Yeah, But It's a Dry Cold: Applicability of Cold Climate Heat Pumps in California

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ABSTRACT

State of California decarbonization goals include installing 6 million heat pumps by 2030, which could begin to shift peak electrical load in California from summer to winter. While heat pumps efficiently provide space heating (COP > 3), they are traditionally installed with inefficient electric resistance strip heating (COP = 1). This strip heat supplements a heat pump's reduced output during the hours of coldest outdoor temperatures, which can be 20-30°F in mild California climates. Strip heat also provides comfort during defrost cycles. If these 6 million heat pumps all have an average of 5 kW strip heat, the winter peak caused by these heat pumps would increase by an additional 30,000 MW. "Cold climate" heat pumps have the capacity to efficiently provide heating in virtually all California climates, potentially without supplemental heat, but are typically more expensive than traditional heat pumps. This paper addresses ways to eliminate the need for strip heat in most applications and evaluate grid stability and carbon content impacts. Does this require more expensive "cold climate" heat pumps? If so, what are the cost trade-offs between higher heat pump costs and the reduction in grid upgrades? In what climates can "standard" heat pumps be used without strip heat? Can "right-sizing" heat pumps be a solution? How can comfort issues be addressed if strip heat is not used? How should heat pumps be designed and controlled to avoid/minimize strip heat? What is the feasibility of having winter demand response events to help reduce the winter peak?

Introduction

Heat pump technology has progressed steadily over the past few decades from when they were first introduced into the residential market in the 1950s (Amana 2024). These residential air-to-air heat pumps operate by extracting heat from outdoor air (heat source) and delivering warm air into the home. Cooling can also be supplied into the home by reversing the refrigerant flow and extracting heat from the indoors. This paper focuses on the heating capabilities of the most common configuration of heat pump used for residential space heating in California - the air-to-air split system (one coil outdoors and one indoors)[1].

Early heat pumps were most effective in milder climates (above freezing) where the "lift" from the outdoor air heat sink to indoor supply air temperatures was not large. As outdoor

[1] Other heat pump space heating configurations and technologies include single-packaged heat pumps, ground source heat pumps and air to water heat pumps, including "three-function heat pumps" that provide domestic hot water and space heating/cooling.

temperatures fall, more "work" (compressor energy) and more heat transfer is required to extract and deliver heat. Early heat pump performance curves indicated that both the heating capacity and efficiency (COP – Coefficient of Performance) plummeted when outdoor temperatures were below freezing when the heat is needed the most. Heat pumps also had cut-off controls that stopped compressor operation below set temperatures to prevent damage to the compressors that were designed to only operate within narrow parameters. These issues were compounded by the perception that refrigerant reversing valves that switched the heat pump from heating to cooling, were unreliable and thus heating might not be available when needed. As frost accumulated on outdoor coils (similar to frost build-up in an older refrigerator), heat pumps switch to cooling ("defrost mode") to melt the frost. This can cause a "cold blow" where cold air is blown into the home until the frost melts. To mitigate these issues of inadequate heat capacity at lower temperatures, poor reliability, and defrost cold blow, auxiliary electric resistance heating elements or "strip heat" were added to virtually all early heat pumps in all climates throughout California. More detail about strip heat as applied to currently available heat pumps is discussed below.

While heat pumps have progressed steadily with higher efficiencies, greater reliability, and a wider availability of form factors, the most substantial improvements have been made in the past 15 to 20 years with the adoption of variable capacity technologies allowing aptly named Variable Capacity Heat Pumps (VCHP). These technology improvements include thermostatic expansion valves for more precise control of the refrigerant flow to the indoor coil, variable speed fans and compressors, improved coil design, improved electric motor and compressor designs, newer refrigerants, improved heat exchangers with grooved copper tubing, and flash injection[2].

Why do Heat Pumps Matter?

California has a policy goal of attaining net zero carbon neutrality by 2045 in accordance with the changes needed to limit global temperature rise to 1.5°C. The implementation of this goal is described in the California Air Resources Board (CARB) Carbon Neutrality Scoping Plan (CARB 2022). This scoping plan calls for *"transitioning away from fossil gas in residential and commercial buildings, and will rely primarily on advancing energy efficiency while replacing gas appliances with non-combustion alternatives."* For space heating, the non-combustion alternative is electric heat pumps which are about 3 times more energy efficient than electric resistance heating.[3] In the near term, California's proposed 2025 Title 24 Energy Code, prescriptively requires that heat pumps provide residential space heating in all climate zones for new homes and new multifamily units. Similar requirements apply to single zone HVAC systems in nonresidential buildings in most climate zones. Additionally, the California governor has called for the installation of 6 million heat pumps by 2030. CARB is also developing a regulation that would require zero-emission water and space heaters to be sold by 2030, essentially banning the sale of non-electric water and space heaters in the future. The South Coast Air Quality

[2] The flash injection process uses a bypass circuit to reroute a portion of the refrigerant to two places, 1) hot refrigerant flows back to the indoor coil to enhance heating and 2) colder refrigerant is injected back into the compressor to allow it to run at faster speeds to produce high-performance heat exchange. *Source:* Mitsubishi
[3] Based on 10 to 11 HSPF. See p. 107, (E3 2019)

Management District recently announced the most aggressive timeline for ending the sale of gas water and space heaters starting as early as 2026.

Prior work (McHugh, et al. 2022) (Heinemeier 2023) has summarized studies showing that actual heat pump performance does not match the idealized performance of heat pumps as modelled by simulation tools such as by the California Simulation Engine (CSE). A large concern is that heat pumps with can regularly invoke strip heating (if installed) any time there is a step change in the setpoint such as in the morning when setback is released from a space temperature that is more than 5°F or lower than the morning setpoint. When a significant fraction of systems engage strip heating, it results in a morning peak that is several times larger than the base power draw of the heat pump portion of the heating system. A smaller but similar peak is associated with the change in setpoint when people come home from school and work in the evening, turn up the heat and engage strip heat. These new evening winter peaks are also coincident with cooking, hot water use and lighting. As described later in this paper, the magnitude of this potential new strip heat load in California is comparable in magnitude to the current summer peak. The repercussions on required electric grid capacity and consumer expense are enormous.

Cold Climate Heat Pumps

A mitigating technology is the advent of heat pumps that have sufficient heating capacity at very low temperatures (such as 5°F and below), and with minimal efficiency degradation. For the remainder of this paper, “cold climate air-source heat pumps” will be referred to as “ccASHP,” the designation used by ENERGY STAR cold climate criteria. In general, the ENERGY STAR criteria for ccASHP is for operation at 5° F with a COP > 1.75 and a heating capacity of 70% of the capacity at 47° F. Northeast Energy Efficiency Partnerhip (NEEP) and Natural Resources Canada have slightly different but similar criteria.

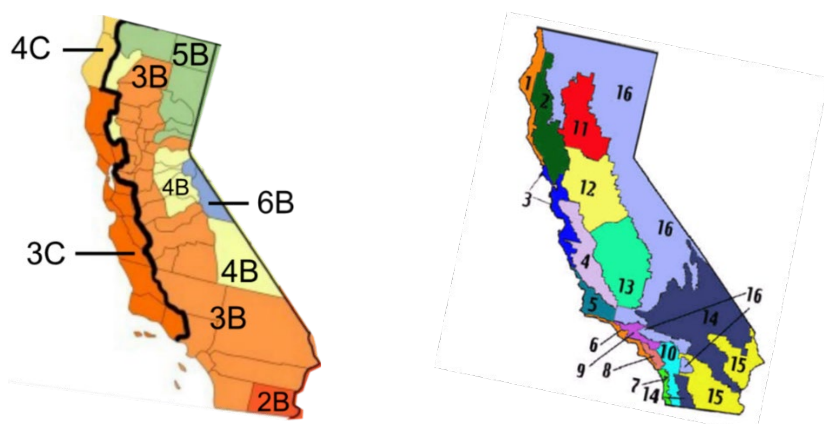

Figure 1: a) California IEEC Climate Zones b) California Title 24 Climate Zones

Figure 1 indicates that most of California is in IECC Climate Zone (CZ) 3, with some areas in CZ 4 through 6 that roughly correlate to portions of California Title 24 CZ 1 (North Coast), 14 (High Desert) and 16 (Mountains). In general, these colder areas of California are less densely populated (around 1% of the state population) but use a disproportionate amount of energy for heating. Although these climate zone designations for ccASHPs are generalized, for this paper's purposes, these climate zone designations are useful to estimate the need for cold climate heat pumps or other mitigating strategies to address colder climates.

There are various definitions of what constitutes a cold climate heat pump as the term “cold” is a relative and subjective term. Although California weather is generally regarded as the antithesis of a cold climate, there are a few mountain, desert, and coastal areas that are considered to have “cool” or “cold” climates as defined by the IECC. There are also mild climates (“warm/dry” IECC CZ 3B) zones in California that have winter design temperatures well below freezing such as Palmdale (Title 24 CZ 14) where the winter design temperature is 12° F[4]. So, are ccASHPs appropriate for this climate zone or for other climate zones to avoid strip heat? Are there other alternatives to ccASHP besides strip heat?

Table 1 shows a summary of NEEP and ENERGY STAR ccASHP requirements for comparison. (NEEP 2023) (US EPA 2022)

Table 1. Summary of NEEP and ENERGY STAR ccASHP requirements. (NEEP 2023) (US EPA 2022)

	SEER2	HSPF2	COP @ 5°F	Cap. @ 5°F
Code Minimum	≥14.3	≥7.5	N/A	N/A
NEEP Cold Climate	≥14.3	≥7.7	≥1.75	No req.
ENERGY STAR Cold Climate	≥15.2 (a)	≥8.1	≥1.75 (b)	≥70% of Cap @ 47°F (c)

(a) Seasonal heating efficiency, HSPF2, is approximately 10% higher than ENERGY STAR standard heat pump specifications. Non-ducted split systems must have an HSPF2 of 8.5 or greater, and ducted split systems and single packaged systems must have an HSPF2 of 8.1 or greater. (b) This is evaluated using the Appendix M1 $H4_2$ test. (Code of Federal Regulations 2023) (c) The 5° F capacity measured using the Appendix M1 $H4_2$ test. For VCHPs the 47°F (nominal) capacity, is tested using the Appendix M1 $H1_N$ test and the compressor speed must be at maximum speed that the system controls would operate at 47°F. For all other systems the 47°F (nominal) capacity, is tested using the $H1_2$ test (Code of Federal Regulations 2023).

In addition to these requirements, ccASHPs certified by ENERGY STAR are not allowed to have a non-representative “test mode,” that does not represent normal operation. There is also a “Connected Product” optional designation, which means the device can communicate using CTA2045-A or OpenADR 2.0b. With this optional designation, consumer override of demand response events cannot last longer than 72 hours and the unit must be capable of a general curtailment of 30% power and critical curtailment of 60%. (US EPA 2022)

The differences between a ccASHP and a “standard” heat pump vary between manufacturers, but are generally related to the ability to transfer a similar amount of heat from a lower temperature heat source (e.g., 5° F) as compared to a milder temperature (e.g., 47° F) at a reasonable level of efficiency (COP substantially higher than 1.0). As expected, the increase in cold climate performance of a ccASHP is attributed to greater outdoor heat transfer coil surfaces, larger compressor capacities, use of variable-speed compressors that can be driven beyond nominal capacity, controls, and other proprietary revisions. One manufacturer reportedly indicated that their cold climate heat pump is generally one nominal size larger with a derated

[4] This temperature is the median of extremes and is the recommended value for residential construction for the Palmdale Airport from ASHRAE Climatic Data for Region X. (ASHRAE 1982)

capacity with an additional installed cost of approximately 25%. Although optimized for colder outdoor temperatures, the added coil surface and larger compressor also improve summer cooling efficiency for some heat pump models.

Strip Heating

In California, electric resistance heating was essentially banned due to its low energy efficiency (COP < 1) in all new homes since the 1978 Title 24 Building Energy Efficiency Standards were implemented. Therefore, the primary heating options were gas furnaces or electric heat pumps. However, as noted above, early heat pumps either did not have sufficient capacity or would simply stop working during cold outdoor temperatures. Consequently, they were limited to milder climates or were supplemented with other heating systems that include fossil fuel-fired furnaces and boilers, wood or pellet stoves, or strip heat which was allowed by Title 24 if it were used as auxiliary heat for a heat pump.

Strip heaters are mounted in the ductwork or air handler. Because strip heaters are the cheapest and simplest way to ensure that there is always enough capacity "just in case," even in the mildest of climates of California it became "standard practice" to include them in virtually all residential heat pumps. However, as we explore further in this paper, the added electric load of inefficient strip heating at scale has significant impacts for the electric grid. Any serious consideration of heat pumps as a policy solution must confront overuse of strip heating.

Why Is Strip Heating Used?

So, why is strip heating still specified and installed in heat pumps in California? The reasons for this continuing trend are: 1) Many specifiers and installers are not aware of the availability of advanced heat pumps and continue to have the perception that all heat pumps are like those from over 25 years ago and recommend strip heat as "standard practice," 2) Older style single speed heat pumps continue to be available at generally lower price points (including strip heat) so, until advanced VCHP heat pumps become minimum efficiency heat pumps, the less expensive heat pumps will continue to be installed, 3) Installers and consumers familiar with only gas furnaces who are concerned about the real or perceived lower supply temperatures and install strip heat to ensure higher supply temperatures, 4) Incorrect sizing and poor installations of heat pumps are less forgiving for ensuring comfort whereas gas furnaces and strip heat can better compensate for poor installations, 5) An undersized heat pump with strip heat is less expensive and may not substantially increase energy consumption in milder climates, 6) For colder climates where a ccASHP is a better fit, installers may recommend the less expensive standard heat pump with strip heat at the expense of higher energy bills, 7) Strip heat used to maintain comfort and offset cold air during defrost resulting from heat pump temporarily placed in air conditioning mode to melt ice on outdoor coil, and 8) Strip heat installed as an insurance policy to provide space heating if and when heat pumps fail.

Alternatives to Strip Heat

Can strip heating be avoided altogether in California Climates? This section describes several alternatives, including ccASHP. Table 2 shows several additional means of avoiding using strip heating.

Table 2. Additional Means of Avoiding Strip Heat Use

Alternative	Pros	Cons
Slightly over-sized cold climate heat pump	Design for the unit's capacity at the most extreme temperature (not design temp). Capacity doesn't drop off as much at lower temperatures.	If it's big enough for the most extreme conditions, it is oversized 99.9% of the time. Potentially higher cost.
More over-sized normal heat pump	Potentially less expensive than ccASHP. More prevalent on the market. More likely to meet requirements in milder to moderate climates.	Less efficient at colder temperatures than a ccASHP. Significantly oversizing may be needed.
Air-to-Water Heat Pump (AWHP)	Elimination of need for strip heat by extracting heat from hot water storage for defrost. Storage can facilitate load shifting. Stored heat in hot water tank allows for stored capacity for change in setpoint or during coldest time of day. Monobloc AWHPs can safely use ultra-low GWP natural refrigerants and lose less refrigerant than air-to-air split systems.	Higher cost. Residential installers less familiar with hydronic heating/cooling systems, though ducted hydronic fan coils are closer to traditional systems.

It is worth noting that oversizing the system is a concern as a system that cycles frequently has a shorter system life and lower efficiency. However variable capacity systems have higher efficiency at part load and cycle less frequently, resolving many of these concerns.

Cold Climate Heat Pumps

The major benefit of ccASHP is that they maintain capacity at low outdoor air temperatures. While this may come at the sacrifice of efficiency, especially in cooling for some heat pumps, maintaining capacity over a lower temperature range avoids the use of very inefficient auxiliary strip heat. This tradeoff is generally judged on a case-by-case basis. In a heating dominated climate, such as Title 24 CZ 16, a cold climate heat pump could avoid substantial strip heat operation, improving the installed seasonal efficiency.

Proper Installation and Sizing

Especially in the California central valley (Title 24 CZ 12 and 13, IECC CZ 3B), auxiliary heat can be completely avoided and high cooling savings can be realized with almost any heat pump by following Measured Home Performance best practices. These basic best practices involve improving air sealing and insulation, conducting a blower door test to right size indoor air quality ventilation and enable accurate ACCA Manual J calculations, installing well-sealed short ducts either deeply buried in blown-in attic insulation or within conditioned space, and utilizing physical measurements during system commissioning. (Chitwood and Harriman 2012) The effectiveness of these methods have been demonstrated in many projects over the years, including research at the Central Valley Research Homes by the Energy Commission's PIER program (Proctor, Wilcox and Chitwood 2018) and PG&E and SCE's Emerging Technology (Wilcox, Conant and Gartland, et al. 2022) and Codes and Standards programs (Wilcox, Conant and Chitwood 2019) (Conant, et al. 2023).

Sizing is critical to avoiding the use of strip heaters. Systems should be designed to match the load on the building at fairly extreme conditions: typically heating system are designed at the median of extremes winter outdoor drybulb temperature (ASHRAE 1982).

Variable Capacity Heat Pumps (VCHPs)

The benefits of ccASHPs are not currently captured by CSE for Title 24 compliance modeling. To model space conditioning systems, CSE requires the user to enter the capacity and efficiency of the desired heat pump for several defined ambient temperatures. CSE uses these to estimate the capacity and energy use of the heat pump at part load conditions at different ambient conditions, taking into consideration the system type and other options selected. CSE also requires that space conditioning system capacity always meet the modeled load. When the modeled heat pump capacity cannot meet the modeled heating load, CSE assumes supplemental heat with a COP of 1 is provided equal to the unmet load. The user enters the capacity and efficiency of the heat pump for several defined ambient temperatures which are used by CSE to estimate the capacity and energy use of the heat pump at part load conditions at different ambient conditions, taking into consideration the system type and other options selected. CSE also assumes that space conditioning system capacity always meet the modeled load. When the modeled heat pump capacity cannot meet the modeled heating load, CSE assumes supplemental heat with a COP of 1 is provided equal to the unmet load.

Most ccASHPs are VCHPs and therefore cold climate variable capacity heat pumps (ccVCHPs). There are two VCHP models in CSE: (1) A "standard" model that meets the requirements of the VCHP compliance option, and (2) A "detailed" model that requires the input of detailed performance data. The detailed model is not currently allowed for compliance under 2022 code rules, but such an option would better represent the advantages of VCHPs and ccVCHPs, as it would reflect maintained capacity at low outdoor temperatures. This can be seen with two runs of the 1story Example model included with CBECC-Res 2022: once with a VCHP using the detailed model option and once with the minimum requirements option, but both times with the performance data for the same VCHP. Table 3 below compares the results using the inputs for a Daikin Fit VCHP (AHRI 213613334), a NEEP certified ccASHP in Title 24 CZ 12, and the same for CZ 16 in Table 4.

The detailed VCHP model shows a small increase in site energy use for primary heating (compressor and fan heat) as it is meeting nearly all of the loads at low temperatures, while nearly eliminating strip heat use, despite being the same VCHP in both cases. This demonstrates how current methods in Title 24 compliance modeling give the impression that auxiliary heat is needed when it is not for systems capable of maintaining capacity at low ambient temperatures.

Cooling site energy in Title 24 CZ 16 is reduced by two-thirds under the detailed model as the VCHP gets more credit for part-load efficiencies in the low cooling load climate.

Table 3. Comparison of CSE results modeling a VCHP using the standard and detailed models for climate zone 12 (Central Valley).

Title 24 Climate Zone (CZ) 12	**Standard Model**	**Detailed Model**	**Detail vs Std % Difference**
Primary Heating, Site Energy (kWh)	830.4	843.9	1.63%
Auxiliary Strip Heating, Site Energy (kWh)	166.9	1.5	-99.10%
Total Heating Energy (kWh)	**997.3**	**845.4**	**-15.23%**
Cooling, Site Energy (kWh)	237.4	226.6	-4.55%
Annual Heating and Cooling Energy (kWh)	**1234.7**	**1072**	**-13.18%**

Table 4. Comparison of CSE results modeling a VCHP using the standard and detailed models for climate zone 16 (Mountains).

Title 24 Climate Zone (CZ) 16	**Standard Model**	**Detailed Model**	**Detail vs Std % Difference**
Primary Heating, Site Energy (kWh)	2673	2754.2	3.04%
Auxiliary Strip Heating, Site Energy (kWh)	653.9	14.4	-97.80%
Total Heating Energy (kWh)	**3,326.9**	**2,768.6**	**-16.78%**
Cooling, Site Energy (kWh)	5.7	1.9	-66.67%
Annual Heating and Cooling Energy (kWh)	**3,332.6**	**2,770.5**	**-16.87%**

In its current form, the detailed VCHP model requires the user to find manufacturer performance data for their selected heat pump at five outdoor conditions that includes the capacity and COP at minimum and maximum speeds. While such data is available from public databases, such as from NEEP, these databases do not include all heat pump models and may not be entirely accurate.[5] CBECC could switch from data entry to model specification, as is done with NEEA-rated HPWHs, but that process with HPWHs has been fraught with issues and complaints from manufacturers and stakeholders. Ideally, Title 20 would require manufacturers to report the data necessary to use the detailed VCHP model for inclusion in the Energy Commission's Appliances Database, which CBECC could reference.

Using CBECC's research tools, the authors conducted a parametric study comparing a ccVCHP to a typical VCHP of the same manufacturer and model series in each CZ.[6] CBECC's

[5] For example, the Mitsubishi MXZ-SM48NAMHZ2 (AHRI# 211016460). NEEP lists the minimum heating capacity at 47F outdoor and 70F indoor as 27,000 Btu, but the manufacturer data tables list the minimum capacity for the same conditions as 15,976 Btu. (NEEP 2024) (Mitsubishi Electric Trane HVAC US LLC 2024) It is the understanding of the authors that efforts are underway to improve the accuracy of the NEEP database.

[6] A Mitsubishi P-series H2i pairing (AHRI # 211497046) was used as the reference for the ccVCHP and a standard Mitsubishi P-series pairing (AHRI # 211497113) was used as the reference for the typical VCHP.

autosizing algorithm was used to ensure that both ccVCHP and VCHP were sized to the design heating day for each CZ. Using autosizing in the detailed model effectively eliminated electric resistance operation for both ccVCHP and VCHP, as the model assumes that supplemental heating is only invoked when the system cannot meet the load for the time step, setpoints are not varied and hourly ambient temperature never drop below the autosizing temperature. Due primarily to the limitations of CBECC (including that none of CBECC's default weather files have a minimum temperature below 17°F, and that the autosizing algorithm adjusts capacity curves, but not efficiency curves) the results were not stunning. However, the exercise did demonstrate a heating energy use reduction in all but three CZs with the ccVCHP, and an annual space conditioning energy use reduction in nine CZs. Additionally, in CZ 16 the nominal size of the ccVCHP was 29% smaller than that of the typical VCHP. Being able to specify a smaller nominal capacity unit means smaller CFM requirements and duct sizes, potentially resulting in easier and cheaper installations. Further parametric studies are warranted to evaluate the impacts of sizing and more realistic weather conditions on the compliance model results.

Dual Fuel Heat Pump

A dual fuel heat pump generally refers to a split system air-to-air heat pump coil that is attached to a natural gas or propane furnace in the same way that a cooling-only coil would be attached. These systems have been generally used in extremely cold climates and are allowed in Title 24 in CZ 1 and CZ 16. In some circumstances, the furnace may remain in place with the heat coil replacing the cooling-only coil. This configuration requires a careful control strategy to ensure the proper staging.

Recent dual fuel heat pump research by Minnesota Center for Energy and Environment (MNCEE) has also demonstrated that improving installation quality, right-sizing, and optimizing controls settings for long VCHP runtimes have a higher impact on reducing secondary heat use and increasing energy savings than higher AHRI ratings. The project monitored the performance of over 50 installed systems in the Midwest and also found that these heat pumps retained much of their nominal capacity in the 0° to 10° F temperature bin. (Schoenbauer 2024)

Avoiding Nighttime Setback

Use of nighttime setback control of heating temperatures has important implications for heat pumps. If no nighttime setback is used, then there will not be an extreme load on the heat pump in the early morning, typically the coldest part of the day. With nighttime setback, the heat pump has to overcome the heat lost overnight, which can be a much larger load, at this coldest time of day, typically requiring the use of strip heating. This is a particularly insidious problem for the grid, as many homes throughout the state all attempt to recover from nighttime setback at the same time. This recovery may be similar to the sharp spike in residential air conditioner loads on the grid after a demand response event where the "snap back" (several air conditioning compressors resuming full power) creates an electrical demand peak higher than the peak if no demand response event had occurred. If this is accomplished with inefficient strip heating, this will create a huge winter morning peak demand problem. This can be avoided by not using nighttime setback. The energy penalty of using strip heating to reheat the home more than negates the savings from the setback. However, many households use nighttime setback because they prefer sleeping in a colder room. According to an analysis of housing characteristics and behavior collected in the Residential Energy Consumption Survey (EIA 2020), about half of all homes use nighttime setback in the winter. This is true whether they have heat pumps or furnaces. With furnaces, the median setback is about 5°F, and with heat pumps, the median setback is 3°F. A behavioral program could discourage the use of nighttime setback or encourage smaller setbacks with heat pumps, educating people that nighttime setback is not efficient with their system. Of course, behavioral interventions can be unreliable.

Optimal Start Thermostats

Another solution to the nighttime setback problem is to use thermostat programing or advanced functionality to start warming up the home more gradually in the morning. This could be as simple as a multi-step ramped up setpoint schedule over several hours prior to waking, or using internet-connected thermostats with this feature built-in. Smart thermostats have had this feature for many years, with some learning from recent performance to start heating at the right time to ensure comfort prior to waking and others using weather forecasts to further optimize this operation.[7] This is sometimes called smart or adaptive recovery that can predict the optimal start time for the heat pump (without strip heat) by using an algorithm that often references the length of timeto reach the setpoint temperature for the previous morning. Thermostat manufacturers should be encouraged to develop and market this capability and code requirements can be defined to further encourage this.

Minimizing Impacts of Defrost

Another factor that creates the need for strip heating is defrost operation. If the indoor fan is operating during or just after defrost, the occupants will experience a blast of cold air. This can be counteracted with strip heat. Some ways to prevent (or at least minimize) this are to minimize the amount of time the system is in defrost mode by using intelligent controls that identify when it is truly needed or setting up the defrost delay timer (e.g. to 90 minutes or more). Air distribution systems should also be designed in a way that minimizes blowing air directly on people (though this is just good practice anyway). Heat pumps could also be designed so that they rely only on the heat of the compressor to warm the outdoor coils and do not require cooling the indoor coil.

Stakeholder Impacts

Consumers, Including ESJ Customers

Homeowners and residential building owners should research their options and, at a minimum, know what choices they have when installing a heat pump. Comfort is a top concern as well as impacts on energy bills and their carbon footprint. Energy efficiency of the building envelope (minimizing air leakage, adding insulation, replacing/retrofitting windows, etc.) should be the first consideration. Guidance from passive house principles such as Passive House

[7] Such as the ecobee smart thermostat (ecobee 2024), Trane Pivot (Trane 2024), and others (Moor 2023).

Institute of the United States or Passive House Institute sets some of the highest levels of achievable energy efficiency appropriate for each climate zone. Added energy efficiency provides a more comfortable and healthier environment and lowers costs for both energy bills and reduces the heat pump size and would likely eliminate the need for auxiliary strip heat or a ccASHP in milder climates. A smaller heat pump and the elimination of strip heat may also eliminate the need to upgrade the home's electrical system.

The ability to optimize comfort, energy bills, and greenhouse gas emissions is tied to the level of controllability for each application. Greater controllability allows the heat pump to better match comfort requirements as well as responding to time-of-use rates, demand response events, and carbon signals. VCHPs offer the greatest levels of both controllability and efficiency and generally able to operate with higher levels of efficiency and capacity at lower temperatures whether they are ccASHPs or standard heat pumps.

Manufacturers and Distributors

Many of the major manufacturers of heat pumps are offering or beginning to offer ccASHPs meeting the ENERGY STAR criteria in addition to their standard single speed and VCHP heat pumps. Auxiliary strip heat is generally offered as an option, but heat pump distributors are reporting that very few heat pumps in California are sold with strip heat with exceptions in desert climates. In cold sparsely populated California mountain climates, ccASHPs are sold. Since very few areas in California have winter design temperatures below 5°F, the majority of ccASHP are not sold with strip heat. Manufacturers are also increasing availability of 120-volt indoor heat pump air handlers that enable gas furnace retrofits without electrical upgrades and eliminate the possible use of strip heaters that require 208/240-volts.

It is the viewpoint of at least one manufacturer that it is likely that within 10 years, all heat pumps will be VCHPs which would allow for more standard heat pumps to operate at lower temperatures without strip heat. As noted above, this may be beneficial to those desert and valley climates in California that have both high summer temperatures and low winter temperatures.

Installers and Specifiers

HVAC installers and specifiers are responsible for appropriately sizing heat pump systems using industry-accepted calculation procedures. They also carry liability for heat pump system performance and therefore tend to oversize equipment and to avoid complaints and call-backs, install strip heat to ensure that more than sufficient heating capacity is available. In addition, strip heat can mitigate cold blow during defrost, compensate for poor-quality installations and maintenance, provide for a more rapid increase in room temperature after a night set-back, and provide a belts and suspenders assurance for adequate heating.

In many cases, the heat pump installer relies on the owner to hire an electrical contractor if electrical system upgrades are required. Therefore, it is possible for the overall cost of the heat pump to be higher if the heat pump is oversized and/or installed with strip heat and triggers a costly electrical system upgrade.

Utilities and the Grid

Electric utilities are obligated to serve electricity safely to their customers. As a result, the grid has grown at a relatively steady pace for the past 100 plus years in response to population increases, new appliances and equipment, and widespread air conditioning in the warmer climates of California. However, in response to the climate crisis and California's goals for decarbonization, this is leading to unprecedented levels of electrification in the building and transportation sectors.

SCE's Countdown to 2045 (Edison International, 2023) white paper lays out a plan to meet California's 2045 decarbonization goals that includes the electric generation sector (100% of electric sales to come from renewable sources), transportation (90% electrification of light and medium duty vehicles) and 95% of water and space heating in buildings to be electric. This represents a sharp increase in electric energy use of more than 80% above 2022 levels, and subsequent growth in the electric grid of approximately 30% assuming a ~90% utilization.

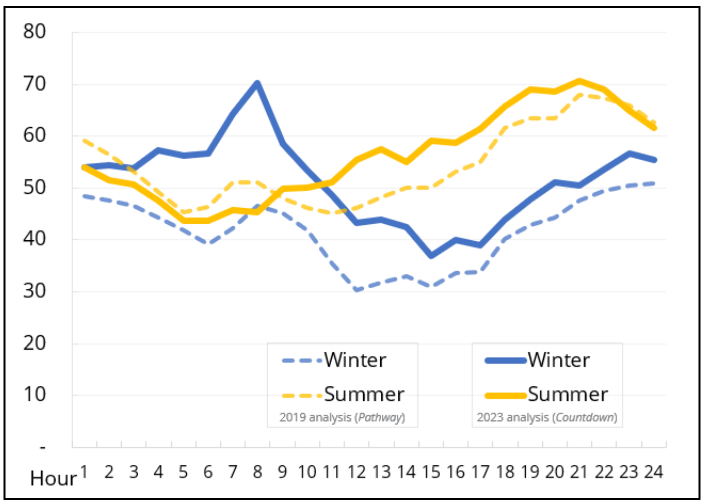

Figure 2: 2045 California Independent System Operator peak load forecast (GW). *Source*: Edison International Countdown to 2045

A key result of this analysis is that the electrification of buildings and transportation will cause the 2045 winter peak demand to be equivalent to the 2045 summer peak as shown in figure 2. The new winter peak will be driven by heat pump space heating during cold nights just before dawn. A critical assumption built into this winter peak forecast is that the new heat pumps coming online will have little to no strip heat. As previously noted, if 6,000,000 new heat pumps are installed in California each with a 5 kW strip heater (generally the minimum size available), this would theoretically add 30 GW of load (assuming simultaneous operation when the grid is peaking with space heating heat pumps) to the 2045 forecasted CAISO peak of 70 GW. While not all strip will be on at the same time, some homes may have more than 5 kW of strip heat. The likelihood of an incremental peak load of this magnitude is becoming more likely as extreme weather occur. This strip heat incremental peak could be potentially worse considering the number of households in California was just over 14 million in 2022. (US Census Bureau n.d.). Assuming a housing growth rate of 1% per year, this would result in approximately 18 million homes in 2045. Using the Countdown to 2045 heat pump market penetration of 95% that would yield approximately 17 million heat pumps, approximately triple the 6 million heat pump goal for 2030 resulting in a strip incremental load over 80 GW which is more than double forecasted peak of 70 GW. Of course, this is an extreme worst-case scenario, but it does bound the magnitude of the problem if left unchecked.

Another key concern for utilities and grid operators is that if strip heat is installed, electrical infrastructure is required to accommodate this incremental load from the home's electric panel to the transformer to distribution lines to substations and upstream to transmission lines. Diversity factors can be applied at each section of the electric grid but there is no data available that can be applied. In the past, strip heat was not a concern since the California grid peaks have occurred only in the summer since space heating has traditionally used natural gas. In general, absent empirical data that can provide statistically valid diversity factors, utility planners as well as the National Electric Code tend to be conservative and either not include or have small levels of diversity. Therefore, given that the majority of the winter peak will be from space heating heat pumps in 2045 in California, the strip heat would be additive to that peak for the purposes of grid planning.

Conclusions

Energy efficiency is a key strategy for California's successful transition heat pumps. Energy efficiency not only reduces energy bills but may also reduce the cost of installations by allowing for smaller, less expensive heat pumps and may avoid the requirements of a ccASHP or strip heat. There are also other benefits for added energy efficiency that include better comfort, indoor air quality, sound transmission, and indoor temperature stability during power interruptions.

There are several market indicators that modern heat pumps can fulfill the comfort and efficiency needs of 99% of the homes in California without the use of inefficient auxiliary strip heating. There is also emerging evidence from heat pump distributors that modern heat pumps can adequately serve the majority of the milder climates (IECC CZ 2 and 3) with standard heat pumps. For the other IECC CZ 4-6, ccASHPs can provide adequate heating in all but the most extreme climates of the high elevations of the eastern Sierra mountains (Title 24 CZ 16) and the high desert (Title 24 CZ 14).

Although avoidable, a high penetration of strip heat in heat pumps may have a significant impact on the electric grid. In a worst-case theoretical scenario, auxiliary strip heat can more than double the forecasted winter peak in 2045. Even if the actual strip heat installation is 5% of the worst case, this would add significantly to California's peak demand. The additional grid infrastructure to accommodate this incremental load will result in higher rates to offset the cost for the infrastructure upgrades.

ENERGY STAR has facilitated the market for cold climate heat pumps by developing clear criteria for ccASHPs. This will provide consumers and installers a clearer indication of a heat pumps' capabilities. Other cold climate heat pump criteria are available and may be more appropriate and specific to other areas in US and Canada. However, ENERGY STAR has the highest brand recognition and is the most applicable for California as few areas have outdoor design temperatures below 5° F. Another potential role for ENERGY STAR is to identify heat pumps that are between single speed and VCHP models.

While this paper attempts to look at the heat pump market for the entire state by climate zone, each home heat pump project is unique and requires careful consideration of the characteristics of the home, energy efficiency opportunities, and the configuration of the heat pump equipment to determine the appropriate type of heat pump to install.

According to the 2019 Residential Appliance Saturation Survey (CEC 2021) the statewide penetration of residential heat pump space heating is around 4%. As a result, there is little empirical data available on the actual use of auxiliary strip heat since it has been an imperceptible load that hasn't impacted grid planning. Sales of heat pumps with strip heat have not been tracked.

The widespread use of strip heating in the milder areas of California is primarily due to the misconception that currently available heat pumps are unable to provide sufficient heat output. Most of the misconceptions stem from early generation heat pumps that are no longer manufactured. Therefore, the misapplication of strip heat can be addressed by better informing consumers, installers, and specifiers of the capabilities of properly sized and installed heat pumps that are available today.

Recommendations

Excessive use of strip heat would be detrimental to the planned GHG reductions and cost-effectiveness of building electrification while imposing large societal costs to build an energy infrastructure to support this unnecessary load. One can design and install and commission strip heating controls that would reduce the impact, but the reliability of the savings would be lower than having no strip heat at all. It is recommended that the following actions be pursued:

- Gather data on prevalence of strip heat being added to heat pumps and collect information from designers on the rationale behind its specification.
- Collect data on strip heat performance, how it is being controlled and under what conditions it is energized to determine load diversity factors.
- Collect empirical data on ccASHP and standard heat pump performance and compare to extended performance data from manufacturers.
- Develop a standardized database of extended heat pump performance data for use in validated software tools including the California Simulation Engine.
- Provide outreach and education on the application of ccASHPs, standard HPs, and strip heating.
- Design heat pump incentive programs where the default outcome provides customer comfort without the use of supplemental heat. In the few applications where supplemental heat is needed, develop product and commissioning specifications that limits the size and operation of strip heating.
- Collect information to evaluate restrictions on strip heat in Title 24.
- As a starting point, consider NEEP's (and ACEEE's) recommendation of ccASHPs being a best fit for IECC CZ 4 (4,500 HDD) and above.
- Consider a wider use of heat pumps with 120V indoor air handlers that have the same electrical requirements as a gas furnace and would eliminate the option for strip heat.

References

Amana. 2024. "Today's Heat Pumps: That Cozy Comfort Feeling, Decades in the Making." *Amana Heating & Air Conditioning website.* https://www.amana-hac.com/resources/hvac-learning-center/hvac-101.

ASHRAE. 1982. "Climatic Data for Region X, Arizona, California, Hawaii, Nevada, 1982."

CARB. 2022. "2022 Scoping Plan for Achieving Carbon Neutrality." *California Air Resources Board.* November 16. https://ww2.arb.ca.gov/sites/default/files/2022-11/2022-sp.pdf .

CEC. 2021. "2019 California Residential Appliance Saturation Study (RASS): Executive Summary." *California Energy Commission.* July. https://www.energy.ca.gov/sites/default/files/2021-08/CEC-200-2021-005-ES.pdf.

Chitwood, Rick, and Lew Harriman. 2012. *Measured Home Performance: A Guide to Best Practices for Home Energy Retrofits in California.* Prepared for the California Energy Commission.

Code of Federal Regulations. 2023. "Section 3.6 of Appendix M1 to Subpart B of Part 430, Title 10." https://www.ecfr.gov/current/title-10/part-430/appendix-Appendix M1 to Subpart B of Part 430.

Conant, Abram, Mike MacFarland, Marshall Hunt, David Springer, and James Haile. 2023. "Best Practices Guide: Residential Variable Capacity Heat Pumps." *ETCC-CA website.* July. https://www.etcc-ca.com/reports/best-practices-guide-residential-variable-capacity-heat-pumps.

E3. 2019. "Energy and Environmental Economics. Residential Building Electrification in California." April. https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf .

ecobee. 2024. *What is Smart Recovery and how does it work?* June 7. https://support.ecobee.com/s/articles/What-is-Smart-Recovery-and-how-does-it-work.

EIA. 2020. *Residential Energy Consumption Survey (RECS) 2020.* U.S. Energy Information Administration.

Heinemeier, Kristin. 2023. "Residential HVAC Performance. 2025 California Energy Code. Codes and Standards Enhancement (CASE) Initiative." *Title 24 Stakeholders website.* November. https://title24stakeholders.com/wp-content/uploads/2023/11/Revised_2025_T24_Final-CASE-Report-RES-HVAC-Performance.pdf.

McHugh, Jon, Alea German, Amy Dryden, Ben Larson, Dove Feng, John Bade, and Mark Alatorre. 2022. "Heat Pump Controls: Decarbonizing Buildings While Avoiding Electric Resistance Heating and Higher Net Peak Demand." *Proceedings of the 2022 Summer Study on Energy Efficiency in Buildings.* Washington, D.C.: ACEEE.

Mitsubishi Electric Trane HVAC US LLC. 2024. *Smart Multi Data Book.* February 20. http://s3.amazonaws.com/enter.mehvac.com/DAMRoot/Original/10006/M_MXZ-SM_ENGINEERING.pdf.

Moor, Tom. 2023. "Why Is My Thermostat in Recovery Mode?" *HVAC.com.* September 12. https://www.hvac.com/expert-advice/why-is-my-thermostat-in-recovery-mode/.

Natural Resources Canada. 2024. *Program Requirements, Product Specification for Central Air Conditioner and Heat Pump Equipment, Eligibility Criteria, Version 6.1. Air Source Heat Pumps and Cold Climate Air Source Heat Pumps.* https://natural-resources.canada.ca/energy-efficiency/homes/canada-greener-homes-grant/start-your-energy-efficient-retrofits/plan-document-and-complete-your-home-retrofits/eligible-grants-for-my-home-retrofit/23504#s5.

NEEP. 2023. *Cold Climate Heat Pump Specification (Version 4.0).* https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final.pdf.
—. 2024. *MXZ-SM48NAMHZ2 NEEP Database Listing.* February 20. https://ashp.neep.org/#!/product/112112/7/25000/95/7500/0///0.
Pallin, Simon, and James Haile. 2022. "Residential Hydronic Heating and Cooling Applications by Air-to-Water Heat Pump Systems." *Sonoma Clean Power website.* June. https://sonomacleanpower.org/uploads/documents/Task-4.2-Lead-Locally-EPC-2017-041_-Hydronic-Heating-and-Cooling-by-Air-to-Water-Heat-Pump.pdf.
Proctor, John, Bruce Wilcox, and Rick Chitwood. 2018. *The Central Valley Research Homes Project.* Sacramento: California Energy Commission.
Schoenbauer, Ben. 2024. *Dual Fuel Heat Pump Field Research.* Yosemite: Presentation to the Dry Climate Forum.
Springer, David, Mike MacFarland, and James Haile. 2021. "Air-to-Water Heat Pump Design and Installation Guide." *Sonoma Clean Power website.* October. https://sonomacleanpower.org/uploads/documents/Task-4.3-RCP-AWHP-Design-Guide.pdf.
Trane. 2024. "Trane Pivot Smart Thermostat." *Trane website.* June 7. https://www.trane.com/content/dam/Trane/Commercial/global/controls/equipment-controls/thermostats/web-enabled/BAS-SLB084-EN_06162020.pdf.
US Census Bureau. n.d. *2022 Census* . United States Census Bureau.
US EPA. 2022. "ENERGY STAR® Program Requirements Product Specification for Central Air Conditioner and Heat Pump Equipment Eligibility Criteria Version 6.1 (Rev. January – 2022)." https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Version%206.1%20Central%20Air%20Conditioner%20and%20Heat%20Pump%20Final%20Specification%20%28Rev.%20January%20%202022%29.pdf .
Wilcox, Bruce, Abram Conant, and Rick Chitwood. 2019. "Central Valley Research Homes: Evaluation of Sizing and Controls Settings 2017-2018." *ETCC-CA website.* May 3. https://www.etcc-ca.com/reports/central-valley-research-homes-evaluation-sizing-and-controls-settings-2017-2018.
Wilcox, Bruce, Abram Conant, Lisa Gartland, and Mike MacFarland. 2022. "Central Valley Research Homes: Variable Capacity Heat Pumps Evaluation of Refrigerant Charge Effects 2019-2020." *ETCC-CA website.* June 8. https://www.etcc-ca.com/reports/central-valley-research-homes-variable-capacity-heat-pumps-evaluation-refrigerant-charge.