Title

Smart Thermostats Plus Heat Pumps: Incompatible? Or Just Need Counseling?

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Smart Thermostats plus Heat Pumps: Incompatible? Or just need counseling?

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ABSTRACT

Advanced, colorfully-graphic touch-screen thermostats entered the market over ten years ago, providing a much-needed improvement to the control of home heating and cooling systems. And in the last few years, climate change mitigation concerns and rebates from the Inflation Reduction Act (IRA) have accelerated heat pump installations in homes across the U.S. But the relationship of smart thermostats to typical air source heat pumps (ASHP) has been rocky at best: ASHPs with variable speed drives require a deeper integration with a thermostat, and most third-party smart thermostats have step-level staged control. Proprietary thermostats that come with the ASHP units are typically not as easy to understand and use as the popular smart thermostats on the market. Moreover, heat pumps with supplemental electric resistance heating require a different control approach that respects the lower temperature/long cycle heat transfer of heat pumps and understands the impact on the electrical grid, especially with high power peaks on cold winter mornings.

This paper combines a literature review of the smart thermostat+heat pump relationship and interviews with stakeholders to outline trends, issues, barriers, and areas for further study in the relationship between variable capacity heat pumps and smart thermostats.

Introduction and Background

The functionality and usability of thermostats affect residential *energy consumption* (and thus greenhouse gas (GHG) emissions) and *grid stability*, with implications for *equity*. About half of residential energy is consumed by heating (42%) and cooling (9%) systems (U.S. Energy Information Administration (EIA) 2020). A popular means of reducing energy and GHGs are space conditioning heat pumps—currently experiencing a huge growth in installations globally—which often require a specialized type of thermostat to work properly. Since the early 1980s, thermostats have been designed to reduce Heating, Ventilation, and Air Conditioning (HVAC) system energy by relaxing comfort settings at night or when the home is unoccupied. However, the usability of those early programmable thermostats hindered energy savings (and led to EPA's Energy Star to discontinue certification (Kaplan 2009)). Over the last decade, thermostats are increasingly used by utilities in "demand response" programs, which reduce energy consumption during peak demand periods when the capacity of the electric grid is strained. These network thermostats require communication, of which the most common modality is Wi-Fi. This raises equity issues: while 85% of American households enjoy high-speed internet, this drops to 76% for low-income households (Starr, Hayes, and Gao 2023). In addition, today's thermostats often have small text and low contrast icons (difficult for seniors), and many only provide English language text (difficult for people whose first language is not English). Thus, how a thermostat works and how well people can use it has equity, grid, and climate repercussions.

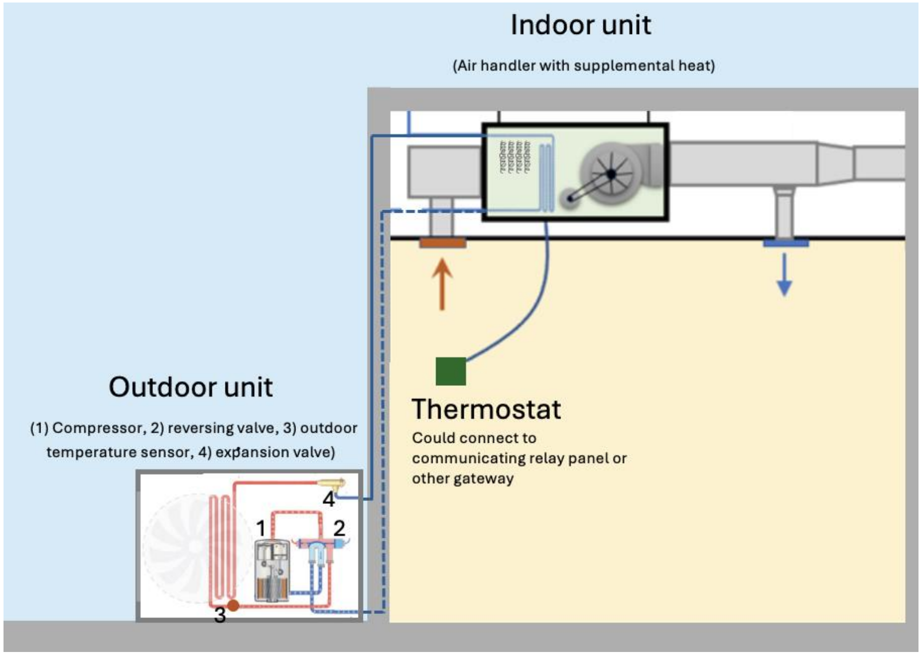

Figure 1: Schematic of a residential variable capacity heat pump.

Sales of this new carbon-reducing technology—space conditioning heat pumps (Figure 1)—increased 2.5 times from 2012 to 2022 (Belloli 2024), surpassing gas furnace sales in 2021, although the market is still settling after 1) the peak of pandemic-driven growth, 2) the U.S. Department of Energy (DOE)'s new efficiency standards in 2023, 3) increased costs driven by inflation, and 4) IRA rebates (ibid). Related to the type of control needed, heat pumps can be categorized into three types: single-stage, multi-speed/two-stage, and inverter or variable speed/capacity heat pumps (Bailes 2023). **Single-stage systems**—the oldest and simplest technology—have a fixed capacity for heating and cooling: when the system is called on by the thermostat, it ramps up to the full heating or cooling capacity until the target temperature is reached, then turns off. These systems are often oversized (or sized for heating loads and thus oversized for cooling) (Woerpel 2023). In homes with oversized systems, the target temperature is reached quickly, which uses a great deal of power for a fast ramp rate and results in a longer off-period. In warm humid climates, long stretches of time without dehumidification may create uncomfortable and unhealthy conditions (mold, allergy/asthma issues (Maple Air 2024)). The lack of modulation can make for expensive operation (Trane 2023). Next is **two-stage or multi-speed** systems. Some manufacturers produced two-stage furnaces as early as the '60s and two-speed compressor air conditioners in the '80s. A two-stage system has a low-capacity output (65-70%) and high-capacity output (100%). Most of the time, outdoor temperatures are less extreme than the design temperatures used to properly size the system, so having a lower stage to handle part-load conditions leads to more efficient operation and better comfort (Bailes 2015). Multi-stage heat pumps may have up to five discrete stages, based on the speed of the refrigerant flow (Bailes 2023). Finally, **variable capacity** heat pumps (VCHP) can vary the heating or cooling capacity continuously from its low to high end of capacity. U.S. manufacturer Bryant introduced variable speed gas furnaces in 1981[1], and Toshiba pioneered the variable speed (inverter-based) air conditioner that same year. Variable heat pump technology spread rapidly from Japan to Europe and Asia, but grew more slowly in the US—only 13% of air conditioners were variable speed in the US in 2018 compared to 82% in Europe. More recently, however, the adoption of heat pumps in the U.S. has quickly increased (Institute of Electrical and Electronics Engineers (IEEE) 2021). These variable capacity heat pumps usually modulate with special electronic controls on the compressor; "the term 'inverter-driven compressor' applies to most variable capacity systems" (Bailes 2023). VCHP are the most energy-efficient, provide the best comfort—and are the most expensive.

Another distinction in heat pump design and control is **central ducted** (with one outdoor unit and two or more indoor units) versus **ductless (or mini-split)** systems (intended for a single zone, with a single indoor unit "head" and single outdoor unit, either of which can act as condenser or evaporator). Mini-split heat pumps are highly effective for managing zoning issues within homes. Each indoor unit, or "head," can be individually adjusted to provide tailored heating or cooling to specific rooms or areas. This flexibility not only enhances comfort but also significantly improves energy efficiency by avoiding the unnecessary heating or cooling of unoccupied spaces. By contrast, traditional HVAC systems often struggle with such granular control, making mini-split systems an advantageous solution for achieving precise temperature regulation across different zones in a home. Further, distribution losses are reduced in refrigerant lines, compared to air ducts (Ashley et al. 2020).

Another issue related to thermostat control that impacts energy consumption is **supplemental or auxiliary back up heat**, usually provided via electric resistance heating elements. Supplemental electric heat can defrost the coils, boost heat delivery, and can make up for insufficient heating capacity due to lower performance of heat pumps on cold days. This additional heat can be triggered by the difference among the target, outside, and inside temperatures. A well-insulated and sealed home reduces the need for back-up heat; the extent of nighttime setback impacts auxiliary heat and contributes to morning electric peak demand periods.

Thermostats have evolved in aesthetics, function, and usability over the years. Table 1 shows a brief history of thermostats and defining characteristics. Released in 1953, the Honeywell Round (first column)—one of the most popular thermostats ever made—provided a simple elegant interface for controlling heating and cooling systems. The earliest "setback" thermostats (second column) were also mechanical, providing a simple dial to offset the temperature at night. The energy crisis of the '70s drove the development of digital electronic or programmable thermostats (third column): one could set a schedule and target temperatures for several epochs of time (home, away, asleep). However, due to poor aesthetics and usability, the early programmable thermostats did not provide much energy savings (Perry et al. 2011; T. Peffer et al. 2011; T. Peffer et al. 2013). The advent of the internet brought networked thermostats (fourth column) on the market, with improved programming interfaces and ability to control multi-stage equipment. In 2009-2010, smart or advanced thermostats, such as ecobee and Nest (fifth column), hit the market with full color touchscreen displays, occupancy sensors for automatic away setbacks, embedded computation for learning schedules—and a need for power (often scavenged from the air conditioning system).

[1] https://waynepricehvac.com/the-history-of-bryant-heating-cooling-systems/)

Table 1. Thermostats through the ages

Image						
Category	Manual	Early clock/setback thermostat	Programmable/ Digital/ ENERGY STAR introduced	Networked	ENERGY STAR certified Smart/ Advanced	Communicating (variable heat pump)
Era	1950s	1960s	1980s	2000s	~2009-	~2015-
Relay type	Mechanical bimetallic/ mercury temperature switch	Mechanical bimetallic/ mercury temperature switch	Electronic	Electronic	Electronic	Electronic
HVAC type	Single stage	Single stage	1-2 stage, proprietary variable	Two stage, proprietary variable	Two stage, proprietary variable	Proprietary and third-party variable
Energy savings	Off switch!	Setback and off	In theory, but programming is too difficult	Off, program, Demand response (DR) capable	Off, Occupancy, program, DR capable	Potential for DR
Grid Support	None	None	None (through direct load control)	Change based on signal	Change based on signal	Not available
Connection to HVAC	2-4 wires	2-4 wires	2-5 wires	4-6 wires	5-7 wires/ networked	5-7 wires, networked via protocols
Power	None	None	Battery	Battery/C-wire	C-wire/ scavenged	C-wire/ scavenged
Usability	High	Med-High	Low	Medium	Med-High	Mixed

The last column of Table 1 is the focus of this paper: to understand the relationship between variable heat pump space conditioning systems and associated thermostats. Variable heat pumps require control not typical of third-party, off-the-shelf smart thermostats, such as Nest and ecobee, which often have a maximum of two or three stages for heating and cooling, but do not accommodate continuous variable control. These variable heat pumps come with their own proprietary thermostat—either a simple **remote control** (for mini-splits) or a **wired "communicating" thermostat**—to provide this variable speed functionality. But how well do customers like and are able to successfully use these thermostats? More limited smart thermostats are sometimes connected to variable heat pumps, either directly or through manufacturer or third-party **adapters.** How well does this work, both in function, energy consumption, and usability?

When used as the designer envisioned, a smart or advanced thermostat can offer substantial benefits, including significant cost savings, enhanced energy efficiency, and overall improved comfort of occupants. However, a poorly programmed thermostat or one frequently adjusted by occupants can lead to discomfort, excessive energy consumption, and increased utility costs. One common culprit is an overly complicated thermostat user interface, which can be confusing for users trying to set appropriate temperature schedules. In addition, a lack of understanding of thermostat features, including the ability to participate in automated demand response programs, can make it hard for users to correctly program their thermostat.

A final consideration is the tension between a utility's goals (reducing and shifting peak energy) and the end user's needs (comfort, convenience, and cost) towards adopting a thermostat that can balance both. The usability of a thermostat interface for heat pumps strongly influences adoption, yet true equity in thermostat design means understanding that there is not a "one-size-fits-all" solution. Some people cannot afford the cost of an advanced thermostat; others do not understand the complexities of the settings. Some want to program and fiddle; others want to "set it and forget it" and let automation control for them. Some are motivated by "games" (like OhmConnect's method of changing energy behavior (Gattaciecca et al. 2021)); others are driven by comfort, convenience, and/or cost. In order for new control technologies/interfaces to be adopted, they must be *useful*—both *usable* (easy to use, learn and remember) and serve a purpose (*utility*), practically acceptable (cost, reliability) and socially acceptable (such as market forces, policy, and supply chain influences) (Nielsen 1993; T. E. Peffer 2023).

This paper explores the current issues with thermostats for variable heat pumps through the lens of contractors, researchers, and end users, reviewing energy consumption, grid support, usability, and equity.

Methods

This project entailed two methods of exploration: a **literature review** of traditional academic literature and so-called non-peer reviewed "grey" literature, and **interviews** of contractors and experts. The literature review looked at published papers or articles on thermostats used to control variable heat pumps; however, since this area is relatively new (less than 10 years) and seems to be evolving, we also looked at contractor and homeowner websites, blogs, and forums (HVAC-talk.com, reddit (r/heatpump, r/heatpumps, r/hvacadvice). We evaluated several areas: contractor installation and programming difficulties (especially with thermostat wiring and various settings), customer understanding (or misunderstanding) of how the system worked, usability of the interface itself, and energy savings and demand flexibility through signals. We received feedback from nine stakeholders by convenience survey; we interviewed five contractors, one manufacturer and one research engineer, and corresponded with two additional contractors.

Systematic Literature Review

We conducted a systematic literature review of both traditional academic and grey literature. We used Web of Science and Scopus to gather academic and peer-reviewed literature, and grey literature sources, including forums, and user reviews and discussions on heat pumps and thermostats. The inclusion criteria were: articles and forums discussing the integration and functionality of heat pumps with smart thermostats, including case studies; user reviews; and discussions that provided insights into real-world usage, challenges, and solutions.

We applied a combination of both deductive (based on predefined themes like usability, energy efficiency, and compatibility) and inductive (emerging from the data) coding approaches, and coded the content. Then we organized codes into broader themes to understand the dynamics between heat pumps and thermostats. Our objective was to understand public sentiment, usability issues, and real-world performance related to heat pumps and thermostats. We used Dedoose, a qualitative data analysis software, for coding and analyzing the data.

Data Collection

We identified relevant grey literature sources including blogs, Reddit threads, Quora discussions, YouTube comments, and Facebook posts/groups focused on heat pumps and thermostats. To find pertinent literature, we used search keywords such as "heat pumps," "smart thermostats," "residential energy efficiency," and "HVAC system control."

Once we identified the sources, we selected a diverse sample from each platform to ensure coverage of various viewpoints and experiences. For instance, Reddit posts were gathered from subreddits such as r/heatpump and r/HVAC, while Quora provided insightful discussions about heat pumps and smart thermostats. We analyzed relevant YouTube videos for comments and examined Facebook groups related to HVAC for user posts and discussions.

After selecting the samples, we extracted the data from these sources and stored them in a structured format suitable for import into Dedoose. This involved copying the posts, comments, discussions, and reviews into a document or database that could be easily manipulated for analysis. Sources were categorized as either “Threads” (Reddit, Stack Exchange); “Videos” (YouTube); “Social Posts” (Facebook, Twitter); “LinkedIn” for LinkedIn articles; “Website”, and “Reviews” for product or service reviews (Yelp, Amazon, Consumer Reports).

Coding Process

We developed an initial coding scheme based on predefined themes such as usability, energy efficiency, compatibility, installation issues, and user satisfaction. Example codes included installation difficulties, energy savings, compatibility issues, user interface, and customer satisfaction. We then imported the collected data into Excel and organized them by source and type (e.g., blog post, Reddit comment). From there, data were imported into Dedoose. We conducted coding using both deductive and inductive approaches: we applied deductive coding based on the initial scheme, while inductive coding allowed for the identification of emerging themes and patterns that were not previously considered. This dual approach ensured a comprehensive analysis of the data.

Data Analysis

We conducted thematic analysis to identify key themes and patterns across the data. We used Dedoose's visualization tools to create charts and graphs illustrating the prevalence of various themes. We performed comparative analysis to compare findings across different platforms and types of grey literature. This involved identifying common issues, unique challenges, and innovative solutions mentioned by users. Finally, we synthesized the findings to provide a snapshot of public sentiment and the real-world performance of heat pumps and thermostats. This synthesis highlighted any gaps in knowledge or areas requiring further research.

Interviews

The second method was directly interviewing contractors and other stakeholders, selected through personal relationships, conference networking, and social media (LinkedIn post), with the following questions:

- What brands of residential heat pumps do you install?
- What climate do you install them in?
- Do these heat pumps have proprietary thermostats (e.g., due to variable speed inverter vs. 1-2 stage control)?
- Are the thermostats handheld remotes or wired?
- Do the thermostats have advanced features: networked, programmable, receive a price signal, occupant sensor?
- Do customers like the thermostats?
- Have you had issues with the thermostats?
- What has been your experience with sizing heat pumps? Do you oversize more than with conventional furnace/air conditioning (AC) units?
- Do you have issues with the freeze-out temperature setting or with the electrical auxiliary backup?
- Do customers ask for smart thermostats (Nest, ecobee, Honeywell Home)? If so, what do you do? Ever use Airdoo or another third-party gateway?

Results

Literature Review

Traditional Review

The first part of the literature review was simply to understand the technology and terms. This review covers variable Air Source Heat Pumps; Variable Refrigerant Flow (VRF) systems were not included. In addition, we decided to limit the study to a select number of manufacturers: according to MonkeyWrenchPlumbers[2], five of the most popular brands are Mitsubishi, Lennox, Goodman, Carrier, and Trane. Consumer Reports recommends American Standard and Trane as the most reliable (5/5), closely followed by Bryant and Carrier (4/5)[3] (Farrell and Krajeski 2023). One of the interviewed contractors who has been installing heat pumps for over 14 years uses Fujitsu and Sanden. Carrier and Mitsubishi are two of the top global heat pump manufacturers

[2] https://www.monkeywrenchplumbers.com/learning-center/best-heat-pump-brands

[3] Mitsubishi and Fujitsu were not included in the CR ratings

and serve the U.S. market. EnergySage lists the best heat pumps for cold (Mitsubishi, Carrier, Gree), warm (Trane, Goodman, Lennox) and in-between climates (Mitsubishi, Gree, Fujitsu)[4]. We decided to focus initially on Daikin, Mitsubishi, Carrier, Trane, and Fujitsu.

The term "communicating" thermostat was coined 20 years ago to describe thermostats that could receive price or demand signals (for example, using the ZWave and WiFi USNAP protocol modules for the Radio Thermostat of America thermostats), but currently the term **communicating** when applied to heat pump thermostats indicates information communicating from the thermostat and many other sensing points to the variable heat pump to control the variable flow of refrigerant and/or fan speed. Non-communicating third-party thermostats (such as single or two-stage thermostats) typically have wired relays, and do not provide this more nuanced information. Variable heat pumps are also categorized as **Wi-Fi** and **non-Wi-Fi**; this may be related to using the proprietary infrared (IR) controller (non-WiFi) versus a gateway that communicates between the heat pump and a sophisticated wall-mounted thermostat.

Heat pump **energy efficiency** (or coefficient of performance (COP)), can vary 20% throughout the day, as the efficiency is negatively correlated with the difference between indoor and outdoor temperatures (Lee and Zhang 2021). An older article suggests that the conventional control strategy for heat pumps with auxiliary heat is a constant temperature—no setbacks during unoccupied periods or at night (Ruelens et al. 2015). As of this writing, the US DOE's website on programmable thermostats suggests that these thermostats are not recommended for use with heat pumps. Setting up the temperature in cooling is fine, but setting back the temperature during the day in heating mode is inefficient (due to the potential triggering of auxiliary heat); "maintaining a moderate temperature" is recommended (US Department of Energy (DOE) 2021). Heat pump efficiency is also impacted by how often the unit cycles on and off; short-cycling (turning on and off frequently before reaching temperature) can increase costs and needlessly wear out equipment (Moor 2023).

Correct heat pump **sizing** to best match the heating and cooling loads of the home affects energy efficiency as well as comfort. Variable capacity heat pumps improve upon single-stage systems "by providing an opportunity to intentionally size systems for the dominant heating season load without adverse effects of short-cycling or insufficient dehumidification in the cooling season" (Munk, Gehl, and Jackson 2014).

Most heat pumps rely on a proprietary thermostat (whether using IR or WiFi communication) to feed the user preferences or the control commands to the heat pump (e.g., to the compressor and fan). Smart thermostats that are not integrated with the vendor's communication system (e.g., an ecobee controlling a Mitsubishi heat pump) just send on/off relay signals to the equipment: fan, heating system (stages), cooling system (stages). Thus, a single-stage or two-stage thermostat would render this variable heat pump into a single to two stage heat pump, negating the full modulation functionality and thus potential efficiency of the heat pump. Some heat pumps have a relay board with which third party thermostats can interface. A few heat pumps have the sensor data aggregation and decision-making computation occurring on the heat pump compressor itself[5], and can be controlled by simple single-stage thermostats. In some variable speed heat pumps, the communicating thermostat manages thousands of sensor data points (room temperature, coil temperature or return air temperature, or

[4] https://www.energysage.com/heat-pumps/best-heat-pumps/

[5] https://www.reddit.com/r/heatpumps/comments/154887n/best_thermostat_for_variable_speed_heat_pump/

refrigerant pressure and flow), and sends control signals to the compressor, pumps, and fan to adjust its speed or flow, and to the auxiliary heat if necessary.

Modern heat pump thermostats, both remote and wired, come equipped with various control features designed to enhance user comfort and system efficiency. These features include **timers** that allow users to set specific times for the system to turn on or off; one manufacturer features **slow ramp settings** for sleep, which gradually adjust the temperature to improve comfort without sudden changes. Many third-party advanced thermostats offer **demand response** capabilities, enabling adjusted settings based on signals from the utility company to reduce energy use during peak periods. Some third-party thermostats also incorporate **learning algorithms** that adapt to the user's schedule and preferences over time, and optimize settings automatically for improved efficiency and comfort.

A heuristic usability review of select thermostats reveals significant differences in ease of use and functionality. Popular smart thermostats like the Nest and ecobee are praised for their interfaces, featuring intuitive touchscreens and easy-to-navigate menus. These devices often include helpful prompts and clear visual indicators, making them accessible even to users with limited technical knowledge. In contrast, proprietary thermostats can challenging to use due to less intuitive interfaces. While proprietary systems may offer greater control over the heat pump's advanced features, they often require a steeper learning curve.

Supplemental electric resistance heating may be a critical component for heat pumps in colder climates. This backup heating system activates when the outdoor temperature drops too low for the heat pump to operate efficiently on its own. However, improper control of supplemental heat can lead to high energy consumption and utility bills. Ideally, thermostats would manage the integration of supplemental heat carefully, activating it only when necessary. The thermostat settings must account for the lower temperature/long cycle characteristics of heat pumps, ensuring a balance between maintaining comfort and minimizing energy use. Mismanagement of supplemental heat can result in “peaky” electricity demands, particularly in the mornings, which can strain the electrical grid.

The adoption and effective use of advanced thermostats and heat pumps raise several equity concerns. Firstly, the cost of these systems can be prohibitive for low-income households. Additionally, the complexity of configuring and using advanced thermostats can be a significant barrier for individuals with limited technical skills or those who are not fluent in English. Many modern thermostats feature small text and low-contrast icons, which can be difficult for seniors to read. Addressing these equity concerns requires concerted efforts from manufacturers to create more affordable, usable devices, and from policymakers to provide financial incentives and educational programs that make these technologies accessible. An accessibility review of the Emerson Sensi Wi-Fi Programmable Thermostat highlights points for users with visual impairments. The thermostat offers voice control through a connected app, which is accessible using screen readers such as VoiceOver and TalkBack. However, some features, like creating and editing schedules, are not fully accessible through the app, leading to challenges for visually impaired users. The Emerson Sensi also supports integration with Amazon Alexa, allowing for voice commands to adjust the temperature (American Foundation for the Blind 2017).

Grey Literature Review

Researchers reviewed 125 online sources: blogs, forums, social posts, videos, and product reviews, entered the data into Dedoose, and analyzed emerging themes. The sources reveal several unifying themes:

- Installation Difficulties: Contractors and customers noted challenges with thermostat wiring and settings. “In your picture, it looks like you have a Honeywell thermostat. This may not support variable speed heat pumps fully.” [OrganicStructure1739, r/ecobee, 2023].
- Customer Understanding: Customers often misunderstood how their systems worked.
- Usability: Interfaces of proprietary thermostats were found to be less usable compared to popular third-party thermostats. “Customers often ask for Nest or ecobee thermostats, but we usually talk them out of it as it would greatly increase energy consumption.” [ItsDijital, r/ecobee, 2023]
- Energy Savings and Demand Flexibility: Advanced thermostats could potentially improve energy savings and demand flexibility through better control sequences.

A prevalent issue identified in the literature is the **inappropriate connection of variable heat pumps** to single-stage thermostats. This often leads to operational inefficiencies and user frustration. For instance, one user reported, “I have a York system with an Affinity thermostat. I get frequent communication fault messages. The AC techs don’t have any good tools to troubleshoot communication problems and York isn’t any help. I like Nest thermostats but the York unit only works with their proprietary Affinity thermostat.” This example illustrates how variable speed heat pumps, when connected to incompatible thermostats, fail to function optimally, causing frequent communication faults and dissatisfaction among users. Similarly, another user shared their confusion regarding compatibility, stating, “I was under the impression the Nest supported multi-stage but found out the hard way it doesn’t work well with my system.” Such instances highlight the need for better compatibility and clearer communication from manufacturers to prevent these common mistakes. The Tosot and Bosch heat pumps house the computation of refrigerant flow variability on the compressor itself, allowing it to use any thermostat. “The inconsistency in communication protocols among different manufacturers complicates installations and leads to compatibility issues with popular smart thermostats like Nest and ecobee, which many homeowners prefer for their [usable] interfaces and additional smart home integration features” (Energy Vanguard 2023).

Smart thermostats require specific settings to effectively control heat pumps, particularly for handling auxiliary heating. One critical observation from the literature states, “For homes with heat pumps, the thermostat must be able to identify the auxiliary heat function. If it is specific to a gas furnace, you may not be able to control this additional function.”

In addition to single themes, we examined when these were mentioned with other issues. The integration of smart thermostats with variable heat pumps reveals a complex interplay of issues experienced by users and contractors. Notably, the most frequent co-occurrences highlight several key areas of concern:

1. **Installation Difficulties & Customer Understanding**: This co-occurrence, mentioned 17 times, underscores the significant challenges users face after installation, often compounded by a lack of understanding of the system's functionality. Contractors frequently report that customers struggle with the complexity of the installation process, necessitating considerable support to ensure proper setup and operation.
2. **Usability & Customer Understanding**: With 14 mentions, this co-occurrence reflects the difficulties users encounter in interacting with smart thermostats. The advanced

features and interfaces often lead to confusion and poor operation. Clearer guidance and usable designs are essential to improve user experience.

3. **Energy Savings and Demand Flexibility & Advanced Features**: Documented 12 times, this co-occurrence highlights the potential for energy savings and demand flexibility offered by advanced thermostat features. However, realizing these benefits requires users to fully understand and correctly utilize these features—not often the case.
4. **Cost & Comfort**: Mentioned 10 times, this pairing emphasizes the balance between the cost of these advanced systems and the comfort they provide. Users are concerned about high upfront costs, though these can be offset by long-term energy savings and enhanced comfort.
5. **Compatibility & Advanced Features**: With 9 mentions, this co-occurrence points to the challenges in ensuring compatibility between various thermostats and heat pump systems. "There is no official communication standard/protocol for inverter heat pumps and their thermostats. Thus each brand is unique" [JeffFromCali, StackExchange 2023].
6. **Maintenance & Reliability**: Highlighted 8 times, this co-occurrence stresses the concerns regarding the need of regular maintenance to ensure the reliability of sophisticated heat pump systems.
7. **Customer Support & Installation Difficulties**: Documented 7 times, this co-occurrence indicates the necessity of robust customer support to address the intricate installation challenges.
8. **Proprietary Systems and Frustration & Compatibility Issues**: Mentioned 6 times, this co-occurrence reflects user frustration with proprietary systems that limit compatibility with other components. The reliance on proprietary thermostats reduces customer choice, and hinders the overall functionality and user satisfaction.
9. **Energy Savings and Cost Efficiency & Compatibility Issues**: Documented 5 times, this pairing underscores the importance of compatibility in achieving energy savings and cost efficiency.
10. **Installation and Setup Challenges & Usability and Learning Features**: Highlighted 6 times, this co-occurrence points to the steep learning curve associated with the installation and setup of these systems.

Interview Results

We spoke with five contractors, an engineer, and a variable heat pump manufacturer; each interview lasted approximately 30 minutes. The contractors were from the San Francisco Bay Area, Central and Southern California, and Southern and Upstate New York; Table 2 shows the mix of mild, hot, and cold climates across these areas.

Table 2: Locations of Interviewed Contractors Installing Variable Heat Pumps

Area	***ASHRAE climate zone***	***Cooling***	***Heating***
San Francisco Bay Area, CA	3C Warm Marine	CDD50ºF ≤ 4500	HDD65ºF ≤ 3600
Central/So California	3B Dry	4500 < CDD50ºF ≤ 6300	
So New York	4A Mixed Humid	CDD50ºF ≤ 4500	3600 < HDD65ºF ≤ 5400
Upstate New York	5A Cool - Humid		5400 < HDD65ºF ≤ 7200

CDD = Cooling Degree Day or sum of the degrees daily mean temperature is above 50F over a year; HDD = Heating Degree Day or sum for degrees daily mean temperature is below 65F over a year.

The contractors primarily installed central ducted variable heat pump retrofits in single family homes, and mini-splits (ductless) when needed; only one contractor said his business was half ducted and half mini-splits. One contractor said he started installing variable heat pumps 7-8 years ago; another contractor started installing heat pumps last year. Advantages include filtered air, better comfort control, and less refrigerant lines for leaks. Mini-splits are commonly used when a room has unique loads or needs separate from the house, or when there are conditions that make a central system difficult to install (for example, air handling unit (AHU) is too wide for the attic, running power to the site is difficult, etc.). Many contractors only installed one brand; brands ranged from Bosch, Rheem, Trane, Fujitsu (3), Mitsubishi (3), Carrier, and Daikin. The engineer has tested several heat pumps in houses in the Central Valley of California: Daikin, Mitsubishi, Fujitsu, Panasonic, Samsung, Ecoer, and others.

Variable Heat Pump Thermostats

The common thermostat option for mini-splits is a proprietary handheld IR remote control; some brands have a wall mounted option with mobile phone interface (e.g., Mitsubishi Kumo cloud). Some customers like to use Alexa or other voice controls.

The vast majority of central variable heat pumps require a proprietary thermostat. There is a high-end Trane product that has a relay panel that acts as an interface between the equipment and a 24v third party thermostat. Bosch variable speed heat pumps can use a third party 24v thermostat since all the “smarts” are on the unit itself; one Bosch representative says it doesn’t impact the comfort. One contractor remarked that the proprietary thermostats perform better for comfort and likely energy savings on high-performing homes (that are insulated and sealed); third party thermostats like Nest and ecobee will perform better on uninsulated poor performing homes. High end Carrier systems require the proprietary thermostat (Infinity), which is expensive, but you only get the variable capacity with that thermostat.

Thermostat Features

The proprietary thermostats typically have Wi-Fi and are programmable; some do not have a smart phone app nor Wi-Fi, but allow a schedule. However, one contractor remarked that “most people keep [the thermostat] on hold—no programming.” The Trane Nexia thermostat has diagnostics that are very helpful to contractors, such as an alert when the system runs too long without reaching the target temperature or setpoint.

Grid Supporting Thermostats

Thermostats that automatically change setpoints based on a utility or price signal (Demand Response) are not in demand; one interviewee noted that they are installed “only if someone asks, or if required for rebates.” Most people don’t want someone to take control of their system. One contractor works in the Modesto Irrigation District where there is no Time of Use or Critical periods—fundamental for a Demand Response program—at this time. The engineer said that Daikin has one product that is Demand Response capable. A fellow researcher mentioned, of the grid-supporting thermostats certified by Energy Star, none are compatible with variable heat pumps. One contractor mentioned that there is one version of Trane thermostat (TLX8) that does qualify for Energy Star, but it is not the high-end model with sensors and zones, or with the relay panel—these in fact do not qualify. The engineer mentioned that Carrier used to have an Energy Star thermostat, but no longer.

Customers and Proprietary Thermostats

One contractor mentioned that he wished proprietary thermostats were better; another said customers hate the proprietary hand-held control for mini-splits (which does not allow programming, just a timer), and another mentioned that the mini-split cloud interface was terrible. One contractor said that technically-savvy customers like the proprietary thermostats, such as Trane. Trane used to require the contractors to sell their proprietary thermostat to get a promotion; the contractor would install it and then remove it. For customers who are not technically-savvy, especially seniors, the contractor would often install a simple non-Wi-Fi third-party thermostat such as the White Rodgers for the backlight and large numbers. The engineer said that the mini-split manufacturers know that they need to improve thermostat interfaces, and he felt such products would be coming out soon. He said that in general customers don't like the proprietary thermostats—both the interface and the functionality. However, he sees a trend in manufacturers designing systems to work with standard 24v thermostats (Samsung has a product with an adaptor and only sells it with standard third-party 24v thermostats), and building new products (Fujitsu is moving this way as well). Another contractor also mentioned that Fujitsu will enable a mobile phone app interface via Wi-Fi by this Summer 2024; right now, one can use a $600 converter kit if one wants to add a third-party thermostat. The contractor can program the unit through the internet—adjusting the air handler, balance among supply registers, target air flow—and then install the converter, which is hard-programmed. One contractor said about 15% ask for Nest or another third-party thermostat because they want control; the proprietary thermostat doesn't allow them control and doesn't have a fancy app or Wi-Fi. Two contractors tell customers up front that the system will work better with the proprietary thermostat, and try to talk them out of a third-party thermostat. One researcher mentioned installing an ecobee thermostat to interface with her Mitsubishi heat pump. She had to set the dip switches in the adapter box to enable the appropriate control, which the installing contractor did not know how to do. In general customers do not like the learning feature of the Nest, but sometimes ask for a Nest thermostat. One contractor mentioned that customers want to run an app on their phone, not use a thermostat interface; however, some functionality is lost when using the phone app.

Sizing and Setbacks

One contractor said that customers are used to furnaces making the room hot quickly, but heat pumps are different. The contractor says they have this conversation with each customer: don't turn the heat completely off at night and expect the inside temperature to heat up quickly in the morning. Another contractor said that they have never had a customer complain about the system taking too long to heat up; at the time of the initial sale, they explain to the customer that heat pumps may take 50% longer to heat up compared to gas furnaces. Another contractor said he sets heating or cooling setbacks to only 2F or so, nowhere near the 8F setbacks often recommended to save energy; he stated that an 8F setback on a 110F day will cause problems. The engineer said that in California, heat pumps are sized based on the cooling load; if the heating capacity is too low, one can add backup heat. Most interviewed said they use calculations to size to the appropriate load, and that oversizing is not a problem. Undersizing for heating is particularly bad in areas concerned about grid stability and emissions because one is relying on electric backup. Oversizing might help for morning ramp ups and setbacks.

Issues with freeze out temperature or back up heat

One contractor installs in an area that sees freezing temperatures only a few days per year. The systems with the 120V air handlers are pretty cold without the heat strips; systems do in fact use the defrost setting. Another contractor mentioned with periodic defrost, customers may feel cold air and they need to be warned that this will happen. He said that 15-20 years ago, the heat pumps weren't as good as they are today and the heating strips were necessary; in the last 5-7 years the systems have improved so the heating strips are not needed. Another contractor mentioned that the Bosch system doesn't really need the heating strips; the contractor often tells the customer the heating strips can be added later, and they rarely add them. Another contractor said one does not need the heating strips in any climate with good HVAC design and home performance; he mentioned an installation in Minnesota with a 2-ton unit: even with temperatures down to -20F, the heat strip was never used. A contractor from NY said he absolutely deals with the building envelope first, and if the system is sized appropriately, heating strips are not needed 98% of the time.

Energy savings

The engineer has been running a heating season test comparing energy consumption with a constant temperature versus a setback schedule with both proprietary and third-party thermostats in California's Central Valley. The results will become available in Summer 2024, but preliminary results show that energy use is nearly identical due to compressor/fan behavior. There are inefficiencies for both proprietary and third-party thermostats. With the proprietary thermostat, the fan speed was constant and consumed energy; the third-party thermostat was able to modulate fan speed with the compressor.

Other Issues

Sometimes the conversation strayed from the script. One conversation steered towards heat pump **functionality**. The engineer explained that the low-capacity settings for variable heat pumps are quite different for different manufacturers. For example, the Bosch starts off low and then after 10 minutes is at 70% of full capacity, then shuts off when the target temperature is reached. If the target temperature is not reached in a given amount of time, then the system moves into a high-capacity mode. Some models run low for hours and some cannot; some are efficient at low speeds and others not: manufacturers do not publish this information. Another conversation addressed **California energy codes** regarding thermostats and variable heat pumps: does one have to test to ensure that the capacity varies over time? **Cost** was another factor: variable capacity heat pumps are expensive. Instead, one could purchase a two-stage heat pump with higher SEER that works with a 24v third-party thermostat and save the money. This is especially true for cooling-dominated climates (like California). However, heating-dominated climates would benefit with a variable capacity system. **Contractor training** has increased especially over the past five years, but more is needed, especially from the manufacturers. Two contractors mentioned the impact of **duct sizing**: heat pumps deliver more air, and ducts sized for typical AC systems will not work for heating in NY.

Discussion

The review and analysis of the literature, user-generated online content, and interviews reveals a variety of experiences and misunderstandings regarding the integration of smart thermostats with variable speed heat pumps.

The peer-reviewed literature review on variable heat pumps found papers on improving controls through Machine Learning, Model Predictive Control, or using other sources of data to improve energy efficiency given the relatively shallow thermostat setback setpoints used by heat pumps. However, we could not find any papers on customer perspective, usability, and changes in how the end user uses their thermostat with variable heat pump systems.

The grey literature review proved useful in identifying the problems both contractors and residents face with third party or proprietary thermostats and variable heat pumps. Evidence from online forums, blogs, and reviews indicates a significant learning curve for both users and installers. For example, discussions on Reddit's r/heatpump and HVAC forums frequently address the challenges and solutions related to thermostat compatibility and installation complexities.

Customers generally express mixed feelings about the integration of thermostats with their heat pump systems. Many users appreciate the usability and advanced features of smart thermostats like Nest and ecobee, but reported compatibility issues and operational frustrations when trying to connect these to heat pumps.

Contractors emphasize the use of proprietary thermostats to achieve optimal performance. One contractor explained, “I install Fujitsu and Sanden heat pumps and only use the proprietary wired thermostats; if any other thermostat were used, one wouldn’t get the variable speed operation.” Another contactor commented that they would walk away if a customer insisted on a third-party thermostat instead of the proprietary thermostat. Contractors recognize that the proprietary thermostats are not as usable as third-party thermostats, with reliable mobile apps and ease of control, but a few said manufacturers are making product changes to allow these third-party thermostats. However, preliminary testing does not provide conclusive evidence of energy savings with proprietary thermostats compared to third-party thermostats.

This research underscores the need to draw from a wider and more diverse body of data to capture the full spectrum of user experiences and technical challenges, especially for nascent technologies. By analyzing content from forums, blogs, and reviews, researchers can gain a deeper understanding of real problems customers and contractors are facing. Without much quantitative research to pull from, our study relied on qualitative means (literature review and interviews), which was by no means exhaustive or comprehensive, but allowed us to establish themes and identify common problems. This study aimed to spark conversation and encourage further research and testing into the integration of usable, advanced, and grid-supporting thermostats with variable speed heat pumps.

Conclusion

Climate change mitigation is driving electrification across the globe, including the installation of energy efficient variable capacity heat pumps. This technological shift represents a new paradigm in how people use thermostats and how these thermostats reduce energy consumption and promote grid resilience. End users have grown used to colorful touchscreen thermostats with mobile apps that facilitate remote control. Utilities use these smart thermostats in their demand response programs to improve grid resilience. However, the majority of variable speed heat pumps may require the manufacturer’s proprietary thermostat to perform optimally. Key energy savings measures, such as setbacks during unoccupied periods, may not be effective with this new technology.

One finding from this study was methodology. A traditional academic literature review found very little quantitative data on how existing variable capacity heat pumps and thermostats are used by people; much of the research is in modeling or simulation of new algorithms to improve energy efficiency. Through the “grey” literature review of non-peer reviewed blogs, forums, reviews and so on, researchers identified many problems with integrating third-party thermostats with variable heat pumps. Despite the "murky" name, grey literature has been a rich source of information on how contractors and homeowners deal with these technologies, and methods should be further developed for analyzing grey literature in a robust and objective way. Interviews with contractors and other stakeholders corroborated the issues and provide context.

This research uncovered several problems with thermostatic control of heat pumps; we recommend further quantitative field work as well as qualitative research to understand what education is needed for both contractors and residents, as well as which policies or standards might support energy-efficient and grid supportive operation.

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