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Heat Pump Baseline for Non-Residential and High-Rise Residential Buildings FEASIBILITY ANALYSIS

For California Energy Commission

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OBJECTIVE

The California Energy Commission has established goals for decarbonization of California buildings. As the electric grid adds more renewable energy sources to the generation mix, reducing the consumption of natural gas and propane in favor of electricity at the building level will reduce greenhouse gas emissions. However, changes to mandatory or prescriptive code requirements or to the baselines used in the performance approach must be cost-effective and technically feasible while avoiding issues with Federal preemption.

This project looked at options for changing the systems used in the baseline models in the Title 24, Part 6 performance path from gas to heat pump heat for the 2022 code cycle. The performance of heat pumps would be compared to current gas heat systems using the 2022 compliance metrics of TDV and source energy as well as the CO_2e emissions, provided by CBECC-Com, as an informational metric. Heat pump systems that resulted in lower TDV and source energy consumption compared to current gas heat systems would be considered for use as the baseline. In addition, the source energy or TDV consumption of the heat pump system must not be so low that proposed designs using gas heat would not be able to comply. Finally, any system that increases cost must be cost-effective.

BACKGROUND

CBECC-Com is the modeling software used by nonresidential and high-rise residential buildings wishing to comply with the energy code by using the performance approach. The HVAC system used in the baseline model is determined by the “system map”, shown in Table 1. The baseline system is independent of the systems included in the proposed design, but is based on the building type, floor area, and number of stories.

Table 1 – CBECC-Com Baseline System Map

Building Type	Floors	Standard Design (Baseline)
Residential or hotel/motel guestrooms	Any number of floors	System 1 - SZAC
Retail building 2 floors or fewer	Building ≤ 2 floors	System 7 - SZVAV*
Warehouse and light manufacturing space types (per the Appendix 5.4A Schedule column) that do not include cooling in the proposed design		System 9 - HEATVENT
Covered process - computer room with total design cooling load > 3,000,000 Btu/h	Any number of floors	System 10 – CRAH Unit
Covered process - computer room with total design cooling load ≤ 3,000,000 Btu/h	Any number of floors	System 11 – CRAC Unit
Covered process - laboratory space	Any number of floors	System 12 – LAB
Covered process - restaurant kitchen	Any number of floors	System 13 – KITCH
Healthcare Facilities		Same as Proposed Design
All other space types < 25,000 ft^2	Building ≤ 3 floors	System 7 - SZVAV*
	Building of 4 or 5 floors	System 5 - PVAV
	Building > 5 floors	System 6 - VAVS
All other space types 25,000 ft^2–150,000 ft^2	Building ≤ 5 floors	System 5 - PVAV
	Building > 5 floors	System 6 - VAVS
All other space types >150,000 ft^2	Any number of floors	System 6 - VAVS

* SZVAV systems serving all space types except laboratories with standard design total cooling capacity ≥ 65 kBtu/h shall have a minimum fan speed ratio of 0.5. SZVAV systems serving all space types except laboratories with standard design total cooling capacity < 65 kBtu/h shall have a minimum fan speed ratio of 1 (constant volume).

SZAC and SZVAV systems are both single zone systems that use DX cooling and gas furnace heat. Where the system map specifies SZVAV systems, the note to the table specifies that only systems with a cooling capacity of 65,000 Btu/hr or more will be variable speed, systems with smaller cooling capacity will be constant speed, effectively making them SZAC systems. PVAV systems are packaged variable volume multizone systems that use DX cooling and hot water terminal reheat boxes; VAVS systems are built-up variable volume multizone systems that use chilled water cooling and hot water reheat terminal boxes. The hot water for the PVAV and VAVS systems are supplied by central gas-fired boilers.

Heat pump alternatives to SZAC and SZVAV systems are straightforward: simply replace the gas furnace with a heat pump. For the systems with gas boilers and hot water reheat, possible alternatives include water source heat pumps, central heat pump boilers, or conventional electric resistance boilers.

The system map includes several system types that are applied to specific space types or spaces that are used for specific processes identified in the standards, known as covered processes. The systems used for these applications, shown with shading in Table 1, were not addressed in this project.

APPROACH

The project used CBECC-Com modeling with building prototype models to generate EnergyPlus models with baseline gas heat systems and heat pump alternative systems. These models were then modified as needed for each climate zone, specifically, envelope characteristics and HVAC sizing, and run directly in EnergyPlus. In all cases, the heat pump simulations were modified as necessary so that cooling and fan system efficiencies were identical, thereby ensuring that differences were due solely to the change in heating system. Both the gas and the heat pump heating systems were modeled with efficiencies set to the minimum efficiencies as specified in the prescriptive requirements of the standard.

The prototype models used are shown in Table 2. The table also lists the current baseline system type and the conditioned floor area of the building. Systems serving the nonresidential portions of the mixed-use residential building and the storage areas of the warehouse were held constant to isolate the energy savings to the residential and office portions of the buildings, respectively. Changes to the baseline of other non-residential buildings are applicable to the non-residential portions of the residential building. Systems serving the storage areas of the warehouse are defined as a covered process and were not addressed in this analysis.

Table 2 – Prototype Models

Building Name	Conditioned Floor Area (ft^2)	Baseline System Type
10 Story Mixed Use Residential	100,440 – 117 Dwelling Units 24,960 – Retail and Common Areas 125,400 – Total	Dwelling Units – SZAC Retail and Common Areas – SZAC (held constant)
Small Office	5,503	SZAC
Small Retail (Strip Mall)	9,376	1 SZVAV, 3 SZAC
Medium Retail*	24,566	2 SZVAV, 2 SZAC
Large Retail*	240,043	SZVAV
Small School	24,415	1 SZVAV, remainder SZAC
Warehouse	2,550 – Office 49,496 – Storage 52,046 – Total	Office – SZVAV Storage – Heating/Ventilating (held constant)

* These prototypes have large interior zones with large modeled systems. For costing purposes, the interior zones are assumed to be served by an integral number of packaged systems not exceeding 30 tons.

ENERGY RESULTS

The first requirement that must be met for a new baseline system is that the TDV consumption is no higher than the current gas heat baseline. This requirement ensures that the new baseline does not result in a reduction in stringency. Figures 1 through 6 below show the TDV savings of a system using heat pump heat compared to the current baseline, which is otherwise identical except with gas furnace heat. Lower TDV consumption is shown as positive savings.

There are TDV savings in most climate zones except for climate zones 1 and 16. Savings are slightly negative for some other climate zones, such as CZ5 and CZ14, for some buildings, but the negative savings are less than 1% and are usually in the 0.1% range.

In Figures 1 through 6, the heat pump systems are labeled in one of three ways. SZHP means a constant volume heat pump system, SZVAVHP means a heat pump system with a variable speed fan and two speed cooling compressor, and a SZMixedHP means that some zones are served by SZHP systems and some zones by SZVAVHP systems. The current and proposed ACM specifies that single zone systems are used for specific space types. However, if the system cooling capacity exceeds 65,000 Btu/hr, then the ACM specifies variable volume, but smaller systems will be constant volume. The use of constant volume or variable volume systems in a particular project will then be determined by the size of and loads in the zones specified in the proposed design model. Table 2 lists the baseline system type for each prototype. Where both SZAC and SZVAV are shown, the proposed baseline is shown as SZMixedHP in the figures below.

Because of the negative TDV results in climate zones 1 and 16, an additional system configuration was added to the analysis. This is a dual-fuel heat pump, which replaces the conventional electric resistance backup coil with a gas furnace backup. For this system configuration, the lockout temperature setting becomes significant. This is the outdoor temperature below which the gas backup heating coil will provide all heat and above which the heat pump will provide heat. When the outdoor temperature is above the lockout temperature, the gas furnace coil will operate only if the heat pump is unable to meet the load. A range of lockout temperature settings were simulated. As the lockout temperature is decreased, the heat pump meets more of the load, and vice-versa. When the lockout temperature is set very high, the heat pump provides no heating and the system performs just as the current baseline system does. As the lockout temperature is decreased, the heat pump operates at relatively warm outdoor temperatures with high efficiency and TDV consumption is decreased. As the lockout temperature is decreased further, the heat pump operates at colder outdoor temperature and the efficiency is decreased. Eventually, a temperature is reached where the TDV consumption of the heat pump is equal to the TDV consumption of the gas furnace. However, because TDV multipliers on electricity consumption vary widely, the TDV performance of the heat pump will match that of the gas furnace at a range of temperatures depending on the TDV multiplier for that particular hour. This means that each building in each climate zone will have a somewhat different optimum lockout temperature. As a result, the analysis was simplified to use a 45°F lockout, which was a reasonably good choice in all cases. These cases are all labeled as “Gas45” in the figures below. As can be seen in the figures below, the use of gas supplemental heat provided TDV savings in all cases.

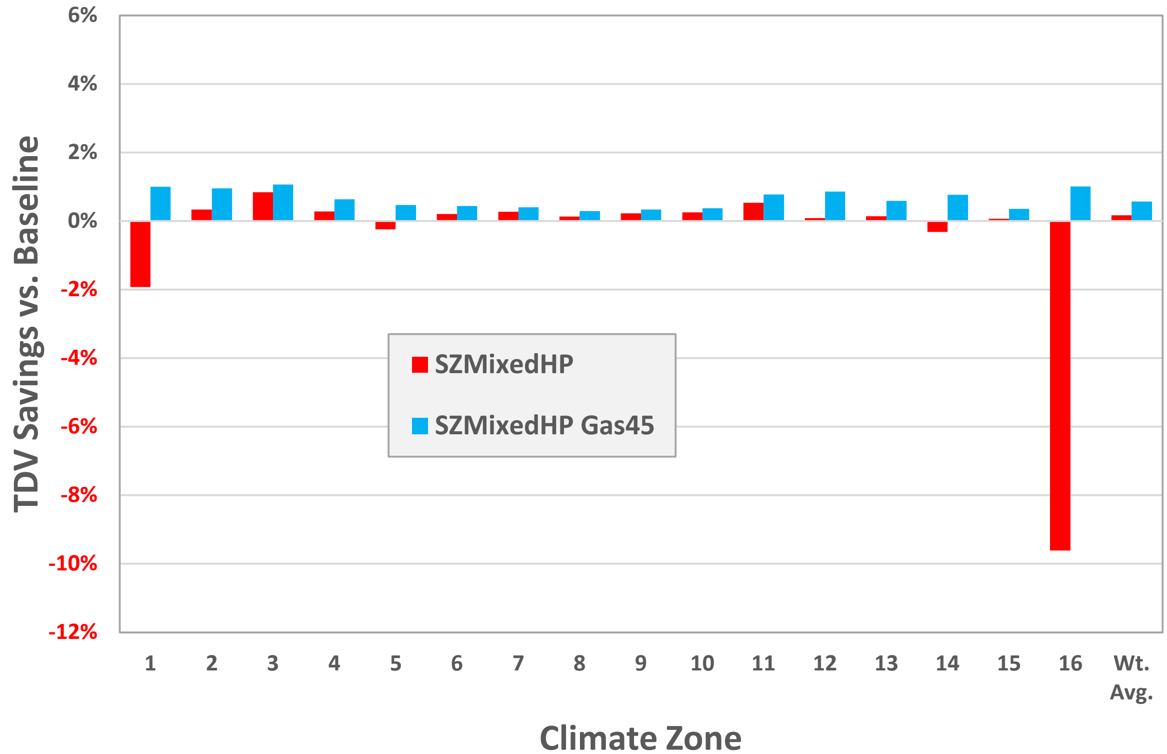

Figure 1 – TDV Savings – Small Retail Prototype Relative to Current Gas Furnace Baseline

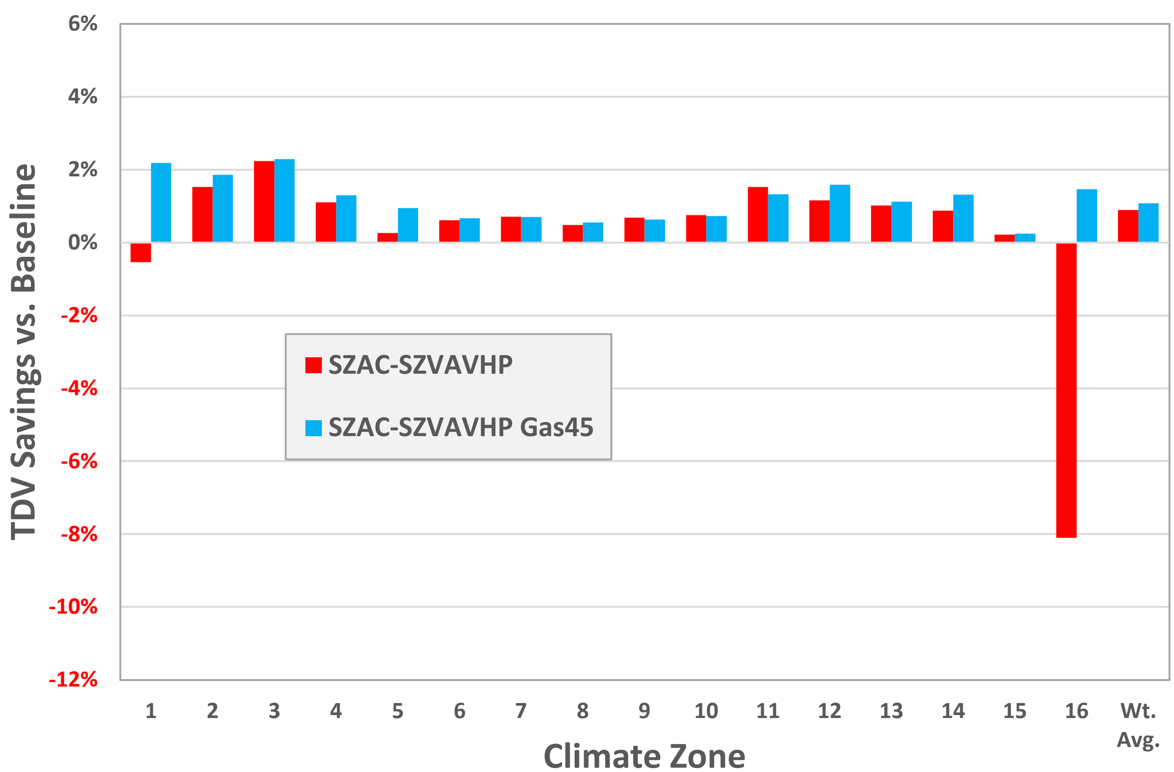

Figure 2 – TDV Savings – Medium Retail Prototype Relative to Current Gas Furnace Baseline

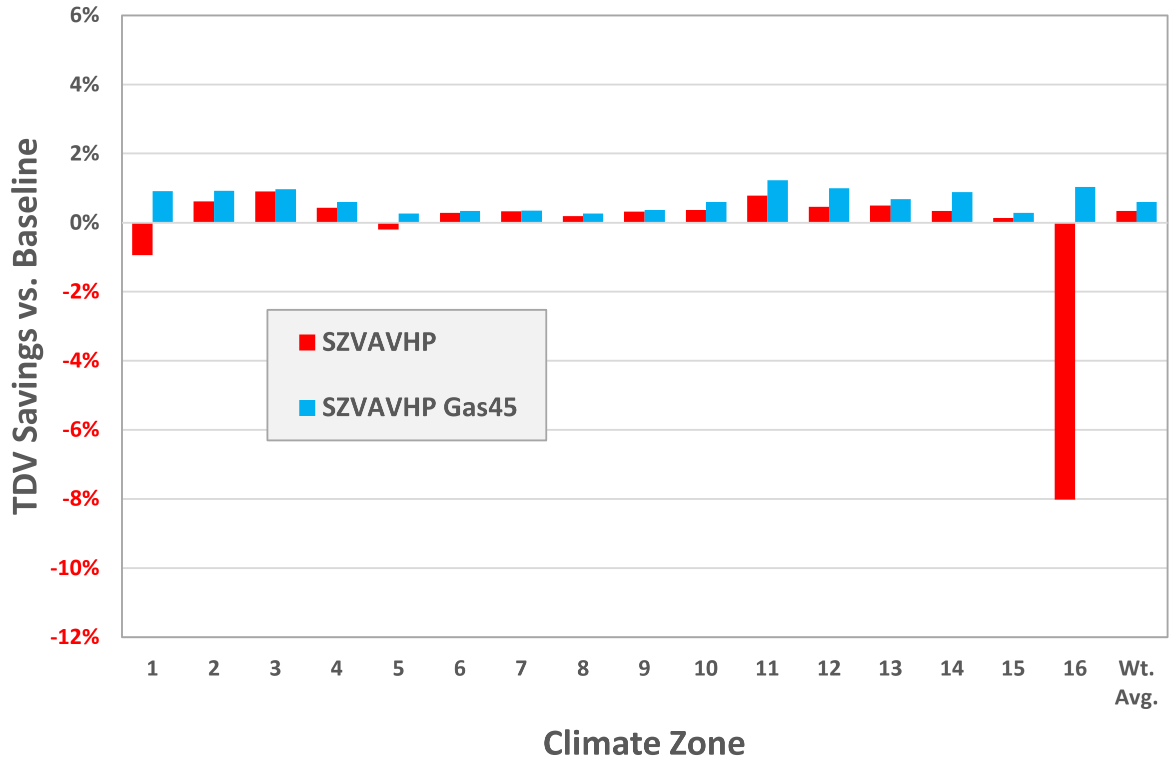

Figure 3 – TDV Savings – Large Retail Prototype Relative to Current Gas Furnace Baseline

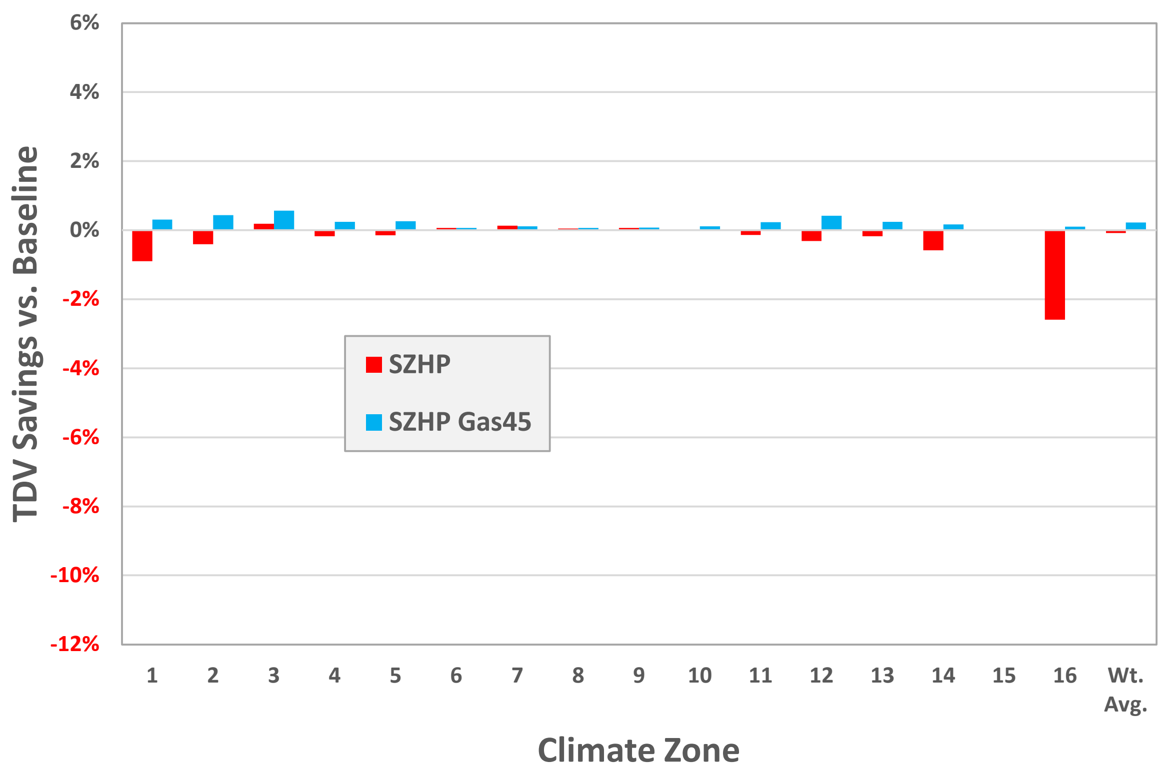

Figure 4 – TDV Savings – Small Office Prototype Relative to Current Gas Furnace Baseline

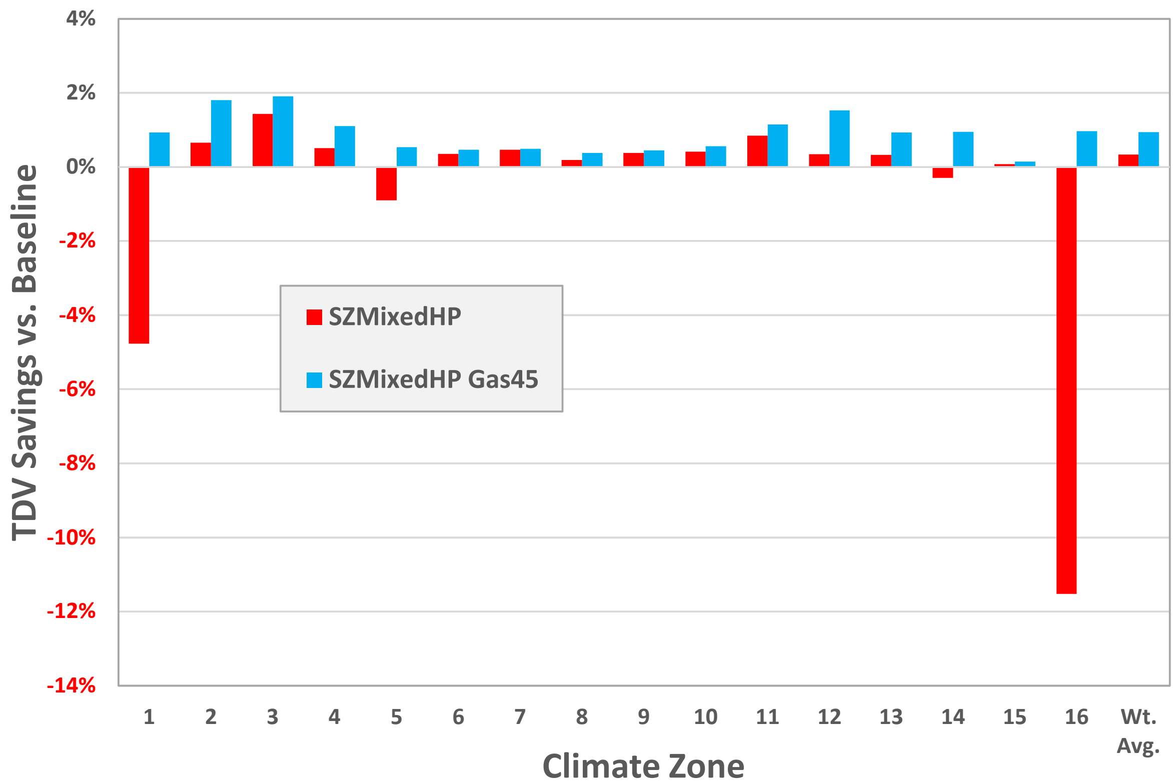

Figure 5 – TDV Savings – Small School Prototype Relative to Current Gas Furnace Baseline

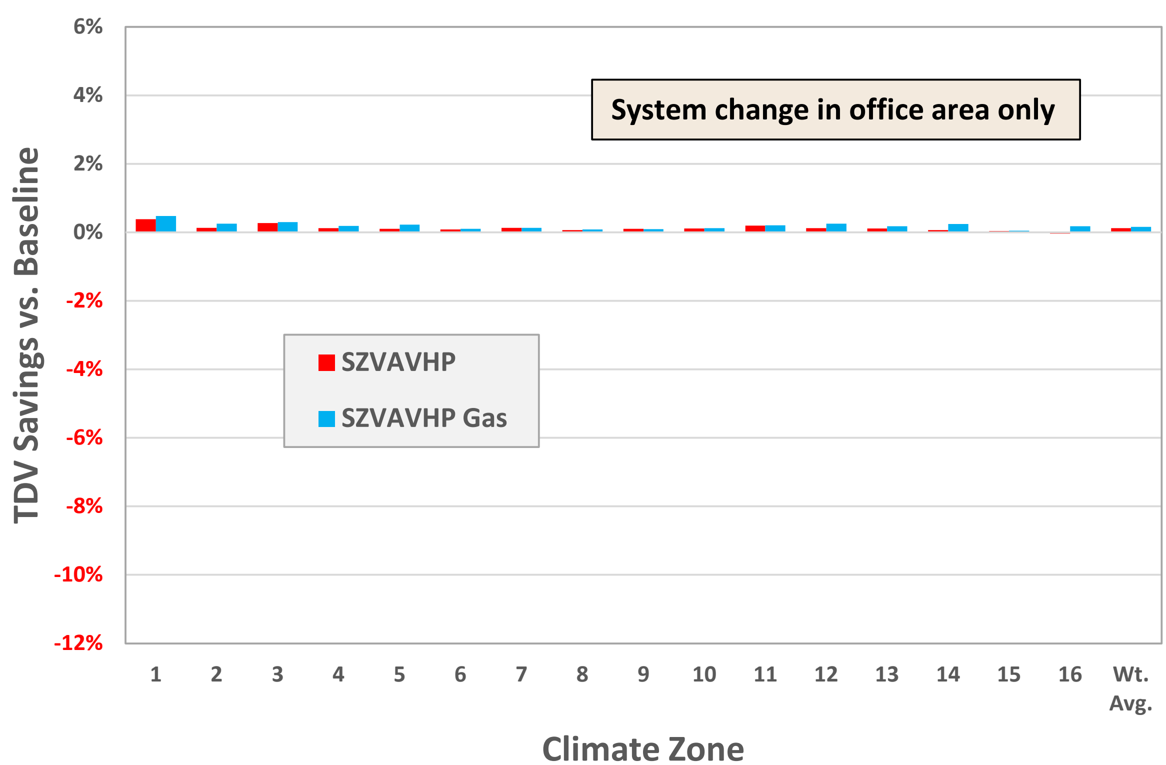

Figure 6 – TDV Savings – Warehouse Prototype Relative to Current Gas Furnace Baseline

The other energy requirement that must be met for a new baseline system is that it not have TDV or source energy consumption that is so much less than the current baseline that other system types are effectively unable to be used in a compliant building. Specifically, heat pump systems are expected to use less source energy than gas heat systems, but the new baseline should not set a source energy target that cannot be met by building designs with gas heat.

Figures 7-12 show source energy results for the different prototypes relative to the current gas heat baseline. Source energy savings using heat pump heat were large except in the cooling dominated climate zones (6-10, 15). Additional efficiency measures were added to the gas heat case to confirm that a design using gas heat could still comply with the heat pump-based source energy requirement. The listed efficiency measures were added incrementally in the order listed in the legend.

In the moderate and heating climates, in general, either the addition of a DOAS or the use of fully VAV systems showed compliance with the source energy performance target set by the heat pumps. This analysis shows that while compliance using gas heating will not necessarily be easy, it is possible.

Notice that the warehouse analysis does not include efficiency measures. This is because the percentage savings for the heat pump were small, less than 2% in climate zones except 16, where they were 2.5%. It was not felt that compliance with this small increase in stringency would be particularly challenging.

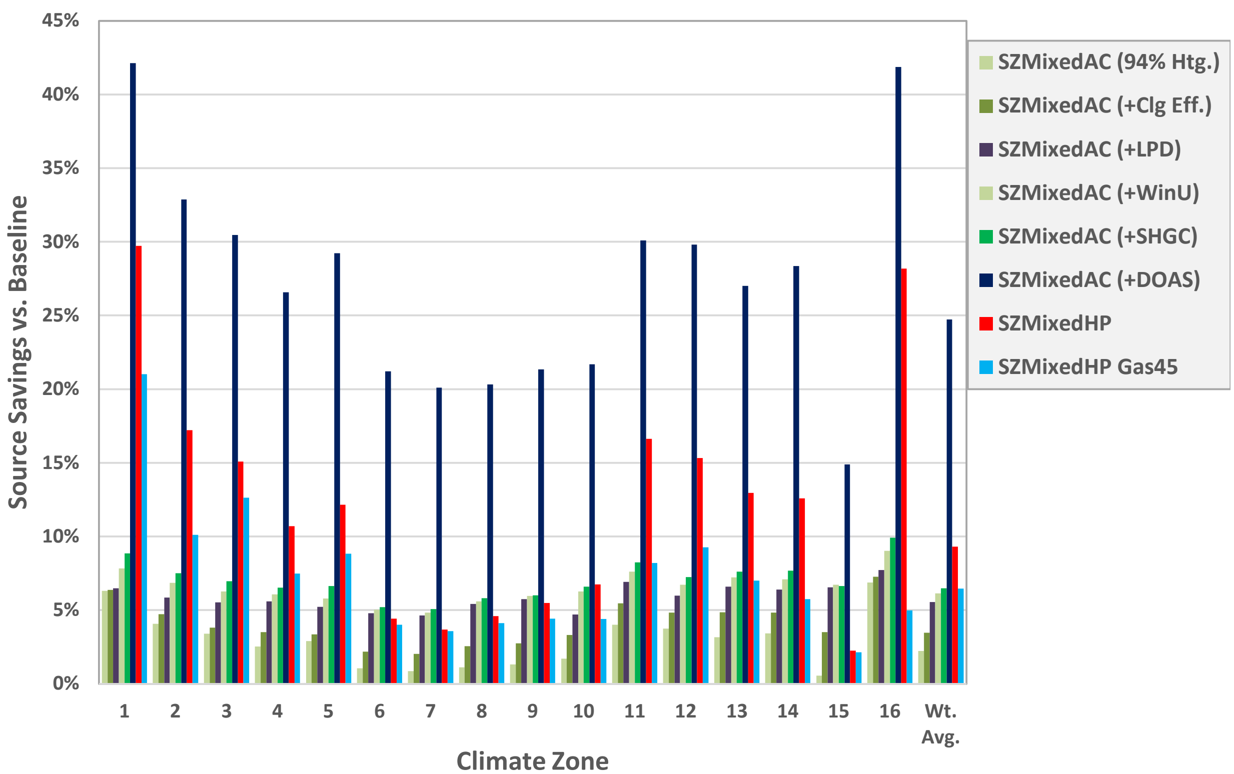

Figure 7 – Source Savings – Small Retail Prototype Relative to Current Gas Furnace Baseline

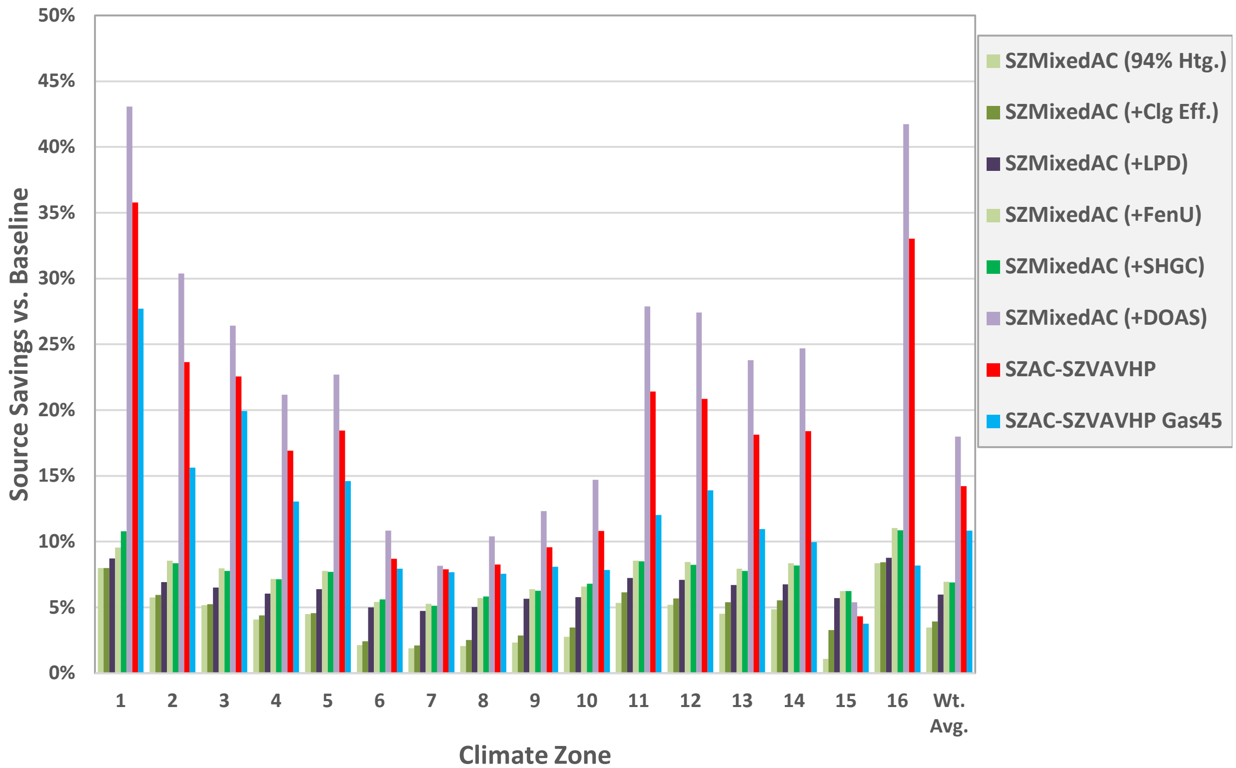

Figure 8 – Source Savings – Medium Retail Prototype Relative to Current Gas Furnace Baseline

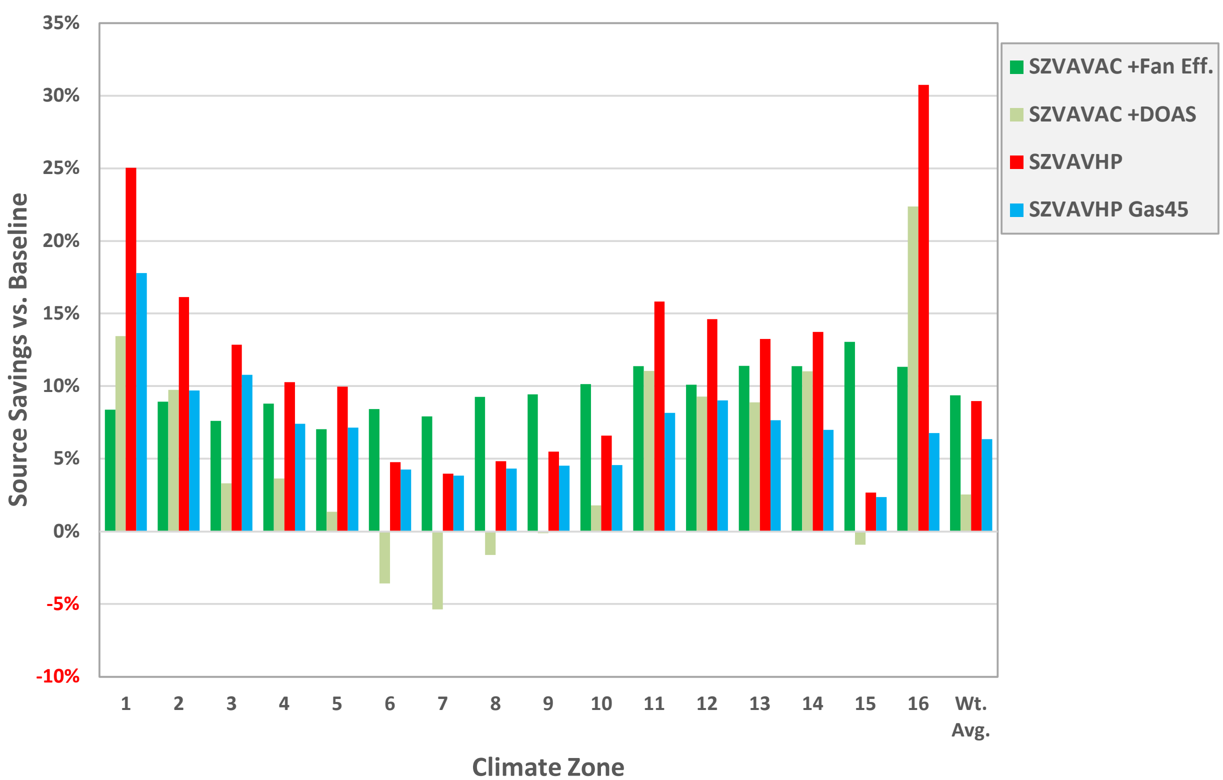

Figure 9 – Source Savings – Large Retail Prototype Relative to Current Gas Furnace Baseline

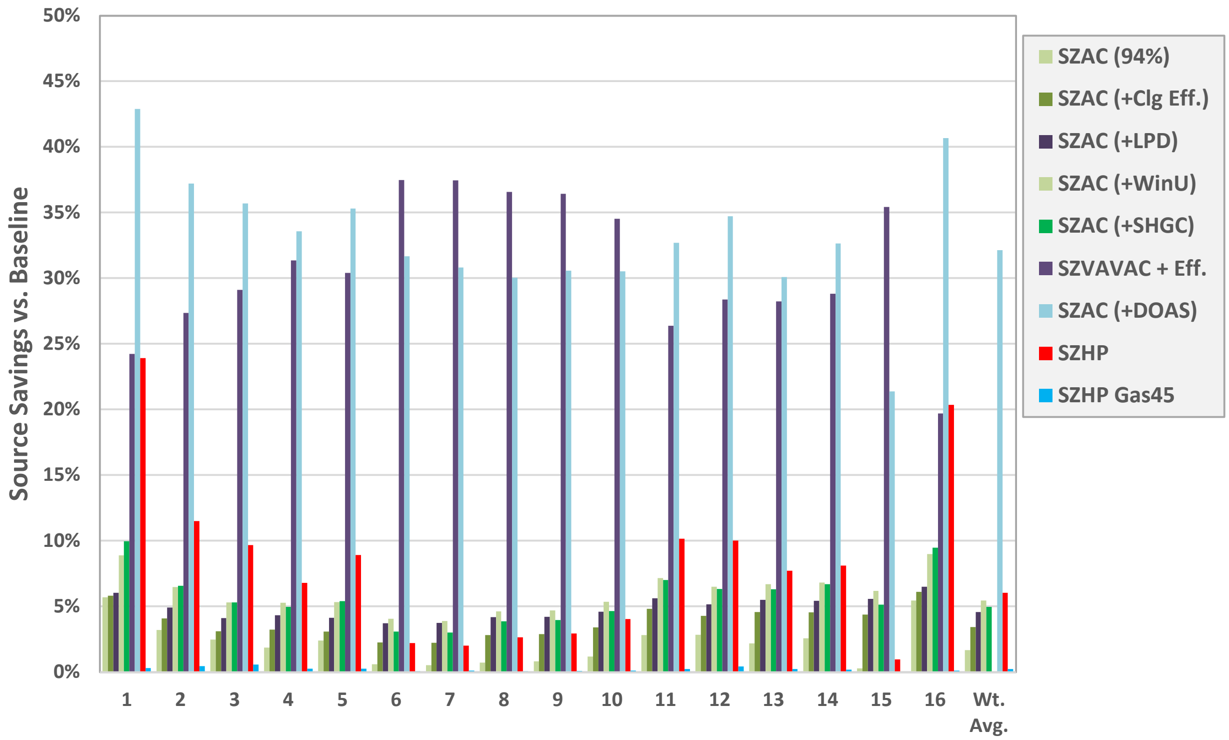

Figure 10 – Source Savings – Small Office Prototype Relative to Current Gas Furnace Baseline

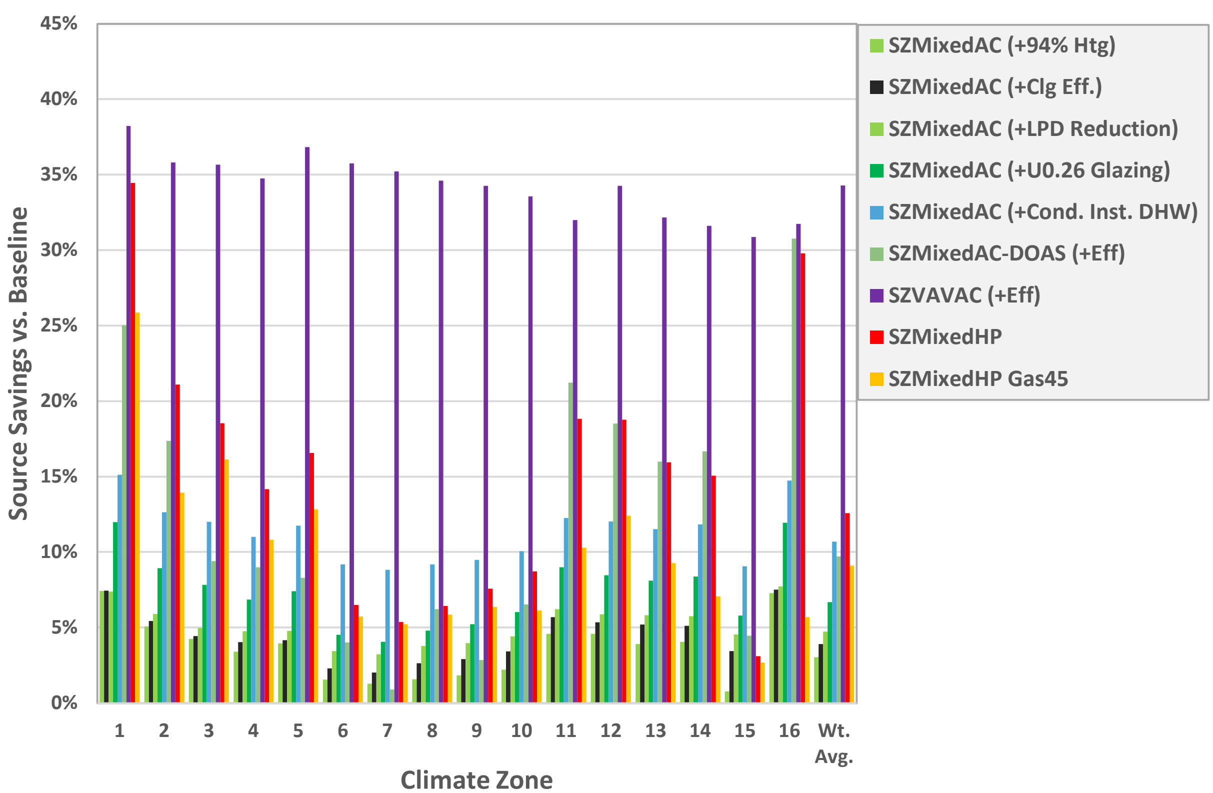

Figure 11 – Source Savings – Small School Prototype Relative to Current Gas Furnace Baseline

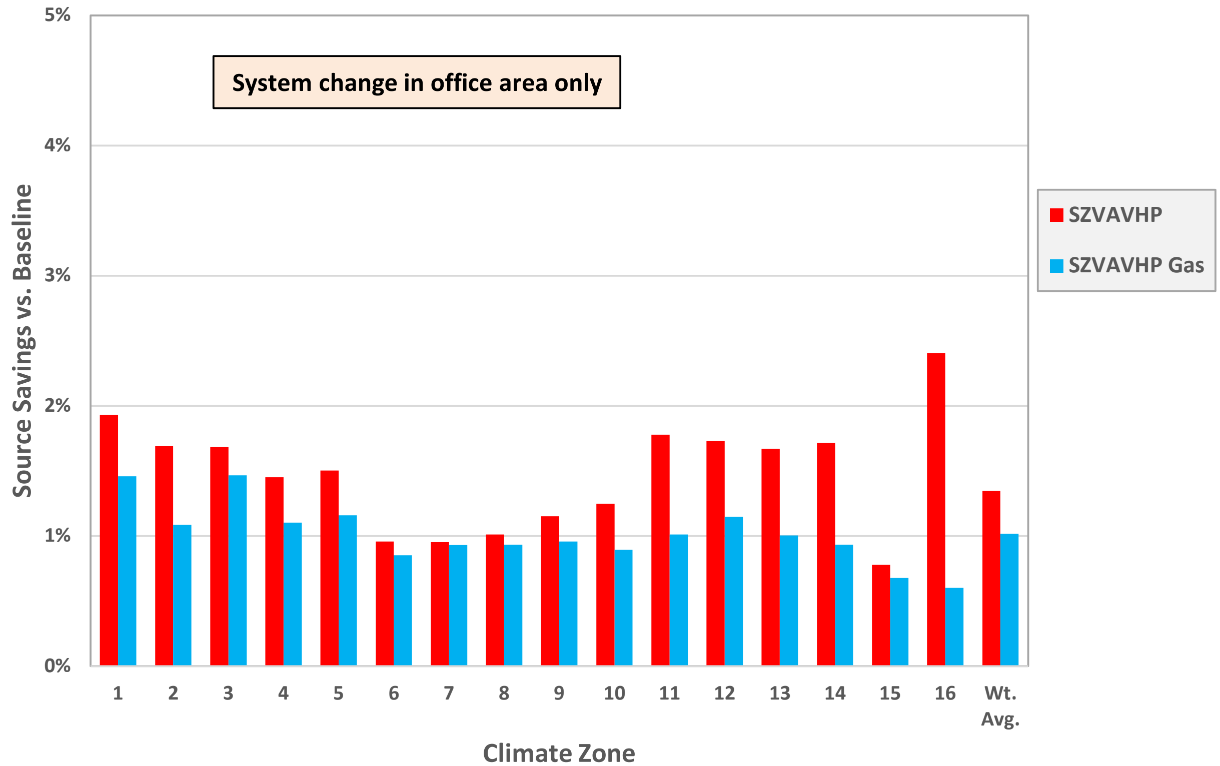

Figure 12 – Source Savings – Warehouse Prototype Relative to Current Gas Furnace Baseline

COST ANALYSIS

INCREMENTAL COST DATA AND ASSUMPTIONS

Incremental cost data was collected for baseline and proposed HVAC systems for the nonresidential building types listed in Table 2. Equipment costs for split HVAC systems in the mixed-use residential prototype were taken from a detailed study (TRC 2020) for an electric baseline evaluation. The cost data components included equipment costs, labor, and installation costs. Material or labor costs for items that are the same in both the current gas baseline and the proposed heat pump baseline, such as a crane rental and setting the units on the roof curb, were not included.

Data sources for equipment data were taken from multiple distributor sources and from several direct quotes from manufacturers. Equipment costs were gathered for rooftop package and federal minimum-efficiency equipment with nominal capacity in the range of 2 to 30 tons. Cost data was matched to HVAC equipment in the model by selecting the next larger nominal equipment capacity relative to the modeled sizes. For the Large Retail model, the zoning resulted in some zones with large capacities (over 100 tons). The equipment costs correspond to integral numbers of units in the 15 to 30-ton size range commonly found at big box retail stores. When switching from packaged rooftop units to packaged heat pumps, the avoided cost of running gas piping from the main service to each of the units on the roof was estimated by a general contractor with direct experience with commercial retail and office installations in California.

Incremental cost data was gathered to switch from the standard design HVAC system from the system map to heat pumps. Costs gathered include both equipment costs and labor and material costs for installation. Because heat pumps do not require a gas line or connection to the gas service, avoided costs for the elimination of gas lines were included in the estimate. The proposed change affects only HVAC systems, and for some buildings, water heating systems. Therefore, gas service is assumed to be present for the building, and the avoided gas lines are the lines from the meter to the rooftop units.

Equipment costs were developed from distributor and manufacturer estimates of commercial, three-phase packaged rooftop units, with capacities ranging from 2 tons to 20 tons. For climate zone 16, which has a considerable amount if hours where the outside air temperature is less than 30F and a significant number of hours where the outside air temperature is below 0F, a dual-fuel heat pump system was considered. The dual-fuel heat pumps have a gas heating as a backup for colder outside air temperatures (<35-45F, adj.) where the heat pump heating is less efficient. Several manufacturers offer dual fuel heat pumps over the capacity range used in the analysis. Table 3 describes the various cost components evaluated for this analysis.

Table 3 – Cost Data Components

Baseline	**Proposed**	**Material**	**Installation**			**Labor**	**Overhead**
		Equipment	**Avoided Gas Piping**	**Controls**	**Electrical / Panel**		
SZAC, CAV	SZHP, CAV	X	X		X	X	X
SZAC, VAV	SZHP, VAV	X	X		X	X	X
SZAC, CAV	SZHP, CAV dual fuel	X		X		X	X
SZAC, VAV	SZHP, VAV dual fuel	X		X		X	X

Table 4 summarizes incremental equipment costs for heat pumps and dual-fuel heat pumps. Heat pumps carry a significant incremental equipment cost over the rooftop units with gas heating. The dual-fuel units carry a larger incremental equipment cost of about $400 to $1200 per unit. The heat pump equipment cost is offset by the avoided cost to install gas lines to the unit (Table 5). Because the dual-fuel heat pumps have a gas backup, there is no avoided cost for gas lines.

Table 4. Equipment Cost Data: Distributor and Manufacturer Estimates

Capacity	SZAC Material	SZHP Material	DFHP[1] Material	HP Incremental Cost	HP % Change	DFHP Incremental Cost	DF % Change
2	$2,330	$2,444	$3,313	$387	16.6%	$983	42.2%
2.5	$2,432	$2,585	$3,494	$22	0.9%	$1,062	43.7%
3	$2,531	$2,678	$3,697	$167	6.6%	$1,166	46.1%
4	$2,955	$3,151	$4,178	$704	23.8%	$1,223	41.4%
5	$3,440	$3,513	Note 1	$597		$379	11.0%
7.5	$7,427	$7,149	Note 1	$194		$379	5.1%
10		$11,423	$12,630		11%	$1,207	14.2%
12.5	$9,548	$10,364	Note 1	$816		$1,266	13.3%
15	$14,942	$15,192	Note 1	$250		$1,266	8.5%
20	$16,254	$16,504	Note 1	$250		$1,266	7.8%

[1]DFHP = dual-fuel heat pump

Where a heat pump is the recommended system, avoided costs were provided by a mechanical contractor who has worked on many new construction and end-of-life replacement projects for retail buildings in California. The contractor provided installed cost estimates for gas piping, pipe supports at 8 to 10 ft intervals, and gas pressure regulators. NORESCO estimated pipe length runs from estimates of rooftop installations on retail and office commissioning projects. Based on the required capacity, NORESCO estimated 1 ¼" steel pipe to run from the meter to the roof, with 1" sized pipe for the branch piping to the units. Table 5 summarizes the avoided costs for rooftop heat pump systems relative to systems with gas heat.

Table 5. Avoided Cost Estimate for Rooftop Heat Pump Baseline

Items	**Components**	**Small Office (5 SZHP Units)**	**Small Retail (5 SZHP Units)**	**Large Retail (19 units)**
		Costs per linear foot		
Equipment	Gas Pipe 1"	$3.00	$3.00	$3.00
	Gas Pipe 1 1/4"	$4.00	$4.00	$4.00
	Pipe Supports	$8.13	$8.13	$8.13
	Gas Line to Roof	$8.13	$8.13	$8.13
	Electrical circuits	0	0	0
Labor	Gas Pipe 1"	$12.30	$13.25	$0.00
	Gas Pipe 1 1/4"	$13.25	$0.00	$0.00
Subtotal	Gas Pipe 1"	$23.43	$25.38	$0.00
	Gas Pipe 1 1/4"	$25.38	$0.00	$0.00
	1" Pipe length (ft)	150 ft	150 ft	
	1 1/4" Pipe length (ft)			950 ft
	1 1/4" Main line to roof	100 ft	100 ft	100 ft
Total Cost	Avoided BOS Costs	**($5,544)**	**($5,544)**	**($25,746)**

Incremental costs for the baseline system change are presented in Table 6. The heat pumps have a small incremental equipment cost, which is offset by the avoided cost of installing gas lines and gas pressure regulators at the roof. The Small School prototype is the only building type with an incremental cost to change the baseline water heating system to a HPWH. The quantity of HVAC single zone units matches the building prototype models for all models except the large retail building. For the large retail building, package units were assigned to interior zones so that no packaged unit exceeded 30 tons nominal capacity. This is representative of big box retail building HVAC system layout California[1].

[1] This assumption is based on the contractor's experience commissioning dozens of retail buildings throughout California. The assumption is used to generate the cost estimate.

Table 6. Incremental Cost Summary, Heat Pump Baseline

Component Cost	Small Office	Small Retail	Medium Retail	Large Retail	Small School	Warehouse
Number of Systems	5	4	6	19	23	1
HP Cost	$818	$654	$982	$3,108	$3,763	$164
HPWH Cost	-	-	-	-	$1,700	-
Avoided Gas Cost	$(5,544)	$(4,841)	$(6,247)	$(25,746)	$(18,193)	$(2,733)
Incremental Cost	$(4,726)	$(4,187)	$(5,265)	$(22,638)	$(12,730)	$(2,569)

Incremental costs for dual fuel heat pump (DFHP) units were derived from several sources, including wholesale distributor estimates and quotes from manufacturers. Wholesale distributor estimates were marked up by 20% to represent project costs. Incremental equipment costs varied from $379 to $1200, based on capacity. For this cost effectiveness study, a weighted average incremental cost of $765 is used for all projects. Since DFHPs have the same components as a conventional rooftop air conditioner with gas heating, there are no additional installation or maintenance costs. The only incremental cost for the DFHP is the equipment cost. These systems are readily available from at least four separate manufacturers. It is likely that the cost of dual-fuel heat pumps would decrease over time as manufacturers ramp up supply to provide code-compliant systems for climate zones 1 and 16.

LCC Analysis Results

Life-cycle cost estimates for the proposed change were developed by adding the estimated 15-year lifecycle savings to the present value equipment installation cost and any maintenance costs. The net present value (NPV) of the proposed change is determined by comparing the energy use of the proposed change to the energy use of the base case, estimated from energy simulation. A conversion factor of 0.089 $/kBtu converts annual TDV energy to present value cost of energy in dollars. Wherever the NPV is positive, the measure is considered cost-effective. Tables 7 through 12 show the results of the cost-effectiveness analysis.

For the Small Office prototype, the heat pump baseline saves energy in all climates except climate zone 1 (north coast) and 16 (Lake Tahoe and mountains), as shown in Table 7. For these climate zones, where the nominal cooling capacity of each packaged HVAC system does not exceed 5 tons, the baseline system will remain a packaged air conditioner with gas furnace (SZAC). Therefore, for small office buildings in climate zones 1 and 16, there is no change. A similar result is seen for the Small Retail prototype (Table 8).

Larger office buildings with a floor area greater than 25,000 sf have either a packaged VAV system with reheat or a built-up VAV system with central heating and cooling as the baseline, according to the system map in Table 1. Since these buildings do not use single zone systems in the baseline, they are not affected by this proposed change.

Table 7. Small Office Life-Cycle Costs

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
SZHP	1	-12,104	0.089	-$1,077	$3,825	-$4,902
SZHP	2	-6,311	0.089	-$562	($5,234)	$4,672
SZHP	3	2,337	0.089	$208	($5,234)	$5,442
SZHP	4	-3,228	0.089	-$287	($5,234)	$4,947
SZHP	5	-2,110	0.089	-$188	($5,234)	$5,046
SZHP	6	757	0.089	$67	($5,357)	$5,424
SZHP	7	1,632	0.089	$145	($5,234)	$5,379
SZHP	8	991	0.089	$88	($5,234)	$5,322
SZHP	9	2,053	0.089	$183	($5,234)	$5,417
SZHP	10	14	0.089	$1	($5,357)	$5,358
SZHP	11	-3,516	0.089	-$313	($5,234)	$4,921
SZHP	12	-5,434	0.089	-$484	($5,234)	$4,750
SZHP	13	-2,438	0.089	-$217	($5,234)	$5,017
SZHP	14	-11,126	0.089	-$990	($5,234)	$4,244
SZHP	15	3	0.089	$0	($5,603)	$5,603
SZHP	16	1,428	0.089	$127	$3,825	-$3,698

Table 8. Small Retail Life-Cycle Costs

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
No change	1	n/a	0.089	n/a	n/a	n/a
SZHP	2	11,085	0.089	$987	($5,234)	$6,221
SZHP	3	25,045	0.089	$2,229	($5,234)	$7,463
SZHP	4	9,183	0.089	$817	($5,234)	$6,051
SZHP	5	-6,911	0.089	-$615	($5,234)	$4,619
SZHP	6	6,355	0.089	$566	($5,357)	$5,923
SZHP	7	8,231	0.089	$733	($5,234)	$5,967
SZHP	8	4,324	0.089	$385	($5,234)	$5,619
SZHP	9	7,579	0.089	$675	($5,234)	$5,909
SZHP	10	8,560	0.089	$762	($5,357)	$6,119
SZHP	11	19,554	0.089	$1,740	($5,234)	$6,974
SZHP	12	2,954	0.089	$263	($5,234)	$5,497
SZHP	13	5,188	0.089	$462	($5,234)	$5,696
SZHP	14	-11,912	0.089	-$1,060	($5,234)	$4,174
SZHP	15	2,694	0.089	$240	($5,603)	$5,843
No change	16	n/a	0.089	n/a	n/a	n/a

The Medium Retail prototype contains a mixture of packaged single zone air conditioners (SZAC) and packaged single zone variable air volume air conditioners (SZVAVAC) for the larger units of capacity of 6 tons or larger. (The current SZVAVAC baseline aligns with current prescriptive requirements for VAV control in single zone systems with capacity exceeding 65,000 Btu/h.) The proposed SZHP and SZVAVHP system for climate zones 2 through 15 is shown to be cost effective (Table 9). For climate zones 1 and 16, a conventional heat pump would use large amounts of electric resistance heat in the winter. Therefore, for these two climate zones, a dual-fuel heat pump system is proposed. The dual fuel systems do carry significant additional cost, but this cost is outweighed by the energy cost savings. The Large Retail prototype shows similar results as the Medium Retail, with significant savings for the heat pump baseline for climate zones 2 through 15, and positive savings for the dual-fuel heat pump system for climate zones 1 and 16.

Table 9. Medium Retail Life-Cycle Costs

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
SZDFHP	1	125,612	0.089	$11,179	$3,825	$7,354
SZMixedHP	2	99,966	0.089	$8,897	($5,234)	$14,131
SZMixedHP	3	124,635	0.089	$11,093	($5,234)	$16,327
SZMixedHP	4	67,273	0.089	$5,987	($5,234)	$11,221
SZMixedHP	5	-2,252	0.089	-$200	($5,234)	$5,034
SZMixedHP	6	19,152	0.089	$1,705	($5,357)	$7,062
SZMixedHP	7	30,472	0.089	$2,712	($5,234)	$7,946
SZMixedHP	8	31,934	0.089	$2,842	($5,234)	$8,076
SZMixedHP	9	35,882	0.089	$3,194	($5,234)	$8,428
SZMixedHP	10	50,959	0.089	$4,535	($5,357)	$9,892
SZMixedHP	11	112,217	0.089	$9,987	($5,234)	$15,221
SZMixedHP	12	70,703	0.089	$6,293	($5,234)	$11,527
SZMixedHP	13	67,551	0.089	$6,012	($5,234)	$11,246
SZMixedHP	14	48,965	0.089	$4,358	($5,234)	$9,592
SZMixedHP	15	10,612	0.089	$944	($5,603)	$6,547
SZDFHP	16	124,941	0.089	$11,120	$3,825	$7,295

The life-cycle cost analysis for large retail buildings shows a significant savings (net present value) for climate zones 2 through 15, for a heat pump baseline system (Table 10). Climate zone 16 shows a modest life-cycle savings for a baseline of a dual-fuel heat pump. Climate zone 1 shows a very small cost increment (estimated savings are 3% less than incremental costs) for the dual-fuel heat pump.

Table 10. Large Retail Life-Cycle Costs

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
SZVAVDFHP	1	495,139	0.089	$44,067	$45,600	-$1,533
SZVAVHP	2	436,057	0.089	$38,809	($5,234)	$44,043
SZVAVHP	3	503,007	0.089	$44,768	($5,234)	$50,002
SZVAVHP	4	295,798	0.089	$26,326	($5,234)	$31,560
SZVAVHP	5	-39,385	0.089	-$3,505	($5,234)	$1,729
SZVAVHP	6	173,705	0.089	$15,460	($5,357)	$20,817
SZVAVHP	7	182,998	0.089	$16,287	($5,234)	$21,521
SZVAVHP	8	138,270	0.089	$12,306	($5,234)	$17,540
SZVAVHP	9	217,226	0.089	$19,333	($5,234)	$24,567
SZVAVHP	10	257,117	0.089	$22,883	($5,357)	$28,240
SZVAVHP	11	610,901	0.089	$54,370	($5,234)	$59,604
SZVAVHP	12	359,583	0.089	$32,003	($5,234)	$37,237
SZVAVHP	13	410,535	0.089	$36,538	($5,234)	$41,772
SZVAVHP	14	308,826	0.089	$27,486	($5,234)	$32,720
SZVAVHP	15	117,275	0.089	$10,437	($5,603)	$16,040
SZVAVDFHP	16	593,645	0.089	$52,834	$48,000	$4,834

The heat pump baseline for high-rise residential buildings is very cost effective (Table 11), due to the large avoided costs of running gas lines to the split systems at each dwelling unit. The mixed-use, high-rise residential prototype building has 117 units. The avoided cost corresponds to a decrease in installed product cost from $11,000 per unit to $6,946 per unit, and an avoided cost of $237 per unit for gas piping to the heat pumps (TRC 2020). There is no change to the standard design system for high-rise residential buildings in climate zone 16 in the performance approach. For buildings in this climate zone, the standard design system is a single-zone split air conditioner with a gas furnace.

Table 11. High-Rise Residential (Mixed Use) Life-Cycle Costs

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
Split SZHP	1	341,933	0.089	$30,432	($502,047)	$532,479
Split SZHP	2	166,645	0.089	$14,831	($502,047)	$516,878
Split SZHP	3	195,674	0.089	$17,415	($502,047)	$519,462
Split SZHP	4	90,516	0.089	$8,056	($502,047)	$510,103
Split SZHP	5	73,858	0.089	$6,573	($502,047)	$508,620
Split SZHP	6	35,914	0.089	$3,196	($502,047)	$505,243
Split SZHP	7	36,358	0.089	$3,236	($502,047)	$505,283
Split SZHP	8	31,229	0.089	$2,779	($502,047)	$504,826
Split SZHP	9	58,814	0.089	$5,234	($502,047)	$507,281
Split SZHP	10	64,237	0.089	$5,717	($502,047)	$507,764
Split SZHP	11	382,440	0.089	$34,037	($502,047)	$536,084
Split SZHP	12	192,471	0.089	$17,130	($502,047)	$519,177
Split SZHP	13	156,891	0.089	$13,963	($502,047)	$516,010
Split SZHP	14	172,773	0.089	$15,377	($502,047)	$517,424
Split SZHP	15	23,884	0.089	$2,126	($502,047)	$504,173
SZAC (no change)	16	n/a	n/a	n/a	n/a	n/a

The life-cycle cost effectiveness of installing heat pumps in schools was evaluated. A modification to a heat pump water heating baseline was also evaluated. Incremental costs included an additional $3,763 in equipment costs for the air source heat pumps and an avoided cost (cost savings) of $18,193 for eliminating the gas lines run to the units on the roof. The heat pump water heater carries an additional cost of $1,700 over the 2019 Title 24 baseline system, a gas storage water heater. Table 12 and Table 13 show a large life cycle savings (net present value) for the majority of the climate zones. The proposed changes apply to schools that use single zone units to condition classrooms and the other school spaces.

Table 12. Small School Life-Cycle Costs (SZHP only)

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
DFHP	1	113,169	0.089	$10,072	$17,595	-$7,523
SZMixHP	2	39,237	0.089	$3,492	($14,430)	$17,923
SZMixHP	3	74,335	0.089	$6,616	($14,430)	$21,046
SZMixHP	4	28,232	0.089	$2,513	($14,430)	$16,943
SZMixHP	5	-44,039	0.089	-$3,919	($14,430)	$10,511
SZMixHP	6	18,998	0.089	$1,691	($14,430)	$16,121
SZMixHP	7	23,473	0.089	$2,089	($14,430)	$16,520
SZMixHP	8	10,363	0.089	$922	($14,430)	$15,353
SZMixHP	9	22,424	0.089	$1,996	($14,430)	$16,426
SZMixHP	10	25,808	0.089	$2,297	($14,430)	$16,727
SZMixHP	11	59,328	0.089	$5,280	($14,430)	$19,711
SZMixHP	12	21,393	0.089	$1,904	($14,430)	$16,334
SZMixHP	13	22,616	0.089	$2,013	($14,430)	$16,443
SZMixHP	14	-20,914	0.089	-$1,861	($14,430)	$12,569
SZMixHP	15	6,029	0.089	$537	($14,430)	$14,967
DFHP	16	36,833	0.089	$3,278	$17,595	-$14,317

Table 13. Small School Life-Cycle Costs (with HPWH)

System	CZ	Annual TDV (kBtu)	PV TDV ($/TDV kBtu)	PV Energy Cost Savings ($)	Incremental Cost ($)	NPV Savings ($)
DFHP	1	113169	0.089	$10,072	$17,595	-$7,523
SZMixHP, HPWH	2	90401.49	0.089	$8,046	($12,730)	$11,346
SZMixHP, HPWH	3	130810.5	0.089	$11,642	($12,730)	$14,942
SZMixHP, HPWH	4	92327.49	0.089	$8,217	($12,730)	$11,517
SZMixHP, HPWH	5	2851.087	0.089	$254	($12,730)	$3,554
SZMixHP, HPWH	6	88304.59	0.089	$7,859	($12,730)	$11,159
SZMixHP, HPWH	7	96326.25	0.089	$8,573	($12,730)	$11,873
SZMixHP, HPWH	8	80556.99	0.089	$7,170	($12,730)	$10,470
SZMixHP, HPWH	9	91231.08	0.089	$8,120	($12,730)	$11,420
SZMixHP, HPWH	10	96818.29	0.089	$8,617	($12,730)	$11,917
SZMixHP, HPWH	11	119919.6	0.089	$10,673	($12,730)	$13,973
SZMixHP, HPWH	12	77198.09	0.089	$6,871	($12,730)	$10,171
SZMixHP, HPWH	13	79277.4	0.089	$7,056	($12,730)	$10,356
SZMixHP, HPWH	14	16909.26	0.089	$1,505	($12,730)	$4,805
SZMixHP, HPWH	15	76544.59	0.089	$6,812	($12,730)	$10,112
DFHP	16	36833	0.089	$3,278	$17,595	-$14,317

STATEWIDE COST IMPACT ESTIMATE

Table 14 shows the weighted statewide cost impact of the proposed changes. The statewide energy cost and incremental cost impact from the proposed change is taken by applying the 2023 Nonresidential New Construction forecast by building type and climate zone to the corresponding energy simulation results. Results are expressed as savings per unit (sf) of floor area. The high amount of savings in high-rise residential buildings can be attributed to the avoided costs of bringing gas to each of the dwell unit split heat pumps.

Table 14. Building Type-Weighted Savings by Climate Zone

	Nonresidential			High-rise Multifamily		
CZ	PV Energy Cost Savings ($/sf)	Incremental Cost ($/sf)	NPV ($/sf)	PV Energy Cost Savings ($/sf)	Incremental Cost ($/sf)	NPV ($/sf)
1	$0.11	$0.06	$0.05	$0.24	-$4.00	$4.25
2	$0.15	-$0.36	$0.51	$0.12	-$4.00	$4.12
3	$0.23	-$0.33	$0.56	$0.14	-$4.00	$4.14
4	$0.13	-$0.33	$0.46	$0.06	-$4.00	$4.07
5	-$0.02	-$0.34	$0.32	$0.05	-$4.00	$4.06
6	$0.09	-$0.33	$0.42	$0.03	-$4.00	$4.03
7	$0.11	-$0.42	$0.52	$0.03	-$4.00	$4.03
8	$0.08	-$0.32	$0.40	$0.02	-$4.00	$4.03
9	$0.11	-$0.31	$0.42	$0.04	-$4.00	$4.05
10	$0.12	-$0.36	$0.49	$0.05	-$4.00	$4.05
11	$0.20	-$0.40	$0.61	$0.27	-$4.00	$4.27
12	$0.10	-$0.39	$0.50	$0.14	-$4.00	$4.14
13	$0.13	-$0.41	$0.54	$0.11	-$4.00	$4.11
14	$0.04	-$0.34	$0.38	$0.12	-$4.00	$4.13
15	$0.07	-$0.41	$0.48	$0.02	-$4.00	$4.02
16	$0.09	$0.25	-$0.16	$0.00	$0.00	$0.00
Wt. Avg.	$0.12	-$0.35	$0.47	$0.08	-$3.98	$4.05

CODE LANGUAGE

Based on the analysis described above, changes to the prescriptive requirements for HVAC systems are proposed. Buildings which use single zone systems would be required to use heat pump heat to comply with the standards using the prescriptive approach. If the design uses single zone systems with gas heat, the performance approach would need to be used to show compliance.

The language shown below is proposed to be added to the Standards as Section 140.4(a)2:

2. **Space Conditioning System Type.** Single zone space conditioning systems serving the following spaces shall meet the applicable requirements in A-H, or shall meet the performance compliance requirements of Section 140.1:

A. Retail and Grocery Building Spaces in climate zones 2 through 15. The space conditioning system shall be a heat pump.

B. Retail and Grocery Building Spaces in climate zones 1 and 16 with cooling capacity less than 65,000 Btu/hr. The space conditioning system shall be an air conditioner with furnace.

C. Retail and Grocery Building Spaces in climate zones 1 and 16 with cooling capacity 65,000 Btu/hr or greater. The space conditioning system shall be a dual-fuel heat pump.

D. **School Building Spaces.** For climate zones 2 through 15 , the space conditioning system shall be a heat pump. For climate zones 1 and 16, the space conditioning system shall be a dual-fuel heat pump.

E. **Office, Financial Institution, and Library Building Spaces in climate zones 1 through 15**. The space conditioning system shall be a heat pump. In climate zone 16, the space conditioning system with cooling capacity less than 65,000 Btu/hr shall be an air conditioner with furnace. In climate zone 16, the space conditioning system with cooling capacity of 65,000 Btu/hr or greater shall be a dual-fuel heat pump.

F. **Office, Financial Institution, and Library Building Space in climate zones 16 with cooling capacity less than 65,000 Btu/hr**. The space conditioning system shall be an air conditioner with furnace.

G. **Office Spaces in Warehouses**. The space conditioning system shall be a heat pump in all climate zones.

REFERENCES

TRC 2020. *All-Electric Multifamily Compliance Pathway, Final CASE Report, Report 2022-MF-AEP-F*. California Statewide Codes and Standards Enhancement (CASE) Program. Table 53 for cost data. November 2020.