling system performance is performance curves. To develop performance curves for the proposed Efficient Cooling scenarios, Cadeo first identified equipment that met the DOE TSD Efficiency Level 3 requirements. Cadeo then used a spreadsheet tool[12] to produce the required performance curves based on the equipment manufacturers' published performance data at different operational conditions. Finally, Cadeo used these performance curves and the COPs to model RTU cooling equipment meeting the proposed efficiency levels.

2.4.6 Measure Tiers

After developing the models for the individual measures as described in the above sections, Cadeo combined the measures into different tiers based on the Tiers in NEEA's draft performance specification and two additional tiers that included the Efficient Cooling measure. The modeling approach for the tiers did not differ from how Cadeo modeled the individual measures, as described above. The difference in modeling the tiers was that multiple measures were implemented at one time to understand the combined and interactive effects of a suite of specific measures.

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[11] https://www.regulations.gov/document/EERE-2013-BT-STD-0007-0027

[12] https://bigladdersoftware.com/epx/docs/8-3/auxiliary-programs/hvac-performance-curve-fit-tool.html

Section 3 Model Results

This section describes in detail the results of the 275 unique energy models that Cadeo simulated for this analysis. The model results section is broken out into three subsections, each presenting different results summaries with the content and structure of each section tailored to the results being presented.

Section 3.1 presents the results of the baseline simulations. The results here are in terms of absolute energy use intensity (kBtu/ft^2/yr), both for whole building and for HVAC end uses. Averaged across location and building use, these values help to understand how energy performance varies between the different dimensions of the analysis. The total energy use intensity (EUI) and the EUI breakdown between end uses define the feasible scope of energy impacts from the different measures when applied to these baseline buildings.

Section 3.2 presents the outcomes of applying the different measures and tiers across the building types and locations used in this analysis. These results are, in general, presented as relative impacts over the baseline values shown in section 3.1. Using relative impact makes direct comparisons of the energy impacts across building type and location more meaningful. Relative impacts also facilitate the application of the simulation results to buildings not directly examined in the analysis to aid in regional impact extrapolations based on building population data sets.

Section 3.3 compares the measure impacts with those found in the previous P.8 analysis. Results are presented for those regions, building types, and measures where there was direct overlap between the two analysis efforts. The results presented show what, if any, material differences are seen in the results of the two analysis efforts.

3.1 Baseline Energy Consumption Results

The modeled baseline energy use affects savings in two key ways. First, the total energy used defines the scope of available energy savings and, second, the end use (heating, cooling, and fans) breakdown influences how different measures reduce overall energy use relative to each other. The end uses described occur in all seasons, though the heating and cooling energy uses primarily occur in the heating and cooling seasons, respectively. The following sections describe each baseline model's annual total and end-use energy by climate and building type.

3.1.1 By Climate

Figure 2 shows how whole building and HVAC energy use vary between the different climates Cadeo employed in the building simulations. The graphs show the site energy use intensity (EUI) in kBtu/ft^2 as an unweighted average across building types.[13]

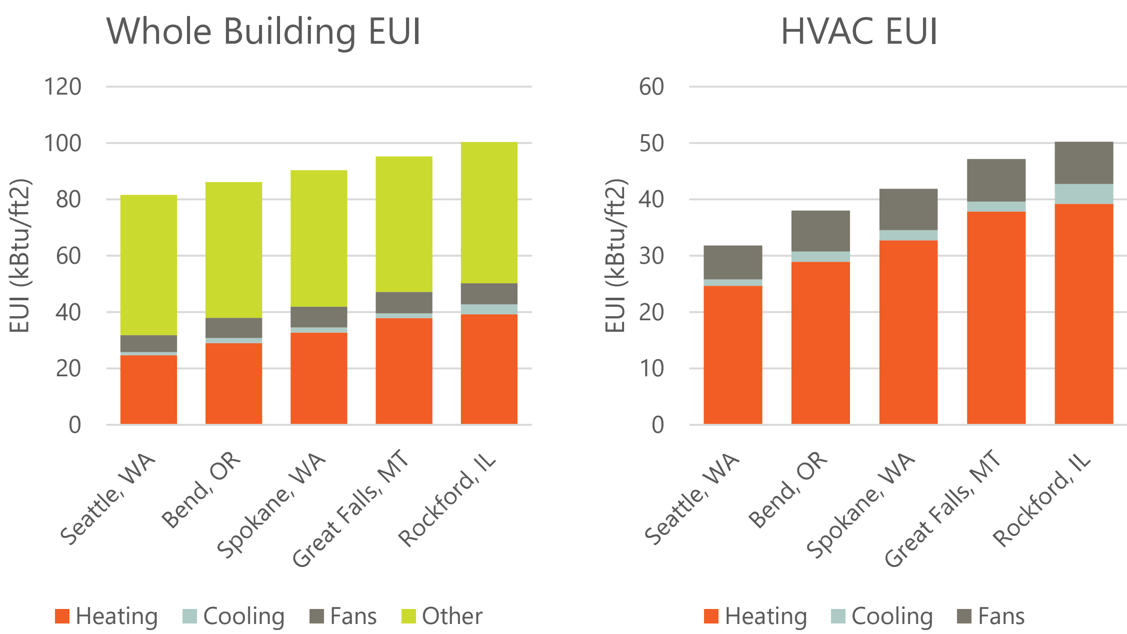

Figure 2. Baseline Model Results by Building Location

Figure 2 shows that the HVAC energy use represents approximately 30-50% of whole building EUI and is approximately 30% greater in Rockford, IL than in Seattle, WA. We would expect to see this based on climate zone and HDD data. The energy use impacts for the measures applied to buildings across these regions will, in general, be strongly correlated to this variation. That is, the greater the HVAC energy use, the greater the savings.

The end use breakdown (EUBD) predicts how measures targeting specific end uses will perform between locations. The EUBD here shows that there is relatively little variation in end use *proportions* between locations. In all the climates Cadeo simulated for this analysis, heating represents most of the HVAC energy consumption (76 – 80%), fans represent the next largest (15-19%) and cooling makes up between 4% and 7% of total HVAC energy used. All simulated climates are substantially heating dominated and, as such, the modeling results will show proportionally similar results across locations, with measures that affect heating energy consumption the most impactful and cooling the least. While the end use proportions are

[13] All results averaged across building types do not include the 100% outdoor case to avoid weighting the summary result too much towards the highly divergent outcomes associated with 100% outdoor air.

consistent across the regions used in this analysis, this is not expected to hold across all climates in the US; cooling-dominated climates would likely show different trends.

3.1.2 By Building Type

Figure 3 shows how whole building and HVAC energy use, respectively, vary between the different building types employed in the building simulations. The graphs show the EUI averaged across all the locations in which Cadeo simulated the building energy models.

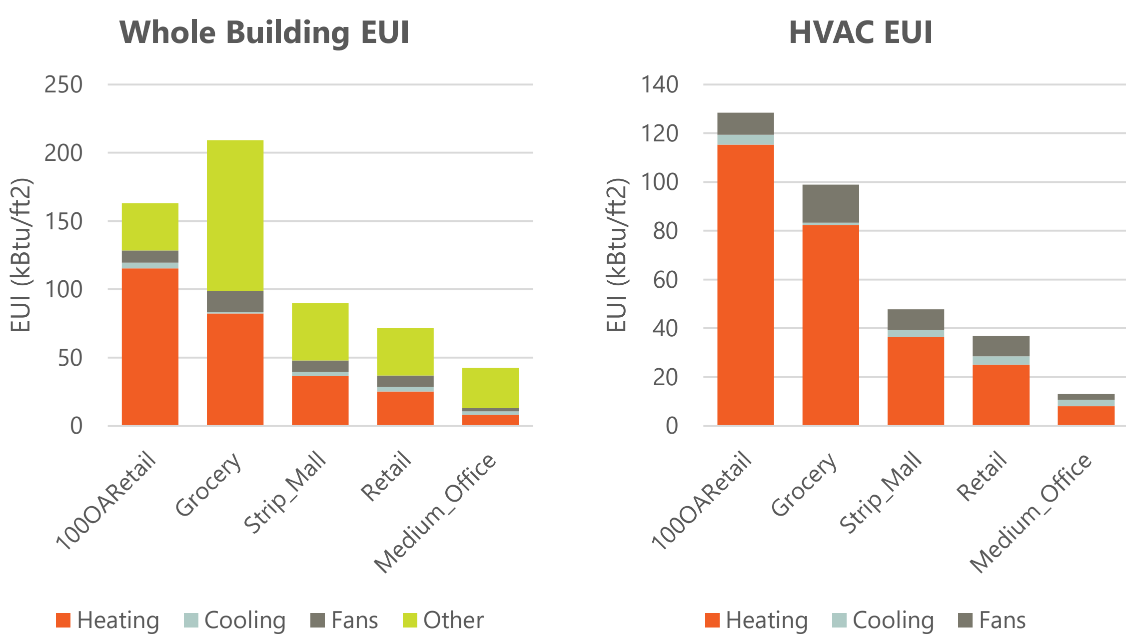

Figure 3. Baseline Model Results by Building Type

There is more sizable variation in both the HVAC EUI and end use breakdown between building types than was seen by location in sections 3.1.1. HVAC EUIs are nearly 7.5 times higher in the Grocery use type (and nearly 10 times in the case of 100% Outdoor Air) than in the Medium Office use type. While all building prototypes are still heating dominated, the relative proportions of the different end uses are also highly variable between building types, with cooling making up only 1% of total HVAC energy in the Grocery baseline and 21% in the Medium Office baseline. This variation in both the total HVAC energy and the relative proportion of end use energy makes each of the baseline buildings unique. Therefore, they have the potential for divergent outcomes – in terms of total energy saved, as well as which measures are best suited to a particular building type. We will discuss this further in section 3.2, but this analysis did find that some measures performed differently in each building type.

3.1.3 By Region and Use

The trends described above are consistent at the individual model result level as well – that is, if we do not average across building type or location. Figure 4 shows the HVAC energy use and EUBDs for each baseline building simulation. Again, consistent use patterns within locations but high variability between building types can be seen. While some trends are exaggerated for specific building types (e.g., the variation from Seattle, WA to Rockford, IL is greatest for the 100% Outdoor Air case), the directionality is the same. The stronger regional variations in some of the baseline models is an indication that those building types are more closely coupled with the exterior environment, while the others are dominated by internal loads.

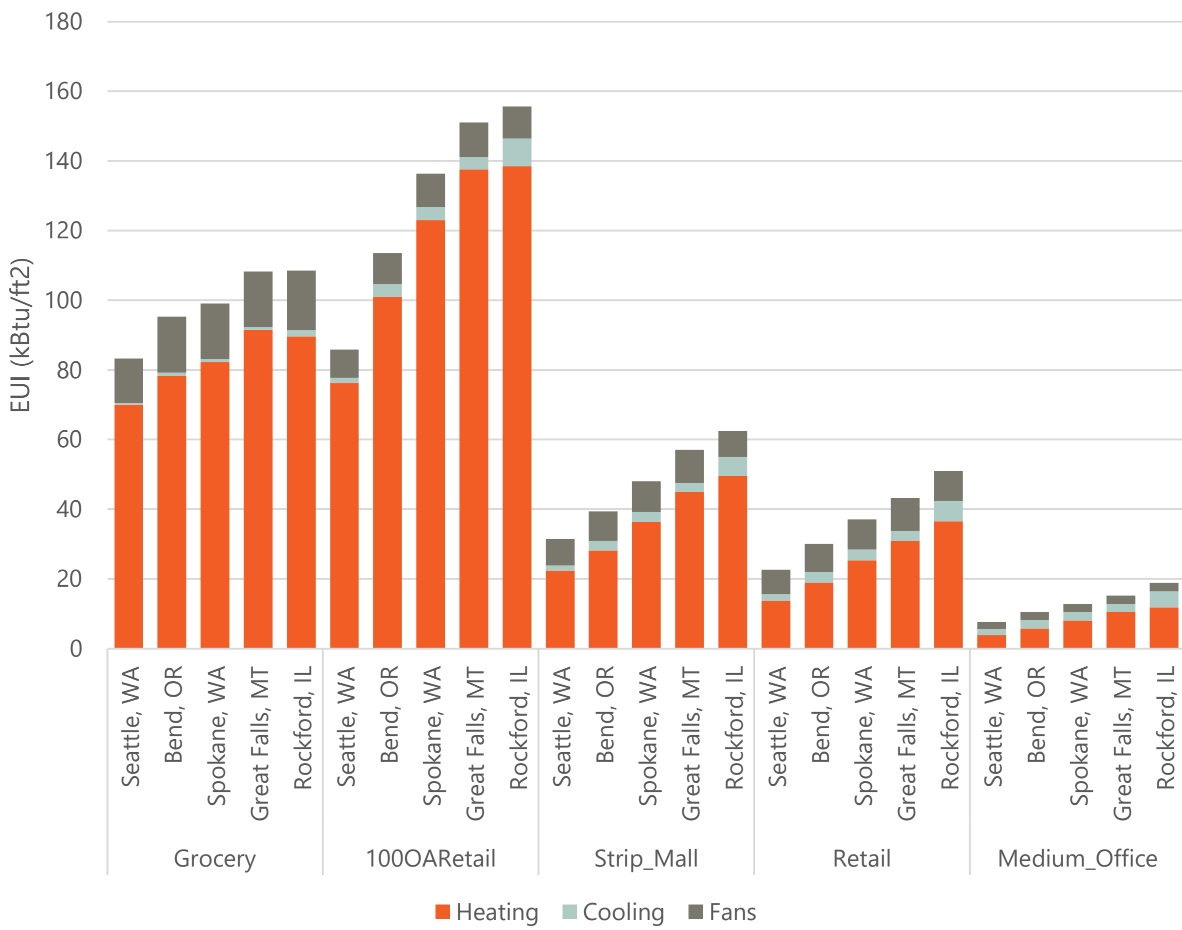

Figure 4. Baseline HVAC EUI by Building Type and Location

3.2 Summary Energy Saving Results

The following sections present the HVAC energy use impacts by measure and tier. The results are first presented across all locations and building types to give a high-level view of how the measures' impacts compare with one another. The latter sections present the results in detail for each measure and tier with comparisons across building types and between locations.

3.2.1 Summary Results by Measure and Tier

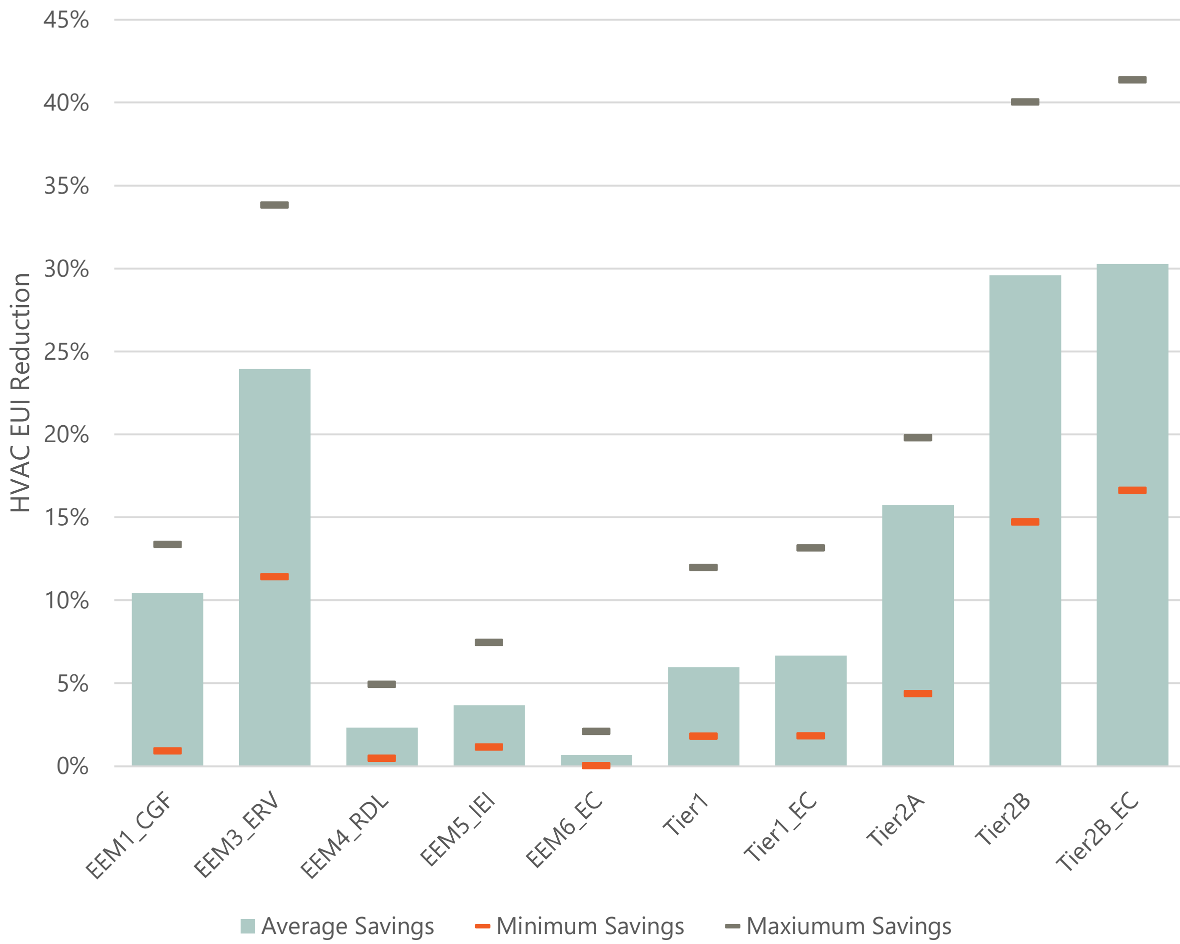

Figure 5. Measure EUI Impacts

Figure 5 shows a summary of all Measure and Tier HVAC savings. The values shown are the average impacts across all locations and building types (except for 100% Outdoor Air, which is excluded in any averages calculated across building types). This figure gives an estimate of expected savings for each measure and tier when applied to commercial buildings in the Northwest and Midwest regions. Because the values represented are averaged across building types and locations, the orange and gray bars indicate the maximum and minimum savings percentage for each measure and tier. While there is some variability in the maximum and minimum savings, the general relationship of savings among the measures and tiers in consistent – the high-savers have the highest savings potential, and the low-savers have the least. Key takeaways from Figure 5 include:

- ERV and tiers that include ERV achieves the highest energy savings (24-30% on an average annual basis).
- A more efficient compressor is the least impactful in all the buildings and climates we modeled due primarily to the limited cooling load in the selected model scenarios.
- While condensing gas furnaces, on average, are the second most impactful measure, there are some building type and location combinations where the measure saves very little.
- The minimum and maximum savings for each measure vary considerably, depending on the building type and location to which the measure or tier is applied.

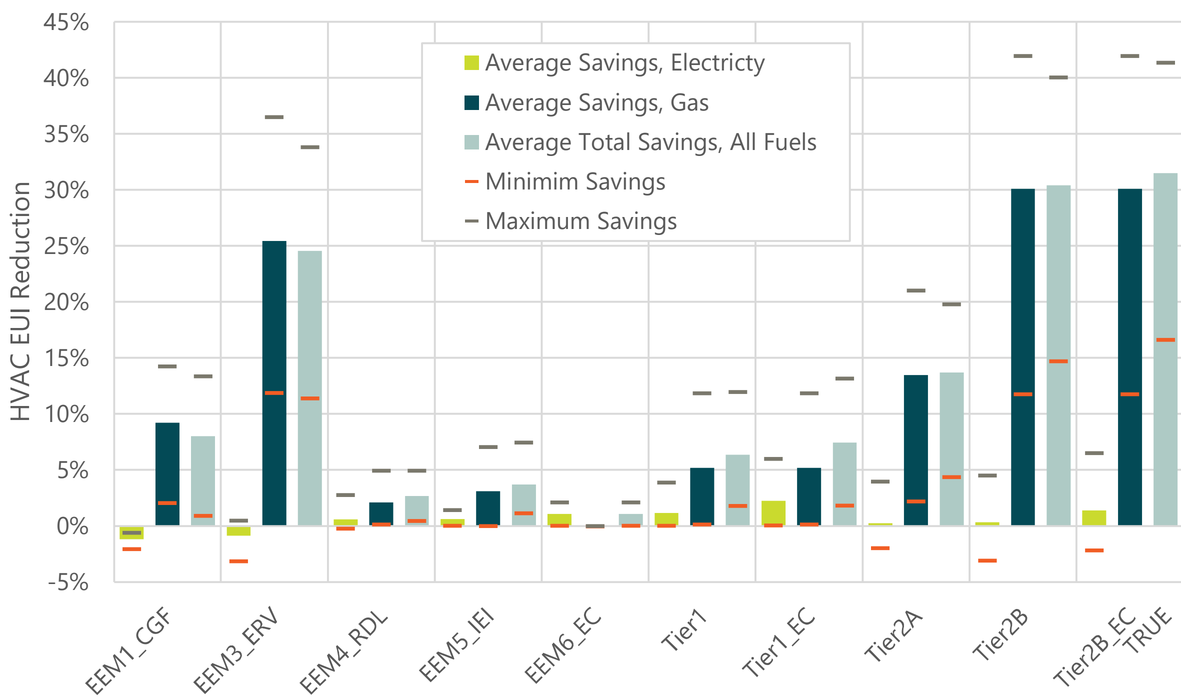

Figure 6. Total EUI Reduction Over Baseline by Fuel Type

When the results are broken out by fuel type in Figure 6, we see that the total savings from Figure 5 hide material variability in terms of fuel use impacts. From the perspective of fuel use, the different measures can be grouped by impacts into:

1. Measures that save gas and electricity. This includes Reduced Damper Leakage and Increased Enclosure Insulation.
2. Measures that save gas but consume more electricity, which include condensing gas burners and ERVs.
3. Measures that only save electricity, which is the case for Efficient Cooling.

The relative fuel impacts from the different tiers reflect the cumulative impacts of the measures of which they are comprised.

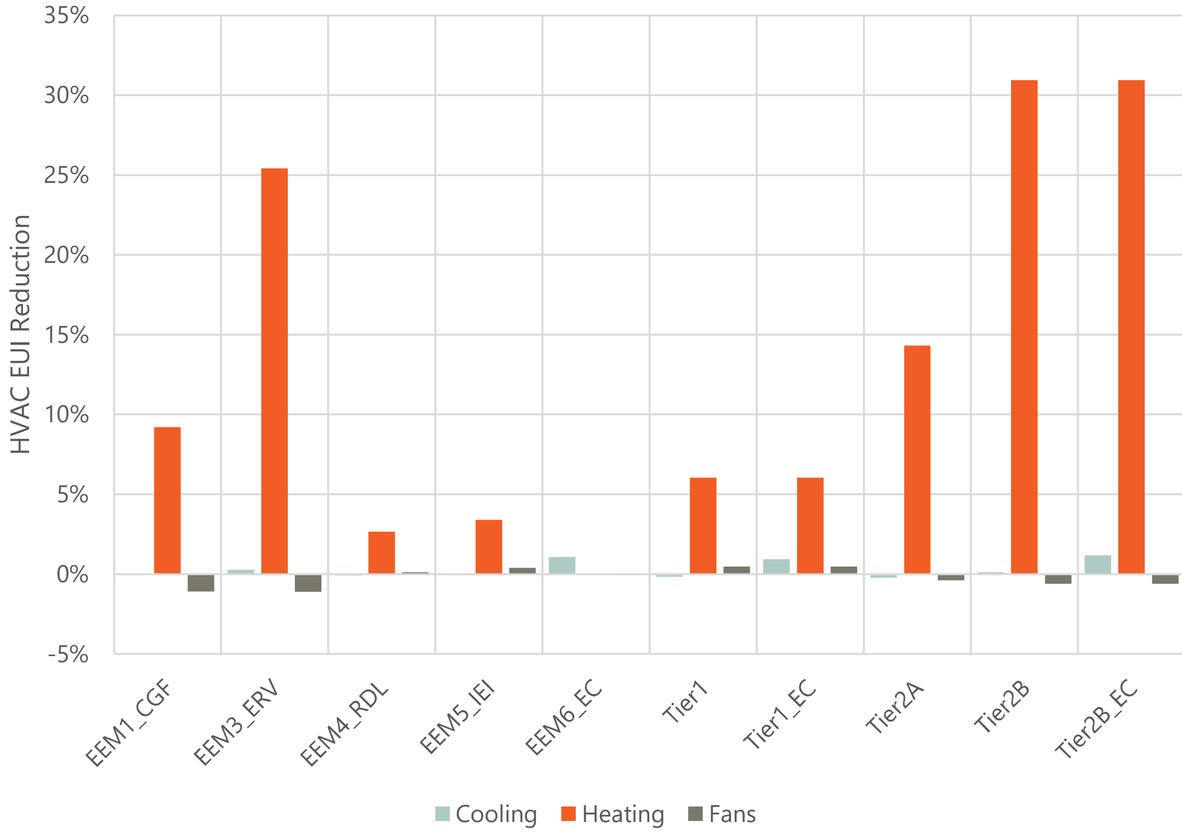

Figure 7. Measure and Tier Impacts by End Use

While our modeling focused on heating-dominated climates, one can consider how the different measures impact energy consumption in the heating end use (those that are important for heating-dominated climates) versus the cooling end use (measures that are more impactful for cooling dominated climates). From the modeling performed, we see that the measures fall into different categories:

1. Those that save energy for both heating and cooling end uses. The only measure that falls in this category, as modeled, is ERVs.
2. Those that save energy in heating only, which include Condensing Gas Furnaces, Reduced Damper Leakage, and Increased Enclosure Insulation.[14]
3. Those that save cooling energy only, which only includes efficient compressors.

[14] For the shell measures, the negative cooling impacts are very small and if the analysis included more cooling dominated climates these measures can be expected to save energy in both cooling and heating end uses.

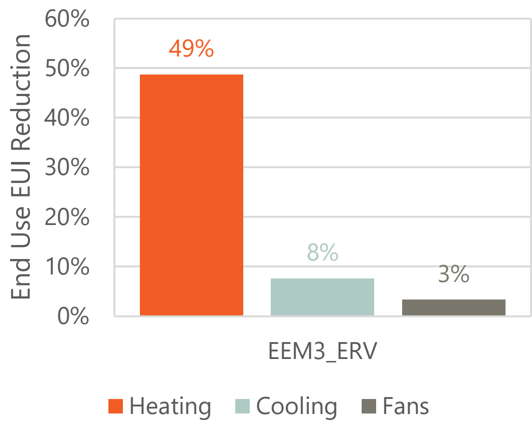

Figure 8. ERV End Use Savings for Rockford, IL

Our modeling revealed, in all cases, the relative proportion of cooling energy savings to heating or fans is very small.. Several factors drive these results; the first is that cooling systems generally deliver three to four times more cooling than gas heating for a given amount of energy input. For example, the 8% reduction in energy used for cooling[15] from Energy Recovery Ventilation shown in Figure 8 represents an over 30% reduction in cooling load, while the 49% gas savings represents closer to a 39% heating load reduction. Another factor impacting cooling savings is the mild and heating dominated climates in the regions examined. These climate conditions mean that the temperature difference between the interior and exterior is quite small in the cooling season relative to the heating season. Not only does this reduce cooling loads, but it also diminishes the effectiveness of measures intended to reduce conductive heat transfer (such as with Increased Enclosure Insulation) or those that rely on large temperature difference for effective operation (such as with Energy Recovery). However, the cooling season air temperature differentials could be increased in real world applications due to elevated (through solar gains) roof temperatures, which the energy models did not account for. The impact of elevated roof temperatures would need to be assessed through field studies of RTU installations. Lastly, all regions examined are well suited to economizing through most of the cooling season, which further diminishes the overall cooling load and reduces the use of the most effective measure (as ERVs are bypassed during economizing).

3.2.2 Results by Measure

Cadeo modeled each measure independently for all building type and location combinations. The sections below describe, at a high level, the percent impact on HVAC energy for each measure, compared across building types and locations. The results show that the performance of each measure changes depending on building type and location. There is little in the way of a consistent pattern between measures (e.g., one location or building type consistently performing the better or worse). However, most measures perform consistently across regions.

3.2.2.1 Condensing Gas Furnace

The Condensing Gas Furnace Measure, on average, saves 8% of overall HVAC energy. The greatest savings (13.2%) occur in Grocery use type located in climate zone 6B (Great Falls, MT) and the least savings (0.4%) occur in Medium Office use type located in climate zone 4C (Seattle,

[15] 8% represents the reduction in cooling energy use, rather than a reduction in overall HVAC energy use.

WA). The savings from this measure are strongly correlated to heating load, so the Grocery use type shows the most savings in all climates zones while the medium office shows the least.

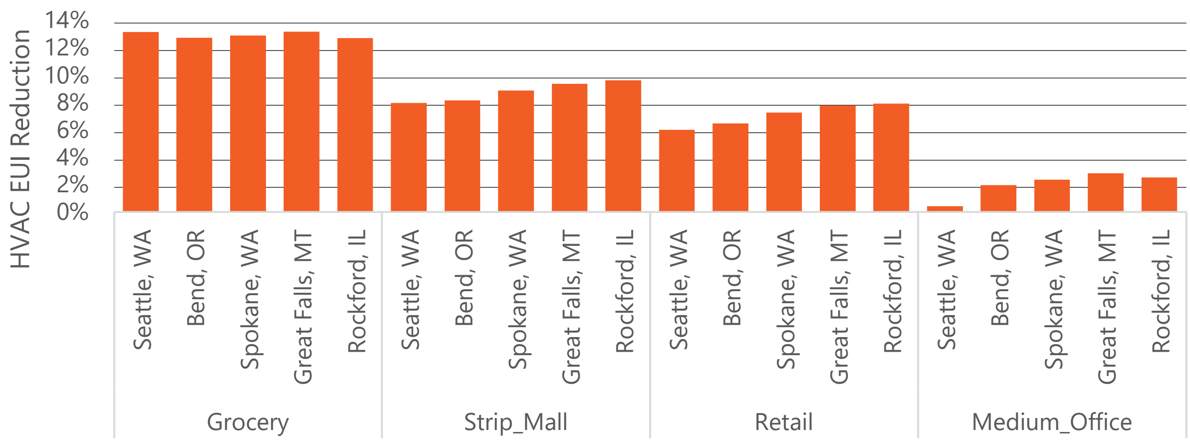

Figure 9. Condensing Gas Furnace Impacts

Across all building types, the Condensing Gas Furnace Measure increases fan energy use due to the pressure drop across the condensing heat exchanger. The fan energy use increases shown in Figure 10 range from 0.7% to 1.5% of total HVAC energy use. The increase in fan energy use was less than the gas savings so total net savings are positive in all locations and building type combinations (as shown in Figure 9).

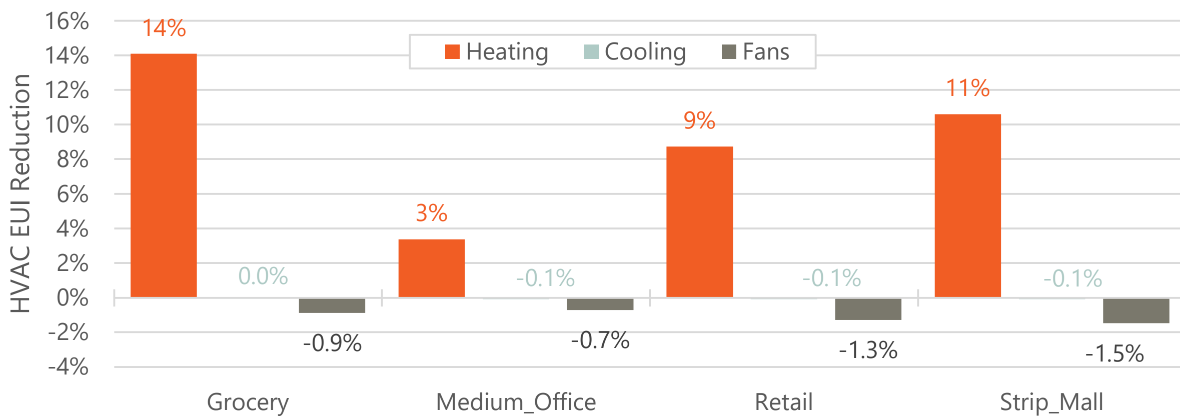

Figure 10. Condensing Gas Furnace Impacts by End Use

When considering condensing on an end use basis (Figure 10), we see that most savings come from heating (gas) and an increase in fan (electric) energy use due to the increased pressure drop on the heat exchanger. Condensing gas furnaces are clearly more appropriate for heating dominated climates.

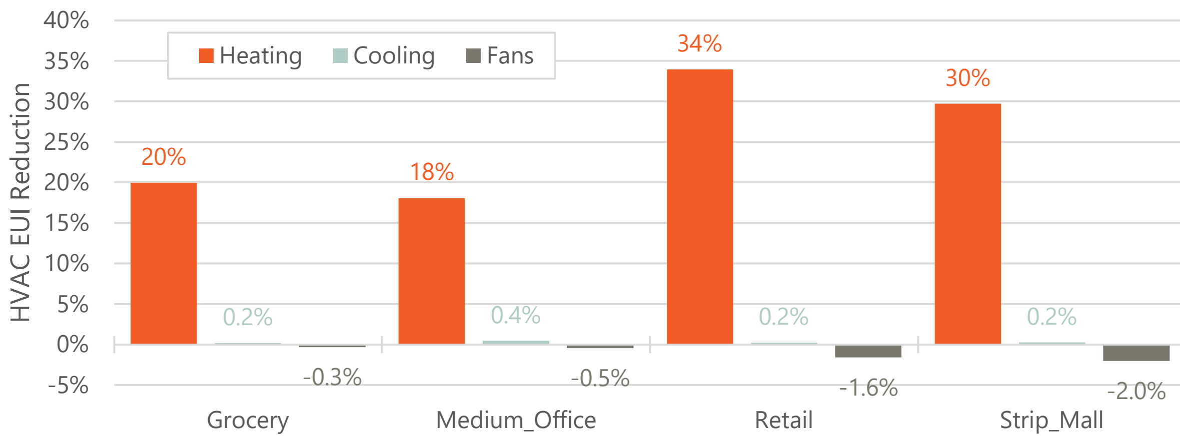

Figure 11. ERV End Use Impacts

3.2.2.2 Energy Recovery

Energy Recovery, on average, saves 25% of overall HVAC energy across all building types and climate locations, consistently performing the best of all measures analyzed. The most significant savings (33.8%) occur in the Retail use type located in climate zone 4C (Seattle, WA) and the smallest savings (11.4%) occur in Medium Office use type located in climate zone 4C (Seattle, WA). The savings from this measure are strongly correlated to outdoor air flow rates and, therefore, favor those building types that require higher levels of ventilation. The exhaust and ventilation air streams bypass the energy recovery ventilators when a system calls for economizing. In heating dominated climates, impacts during the cooling season are diminished for building types that operate mostly during daytime hours.

Adding energy recovery to any system imposes a fan energy penalty due to an increase in the external static pressure from the heat exchangers. Figure 11 shows how this fan energy penalty varies by building type. From a low of -2% in Strip Malls to a high of -0.3% in Grocery. The figure also shows the measure’s impact on cooling. Cooling impact is low but positive for all use types.

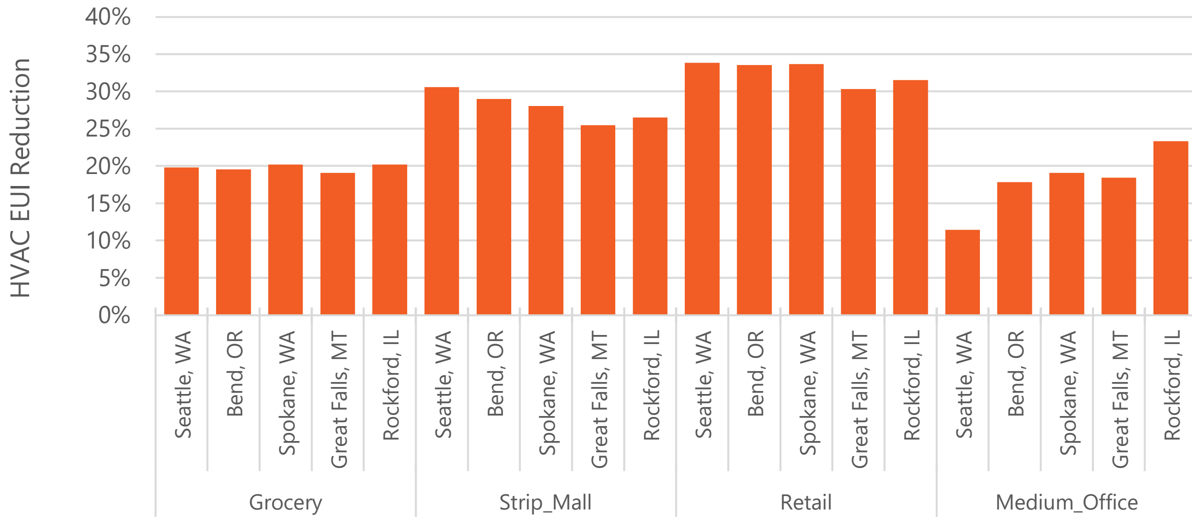

Figure 12. Energy Recovery Impacts

3.2.2.3 Reduced Damper Leakage

Reduced Damper Leakage savings vary consistently by both building type and location. Building type influences energy savings primarily by how many RTUs serve a given load. More RTUs installed increases the number of dampers required consequently raising the leakage rate relative to the total load served. Due to this, Strip Malls, typically with high numbers of single zone RTUs, show the greatest savings (4.9% in Great Falls, MT) and Grocery, having fewer and larger units, show the least savings (0.5% in Seattle, WA). The savings pattern by climate location is more consistent; however, the milder climate of Seattle shows the least savings, while Rockford, IL and Great Falls, MT show the most. One other factor impacting savings from this measure is building height (stack and wind effects are both impacted by building height), which explains why Medium Office shows reasonable savings for this measure despite only having three RTUs serving a 50,000 ft^2 building.

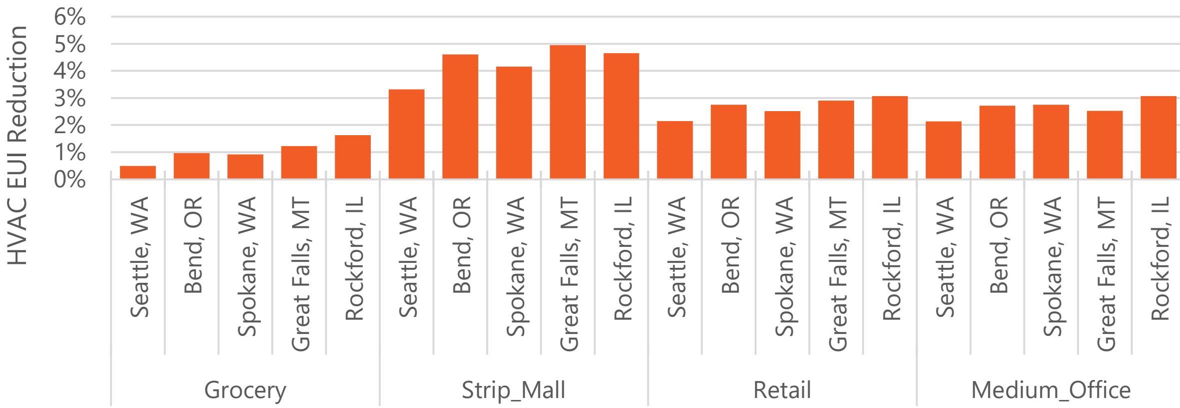

Figure 13. Reduced Damper Leakage Impacts

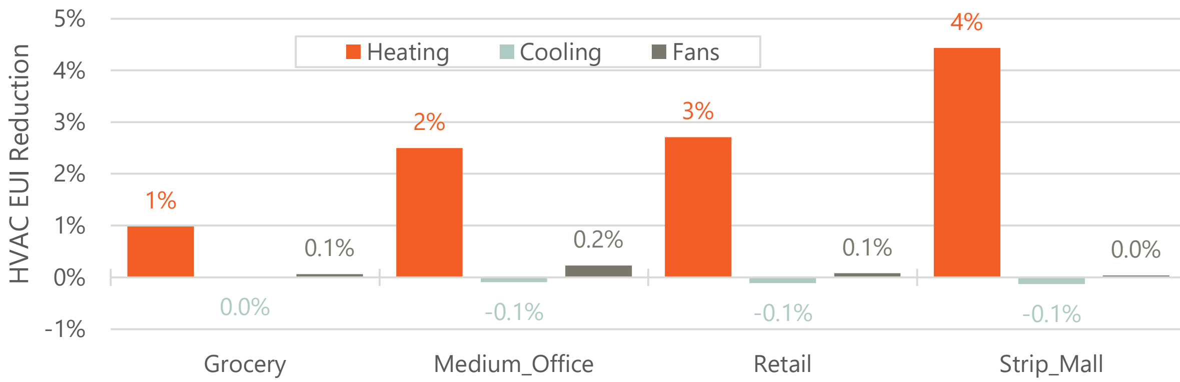

Figure 14. Reduced Damper Leakage End Use Impacts

The impacts of this measure by end use (Figure 14) show small but interesting results for cooling and fans. The cooling impacts are slightly negative for all use type by less than 0.1% of overall HVAC annual energy. While this impact is small, the cooling impact was expected to be slightly positive. Because damper leakage as modeled only occurs only when the HVAC system is not operating, Cadeo believes that when this measure is applied in heating dominated climates the reduced nighttime infiltration also reduces a certain amount of nighttime precooling that was occurring with the baseline leakage rate. The fan savings impacts are also small (0.04% to 0.2%) but positive. Cadeo found these savings to be from a decrease in required heating first thing in the morning, allowing the fans to operate less while getting up to interior set points during the morning start-up periods.

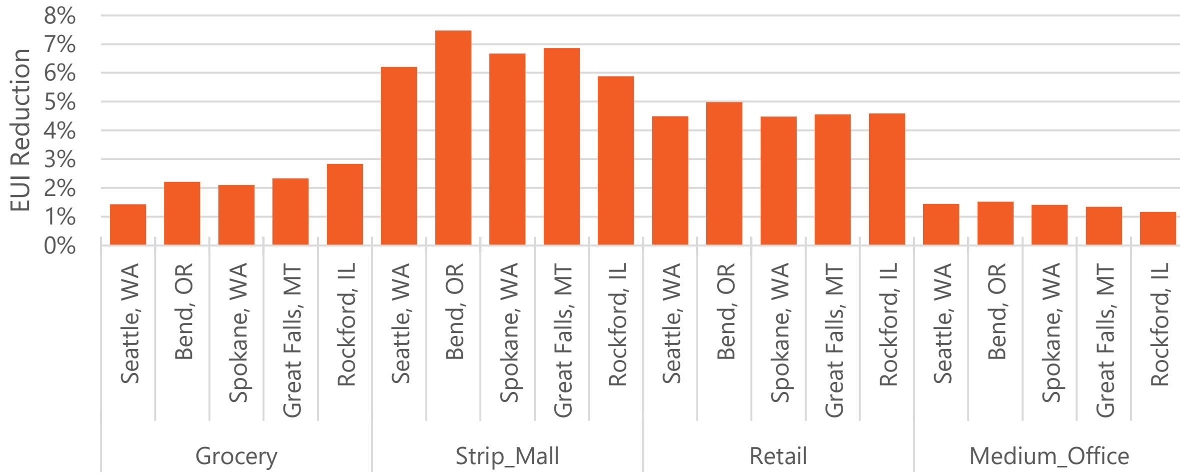

Figure 15. Increase Enclosure Insulation Impacts

3.2.2.4 Increased Enclosure Insulation

The impact of Increased Enclosure Insulation is similar to Reduced Damper Leakage; the impacts vary based on the total number of units employed to meet given conditioning loads. With more small units used, the total RTU surface area increases relative to the systems' capacities. With the greatest zoning density, Strip Mall has the greatest savings (7.5% in Bend, OR) while Medium Office, with only three RTUs, shows the least savings. Savings by climate zone are inconsistent between building types, but the measure generally does not show strong regional variation.

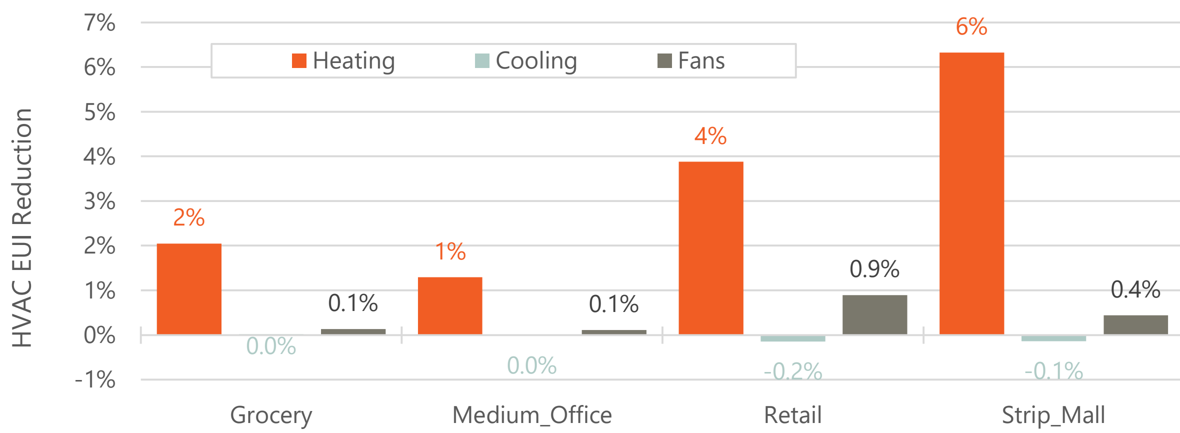

Figure 16. Increased Enclosure Insulation End Use Impacts

Looking at measure impact by end use (Figure 16), trends are like those observed for Reduced Damper Leakage. There is a slight negative impact on cooling and a positive impact on heating. Again, Cadeo believes the cooling energy increase stems from some level of diminished free cooling. This could be through decreased nighttime losses or during a period of cooling when the outdoor air temperature is below the return air temperature (the latter effect would only impact the RTU systems without economizers). Because the increased enclosure insulation measure impacts energy use both during operating hours and at night (unlike the Reduced Damper Leakage measure, which only impacts when the RTU is not running), the fan savings due to decreased heating load are higher in the case of Increased Enclosure Insulation.

Figure 17. Efficient Cooling Impacts

3.2.2.5 Efficient Cooling

The Efficient Cooling Measure shows the least overall HVAC savings out of all the measures simulated. The savings are directly tied to a building's cooling load, which is influenced by building type and Location. The Grocery use type, having very little cooling load relative to total HVAC loads, shows the least savings (< 1%) and Medium Office, with the highest cooling load relative to total HVAC load, shows the greatest (~2%). From a climate location perspective, Rockford, IL consistently shows the highest savings while Great Falls and Seattle, on average, show the least. The low percentage of overall HVAC energy savings from this measure hides the fact that this measure reduces energy used for cooling (as opposed to HVAC energy overall) by 16%, which in cooling dominated climates would translate to significant overall savings. Because this measure only impacts compressor efficiency, there is no impact on any end uses other than cooling, as seen in Figure 18.

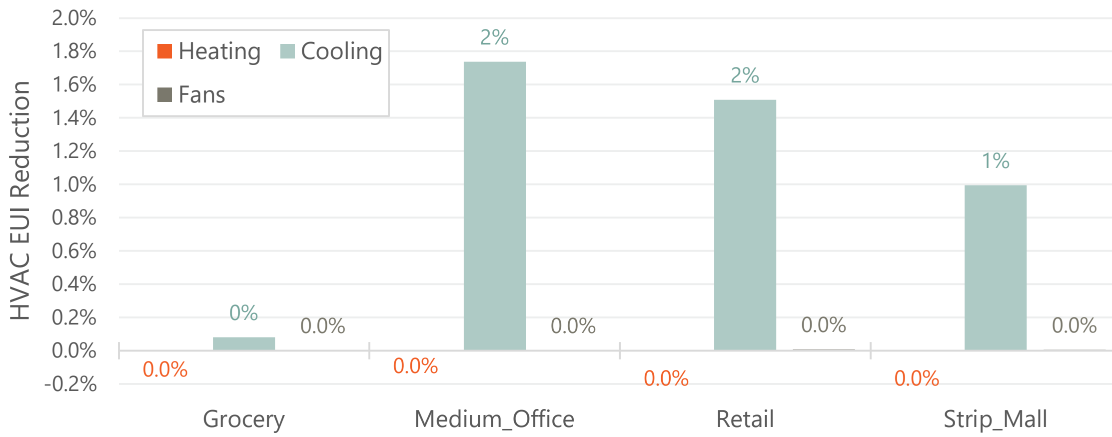

Figure 18. Efficient Cooling End Use Impact

3.2.3 Results by Tier

Like the measure results above, the tier results sections describe the percent of total annual energy savings for each tier. The same general trends seen for the measures are also apparent in the tiers, including consistent outcomes across climate locations and more variation between building types. The aggregate savings for all tiers is similar to the sum of the measures modeled separately, indicating that there is minimal interaction (positive or negative) between the different measures when combined into the tiers.

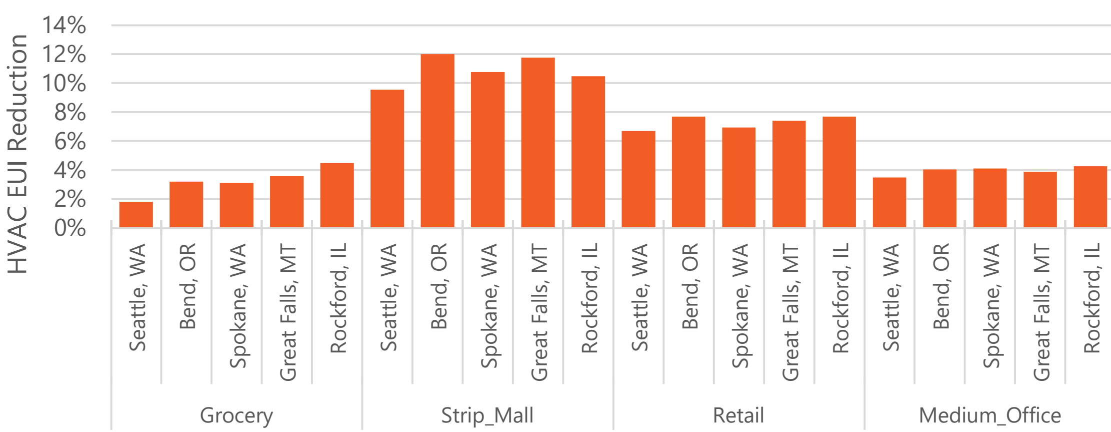

Figure 19. Tier 1 Impacts

3.2.3.1 Tier 1: Shell Measures Combined

Tier 1 combines the two shell measures (Reduced Damper Leakage and Increased Enclosure Insulation). Shown in Figure 19, the savings for Tier 1 range from a high of 12% for the Strip Mall use type simulated in Bend, OR to a low of 2% for the Grocery use type simulated in Seattle, WA. The average energy savings across all building types and locations is 6%. The Tier 1 savings are 98.5% or more of the summed individual impacts of the reduced damper leakage and increase enclosure insulation measure outcomes for all building types and locations, indicating that the individual measures that make up Tier 1 do not strongly interact when combined.

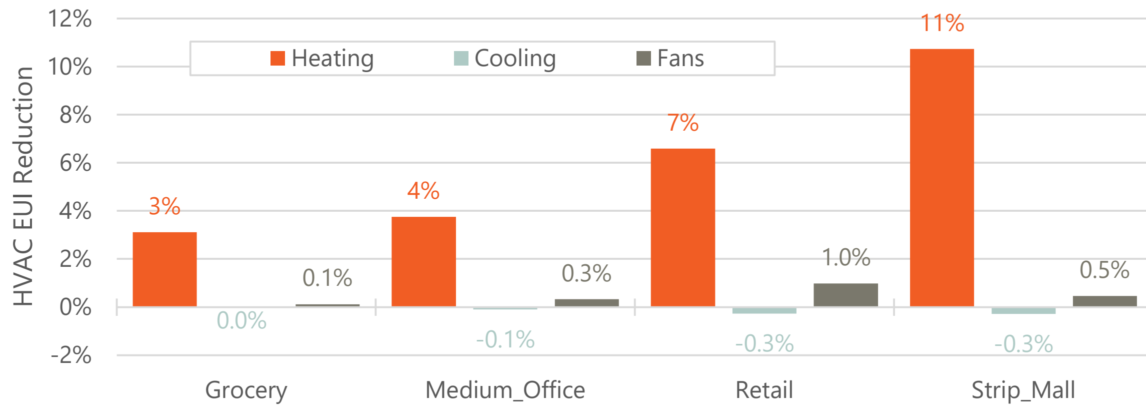

Figure 20. Tier 1 End Use Impacts

3.2.3.2 Tier 1 with Efficient Cooling

This tier adds the Efficient Cooling Measure to Tier 1. The results closely mirror those of the basic Tier 1 as described above. The overall savings for each use and type combination increases on a percentage basis in line with the results for the Efficient Cooling Measure alone (see Section 3.2.2.5). This leads to almost no change for the Grocery use type and an increase of about 2% savings for Medium Office. The end use breakdown is similar to what is seen in Figure 20 except with additional savings (averaging 1.0%) across the board for the cooling end uses.

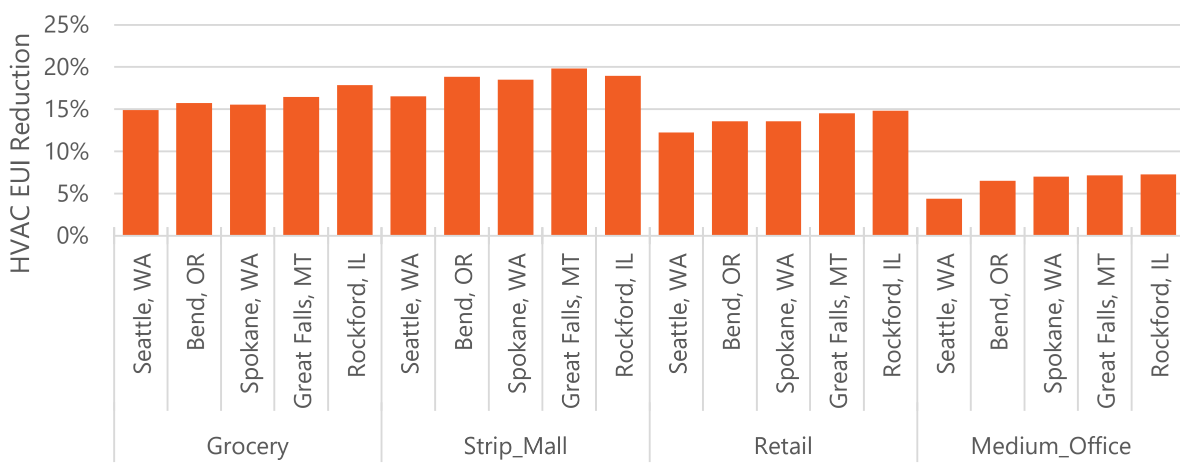

Figure 21. Tier 2A Impacts

3.2.3.3 Tier 2A: Shell Measures and Condensing Gas Furnace

Tier 2A Combines Tier 1 with the Condensing Gas Furnace Measure. The performance of this tier is consistent across all climate locations. Savings by building type range from a low of between

4% and 7% for Medium Office up to a high of between 17% and 20% for a Strip Mall (Figure 21). Like other tiers, the measures making up Tier 2A do not interact strongly with each other.

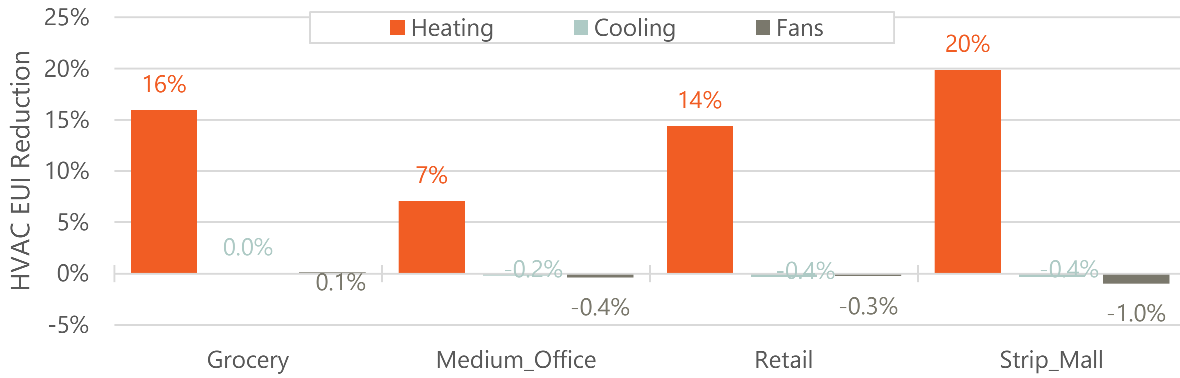

Figure 22. Tier 2A End Use Impacts

The results by end use for this tier show by far the most savings coming from heating, while cooling savings remains small or negative for all building types.

3.2.3.4 Tier 2B: Shell Measures and Energy Recovery

Tier 2B Combines Tier 1 with Energy Recovery Ventilation. The Energy Recovery Measure alone consistently saved the most energy across building types and locations and the performance outcomes when packaged as a tier are similar. Savings are consistent across locations, with Strip Mall and Retail use types performing the best with savings between 37% and 40% across all locations, due to the higher ventilation load in these building types (Figure 23). Energy savings in the Grocery and Medium Office use types are similar to each other, saving between 22% and 25% except for Seattle and Rockford for Medium Office (showing savings of 15% and 28%, respectively).

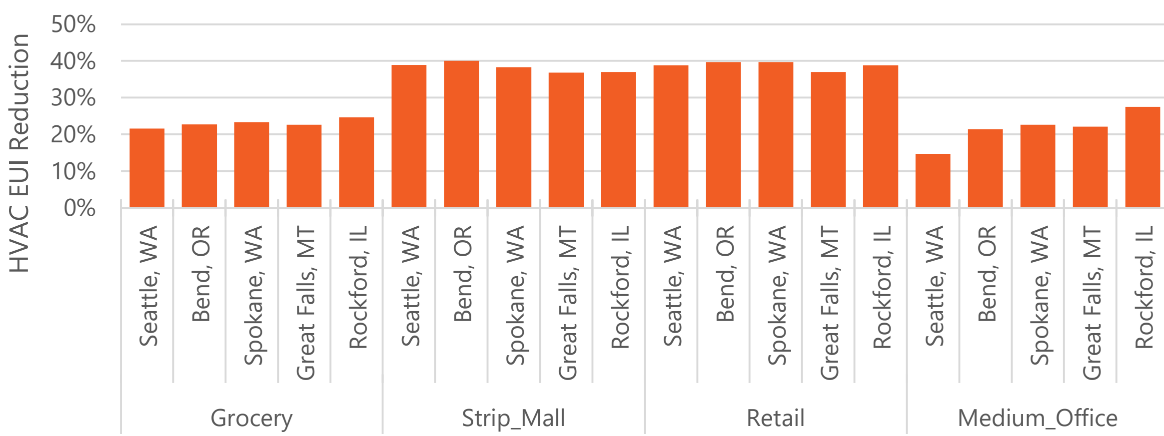

Figure 23. Tier 2B Impacts

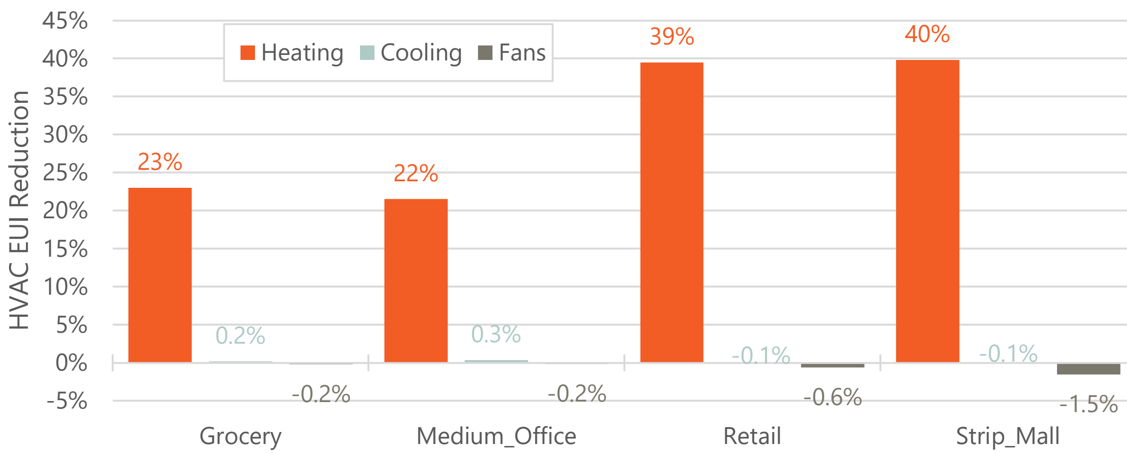

Figure 24. Tier 2B End Use Impacts

The end use breakdown of the impacts for Tier 2B shows the majority of savings coming from heating for all use types. Negative fan savings shown here result from the increased pressure drop through the energy recovery ventilator. It should be noted that the y-axes for measures and tiers involving energy recovery are quite different than for other measures and tiers due to the outsized impact for energy recovery on total energy savings vs. all other measures.

3.2.3.5 Tier 2B with Efficient Cooling

Much like Tier 1 with Efficient Cooling, combining the Efficient Cooling measure to tier 2B has a small impact on each location and building type combination. The impact is consistent with the result reported for the measure alone (Section 3.2.2.5) and is limited due to low cooling loads in the buildings and regions analyzed.

3.2.4 100% Outdoor Air Results

All results presented so far in this report have been for buildings with ventilation rates conforming with ASHRAE Standard 62.1. To better understand how the measures and tiers would perform when applied to a building operating outside of this normal range, Cadeo also simulated the retail building type operating with a 100% outdoor air ventilation rate. Rather than an effort to represent a typical 100% outdoor air design case, this was more to understand how moving from standard ventilation rates to full ventilation is likely to impact the directionality and magnitude of savings, all else held equal. In effect, this looks at the impact of increased HVAC load on measure savings and cost effectiveness. While results will vary for typical 100% outside air applications, such as dedicated outside air systems or make up air units, we expect these more simplified 100% outside air modeling results to be representative of the magnitude of savings that would be observed in these cases and indicative of the most impactful measures in these applications.

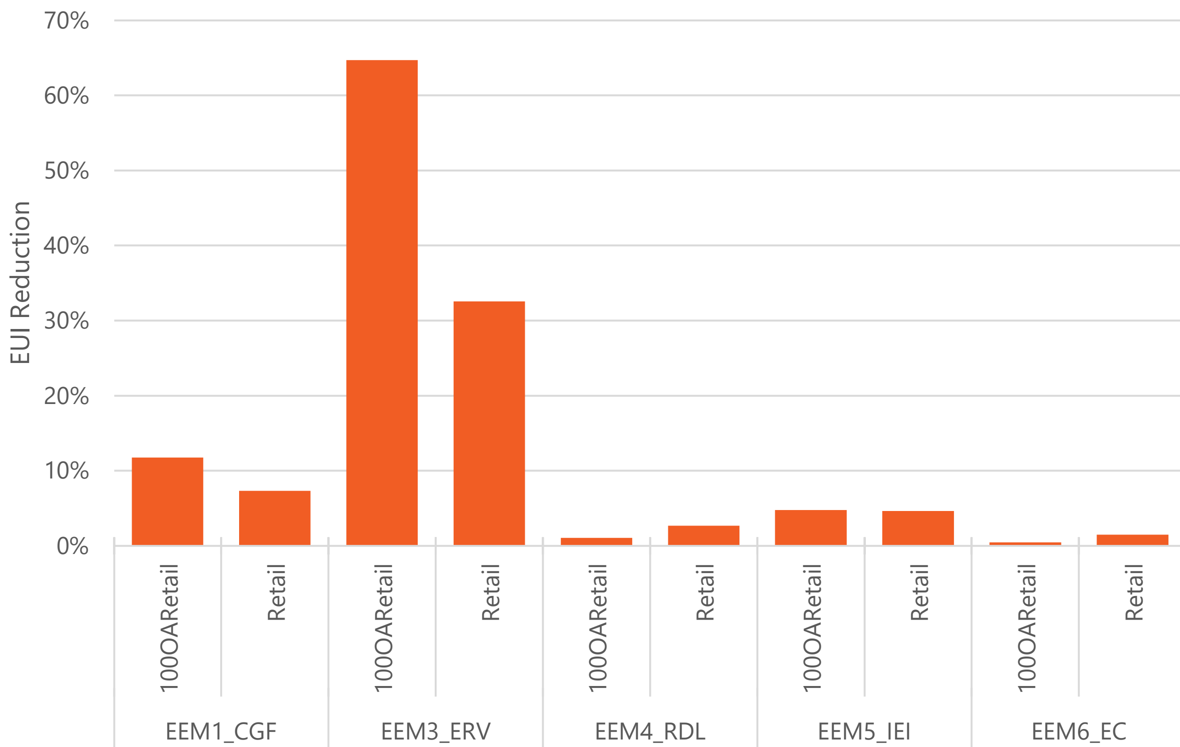

Figure 25. Measure Impact Comparison between 100% and 62.1 Outdoor Air Cases

Figure 25 shows one measure that proportionally saves more than double the energy for the 100% outdoor air case. This measure is Energy Recovery, which is still, by far, the best performing measure. This outcome is in line with expectations because energy recovery directly reduces the impact on loads from bringing in ventilation air.

Another measure, Condensing Gas Furnace, shows a smaller but still compelling impact in relative energy savings. This is expected due to the heating dominance of the climates studied. In these climates, for most of the year, the outdoor air temperature will be well below the supply air temperature when the buildings require heating. This temperature differential will cause an increase in heating load with 100% outdoor air and will raise the relative saving from this measure.

One measure, Increased Enclosure Insulation, shows little impact from the change in ventilation rate. It is not immediately clear what is driving this outcome, but it possibly comes down to an increase in the time the system is in heating which, in turn, increases the time throughout the year where there is an elevated delta T across the RTU shell and this delta T is the primary driver of the heat transfer that is impacted by this measure.

Two measures show less savings for the 100% OA case. The Reduced Damper Leakage measure only applies when the HVAC system is not running, so it is expected that total savings would be similar between the two cases. Because the total savings is similar between cases, but the total HVAC energy is considerably higher in the 100% outdoor air case, it makes sense that the relative savings would decrease. For the Efficient Cooling measure, the relative savings is also less in the 100% outdoor air case. This result is again driven by the measure savings of a similar total amount of energy between the two cases but, relative to the elevated HVAC energy use, the measure impact decreases.

The results described above are summarized in Table 11:

Measure	100% OA Impact	62.1 Impact	Cause
Condensing Gas Furnace	12%	7%	Elevated heating load due to 100% OA
Energy Recovery	65%	33%	Much higher amount of air available for heat recovery
Reduced Damper Leakage	1%	3%	Savings only when system not running, relative impacts lower
Increased Enclosure Insulation	5%	5%	Unclear
Efficient Cooling	0%	2%	Most cooling load internally driven in climates studied

Table 11. Ventilation Rate Impact Summary

It is critical to note that in all cases the 100% outdoor air case saved more energy in absolute terms than the 62.1 complaint ventilation cases. The increase in total energy saving across the board means that in all cases measures applied to buildings operating under 100% outdoor air conditions will be more cost effective than at more typical airflow rates.

3.3 P.8 Modeling Comparison

The analyses described in this report parallel those Cadeo performed in the development of the P.8 test procedure. While there is significant alignment between the general approaches employed for the current analysis and the original P.8 analysis, there are also key differences including: the purposes of the two analyses, what specifically Cadeo modeled and how Cadeo performed the modeling.

The primary goal of the original P.8 modeling was to develop a set of weights representing the amount of time throughout the heating season an RTU spends in different heating operating modes (high fire, low fire, ventilation only, and standby). The CSA P.8 standard uses these operating mode weights to calculate a whole system heating season performance metric ($TCOP_{HS}$) that accounts for the operational behavior of an RTU in average Canadian climate conditions and the performance impacts of different RTU characteristics. While the measure savings values are not referenced directly in the standard, the P.8 energy models also provided an initial look at the heating season performance impacts of Reduced Damper Leakage, Increased Enclosure Insulation, and ERV. The favorable results of these measures on heating season energy use in the P.8 models led to their inclusion in NEEA's draft Efficient RTU Specification.

The current modeling effort is more focused on informing the development of the Efficient RTU Specification for NEEA and Nicor. This shift in focus impacted the analysis approach in five critical ways:

- Regions included in the analysis.
- Building types included in the analysis.
- Simulated outdoor air flow rates.
- Measures simulated and simulation approach.
- Period over which measure impacts were modeled.

Because NEEA and Nicor's territories are situated in the Northwest and Midwest regions, respectively, the climates used in the latest analysis shift from climate zones 5A, 6A, and 7 to climate zones 4C, 5A, and 6B. Though there was some overlap between the climate zones used in both analyses, it is limited to climate zone 5A and not in the same location.

The P.8 analysis examined two building types, retail, and Warehouse. The current analysis shifted the building types by dropping Warehouse and adding Strip Mall, Grocery, and medium office building types. As with climate locations, there is one point of overlap (retail) between the building types used in the two analyses.

For each building type, the P.8 analysis examined three different outdoor air flow rates (0%, 30%, 100% OA) because they needed to account for all configurations possible when developing the standard's calculation methodology. This also provided the opportunity to understand how the different measures would be impacted by varying outside air percentage. Since the current analysis focuses on the most common and most representative applications, OA% was not varied for each building type and held constant at 30% OA. Dropping this dimension also reduced the analysis dimensionality and allowed for more building types and locations to be simulated. However, one 100% outdoor air case (retail) was modeled in the latest effort to facilitate a comparison between the two analyses and to confirm, directionally, the response to outdoor air flow rates for measures not included in the P.8 simulations.

In the current analysis, Cadeo modeled all measures that were included in the P.8 analysis (Condensing Gas Furnaces, ERVs, Reduced Damper Leakage, and Increased Enclosure Insulation). In addition, Cadeo modeled a novel measure: Efficient Cooling. Beyond the addition of the new measure, Cadeo also changed the modeling approach for all the measures. Table 12 summarizes these changes.

Measure	Changes in Current Approach
Condensing Gas Furnace	Added fan energy Impacts of condensing heat exchanger
Energy Recovery Ventilators	Updated fan energy impact modeling approach
Reduced Damper Leakage	Model directly using EnergyPlus
Increased Enclosure Insulation	Model directly using EnergyPlus
Efficient Cooling	Not modeled in original P.8 Analysis

Table 12. Model Approach Changes

Lastly, the P.8 analysis looked only at measure impacts during the heating season, which was defined as October 1 to April 30, whereas the latest analysis determined measure impacts for the entire year. In general, this change diminished the impact of the simulated heating-focused measures as part of both analyses.

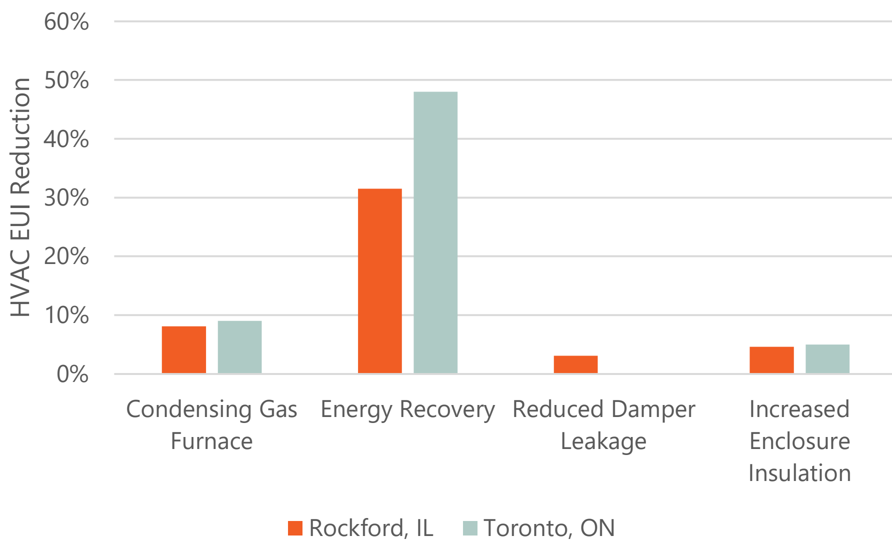

Figure 26. Comparison Between P.8 and Current Results for Climate Zone 5A

As shown in Figure 26, where there is overlap in terms of building type, location, and measure, the results are in general agreement. Condensing gas furnaces show less savings in the latest simulations, but this is likely due to the addition of fan energy impacts and the savings for this heating only measure being calculated over the entire year. ERVs also show a decrease in savings, again, likely due to the change in fan energy modeling approach and the period over which the impacts have been calculated.

Of the overlapping measures, the Reduced Damper Leakage Measure shows the most divergent outcomes, showing substantially more savings in the latest models. Cadeo modeled this measure directly using EnergyPlus in the latest analysis and used an external spreadsheet-based approach for the P.8 work. The EnergyPlus-based approach employed in the more recent effort is more robust than the previous efforts due to how it dynamically models the impact of both wind and stack effect on the damper leakage.

The Increased Enclosure Insulation Measure shows more agreement between the two modeling efforts. Again, bringing the simulation into EnergyPlus where the measure can dynamically interact with the other aspects of the model has produced a more accurate representation of the expected measure behavior.

Section 4 Key Findings & Recommendations

This section discusses key findings of the analysis and their implications for program development/market transformation. We also included recommendations for program development and future research. The findings and tier impacts for the program are outlined in Table 13.

Finding	Possible Program Implications
The Energy Recovery Measure saved the most across all building types and locations, while improved compressor performance saved the least in these heating dominated climates.	Need to consider impacts in cooling climates Could you have a "heating spec" and a "cooling spec"? What would the "heating spec" do in cooling climates?
Relative savings were consistent across climates but vary somewhat across building types, indicating that different efficiency measures may be appropriate for different building characteristics.	Can consider one heating spec but may need to consider different specs or recommendations by application or limit the scope.
In general, measures only have minor interactive effects and should be considered on their own merits for inclusion in any Efficient RTU program.	Interactive effects don't need to be considered when deciding what measures to include.
Measure impact savings varied by gas and electric.	First and foremost, we need to identify priorities in terms of fuel impact goals and design the spec around these.

Table 13. Summary of Study Findings and Implications

4.1 Most Impactful Measures

As described in detail in Section 3.2.2.2 and shown in Table 14, energy recovery saved the most energy across all building types and locations, while improved compressor performance saved the least in the heating dominant climates analyzed. Based on these results, we recommend including energy recovery as a focused end goal for any efficient RTU program in the Pacific Northwest, Midwest, or any heating dominated climate. Condensing gas, as well as improved shell measures (Increased Enclosure Insulation and Reduced Damper Leakage), are also good measures and, especially for improved shell performance, may be more cost effective in milder climates. Cooling is not important to include, and we recommend removing it from the gas focused element of the program to stay focused on the most impactful measures.

Measure	HVAC Energy Savings
Energy Recovery	25%
Condensing Gas Furnace	8%
Increased Enclosure Insulation	4%
Reduced Damper Leakage	3%
Efficient Cooling	1%

Table 14. Average HVAC Impacts by Measure

4.2 Variation by Climate and Building Type

This analysis found that, for the heating dominated climates simulated, the measures that performed the best tended to do so across all climate zones, as shown in Table 15. The best performing measures by climate zone largely mirror the overall ranking of measures shown in Table 14. However, the absolute magnitude of savings varies across the climate, which may impact cost effectiveness for some of the measures in milder climates.

More Impact → Less Impact	Bend, OR	Great Falls, MT	Rockford, IL	Seattle, WA	Spokane, WA
	ERV	ERV	ERV	ERV	ERV
	CGF	CGF	CGF	CGF	CGF
	IEI	IEI	IEI	IEI	IEI
	RDL	RDL	RDL	RDL	RDL
	EC	EC	EC	EC	EC

Table 15. Relative Measure Performance by Location

Table 15 provides clear guidance on which measures NEEA should include in a specification targeting gas savings across all building types in the Northwest and Midwest regions. However, additional analysis will be required to understand if all the measures that have the most impact are also cost effective. The consistency of impacts seen across the climates included in this study suggests that NEEA and Nicor could consider developing one set of consistent recommendations for heating dominated climates, including the Pacific Northwest and Midwest, which could support manufacturers developing equipment specific to heating dominated climates. While this consistency is clear across the regions examined in the study it is likely that in other, more cooling dominated climate zones, the most impactful measures would diverge from the pattern seen here. Depending on the program's overarching goals, it would be important to consider the manufacturing logistics and implications of these "heating-specific" recommendations on cooling climates to understand better how these heating-specific recommendations would impact national market transformation efforts. That is, NEEA will want to consider the following questions in formalizing the market transformation strategy for efficient RTUs:

- What is the impact of these heating-specific measures and recommendations on cooling dominated climates? Which of the heating-specific measures are nationally applicable?
- What measures would be most/more appropriate for a cooling dominated spec or from a national perspective?
- How does the RTU market breakdown nationally between heating and cooling dominated climates?
- How feasible is it to develop and market "heating-focused" efficient RTUs and *different* "cooling-focused" RTUs?

The answers to these questions will help NEEA and Nicor consider how best to move forward with a heating-specific program design in the context of the national RTU market and potential national market transformation efforts.

While impacts across climate zones were consistent, measure impact was considerably more variable by building type, as seen in Table 16.

More Impact → Less	100OARetail	Grocery	Medium Office	Retail	Strip Mall
	ERV	ERV	ERV	ERV	ERV
	CGF	CGF	RDL	CGF	CGF
	IEI	IEI	CGF	IEI	IEI
	RDL	RDL	EC	RDL	RDL
	EC	EC	IEI	EC	EC

Table 16. Relative Measure Performance by Building Type

Though energy recovery again shows the greatest impact in all building types, there is more variation in how the other measures perform when applied to different building types. Only when the measures are applied to the Strip Mall building type are the results in line with the average outcome seen in Table 14. One measure that performed the worst in one use type (Increased Enclosure Insulation in Medium Office) is the third best in all other use types.

This variation opens the possibility of having a specification with multiple paths depending on a participant's building characteristics. This approach would increase the complexity of the specification but would also lead to a higher impact at the building level by ensuring that the most effective measures were applied first. A multi-path specification could also lead to more cost-effective solutions by ensuring that measures are tailored to participating buildings' attributes. Beyond the complexity of developing and administering such a program, there could also be diminished overall impact through not being able to provide manufacturers with a one size fits all solution that could be applied across a particular product or product line. Before pursuing such a multi-path specification NEEA will need to consider the following:

- What aspects of a building most strongly influence the outcomes of the different measures?
- How much more impact would be technically achievable if buildings only implemented those measures with the best outcomes?
- What would be the negative impacts on program uptake due to the added complexity of the specification?
- How feasible is it to reduce building features into two or three groups where a particular set of measures would always be cost effective?
- Is there a subset of measures that will be cost effective under most conditions such that manufactures could apply across all products?
- How would a program tailored to building attributes work in conjunction with one designed to apply across both heating and cooling dominated climates?

Addressing these questions as NEEA refines the specification will aid in shaping the program to ensure an appropriate balance between impact at the sector and building levels. When considering future program design and how to account for the variation of buildings' characteristics, NEEA and Nicor will have to weigh the pros and cons of a more specific, narrow scope of applications for their specification versus a more broad, comprehensive approach. In a broader approach, the modeling suggests that multiple "pathways" may need to be developed for different building characteristics based on the HVAC system design and load considerations. For example, the program could define different tiers and recommendations (or pathways) for:

- Strongly heating dominated HVAC loads (e.g., Grocery and 100% Outdoor Air).
- Small, single-zone systems that have high RTU enclosure losses.
- Applications with smaller RTU heating loads and higher cooling and fan loads (e.g., multi-zone systems with terminal reheat).

The specific building applications may interact somewhat with the climate zones and fully determining the correct "buckets" of applications will require additional analysis.

The relative impact of tiers across the locations and building types examined in this study are much more consistent than the individual measures. In all climates and building types, the relative impact of each tier follows the order shown in Table 17.

Measure	HVAC Energy Savings
Tier 1 (Shell Measures)	6.3%
Tier 1 + Efficient Cooling	7.4%
Tier 2A (Tier 1 + Condensing Gas Furnace)	13.7%
Tier 2B (Tier 1 + Energy Recovery)	30.4%
Tier 2B + Efficient Cooling	31.5%

Table 17. Average HVAC Impacts by Tier

Though the relative order of the tiers is consistent, there is still notable variation due to building characteristics even within the heating dominated region of study and the same questions and considerations outlined at the measure level apply. Understanding how the measures interact with each other is critical to shaping a multi-path specification by showing that, for the region studied, measure impact outcomes alone are sufficient to develop tiers. However, if NEEA adds more regions to the program, further tier simulation is needed to confirm that the limited interactivity applies to all climate zones.

4.3 Interaction of Measures

Table 18 outlines the impacts on energy savings of the different measures that make up each tier. The "Measure Total" is the sum of the modeled outcomes for the measures simulated individually and the "Tier Result" is the outcome when the measures are simulated together in that specific tier. The interactive effects between the different measures are small in all cases, ranging from -0.7% to -0.1%, with no tiers showing positive interactive effects on average.

	Tier1	Tier1_EC	Tier2A	Tier2B	Tier2B_EC
Condensing Gas Furnace	--	--	8%	--	--
Energy Recovery	--	--	--	25%	25%
Reduced Damper Leakage	3%	3%	3%	3%	3%
Increased Enclosure Insulation	4%	4%	4%	4%	4%
Efficient Cooling	--	1%	--	--	1%
Measure Total	**6.4%**	**7.5%**	**14.4%**	**30.9%**	**32.0%**
Tier Result	**6.3%**	**7.4%**	**13.7%**	**30.4%**	**31.5%**

Table 18. Impacts by Tier and Constituent Measures

The limited interaction between measures can make impact accounting easier and could possibly preclude additional tier simulation in the future if adding RTU measures are investigated in similar climates and building types.

4.4 Impact of Measure by Fuel Type

The final consideration that will be important is the relative impact of measures on different fuels. Measures and tiers had a range of impacts and NEEA and Nicor will have to consider these gas- and electric-specific impacts in the context of overall program goals. Specifically, NEEA and Nicor can consider two possible paths for the tiers moving forward.

The first is to remain focused on the original goals of the program and strictly targeting gas savings. Such a program may *include* electricity savings, but not at the expense of maximizing gas savings. This approach would likely be most consistent with also maintaining a heating emphasis in the specification (at least as one pathway of the program). This path has the benefit of keeping the program tightly focused on its original goals and focusing the team's efforts on a clear and specific scope. The downside of a narrowed focus and scope is that it limits the applicability of NEEA's specification to buildings that use gas for heating and are in heating dominated climates. Since there are many buildings and many RTUs outside that scope, this could limit the program's ability to achieve national market transformation goals.

Another option for the structure of a future RTU specification would be to have multiple paths depending on the savings goals of the program and participants. The most immediately obvious approach would include two paths where one would target gas savings and one would target electricity savings. While increasing the complexity of the spec (especially if included in combination with a more comprehensive building scope approach, as discussed in section 4.2), would increase the scope and longevity of the program. Additionally, while full-scale electrification of commercial RTUs is likely still a long way off, broadening the program applicability beyond gas savings could impact the long-term viability of the program. That said, the added complexity of such a broad targeting could have impacts on the program's short-term viability.

Section 5 Conclusions & Next Steps

The analysis described in this report provides an in-depth understanding of how different energy efficiency measures perform, both alone and in combination with each other when applied to common commercial building types located in the Northwest and Midwest regions. All the measures simulated reduced the total HVAC energy used for all building types, in all locations studied, on an annual basis. The savings relative to the baseline energy use (i.e., percent savings) were consistent across climate zones and conformed to previous research efforts using a more limited set of building types and Canadian Climate zones. The research showed that the Northwest and Midwest regions are more like Canadian climates than those of the more cooling dominated regions of the United States.

The level of heating dominance in the regions modeled for this analysis was unexpected. The lack of meaningful cooling load in any of the buildings examined made it difficult to draw conclusions about the applicability of the measures examined in hot and humid climates. Expanding the analysis to include climate zones 1 to 3 would help inform the team's decision-making regarding the viability of the current measures and tiers in all climate zones occurring within the United States.

Keeping the program applicable only to the Northwest and Midwest regions would have the benefit of keeping the program targeting only heating dominated climates; this would simplify all analyses necessary to support program decision making and limit the range of products that need to be made available to allow for a viable program. The challenge of such a regionally limited approach would be a diminished capacity to influence manufacturers to shape the RTU market.

Developing a program applicable to the entirety of the United States' RTU market would increase program impacts both by expanding the possible number of participants and by increasing the capacity to influence manufacturer decision making. The challenge of such a national program is that, to apply to all climate zones in the US, it must either be limited to only the few RTU features that save energy in all climates or have the added complexity of multiple paths that apply under different conditions.

In addition to the climate applicability of any future program, the modeling results showed that building characteristics can strongly influence the energy impacts of an RTU specification. It is difficult to draw broad trends from the small sample of building types examined, but the findings point to the relative proportion of gas versus electricity used for HVAC as a metric that is a strong determinant of which measures produce the most savings. Many aspects of a building (outdoor air flow rate, window to wall ratio, internal gains, etc.) impact this metric, which makes it a useful stand in for these characteristics. While not directly examined in this analysis, electricity use for heating would have an especially strong impact on this metric. Using this metric with a multi-path specification would allow both broader program applicability as well as ensure the program remains viable within context of building electrification.

Some of the possible options for the program specification structures described in the proceeding paragraphs are summarized in Table 19. The options outlined are not mutually exclusive and so the table outlines more of a road map. The road map starts with a regional, gas focused program and ends with a national, multi-fuel program. The single pathway Northwest and Midwest targeted specification also makes up an element of the regional two pathway specification, which adds a pathway for electric HVAC dominated buildings. The regional, dual fuel specification serves as the basis for a national dual-fuel program. The single pathway national program is separate from this program development trajectory but would include all overlapping aspects of each step along the way (i.e., includes those measures that save energy everywhere).

	NW + NE Focused	National Focus
Single Pathway	1. Applies to all gas heated buildings in CZ 4C+	1. Applies to all buildings
Two Pathway	1. Applies to all buildings w/ gas > 50% of HVAC energy use in CZ 4C+ 2. Applies to all buildings w/ gas < 50% of HVAC energy use in CZ 4C+	1. Applies to all buildings w/ gas > 50% of HVAC energy use 2. Applies to all buildings w/ gas < 50% of HVAC energy use

Table 19. Specification Development Options

The results described in this report are sufficient to develop a single pathway specification targeting gas heated buildings in the Northwest and Midwest regions. To move beyond this to a specification targeting electrically dominated buildings in the Northwest and Midwest regions, additional simulation of electrically dominated buildings would help define the transition points between the paths. To move to a nationally focused specification, NEEA would need to leverage the work described in this report by updating the models to represent all the climate zones that exist across the United States. Table 20 summarizes the impacts of the different possible program dimensions, from low impact (1) to high impact (5). *Program Complexity* reflects how many decisions a participant must make when applying the spec, *Program Long Term Viability* describes the how well the spec aligns with any future trends towards building electrification, *Building Level Impact* quantifies the potential energy savings of the spec when applied at the individual building level and *Manufacturer Influence* describes the capacity of any single spec path to be applied across the RTU market.

Case	Program Complexity	Program Long Term Viability	Building Level Impact	Manufacturer Influence
Single-Path Regional	2	1	2	2
Multi-Path Regional	4	3	5	2
Single-Path National	1	4	1	5
Multi-path National	5	4	4	4

Table 20. Program Options Impacts

Another critical piece to aid in program decision making is to examine the cost effectiveness of the measures applied to the different building type and location combinations. While this study focused strictly on energy impacts, the results could easily provide the basis for an in-depth cost effectiveness analysis of the different measures. Such an analysis would allow for comparing measures that have different impacts and different first costs. Such an apples-to-apples comparison would aid in program decision making and ensure that program participants achieved the most savings possible for a given investment.

Lastly, as with any model-based analysis, the results presented in this report would be significantly bolstered through empirical research such as field testing of the different measures. By understanding where modeled results have accurately predicted real world outcomes and if any results fell short, future analyses efforts could be made more accurate and executed more efficiently. Both outcomes would facilitate the further investigations outlined above.

Section 6 Appendices

6.1 Draft Specification

NEEA_EfficientRTU_DraftSpecification_v1.2_

6.2 Full Results Tables

RTU_Model_Results_Full_Data_Table.pdf