Therma-Fuser Energy Analysis Report 2016

Executive Summary

This study compares the annual HVAC energy use of a Therma-Fuser VAV system to that of a conventional VAV box system. A typical 68,800 square foot 4-story office building was built using the EnergyPlus v8.3.0 thermal engine. Energy consumption was simulated in OpenStudio. To realistically represent a real-world building, a detailed model was created where all space type inputs (occupancy, lighting, equipment [rooftop packaged unit and hot water boiler], infiltration, etc.) and equipment efficiencies match the ASHRAE 90.1 2013 standard except that the building is served by two AHU's only and has diverse occupancy, lighting and equipment schedules in offices and conference rooms. Percent energy savings of a Therma-Fuser VAV system over a conventional VAV box system were calculated for a typical city in each of the ASHRAE climate zones.

26%
Heating Energy Cost Savings

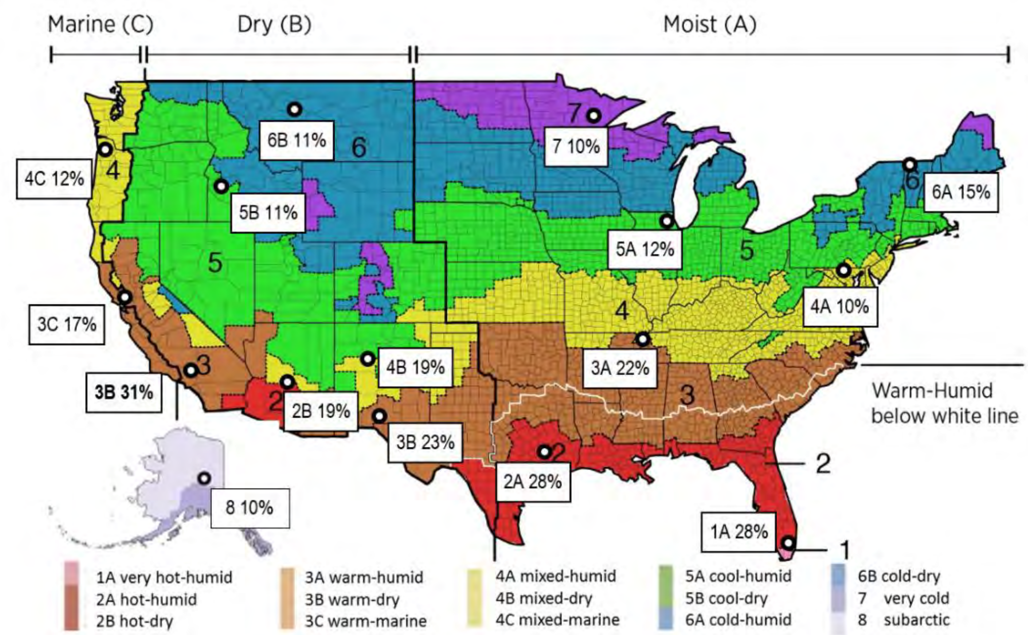
31%
Cooling Energy Cost Savings

36%
Fans + Pumps Energy Cost Savings

HVAC Energy Cost Savings up to 31%*

**Los Angeles, located in ASHRAE Climate Zone 3B*

Overall, the detailed study found that Therma-Fuser VAV yielded 10% - 31% HVAC energy cost savings across the climate zones over conventional VAV. This study analyzed the energy savings in each of the ASHRAE climate zones, from hot to cold, dry to wet. Shown here are the climate zones in the US with regions colored by temperature and humidity. Representative cities are highlighted showing their HVAC energy cost savings potential using the real-world performance modeling approach.



Use of the Therma-Fuser VAV system offers energy savings across all climate zones, primarily due to the following characteristics:

1. Lower minimum turndown capacity. Conventional VAV boxes can turn down to 20 to 30% of their designed airflow rate. The Therma-Fuser VAV system controls allow the airflow to approach the minimum ventilation, lower than conventional systems, and substantially reduces the need for additional cooling and reheat energy.
2. Lower total static pressure. The Therma-Fuser VAV system eliminates the use of a pressure-differential flow meter and damper as typically used in a conventional VAV box, reducing the fan pressure required. This can also simplify the duct layout and further reduce the system's total static pressure and fan energy.

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Therma-Fuser VAV Energy Analysis Report

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1 Goals

In this study, building energy consumption was simulated in OpenStudio, a building energy modeling software widely adopted in building engineering. A typical four-story office building was modeled using weather and utility data for 18 cities, each representing a typical ASHRAE climate zone. The selected code and baseline energy standard is ASHRAE 90.1 2013.

The main goal of the energy study is to determine the real-world energy savings of Therma-Fuser VAV compared to conventional VAV using a detailed energy modeling approach.

2 Building the Model

2.1 General

This study compares the energy performance of Therma-Fuser Variable Air Volume (VAV) systems using the most aggressive building energy codes nationally in the US and internationally where adopted. The energy model compares a four-story conventional VAV packaged unit and hot water boiler building with VAV box system to a Therma-Fuser VAV system.

The analysis was conducted on a 68,800 sf office building, built in the highly sophisticated energy software, EnergyPlus 8.3.0. In this study, building energy consumption was simulated in OpenStudio, a building energy modeling software widely adopted in building engineering. A typical four-story office building was modeled using weather and utility data for 18 cities, each representing a typical ASHRAE climate zone.

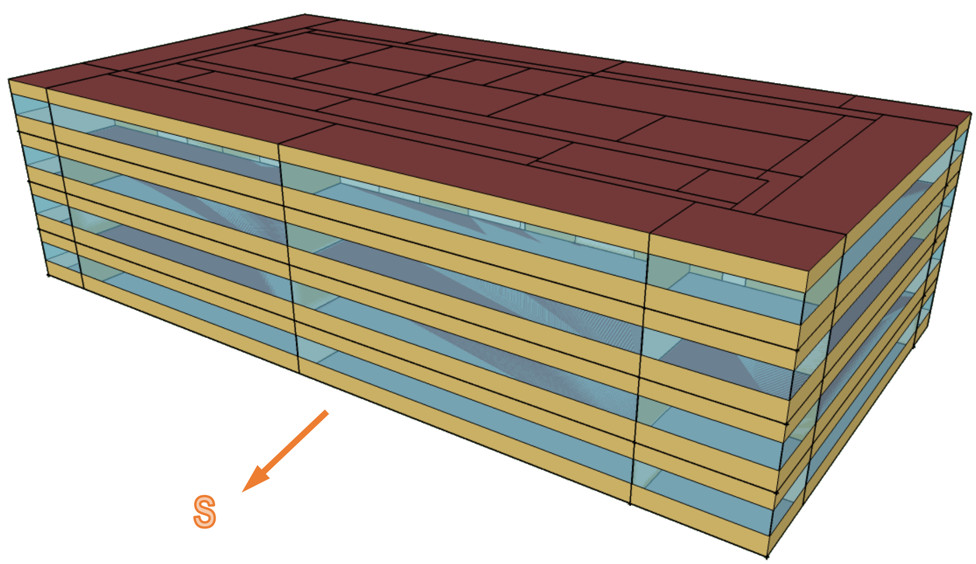

Fig. 2-1 Screenshot of Modeled Building

2.2 Modeling VAV Systems

The conventional VAV system follows the ASHRAE 90.1 2013 guidelines. The two most critical steps to modify a conventional VAV system into a Therma-Fuser VAV system in typical energy modeling software are:

a. Adjust the terminal units to have lowest turndown ratios that match the minimum ventilation requirement.
b. Adjust the total static pressure at the supply fan to be 1.0 in. w.c. lower than conventional VAV.

2.3 Making the Model Realistic

An ideal VAV with reheat system is always controlled to supply cold air at a temperature that meets the cooling demand of the hottest zone at any given time. For any other zone that does not need as much cooling, the air flow rate is turned down to avoid over-cooling, and if over-cooling still exists at the lowest flow rate allowed by the terminal unit or the zone is in demand of heating, reheat coils will start working and raise the supply air temperature. This logic indicates that first, varying schedules across the zones increases HVAC energy use; and second, having fewer but bigger-size air handling units leads to higher HVAC energy. These two trends are present for both conventional VAV and Therma-Fuser VAV, but the energy penalty is less significant for Thermal-Fuser VAV due to its lower turndown ratio and lower total static pressure.

In reality, every space has its unique schedules, and it is common practice for a mid-rise office building to install a total of two air handling units, each serving half of the building. To best represent a real-world building, a set of detailed models was created to compare to the ASHRAE standard model discussed above. The detailed model set consists of a conventional VAV case and a Therma-Fuser VAV case to represent a four-story office building. In the model, the building is served by only two AHU's (not one per floor as required in ASHRAE 90.1 2013). Additionally, the building has diverse occupancy, lighting and equipment schedules in offices and conference rooms instead of using the same schedules for all spaces (as required in ASHRAE 90.1 2013). See Appendix B.1.2 for the customized schedules and Appendix B.1.2 for the layout of the air handling units.

The same number of zones (34 per story) with the same customized schedules were used for both the conventional VAV case and the Therma-Fuser VAV case. As a result, this study is unable to capture the energy savings and penalties of both the small zones of Therma-Fuser VAV (each diffuser is a zone which will more closely follow the occupancy, lighting and equipment needs) and the larger zones of conventional VAV (which can overcool, undercool, overheat and underheat those portions of the zone without the thermostat).

2.4 Regional Energy Performance Study

The energy performance of the Therma-Fuser VAV system was compared against a conventional all air based VAV with reheat distribution system across different regions to determine energy and energy cost savings. Therma-Fuser VAV was modeled against conventional VAV with reheat described in the ASHRAE 90.1 2013 standard. The model was simulated in 18 locations corresponding to the 17 ASHRAE climate zones, representing the combination of cold to hot and dry to moist environments.

One typical city was selected to represent each of the 17 ASHRAE climate zones, with an exception to Climate Zone 3B where two cities (El Pasco, TX and Los Angeles, CA) were selected to demonstrate the possible energy use and energy cost variations within the same climate zone. See **Table 2-1** for a detailed list of the selected cities for this study and their corresponding climate zones.

Table 2-1 Climate Zone List

No.	Location	Climate Zone	Temperature	Humidity
1	Miami, FL	1A	Very hot	Humid
2	Riyadh, SAU	1B	Very hot	Dry
3	Houston, TX	2A	Hot	Humid
4	Phoenix, AZ	2B	Hot	Dry
5	Memphis, TN	3A	Warm	Humid
6	El Paso, TX	3B	Warm	Dry
7	**Los Angeles, CA***	**3B**	**Warm**	**Dry**
8	San Francisco, CA	3C	Warm	Marine
9	Baltimore, MD	4A	Mild	Humid
10	Albuquerque, NM	4B	Mild	Dry
11	Salem, OR	4C	Mild	Marine
12	Chicago, IL	5A	Cold	Humid
13	Boise, ID	5B	Cold	Dry
14	Vancouver, BC, CAN	5C	Cold	Marine
15	Burlington, VT	6A	Cold	Humid
16	Helena, MT	6B	Cold	Dry
17	Duluth, MN	7	Very Cold	N/A
18	Fairbanks, AK	8	Subarctic	N/A

*Los Angeles was selected in this report as the representative city

3 Results

3.1 Key Results

Shown in **Fig. 3-1** is the HVAC energy cost savings of Therma-Fuser VAV compared to conventional VAV.

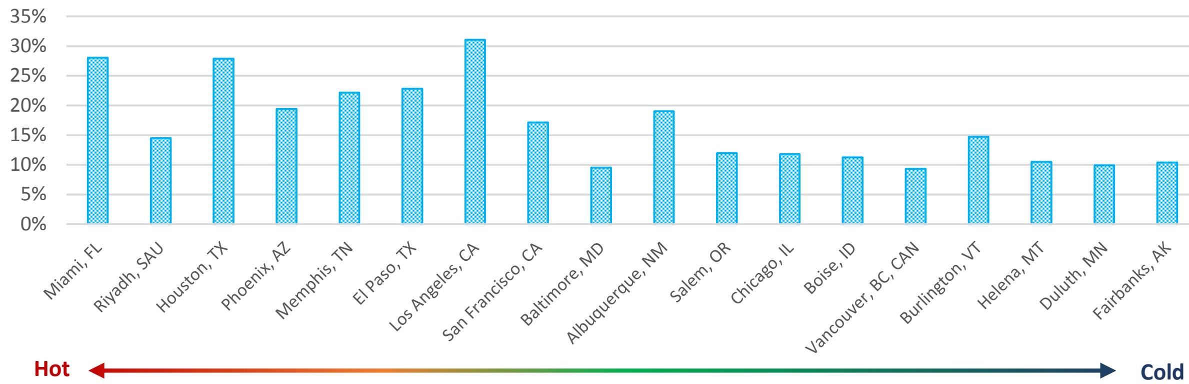

Fig. 3-1 Percent HVAC Energy Cost Savings of Therma-Fuser VAV vs. Conventional VAV

3.2 Results and Discussion

The modeling results (**Fig. 3-2**, **Fig. 3-3**, and **Fig. 3-4**) are presented for the 18 selected locations as follows. Absolute savings are presented first, followed by percent savings.

Energy Savings – The highest energy savings are typically seen in the hottest climates or coldest climates. In Climate Zone 1-2, where the system is sized based on the peak cooling demand, the fan energy savings from having lower total static pressure and the cooling energy savings from having a lower zonal turndown ratio become very significant. In heating dominated Climate Zone 6-8, besides the high fan energy savings, reheat energy during shoulder seasons is also significantly reduced as a result of Therma-Fuser VAV's lower turndown ratio. **Fig. 3-2** lists the energy savings of Therma-Fuser VAV for each climate zone broken out by HVAC component.

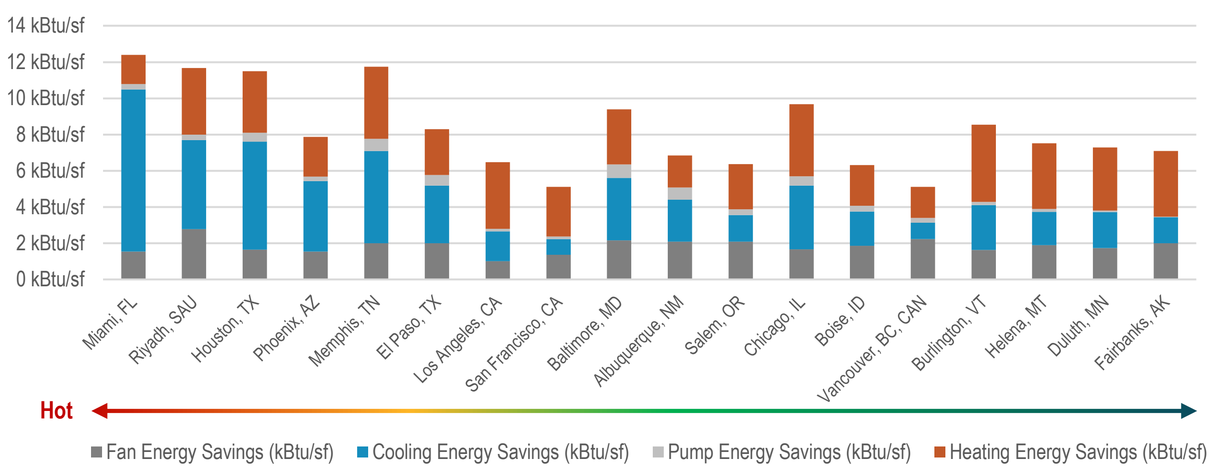

Fig. 3-2 Per SF HVAC Energy Savings of Therma-Fuser VAV by End Use

Energy Cost Savings – The highest energy cost savings are seen either in hot and warm climates where energy savings are significant or in locations with high energy prices (e.g. Burlington, VT and Fairbanks, AK). Energy prices for each city are included in **Table 4-4** in Appendix A – Definitions and Inputs.

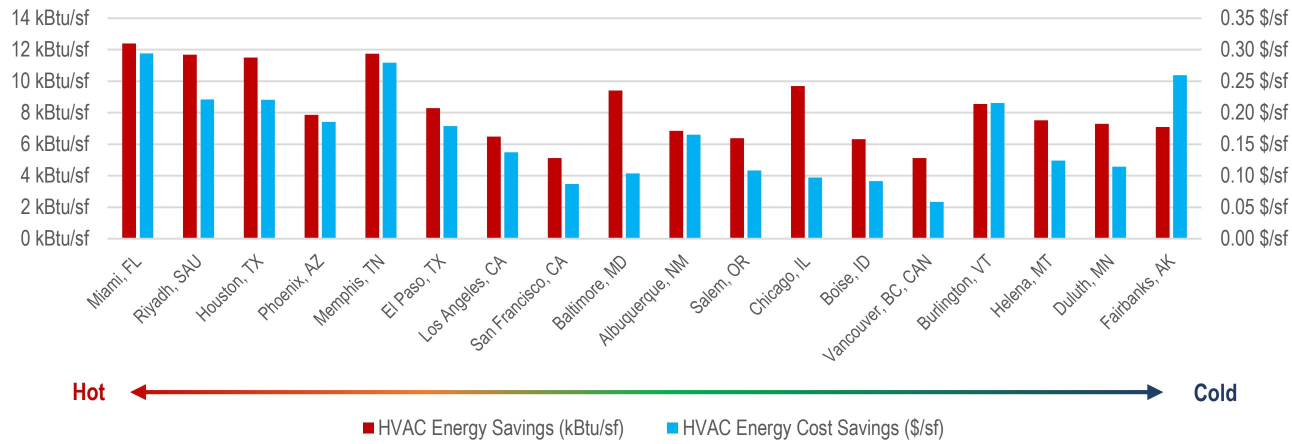

Fig. 3-3 Per SF HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

Percent Energy Savings – High energy percentage savings are mostly present in hot climates – Climate Zone 1, 2, 3a and 3b. The low energy percentage savings in cold climates result from the extremely high heating energy in the denominator of the percent calculation.

Percent Energy Cost Savings – Due to the higher per-unit-energy cost for electricity compared to natural gas, the highest energy cost percentage savings are found in climates with more electric savings (cooling, fans and pumps). This results in warmer climates (Climate Zone 1-4) having higher energy cost savings than colder climates (Climate Zone 5-8). Los Angeles has one of the highest energy cost percentage savings mainly because 1) the base HVAC energy consumption is low due to LA's mild climate, and 2) the shoulder seasons are significantly longer in LA, magnifying the fan and reheat energy savings from having Therma-Fuser VAV's lower turndown ratio.

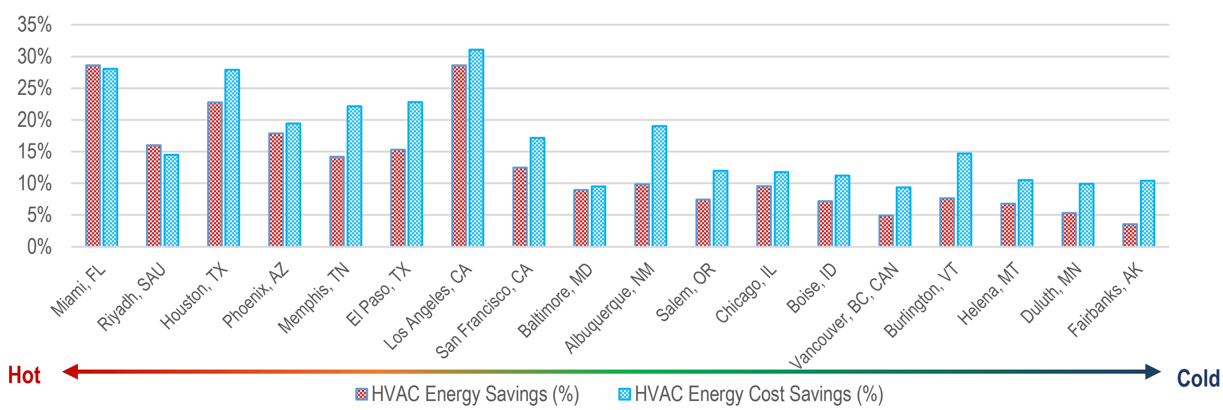

Fig. 3-4 Percent HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

3.3 ASHRAE 90.1 2013 Comparison

The results of the detailed models described above show that diversity of schedules contributes to higher HVAC energy use in all HVAC energy categories, and having fewer but bigger-size air handling units leads to higher overall energy use, including significantly higher cooling and heating energy and slightly lower fan energy. The impact of these two trends is an increase in energy use for both conventional VAV and Therma-Fuser VAV, but also a greater savings associated with Therma-Fuser VAV.

As part of the regional energy performance study, a separate set of models were created strictly following the ASHRAE 90.1 guidelines mainly for building compliance or LEED purposes (Appendix C.2 describes the detailed application of the ASHRAE 90.1 approach). Taking Los Angeles as an example, **Fig. 3-5** shows the energy consumption comparison of conventional VAV and Therma-Fuser VAV using both the ASHRAE 90.1 approach and the detailed modeling approach. An additional 3.0 kBtu/sf of energy savings were predicted between Therma-Fuser VAV and conventional VAV using the detailed modeling approach - almost double the amount of energy savings of the ASHRAE standard model.

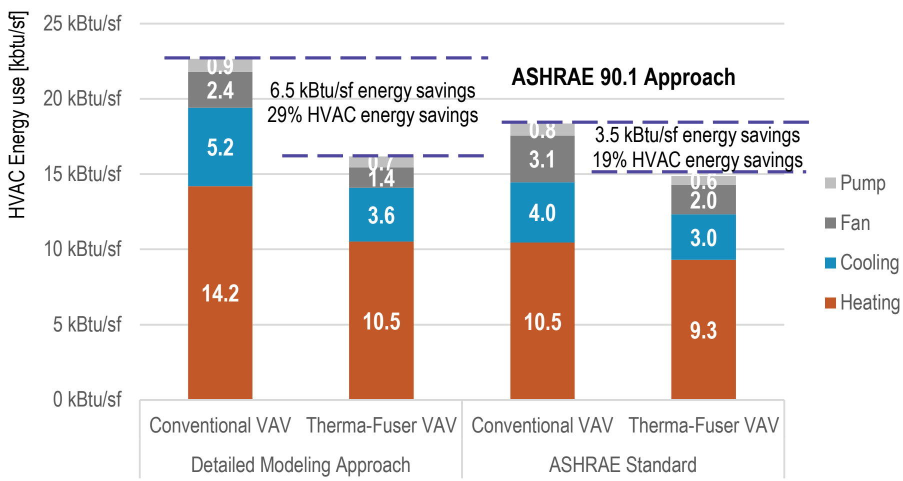

Fig. 3-5 Los Angeles, CA - Building HVAC Energy Use – ASHRAE 90.1 Approach vs. Detailed Modeling Approach

As a result of the additional energy savings, the HVAC energy cost savings increased from \$0.10/sf per year to \$0.15/sf per year. Accordingly, the relative energy cost savings increased from 25% to 31%. Cost results are presented in **Fig. 3-6**.

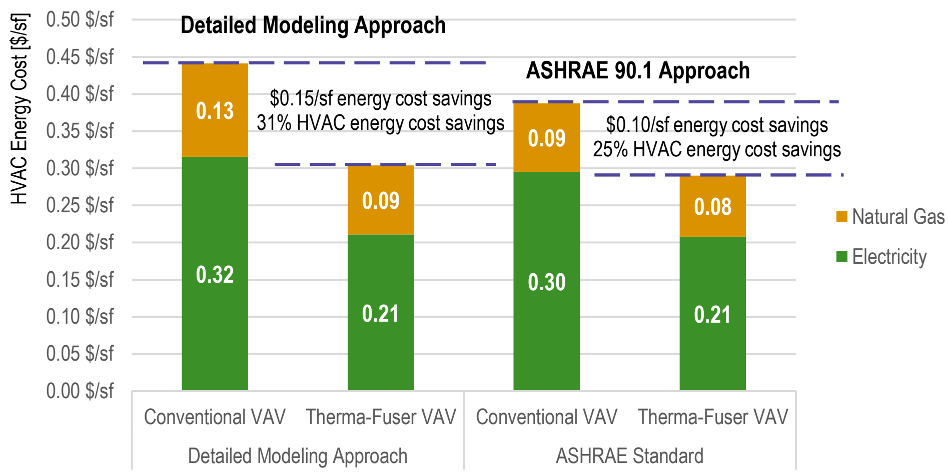

Fig. 3-6 Los Angeles, CA - Building HVAC Energy Cost – ASHRAE 90.1 Approach vs. Detailed Modeling Approach

Fig. 3-7 compares the percent HVAC energy cost savings using the ASHRAE 90.1 approach versus using the detailed modeling approach, indicating that Therma-Fuser VAV could always save more on HVAC energy cost in reality than what would be shown in a typical ASHRAE 90.1 model.

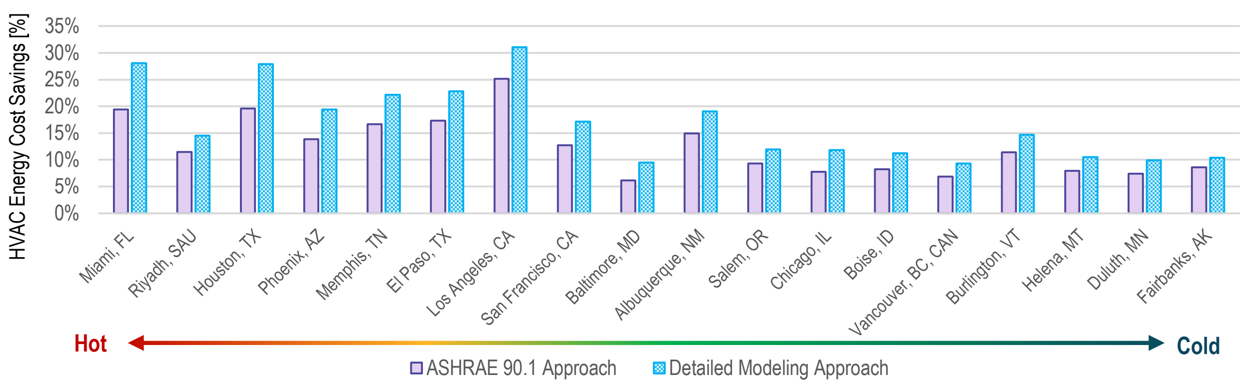

Fig. 3-7 All ASHRAE Climate Zones – Percent HVAC Energy Cost Savings – ASHRAE 90.1 Approach vs. Detailed Modeling Approach

More about the additional savings of Therma-Fuser VAV by end use of the detailed modeling approach can be found in Appendix B.2. Complete results for ASHRAE 90.1 2007, 2010, and 2013 can be found in Appendix C – ASHRAE Compliant Models.

4 Appendix

Appendix A – Definitions and Inputs

A.1 Energy Cost Savings and Percent Energy Cost Savings Definitions

Energy Cost Savings and Percent Energy Cost Savings were frequently used in this study. These two metrics capture the differences in the energy rate structures at different locations seen in each market at the time of this study. Energy cost is also directly translatable to the energy performance under LEED, the USGBCs' green building rating system. The conversion of energy cost savings to Energy and Atmosphere points varies between versions of LEED and categories. In this study, cooling, heating, fan and pump energy costs are grouped as HVAC Energy Cost.

A.2 Modeling Approach

The energy model was built using OpenStudio v1.8.0 and analyzed by the EnergyPlus v8.3.0 engine to represent a 68,800 square foot four-story office building. The balance of the space was corridors, offices, conference rooms, breakrooms, stairs and MEP closets (See floor plan and massing in the Appendix A.3 Modeling Inputs and Massing). All space type inputs (occupancy, lighting, equipment, infiltration, schedules, etc.) match the ASHRAE 90.1 standards.

Per ASHRAE 90.1 standards, each floor of the building shall be served by one dedicated air handler. The OpenStudio model has four stories and is thus served by four dedicated air handlers. The detailed model has two air handlers. For both models, each air handler includes a VSD supply fan, an air-side economizer, a direct expansion cooling coil and a hot water heating coil. Supply air temperature is reset by a warmest air temperature controller to be within the range of 55-60°. Reheat is provided by hot water reheat coils at the zonal level. Heating hot water is served by a single gas boiler for the entire building, delivered to both the central heating coils and reheat coils.

All equipment efficiencies were selected based on ASHRAE 90.1 standards.

A.3 Modeling Inputs and Massing

Fig. 4-1 Floor Plan

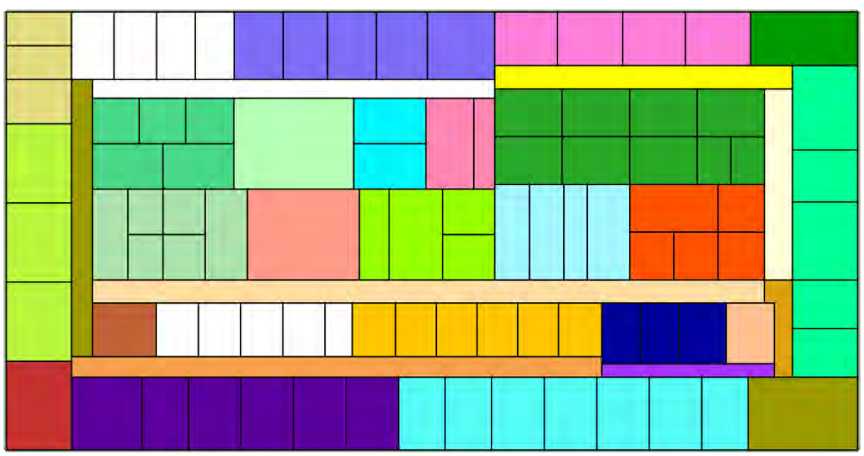

Fig. 4-2 Zoning Diagram

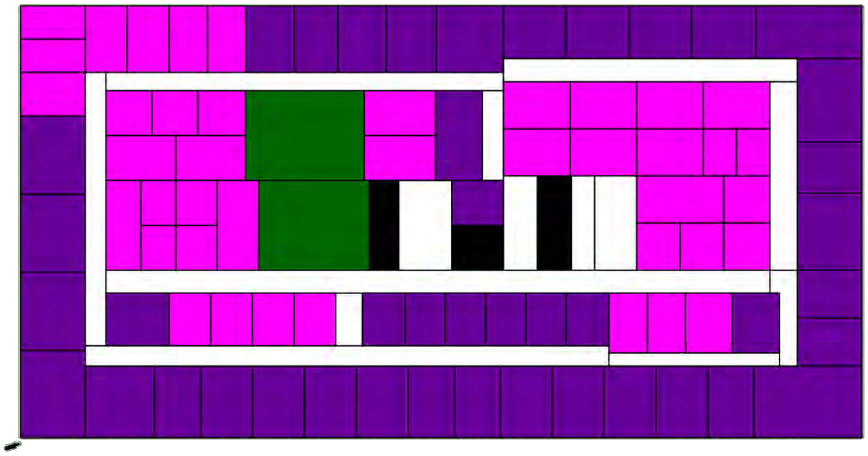

Fig. 4-3 Model Space Type Layout

Table 4-1 ASHRAE 90.1 2007 Space Inputs

Massing Color	Space Type	Area/person [SF]	Lighting [W/SF]	Equipment Load [W/SF]	Outdoor Air Rate per person [CFM/person]	Outdoor Air Rate per area [CFM/SF]	Cooling Setpoint	Heating Setpoint
	Office	210	1.1	0.64	5	0.06	75	70
	Break Room	20.0	1.2	4.46	5	0.06	75	70
	Conference	20.0	1.3	0.37	5	0.06	75	70
	Corridor	1000.0	0.5	0.16	0	0.06	75	70
	Elec/Mech	N/A	1.5	0.27	0	0.12	75	70

Table 4-2 ASHRAE 90.1 2010 Space Inputs

Massing Color	Space Type	Area/person [SF]	Lighting [W/SF]	Equipment Load [W/SF]	Outdoor Air Rate per person [CFM/person]	Outdoor Air Rate per area [CFM/SF]	Cooling Setpoint	Heating Setpoint
	Office	210	1.11	0.64	5	0.06	75	70
	Break Room	20.0	0.73	4.46	5	0.06	75	70
	Conference	20.0	1.23	0.37	5	0.06	75	70
	Corridor	1000.0	0.66	0.16	0	0.06	75	70
	Elec/Mech	N/A	0.95	0.27	0	0.12	75	70

Table 4-3 ASHRAE 90.1 2013 Space Inputs

Massing Color	Space Type	Area/person [SF]	Lighting [W/SF]	Equipment Load [W/SF]	Outdoor Air Rate per person [CFM/person]	Outdoor Air Rate per area [CFM/SF]	Cooling Setpoint	Heating Setpoint
	Office	210	1.11	0.64	5	0.06	75	70
	Break Room	20.0	0.73	4.46	5	0.06	75	70
	Conference	20.0	1.23	0.37	5	0.06	75	70
	Corridor	1000.0	0.66	0.16	0	0.06	75	70
	Elec/Mech	N/A	0.95	0.27	0	0.12	75	70

A.4 Locations, Climate Zones and Utility Rates

There are a total of 17 ASHRAE climate zones. One city was selected for each climate zone. Additionally, Los Angeles in Climate Zone 3B was selected as an additional example to show the significant impact of utility rates on the energy cost savings. Then for each selected location, three models were run using ASHRAE 90.1 2007, 90.1 2010, and 90.1 2013 standards respectively. Please refer to **Table 4-4** for a complete list of modeled locations with the corresponding ASHRAE climate zones and utility rates.

Table 4-4 Locations, ASHRAE Climate Zones and utility rates

Location	Climate Zone	Construction Set	Elec Rate ($/kWh)	Gas Rate ($/therm)
Miami, FL	1A	CZ1 - office	0.087	1.12
Riyadh, SAU	1B	CZ1 - office	0.090	0.28
Houston, TX	2A	CZ2 - office	0.082	0.79
Phoenix, AZ	2B	CZ2 - office	0.102	0.85
Memphis, TN	3A	CZ3a-3b - office	0.107	0.92
El Paso, TX	3B	CZ3a-3b - office	0.094	0.79
Los Angeles, CA	**3B**	**CZ3a-3b - office**	**0.127**	**0.88**
San Francisco, CA	3C	CZ3c - office	0.090	0.88
Baltimore, MD	4A	CZ4 - office	0.039	1.02
Albuquerque, NM	4B	CZ4 - office	0.102	0.76
Salem, OR	4C	CZ4 - office	0.077	0.84
Chicago, IL	5A	CZ5 - office	0.041	0.74
Boise, ID	5B	CZ5 - office	0.062	0.76
Vancouver, BC, CAN	5C	CZ5 - office	0.051	0.49
Burlington, VT	6A	CZ6 - office	0.141	0.90
Helena, MT	6B	CZ6 - office	0.081	0.88
Duluth, MN	7	CZ7 - office	0.081	0.67
Fairbanks, AK	8	CZ8 - office	0.226	0.81

Appendix B – Detailed Model Inputs

B.1 Detailed Model Inputs

B.1.1 ASHRAE 90.1 Schedules

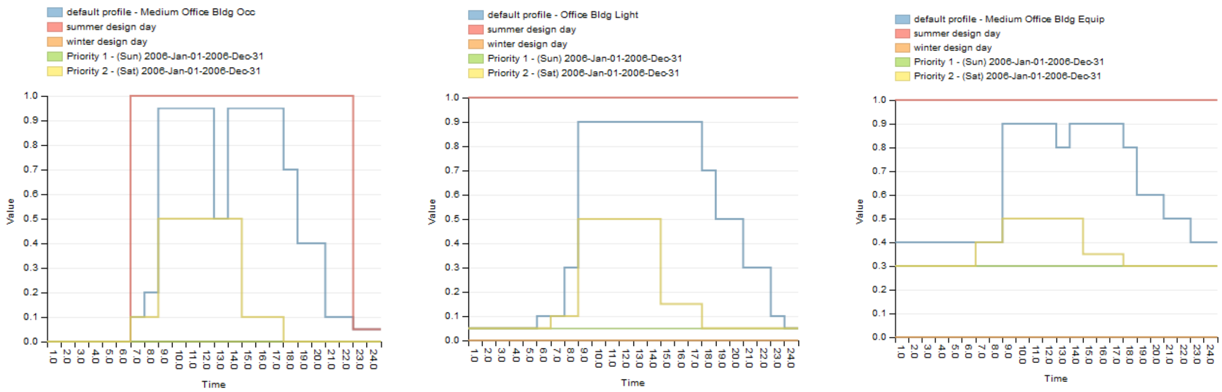

Fig. 4-4 ASHRAE 90.1 Medium Office Occupancy, Lighting and Equipment Schedules

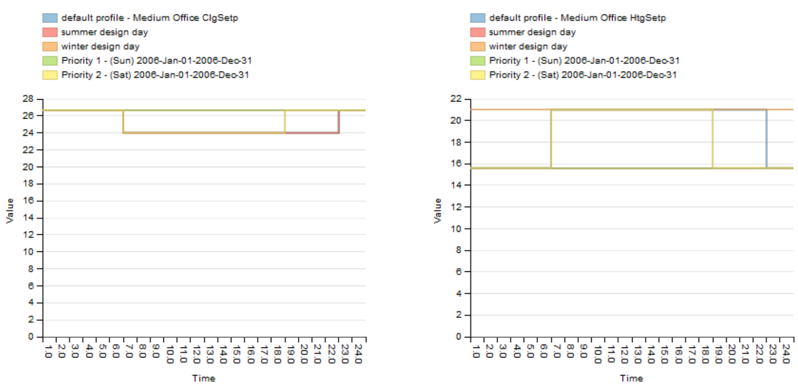

Fig. 4-5 ASHRAE 90.1 Medium Office Cooling and Heating Setpoint Schedules

B.1.2 Customized Schedules

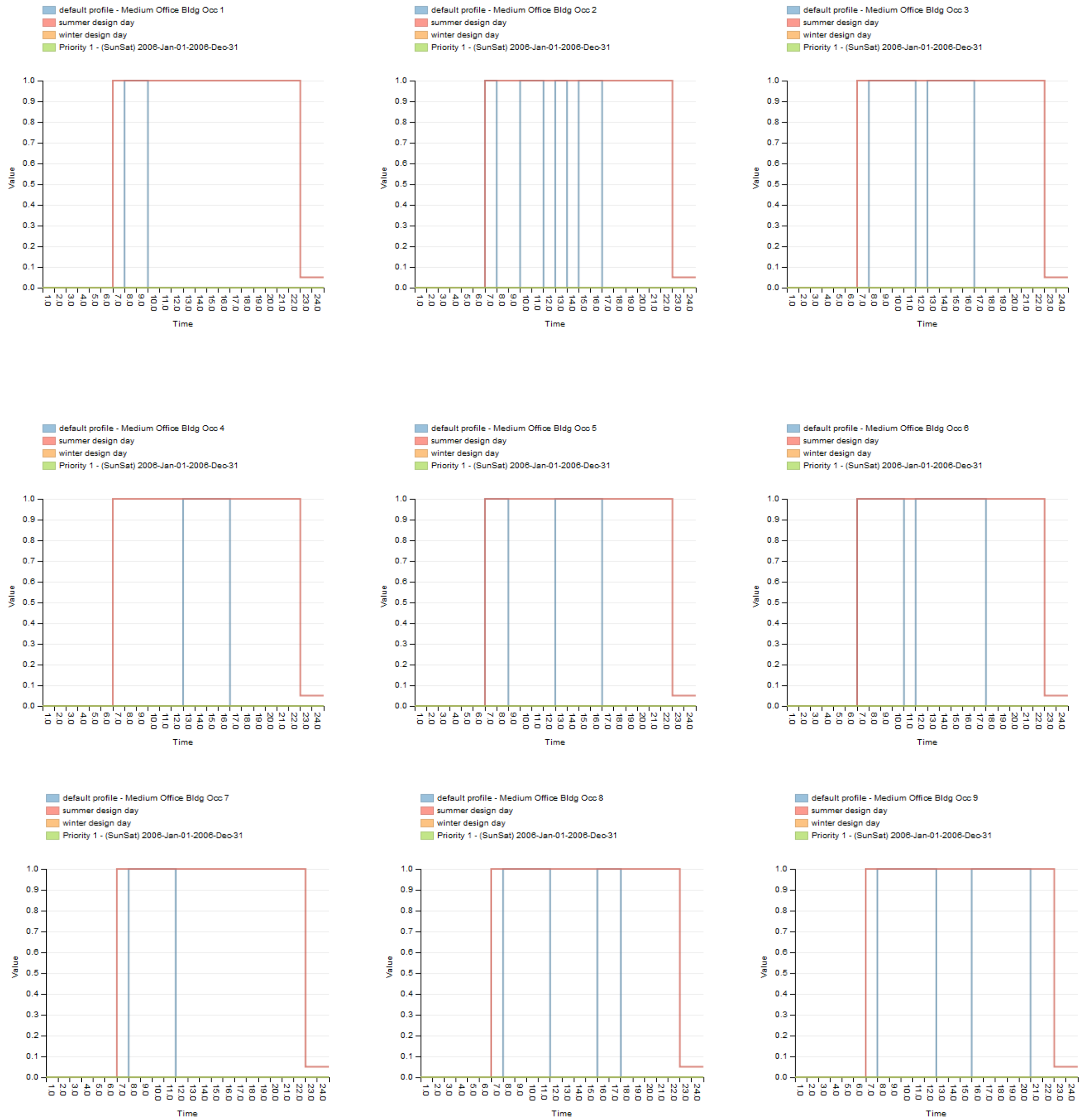

Fig. 4-6 Customized Office Building Occupancy Schedules 1-9

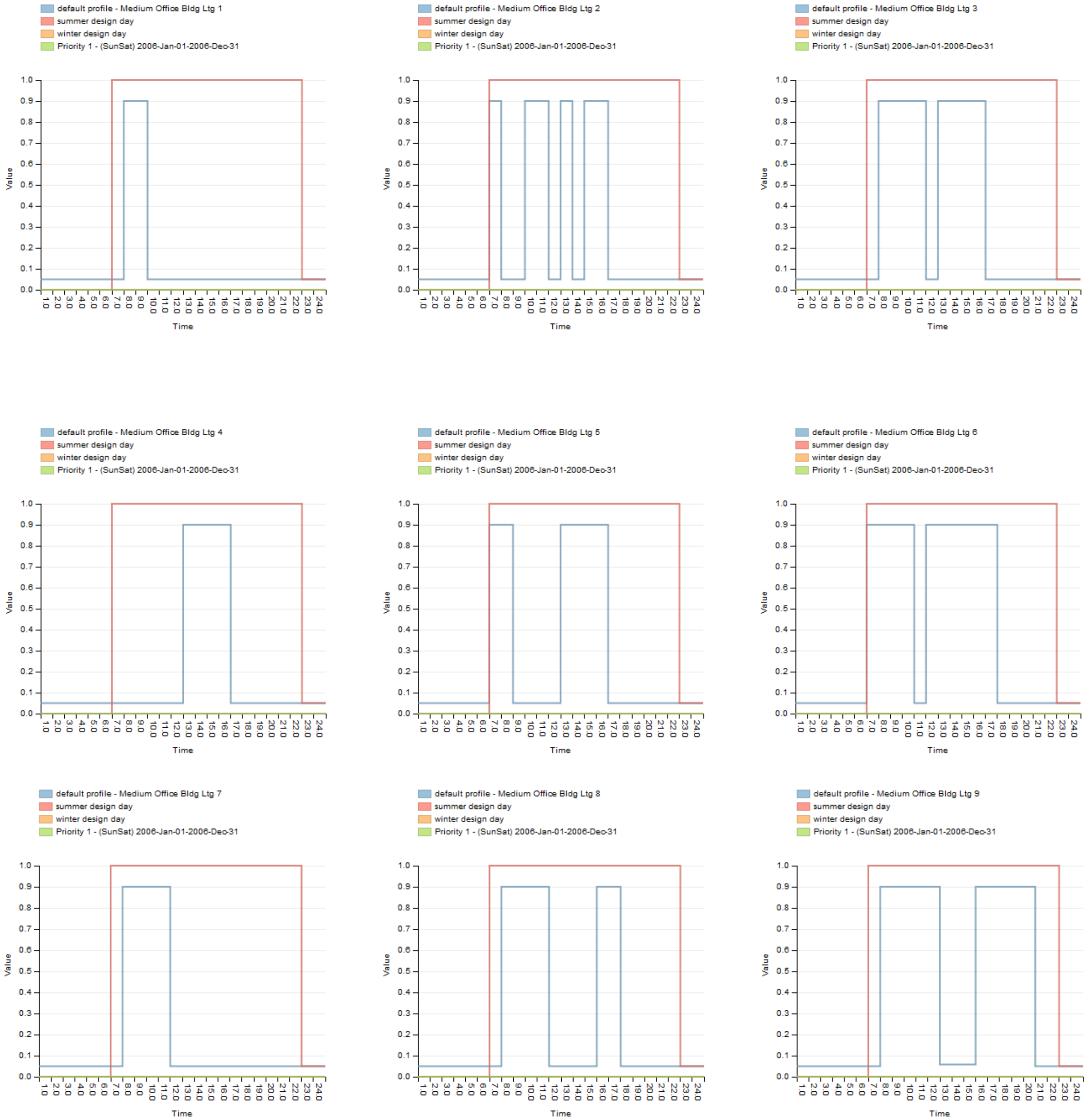

Fig. 4-7 Customized Office Building Lighting Schedules 1-9

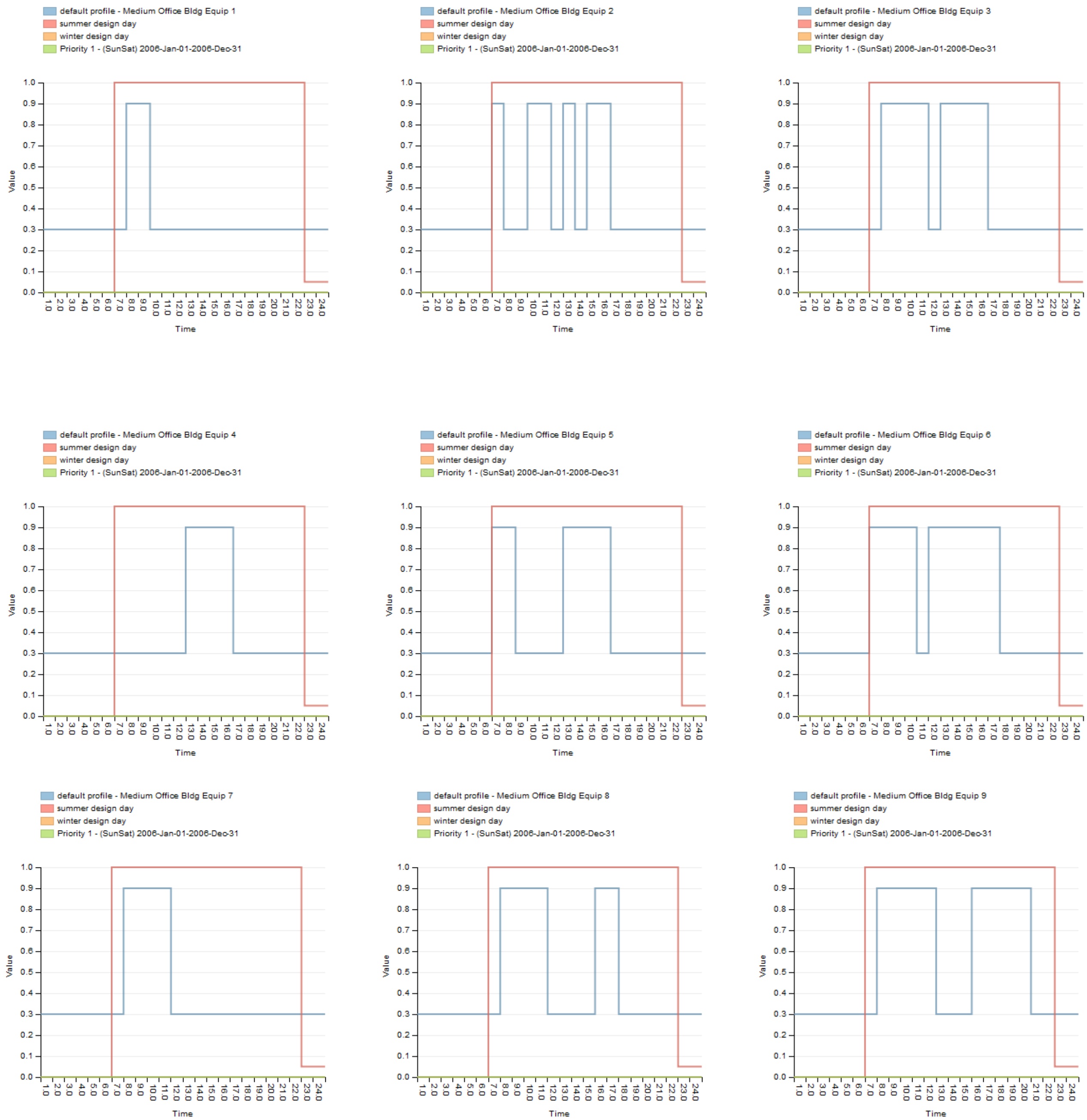

Fig. 4-8 Customized Office Building Equipment Schedules 1-9

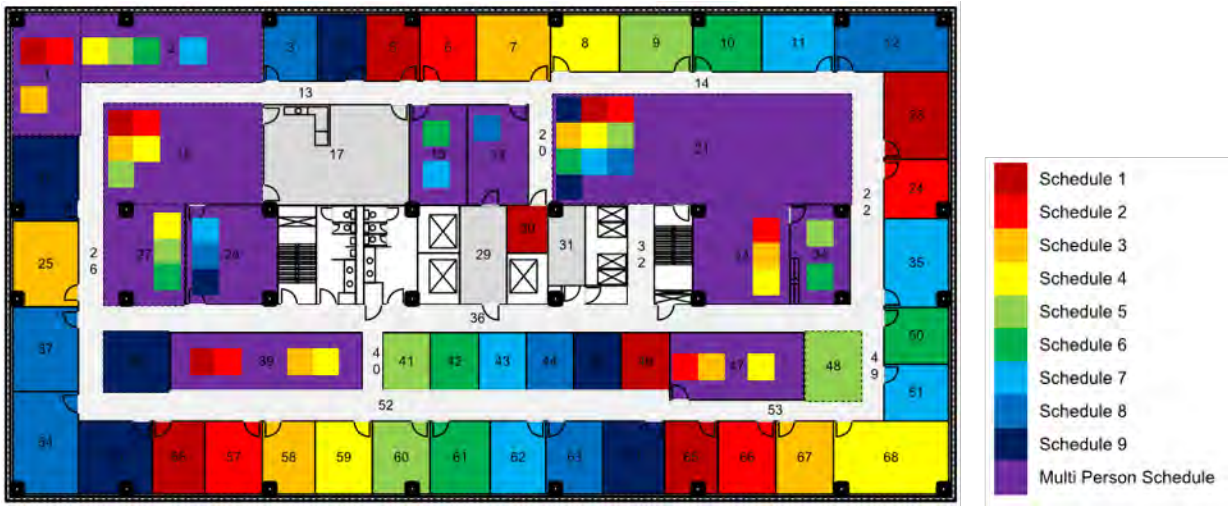

Fig. 4-9 Customized Schedule Assignment

B.1.3 Air Handling Units Layout

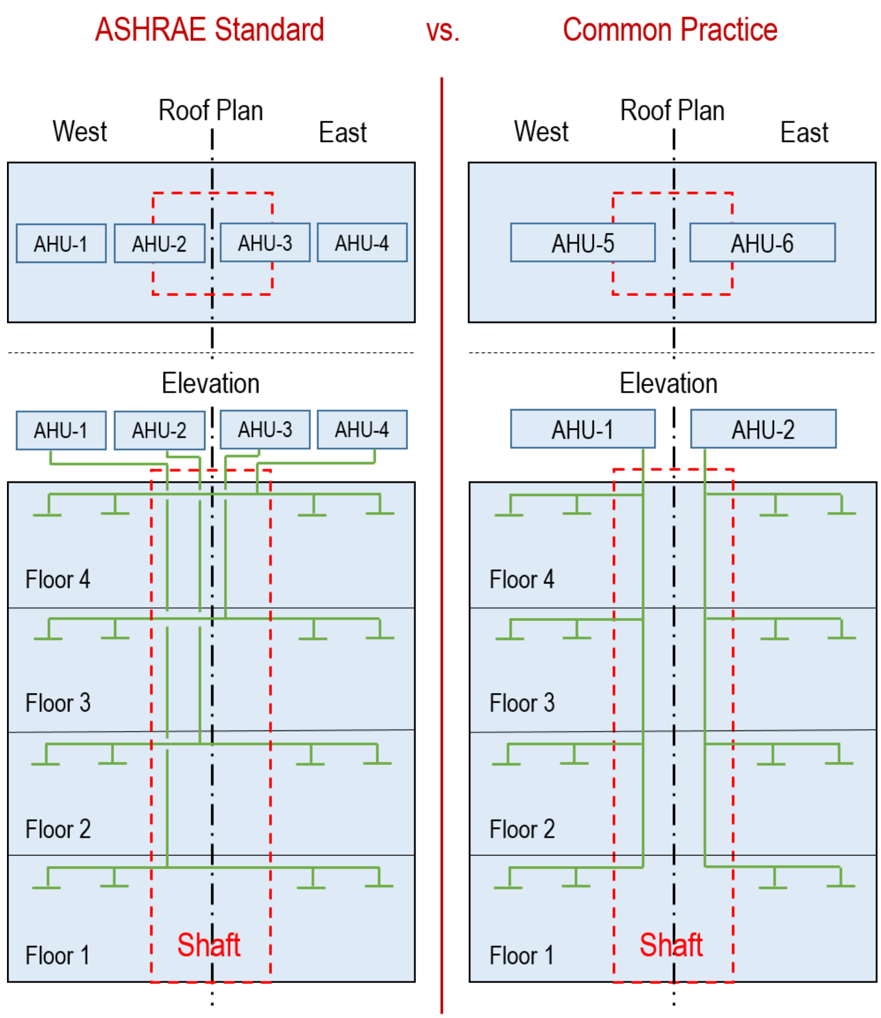

Fig. 4-10 Air Handling Unit Layout Diagram - ASHRAE Standard vs. Common Practice

B.2 Additional Savings of Therma-Fuser VAV by End Use

Taking Los Angeles as an example, **Fig. 4-11** and **Fig. 4-12** present the additional savings of Therma-Fuser VAV by end use of the detailed modeling approach described in Section 2.3 and for the ASHRAE 90.1 modeling approach described in Section 2.4.

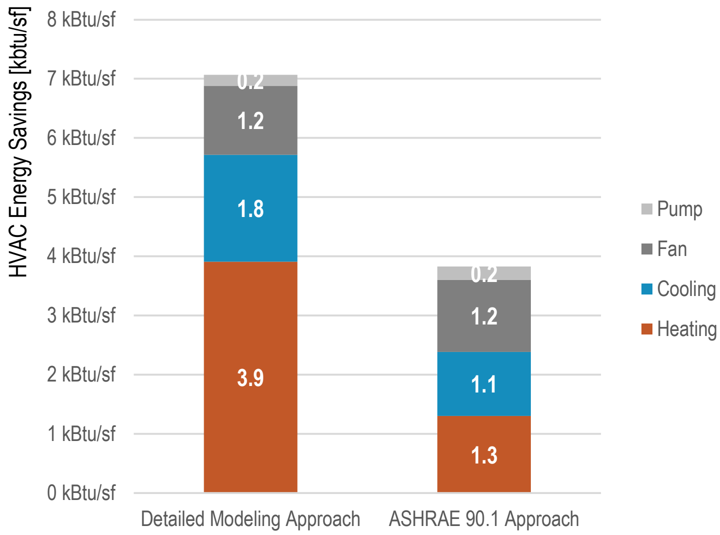

Fig. 4-11 Los Angeles, CA – Annual HVAC Energy Savings of Therma-Fuser VAV by End Use
(Results shown in difference of annual HVAC energy use between Conventional VAV and Therma-Fuser VAV)

As shown in **Fig. 4-11** after customized schedules and the 2-AHU mechanical design were applied to the ASHRAE standard models, an additional 7 kBtu/sf of energy savings could be claimed by switching from conventional VAV to Therma-Fuser VAV - almost double the amount of the energy savings of the ASHRAE standard model.

Similar trend is also seen from an energy cost savings standpoint shown in **Fig. 4-12.** The model is more representative of the real-world scenario with the two changes implemented, both of which create higher diversity. The energy benefits of Therma-Fuser VAV's lower turndown ratio are more realistically captured in the detailed model, which shows much higher energy savings than an ASHRAE 90.1 standard model. The detailed model results are therefore presented in Section 3.2.

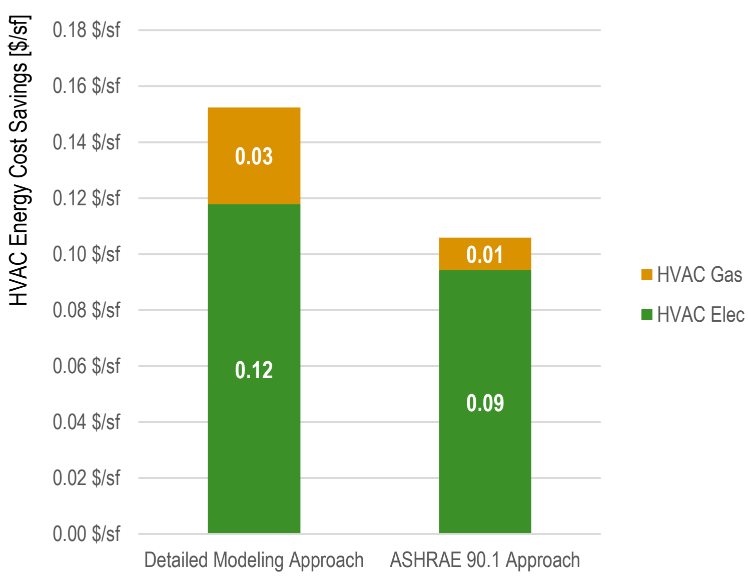

Fig. 4-12 Los Angeles, CA – Annual HVAC Energy Cost Savings of Therma-Fuser VAV by End Use
(Results shown in difference of annual HVAC energy Cost between Conventional VAV and Therma-Fuser VAV)

Appendix C – ASHRAE Compliant Models

C.1 Introduction

A compliant model is a building energy performance model in which all space type inputs (occupancy, lighting, equipment [rooftop packaged unit and hot water boiler] and infiltration), equipment efficiencies, and schedules match the ASHRAE 90.1 standards. Both the conventional VAV and the Therma-Fuser VAV models described in Section 2.3 are compliant with this standard. The energy savings of Therma-Fuser VAV for these compliant models is shown in this appendix.

The realistic detailed model cannot be used for code compliance because 1) the detailed model has only two air handling units as opposed to "one handling unit per floor" as specified in the AHRAE standards, and 2) the detailed model varies the occupancy, lighting and equipment schedules for spaces of the same space type while ASHRAE standards specify identical schedules for all spaces of the same space type.

In addition to ASHRAE 90.1 2013, ASHRAE 90.1 2010 and 2007 were also modeled. The 2010 standard is used for LEED v4 and is code in several states and the 2007 standard is used for LEED v2009 (v3) and is also code in several states. Across all three energy code standard versions (2013, 2010, 2007), Therma-Fuser VAV consistently shows energy savings in cold climates of 2% to 6% and in warm climates 11% to 20%. Results for each are as follows.

C.2 ASHRAE 90.1 2013 Modeling Results

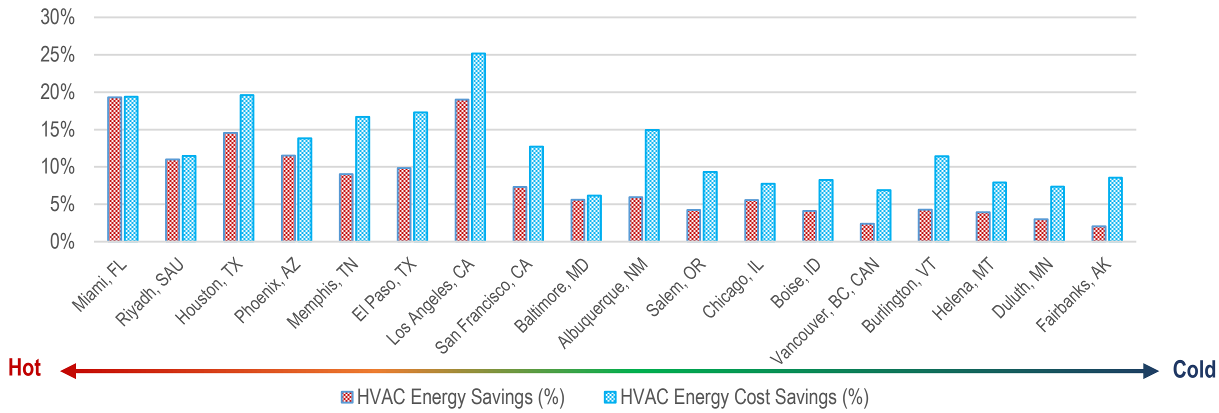

Fig. 4-13 ASHRAE 90.1 2013 – Percent HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

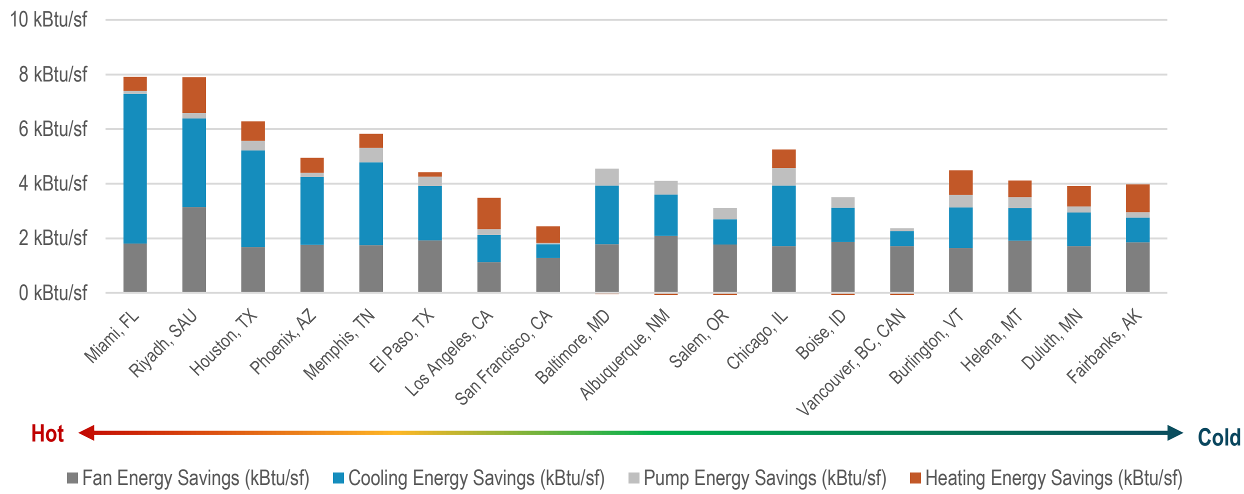

Fig. 4-14 ASHRAE 90.1 2013 – HVAC Energy Savings by End Use of Therma-Fuser VAV

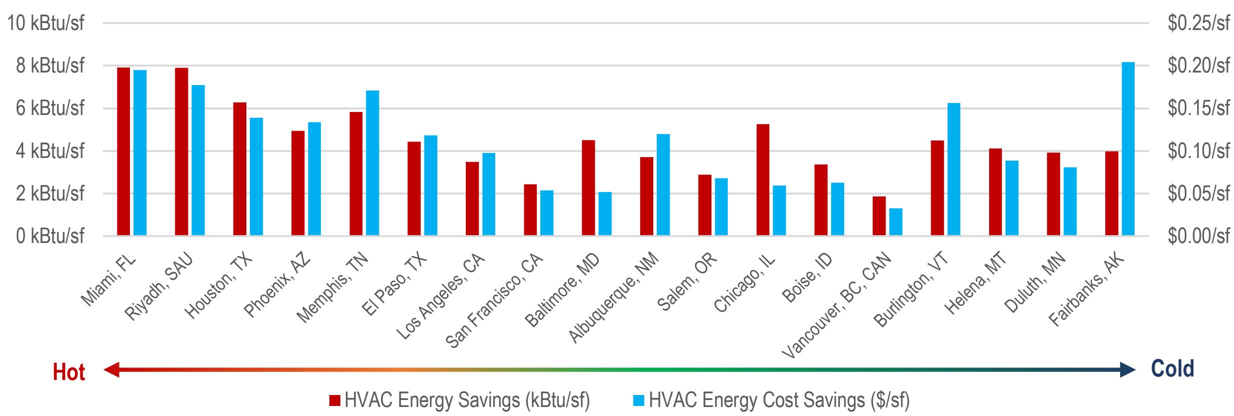

Fig. 4-15 ASHRAE 90.1 2013 – Per SF HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

C.3 ASHRAE 90.1 2010 Modeling Results

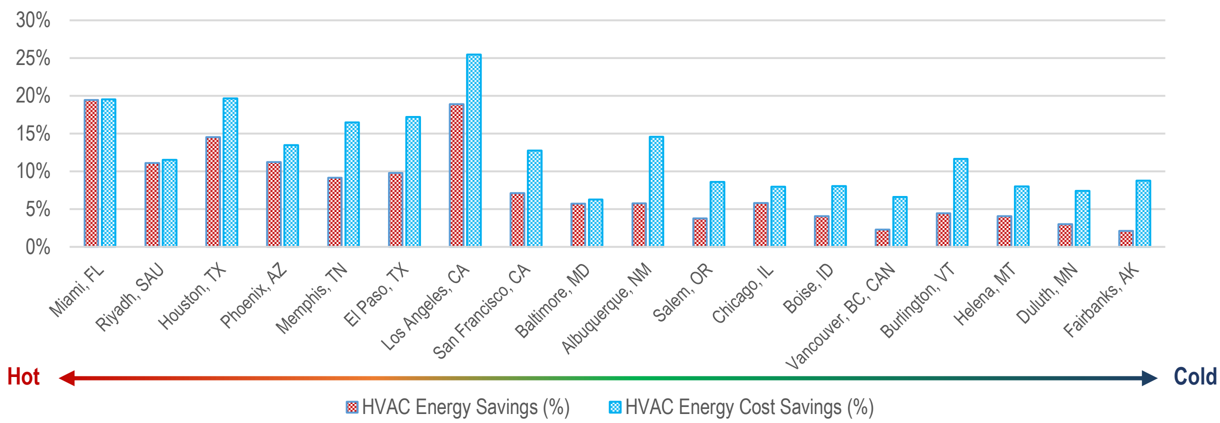

Fig. 4-16 ASHRAE 90.1 2010 – Percent HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

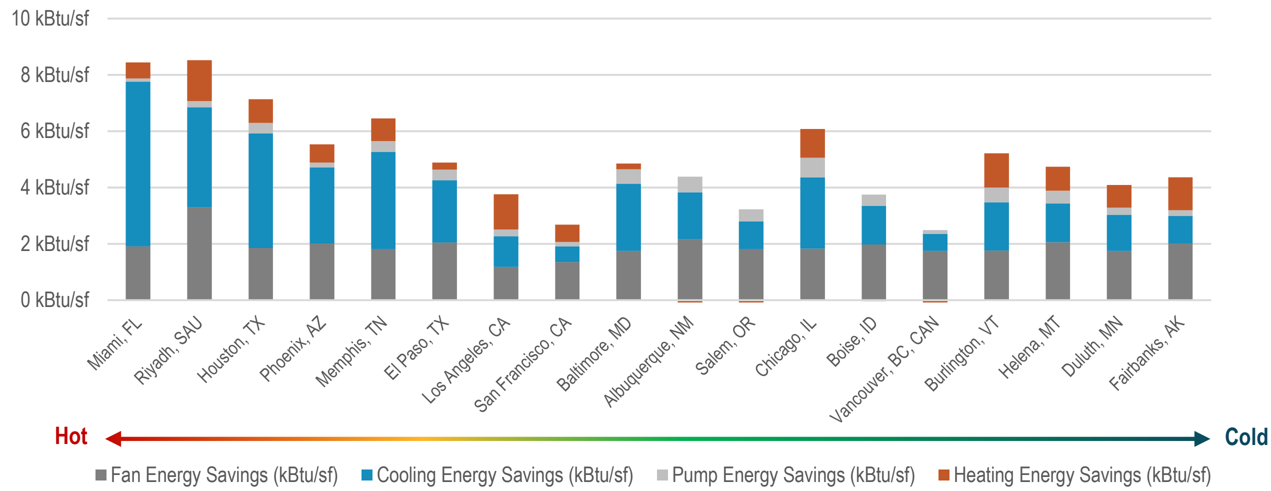

Fig. 4-17 ASHRAE 90.1 2010 – HVAC Energy Savings by End Use of Therma-Fuser VAV

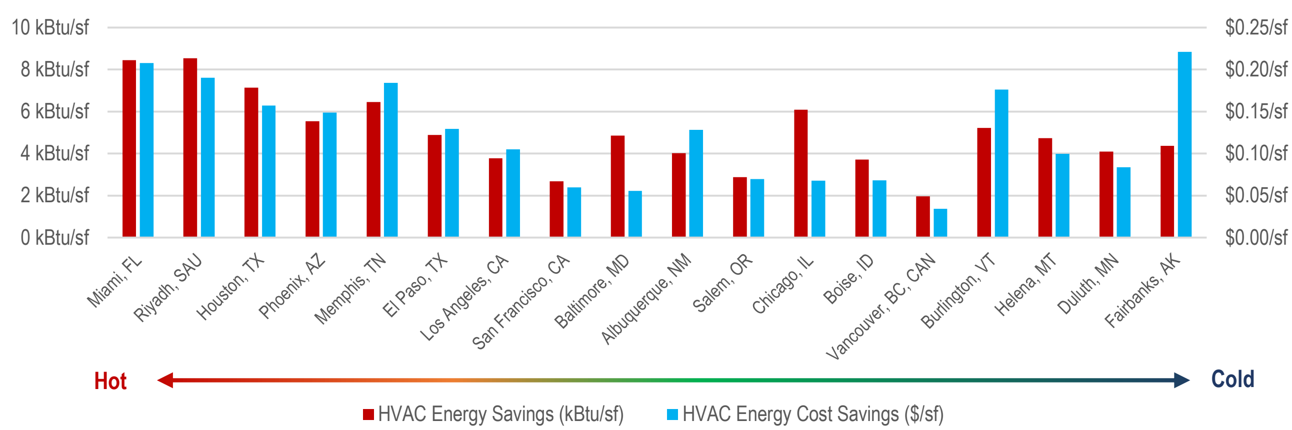

Fig. 4-18 ASHRAE 90.1 2010 – Per SF HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

C.4 ASHRAE 90.1 2007 Modeling Results

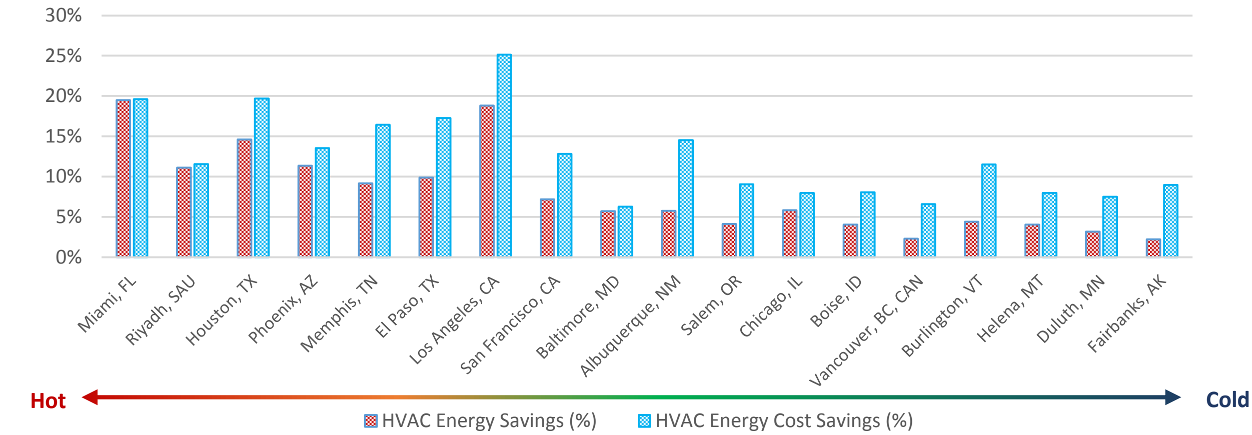

Fig. 4-19 ASHRAE 90.1 2007 – Percent HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

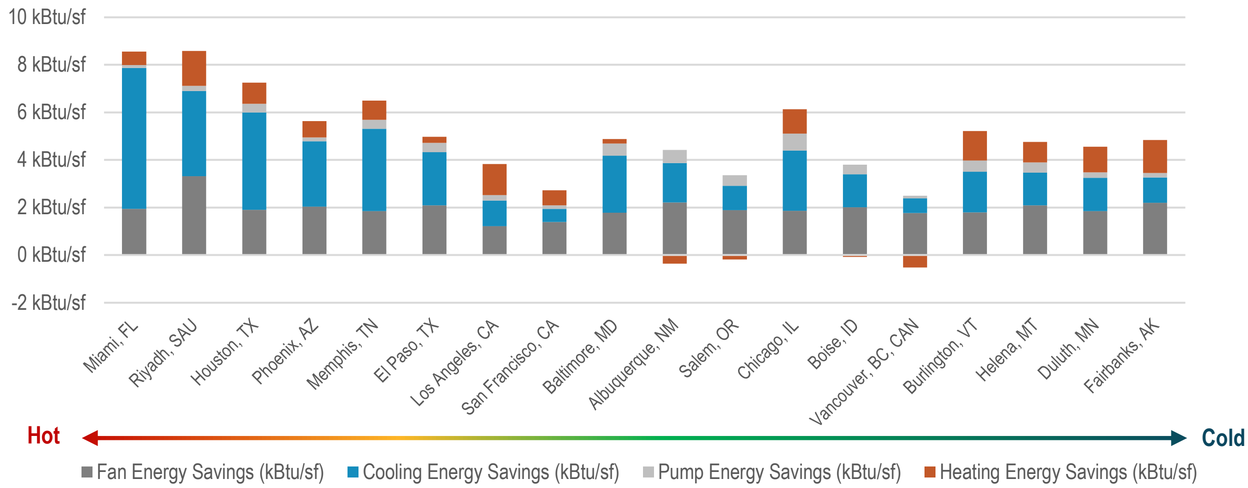

Fig. 4-20 ASHRAE 90.1 2007 – HVAC Energy Savings by End Use of Therma-Fuser VAV

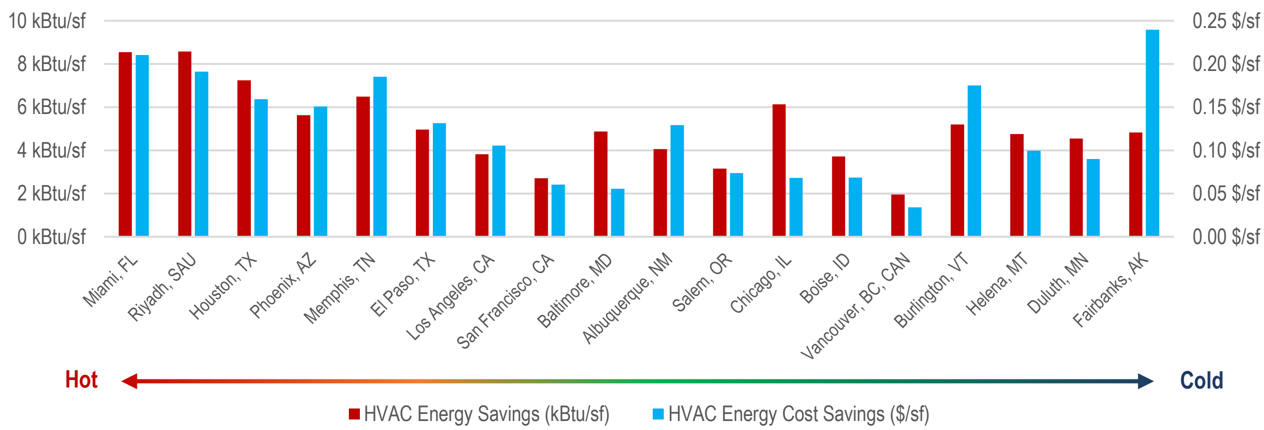

Fig. 4-21 ASHRAE 90.1 2007 – Per SF HVAC Energy and Energy Cost Savings of Therma-Fuser VAV

C.5 Detailed Discussion of Single Location Results following ASHRAE Standard

Overall, the energy modeling results show significant HVAC Energy savings for all climate zones. Taking Los Angeles as an example, **Fig. 4-22** and **Fig. 4-23** show the comparisons of HVAC energy use and HVAC energy cost of a conventional VAV system from ASHRAE 90.1 2013 and a Therma-Fuser VAV system.

Switching from conventional VAV to Therma-Fuser VAV can save 3.5 kBtu/sf-yr of HVAC energy which equals 19% of annual HVAC energy use and 25% of HVAC energy cost. The breakdown of the energy savings is associated with four end uses, heating, cooling, fans and pumps. In Los Angeles, the annual energy savings consist of 1.2 kBtu/sf heating savings, 1.0 kBtu/sf cooling savings, 1.1 kBtu/sf fan savings and 0.2 kBtu/sf pump savings. Fan energy savings is the most significant, with a 36% reduction compared to a conventional VAV system; this is due to a lower static pressure and a lower diffuser turndown ratio.

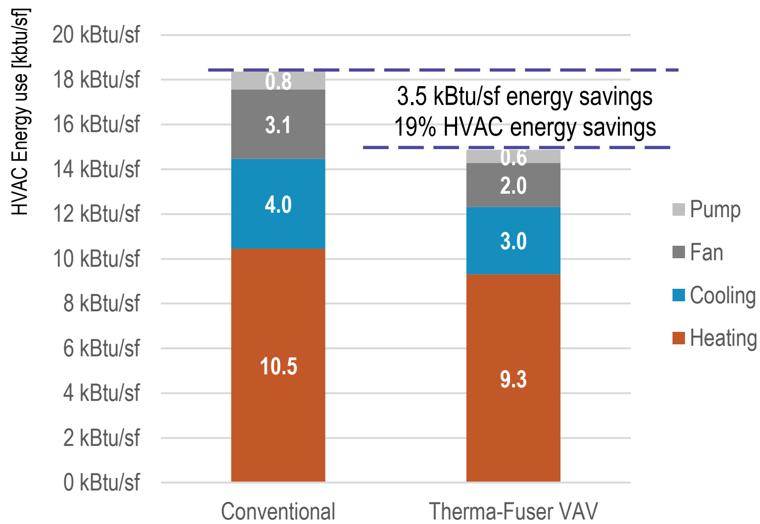

Fig. 4-22 Los Angeles, CA – HVAC Energy Use

The cost savings associated with switching from a conventional system to a Therma-Fuser VAV system are $0.10/sf per year which equals 25% of the annual HVAC energy cost. The fan energy cost savings are again the largest contributor to the cost savings.

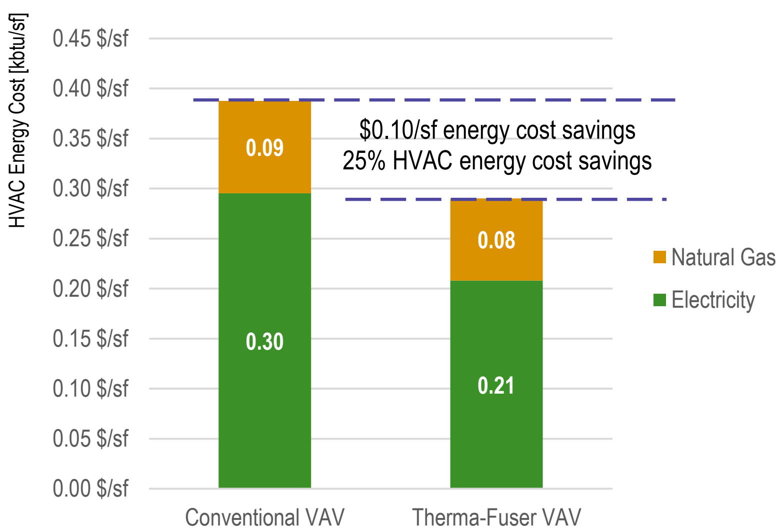

Fig. 4-23 Los Angeles, CA – HVAC Energy Cost