Project Report

Electrification of Nonresidential Space Heating: Designer Interview Report

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Source: Red Car Analytics

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Credits

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INTRODUCTION

All-electric buildings are increasingly prevalent in California due to market demand, local government gas bans and all-electric ordinances, and state carbon reduction goals. Despite the push toward all-electric design, there are still several barriers to wholly electrifying space heating in today's commercial buildings, and numerous risks associated with electrifying buildings without first understanding the implications of different design and equipment choices.

A general skepticism seems to permeate the market, ranging from general unfamiliarity with the idea, to building designers and owners who see electric heating and heat pump technology as untested and less dependable than current technology. Identifying the real and perceived barriers to, and best practices for, all-electric HVAC solutions is critical for long-term adoption and building energy code development.

To address this need, the Code Readiness research team conducted a set of interviews with leading mechanical engineers who have electrification design experience in California to identify technical opportunities and barriers to market adoption. Through personal interviews, these professional engineers shared their views on the opportunities and challenges of all-electric, high-efficiency HVAC technologies. Key goals of this study include providing information to support future enhancements to California statewide Codes and Standards for cost-effective, energy-efficient building electrification and identifying gaps in knowledge that need to be addressed in future studies.

OBJECTIVES

The objectives for this study and report are as follows:

1. Identify unique electrification HVAC technologies being used in nonresidential building design, characterized by building type and size, including new construction and major renovation projects.
2. Prepare a summary for each electrification HVAC technology identified: its technical and code compliance challenges, scenarios where each technology is currently being used, and potential and feasible scenarios for the application of each technology.
3. Identify knowledge gaps and future research needed to improve energy performance for all-electric HVAC systems, and develop Title 24, Part 6 requirements to reinforce best practices and ensure efficient operation.

THE STUDY

Since the majority of non-residential buildings designed and constructed in California use natural gas as the primary fuel source for space heating and reheating, there are relatively few engineers with direct experience designing all-electric buildings. The research team hypothesized that the experiences and challenges encountered by engineers with electrification design experience might provide a preview of the issues and opportunities the building design at large will encounter as all-electric building designs are required by code.

The research team interviewed leading mechanical design engineers to understand client types, construction types, system characteristics, market trends, and barriers to market adoption of all-electric nonresidential buildings. The interviewees in the sample are currently practicing throughout California and some even outside the state; however, the interviews were structured to elicit answers and feedback specific to California design and building codes. All interviewees work for design firms, though their interview responses were based on their personal professional experience and did not necessarily represent their company's views.

Interview questions focused on all-electric applications for space heating, including electric resistance, air-to-air heat pumps, variable refrigerant flow (VRF) heat pumps, and air-to-water heat pumps, as well as thermal energy storage. The questions also included topics such as the benefits and drawbacks of designing all-electric projects, and the technologies, policies, and regulations perceived to promote or hinder a project.

Interviewees had first-hand experiences on various projects ranging from 10,000 sf to 1,000,000 sf, including universities, commercial offices, public or civic facilities, schools, laboratories, and multi-family residential. While all the interviewees' companies have completed all-electric projects, the estimated ratio of current projects designed to be all-electric to other mixed-system projects varied by the interviewee. Of the seven companies represented, 4 companies were currently 100% engaged in all-electric projects, either in design or construction. 2 companies reported at least 50% of the company's projects were all-electric, and 1 company that at least 20% of company projects were all-electric.

The following interview findings are organized by technology. Each technology section contains a general technology overview, opportunities and challenges of the technology, and the considerations for energy code enhancements and informational gaps that might warrant further research.

TECHNOLOGY SPECIFIC FINDINGS

ELECTRIC RESISTANCE HEATING

TECHNOLOGY OVERVIEW

While most designers mentioned heat pumps as the primary means of electrifying space heating, several presented applications for which electric resistance heat may be a beneficial solution to the goal of electrification. Fundamentally this technology uses direct electricity for space heating to maintain thermal comfort. Typical systems using this technology include baseboard radiators, convectors, or a forced air unit with a fan.

OPPORTUNITIES

Applications with High-Performance Envelopes

Electric resistance for space heating as a system is often considered in combination with high-performance building envelopes, such as those constructed using passive house principles, in which case the overall heat losses are substantially reduced, and the size of a heating system can be small and infrequently used. Current compliance pathways prescriptively limit this configuration which is often challenging for multi-family projects that are otherwise not utilizing a performance pathway.

Low First Cost in Affordable Multi-Family Housing

Many projects require design engineers to seek creative solutions for meeting project budget and comfort requirements. Working with affordable housing corporations, a few designers discussed evaluating baseboard unit heaters to save first costs on mechanical systems. The magnitude savings mentioned per unit was nearly 10x more than the cost of using a mini-split heat pump one interview noted. In a different application, another engineer utilized electric cove heaters combined with a high-performance envelope, dedicated heat recovery ventilator (HRV) units equipped with bypass and night flush, and operable windows for natural ventilation with ceiling fans. The interviewed designers primarily work on projects in the greater California bay area, though they note this approach would apply to any region in the state.

CHALLENGES

Limited Prescriptive Compliance Options

While electric resistance is allowed in the performance compliance pathway, electricity costs can be three times the cost of gas for the same unit of heat, making it very difficult to achieve code compliance through the performance path with electric resistance heating as the primary source of building heat. It is also difficult to achieve prescriptive compliance using electric resistance heating, which is prohibited except when meeting one of the allowed exceptions.

Some of the scenarios worth mentioning where electric resistance heating is prescriptively allowed for space heating:

1. Where 60% of a site's heating energy is from site-solar or energy recovery (Exception 1 to Section 140.4(g))
2. Where electric resistance is supplemental to a heat pump, and the heat pump capacity is more than 75% of the design heating load (Exception 2 to Section 140.4(g)). This is most commonly the case for air-to-air packaged heat pumps, though could also apply to a larger central plant based on the language as written with no restriction on electric heat so long as the heat pump's capacity meets the criteria.
3. Several options give allowances for small electric resistance use, under 3kW or in small building areas.

Effectively, electric resistance by energy code prescriptively requires a substantial primary system which makes buildings with only electric resistance limited. While some projects have been able to increase building thermal performance to use electric resistance-only heating, these projects are rare based on comments from the interviewees.

Energy Code Considerations

Several informational gaps and questions were identified throughout the interviews that could serve as areas for further study relating to space-heating buildings with electric resistance heat.

1. Identify what the energy costs are from operating electric resistance heating systems today, even in buildings with high-performance envelopes. What is the gap between how electric resistance and building loads are simulated versus how they operate given the low efficiency and potential market risk of electric heat?
2. Were electric resistance heating systems to be implemented in more commercial and multifamily buildings, what impact, if any, would there be on grid infrastructure costs required to support the connected load? What increase in energy rates could be expected if utilized in larger applications in California?
3. Electric heat was mentioned in several buildings without active cooling and natural ventilation. With increasing extreme climate events due to global climate change, are there heat stress risks or resiliency concerns to constructing housing and workplaces without a cooling system?

Variable Refrigerant Flow (VRF) Heat Pump

Technology Overview

Source: Red Car Analytics

Figure 1: VRF Air Source Heat Pumps

Variable Refrigerant Flow (VRF) systems are a type of heat pump technology that pumps the refrigerant between an outdoor unit and multiple indoor units. The mechanics are the same as other heat pump technologies in terms of compressors and fans; however, heat is transferred primarily through the refrigerant piped through the building. The size of the distribution system is much smaller than conventional mixed-air systems. This system primarily utilizes variable-speed compressors, fans, and modulating refrigerant valves, combined with built-in controls that actively modulate the system's compressor based on the amount of heating and cooling needed. An additional popular feature is the ability to provide simultaneous heating or cooling from the same compressor (i.e., heat recovery), providing increased applications. Multiple indoor fan coil units or cassettes can be used all at once with typical systems ranging from 5 to 20 tons in module size. Though VRF can pull heat from the air or water, the designers interviewed primarily used air-source VRF systems.

VRF systems were mentioned several times by interviewees as a type of baseline or base starting point for several mid-sized and smaller building projects. The interviewees also identified opportunities and challenges of using VRF systems.

Opportunities

Popular in Typical Applications

VRF systems were identified as the most common solution for electrification in smaller commercial buildings. One subject matter expert noted they see VRF in buildings where the peak cooling and heating needs are 100 tons or less, which would equate to a building 50,000 sf or smaller assuming most buildings require 500 sf/ton. In terms of the standard building prototypes used for code change evaluation in California, this would include the small and medium offices, the standalone retail, and small school prototypes.

Use in Multi-Family Buildings

Several designers noted that VRF systems could be a key system for multi-family projects, even if the equipment comes at a premium. In many projects, contractors prefer this system for streamlined installations that save time and reduce costs. Owners also like the equipment warranties and reliability offered by manufacturers.

Many multi-family buildings are currently looking for ways to sub-meter energy use, including heating and cooling. Several VRF systems provide a method for doing this at the individual fan coil level.

One benefit of VRF systems in multi-family projects is the ability to eliminate any additional defrost heaters that would otherwise be installed if each unit had an individual heat pump. With multiple central compressors in each system, the central units can undergo defrost without disruption to indoor units.

Commercial Building Retrofits

In existing buildings, VRF systems can be used for less invasive and, in some instances, allow for partial occupancy of a building while renovating the heating and cooling systems.

Higher Efficiency and Confidence in Compressor Technology

VRF heat pumps are a more advanced technology than other heat pump technologies currently available. Most VRF products come with variable speed inverter-driven compressors to significantly increase operational efficiency; standard heat pumps do not have inverter-driven compressors by default and are lower efficiency in comparison.

CHALLENGES

Refrigerant Quantities and Piping

Several designers mentioned the challenges and fears about the quantity of refrigerant required and the risk of increasing global warming from system leakage. One designer noted that some systems rely on field installation of refrigerant piping, which can be installed using multiple pipe fitting techniques, typically either welded pipe or flared connections with a screwed coupling. In either case, the risk of the installation being successful is dependent on field configurations and skill and the coupling method used. In contrast, other heat pump products come with a factory-sealed refrigerant system and do not require refrigerant piping throughout the building which may lead to reduced refrigerant leakage.

Most products available in California use R-410a with a global warming potential (GWP) of 2,088[1]. Several VRF systems are now utilizing R-32 with a GWP of 644. However, both R-410a and R-32 are classified as semi-flammable refrigerants (known as AL2 types) and are currently not allowed to be used in California for indoor usage, making systems like VRF difficult to specify.

1 Global warming potential is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide. CO_2 has a GWP of 1.

Proprietary Maintenance Contracts and Parts

Most VRF systems are provided by companies that sell the system and maintenance as a whole package. This limitation makes it challenging for certain owners with full maintenance staff who may wish to maintain their equipment and buy off-the-shelf parts.

Energy Code Considerations

Through the perspective of those interviewed, and the authors' knowledge of the current energy code and the code change process, several informational gaps and questions were identified that could serve as areas for further study relating to heating buildings with VRF heat pump systems.

1. What data or studies (from installations inside or outside of the United States) exist on AL2 type refrigerant system installation demonstrations and their associated leakage risks?
2. First cost can be the motivating factor for small buildings to electrify with VRF heat pumps; what are the alternative high-efficiency all-electric systems options and what is the incremental cost and/or construction challenges in using these alternatives?
3. What data and lessons can be leveraged through upstream incentive programs that support inverter-driven compressors in heating and cooling systems?
4. What types of refrigerant piping fixtures and fittings can be used to support low-leakage VRF systems? Is there an incremental first cost or skill requirement to accomplish low leakage VRF system installation?

Packaged and Custom Air-to-air Heat Pumps

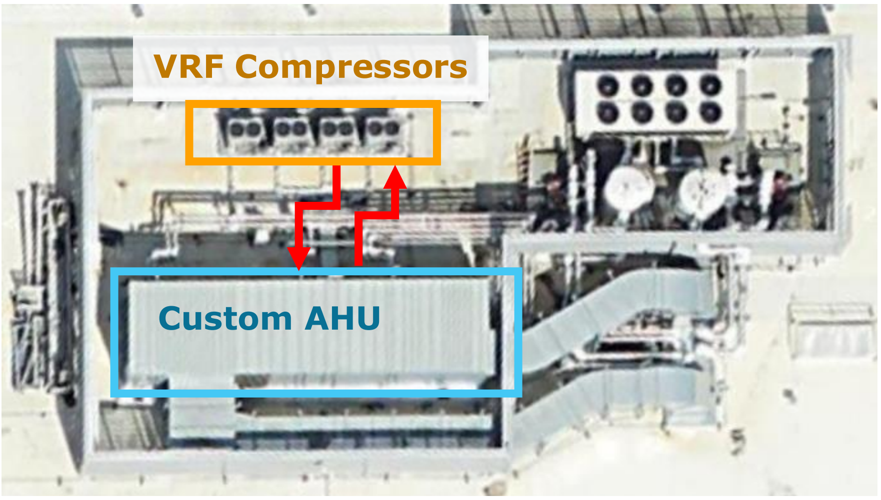
Technology Overview

Air-to-air heat pumps are reversible cooling and heating units. Several packaged products are available with basic functionalities and size ranges. See Figure 2.

Source: www.engineeredproducts.com/seasons-4/

FIGURE 2: PACKAGED AIR-TO-AIR HEAT PUMP

More custom configurations are being utilized for higher-end buildings, where the refrigerant coil in an air handler is serviced by a heat pump system, typically using air source VRF compressors as seen in Figure 3. These systems can provide more customization of controls and components.



Source: Google Earth

FIGURE 3: CUSTOM AIR-TO-AIR HEAT PUMP WITH SEPARATE COMPRESSORS

In the figure above, the air cooled VRF compressors are piped to refrigerant coils, as indicated by the red arrows, providing heating and cooling to a series of refrigerant coils built-up in the custom air handling unit.

Opportunities

<u>Use in VAV System Applications</u>

Air-to-air heat pump units in air handling units, using a compressor for cooling or heating, are a centerpiece of several alternate variable air volume (VAV) systems. Many medium-sized commercial buildings today (25,000 sf to 150,000 sf) are built with natural gas for space heating, DX cooling coil for cooling and a VAV distribution system with zone level heating coils, where 100% of the building heat is provided at the zone level. The air-to-air heat pump device has allowed multiple modified versions of a VAV reheat system and can be used to do some of the space heating centrally, pre-heating ventilation air to a neutral temperature 55F to 60F, and using zone heating coils for final heating. System configurations highlighted by the designers interviewed included:

1. Packaged central Heat Pump with a separate heating-only hydronic heat pump to VAV boxes with hydronic reheat,
2. Dual duct systems with custom air-to-air heat pumps to dual duct boxes with no hydronic piping to zone units, and
3. Thermally zoned buildings with air-to-air heat pumps for each primary façade and zone terminal air diffusers with no hydronic piping to zone units.

<u>Low-Cost Packaged Products</u>

Several designers mentioned using packaged air-to-air heat pumps in projects requiring a low-cost solution. For some projects with limited budgets, designers cited this solution as the go-to means for providing an all-electric solution.

Packaged Heat Pump with Separate Heating only Heat Pump

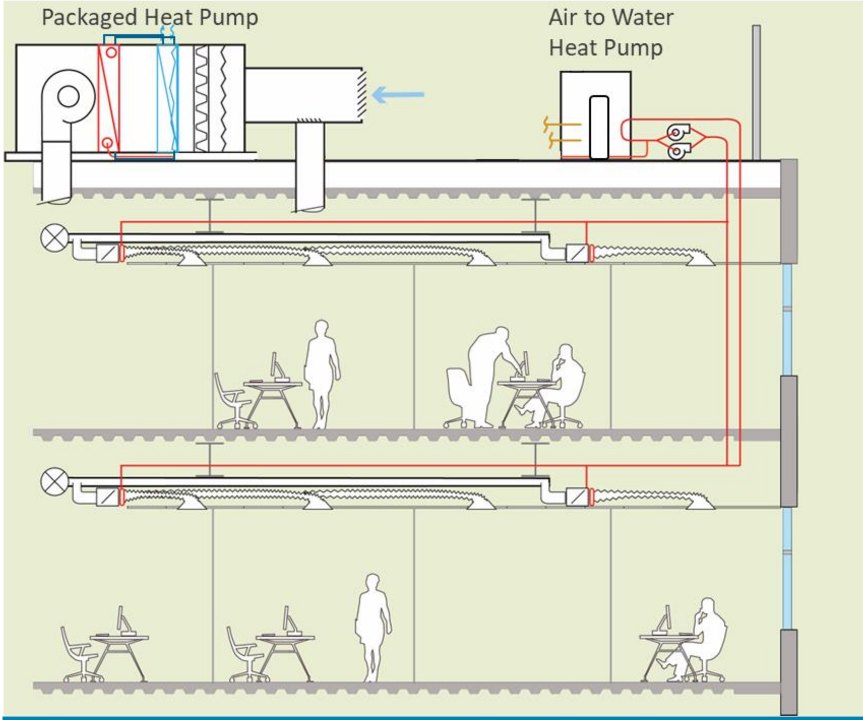


FIGURE 4: VAV REHEAT WITH SEPARATE AIR-TO-AIR HEAT PUMP FOR CENTRAL UNIT AND HEATING ONLY HEAT PUMP FOR REHEAT

Another interesting design strategy was using packaged heat pumps for thermal zones in the building (thermal dynamic zoning), serving a vertical side of a building, such as the North, South, East, or West with variable airflow diffusers to modulate airflow locally.

Thermally Zoned Air-to-air Heat Pumps

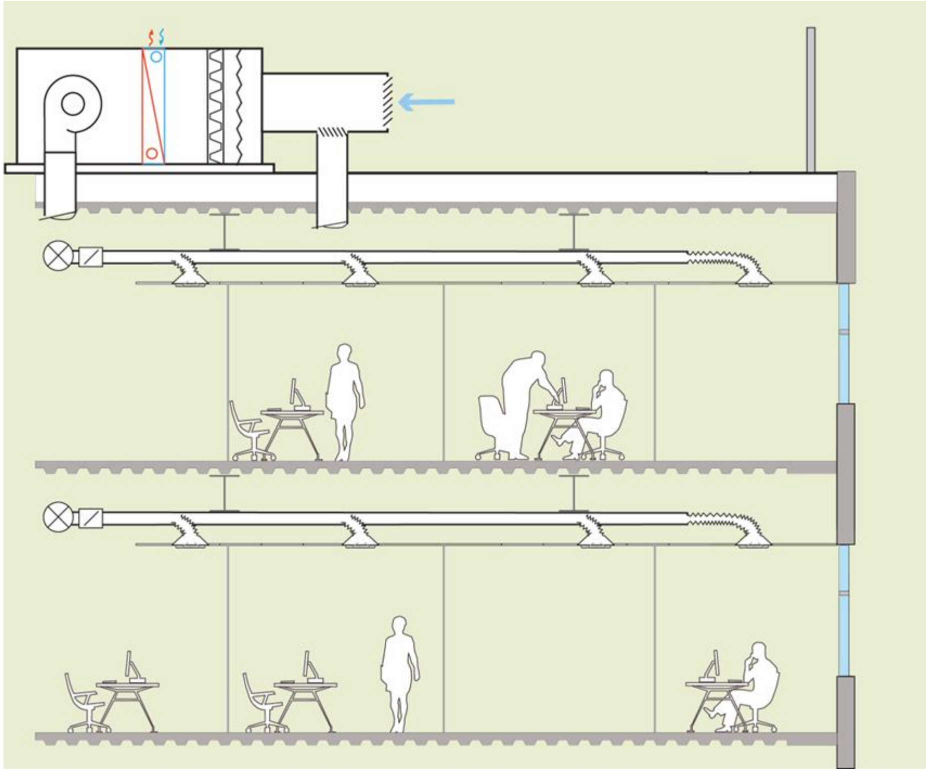


FIGURE 5: THERMALLY ZONED MIXED AIR DISTRIBUTION SYSTEM WITH AIR-TO-AIR HEAT PUMPS

Several designers noted that for small or mid-size buildings, these types of heat pump packaged solutions or VRF are often the go-to strategy for electrification.

<u>Use of Dual Duct Distribution</u>

One designer discussed a strategy of using custom air handler units with a heat pump coil and a dual duct distribution system, providing hot and cold air to each zone, and eliminating reheat. This configuration also benefits from keeping all refrigerant and heat pump components in one location, typically on the roof, and eliminates any hydronic piping inside the building which would typically be used to provide zone heating to VAV boxes with reheat coils.

Dual Duct with Custom Air-to-air Heat Pump

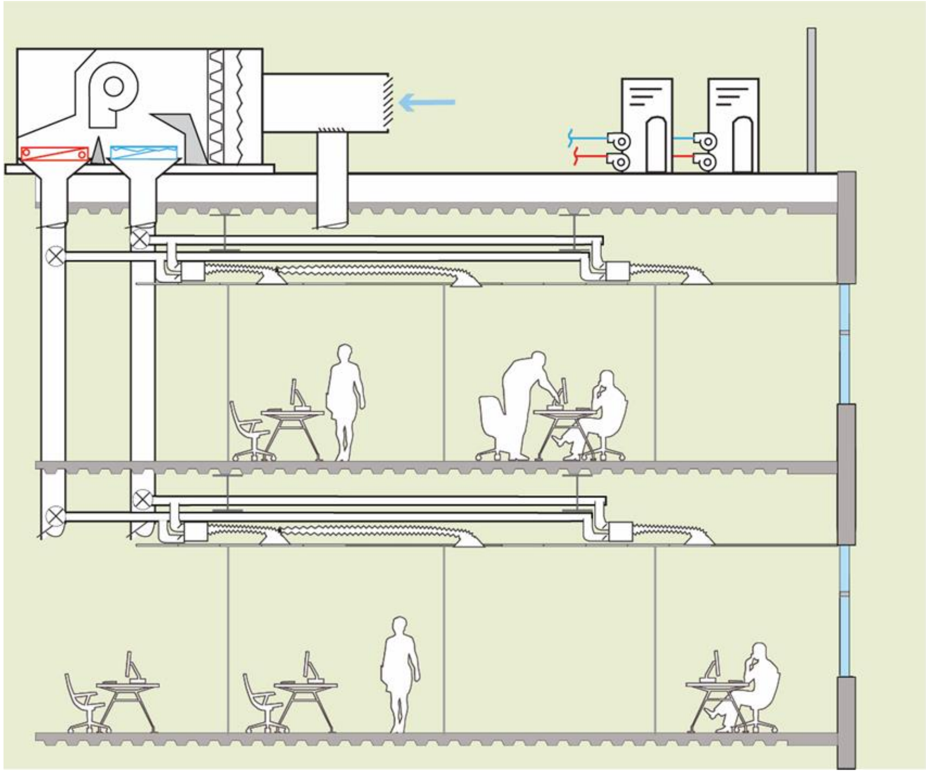


FIGURE 6: DUAL DUCT DISTRIBUTION FROM CUSTOM AIR-TO-AIR HEAT PUMP

CHALLENGES

Detailed Controls in Packaged Equipment

Several designers commented on the common challenge of limited functionalities in packaged air-to-air heat pumps, primarily limited to very basic control configurations. This programming limitation makes monitoring challenging, requiring a more developed Building Management System (BMS) and ultimately increasing a project's cost and operational complexity.

ENERGY CODE CONSIDERATIONS

Through the perspective of those interviewed and the authors' knowledge of the current energy code and the code change process, several informational gaps and questions were identified that could serve as areas for further study relating to heating buildings with air-to-air heat pump systems.

1. Are electric resistance or natural gas backup heating elements used for cold climate conditions in air-to-air heat pump installations? What is the impact and/or added load of backup heating, and how often are new or existing buildings relying on this component?
2. Are supplementary controls or technologies available to effectively shift load or reduce electric resistance backup heating elements?

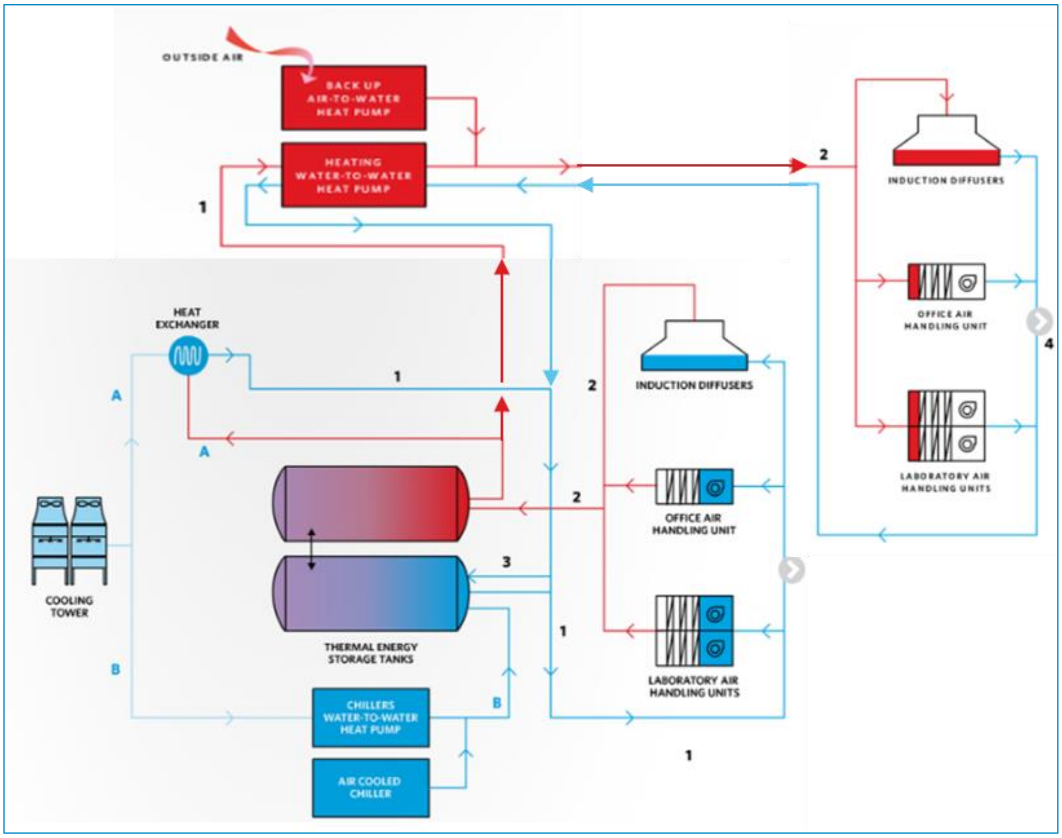
3. Is there a need for additional heating-specific fault detection and diagnostic control sequences in air-to-air heat pumps to ensure equipment life and operational efficiency?

HYDRONIC HEAT PUMPS, AIR-TO-WATER

TECHNOLOGY OVERVIEW

FIGURE 7: AIR-TO-WATER HEAT PUMP PHOTO

Hydronic heat pumps, air-to-water heat pumps, or heat pump boilers are devices that move heat with refrigerant between air and water, creating hot or cold water. There are many variations of air-to-water heat pumps. Some systems only heat or cool at any given time known as 2-pipe systems, and others provide simultaneous cooling and heating, known as 4-pipe systems. Depending on a building's thermal loads and the type of hydronic heat pumps used, additional components are required to maintain stable operations, typically buffer tanks for temperature control. Figure 8 below provides an example of an air-to-water heat pump system configuration.



Source: www.jcvi.org

FIGURE 8: DIAGRAM OF VENTER INSTITUTE HEAT PUMP CENTRAL PLANT CONFIGURATION

In many instances, the use of air-to-water heat pumps will be accompanied by a water-to-water heat pump and or thermal storage tanks, as shown in the figure above.

OPPORTUNITIES

<u>HVAC Applications and Distribution Use Cases</u>

Several interviewee discussions focused on the opportunities for hydronic heat pumps to serve multiple types of building distribution systems for heating, cooling, and ventilation. Systems mentioned range from traditional VAV with hydronic reheat, to fan coils, chilled beams, and radiant slab or radiant panel buildings.

<u>Mixed Air System Options</u>

One engineer described using hydronic air-to-water heat pumps as a means of replacing both cooling and heating functionalities in a traditional mixed air VAV system that would typically use hydronic reheat from a boiler. The diagram below illustrates the system components.

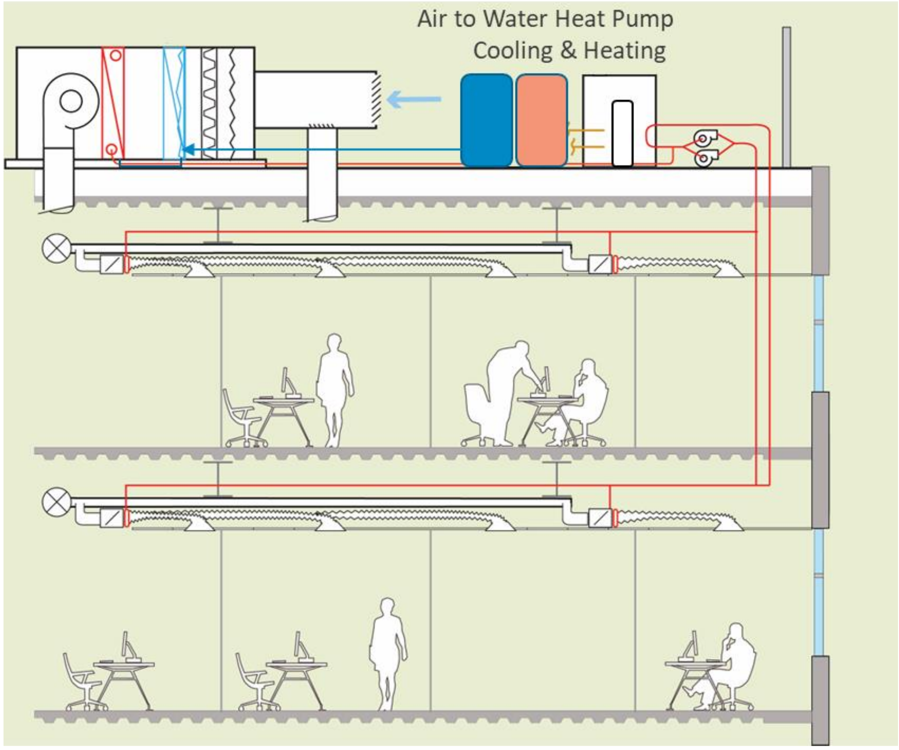


FIGURE 9: VAV REHEAT WITH SHARED AIR-TO-WATER HEAT PUMP UNIT

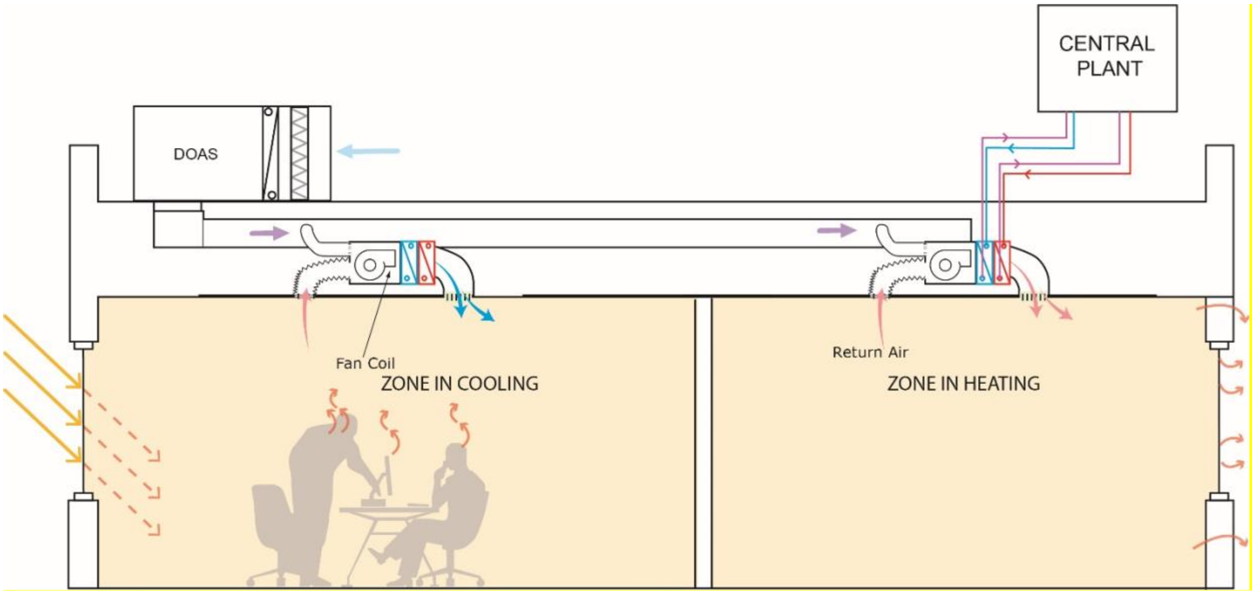
An air-to-water heat pump, typically a 4-pipe unit, serves the air handling unit cooling and heating coils, located at each VAV box. The air handling unit in this configuration is usually required to be a custom air handler, which can result in higher first costs than pre-packaged equipment.

This configuration was discussed as a strategy for larger or higher-end buildings, where the controls may be more advanced, and/or the number of air handling units required could be increased without changing the air-to-water heat pump. The distribution system for space heating and reheating is required to be sized for lower-temperature hot water, between 100°F and 110°F, increasing the size of coils and piping.

The other air-based distribution mentioned was the dual duct configuration which effectively matches the configuration (shown in Figure 6) with a hydronic heat pump instead of a custom air-to-air heat pump.

Fan Coil and Radiant Heating and Cooling

Half of the engineers interviewed noted how the use of air-to-water heat pumps and hydronic distribution systems, including fan coils, chilled beams or radiant, tended to be the ideal configuration in larger building applications or more complex buildings, such as laboratories. Hydronic fan coils were noted as a commonly used distribution system in higher education for all-electric buildings and an alternative to refrigerant-based VRF systems.



Source: Red Car Analytics

FIGURE 10: ILLUSTRATION OF FOUR PIPE FAN COIL DISTRIBUTION TO TWO ZONES WITH DOAS AND CENTRAL PLANT

The use of in-slab radiant piping was mentioned by several engineers as a preferred solution for comfort and energy efficiency though can be at a premium cost. This was primarily for office, civic, or academic buildings and in buildings where the capacity of a central air-to-water heat pump was cost-effective.

CHALLENGES

Industry Reputation

Several designers noted a lack of industry knowledge as a general challenge in adopting larger hydronic heat pumps. Compared to other large systems like chillers, hydronic heat pumps are still relatively new to many designers and installers. There is a lack of industry familiarity in installing and commissioning them, which can lead to difficulty in operations. One engineer noted repeated startup issues with certain hydronic heat pumps. As a result, contractors have asked to use alternate products that are frequently more expensive, believing them to be more reliable.

As with any product, internal control challenges exist when integrating with a building management system (BMS). Designers noted this seemed to be the case for hydronic heat pumps, although mainly dependent on the selected manufacturer and product. Still, every designer interviewed noted a general lag in the industry for available hydronic heat pumps in California, both in the number of manufacturers and in general industry support.

Product Efficiency Ratings

Another challenge identified in designer interviews was the lack of standard efficiency ratings. Several designers noted the challenge of comparing equipment-rated efficiencies and knowing what a manufacturer included in the efficiency or did not, such as accounting for defrost cycles. As of 2020, AHRI Standard 550/590 test procedures now include air-to-water heat pumps for large chillers and heat pumps, though in general, new test procedures lag products and installations by several years.

Additionally, some designers mentioned concerns about maintaining operation and efficiencies at more extreme temperatures, such as below 30F or above 120F for cooling. Their concern focused on capacity and defrost cycles for hydronic heat pumps in colder conditions, and more extreme or hotter conditions, focused on the compressor and refrigerant components and their ability to maintain cooling. While both represent extreme conditions, such functionalities may be necessary to include in product certification to better understand the application boundaries.

Physical Size Requirements

Another challenge designers noted was requiring additional space for hydronic heat pump systems in retrofits or new construction, where boilers would have been the basis of design. One designer noted how heating systems are frequently oversized or include redundancy, and while rightsizing may allow for smaller heat pumps, the typical heat pump footprint requirement is still several magnitudes greater than traditional natural gas heating systems. While a combined cooling and heating system may reduce the impact on physical space this configuration may not always be the case and several designers noted heating only heat pumps as the alternative to a natural gas boiler.

Energy Code Considerations

Through the perspective of those interviewed and the authors' knowledge of the current energy code and the code change process, several informational gaps and questions were identified that could serve as areas for further study relating to space-heating buildings with air-to-water heat pump systems.

1. Lowering the design water temperature setpoint for hydronic systems has been an important evaluation for hydronic heat pump adoption. However, further research is needed: can a lower water temperature setpoint be adopted for *all* distribution systems or are there cost-effective limitations?
2. Do air-to-water heat pumps have minimum product safety requirements (such as fault detection diagnostics or factory certifications) to protect the equipment from breaking or not operating optimally?
3. What level of simultaneous heating and cooling is necessary for different building types to cost-effectively justify 4-pipe heat pumps and 2-pipe heat pumps?
4. What physical area is needed to place an air-to-water heat pump in typical building configurations?
5. Is system oversizing a barrier to deploying heat pumps? How can system sizing calculations be modified to be more accurate?
6. How much power do heat pumps use during peak heating loads, including backup heating element power? What is the impact on the electric grid, and how can the resulting grid infrastructure costs be minimized?

THERMAL ENERGY STORAGE

TECHNOLOGY OVERVIEW

In building heating and cooling systems, a thermal storage tank is considered a technology to provide short-term storage of thermal energy and is typically used in conjunction with hydronic cooling and heating. Water is the medium most used for thermal storage, although new technologies, such as phase change materials, are being used to provide the same thermal capacity as water storage over a smaller footprint.

Source: www.jcvi.org/blog/building-solid-foundation

FIGURE 11: THERMAL STORAGE TANKS IN A COMMERCIAL BUILDING FOR HEATING AND COOLING

Thermal storage has traditionally been used in cooling configurations as a means of shifting the time of use for operating chillers. Several large campuses in California use thermal storage in central plants for both cooling and heating to increase overall energy efficiency and to recover thermal energy from one building to the next. Thermal storage is used in two different configurations in most central hot water and chilled water plants:

1. In a primary configuration, where the tank is storing hot water or cold water at the distribution temperature for the building. The tank is charged over time and can discharge without running a heat pump or in parallel to a heat pump.
2. In a secondary configuration, where the tank is storing ambient energy and serves as the thermal reserve for a heat pump or heat pumps. In this configuration, the tank is depleted of heat when the heat pump is heating the building and filled with heat when the heat pump is cooling the building.

The sizing, configuration, and control of thermal energy storage remain a unique engineering challenge in modern design to select the right kit of parts for each building.

OPPORTUNITIES

<u>Thermal Energy Storage Sizing</u>

Several designers discussed the challenge of space requirements when sizing a heat pump for peak heating needs and the potential solution of using thermal energy storage. Thermal energy storage can be sized to help supplement a heat pump on the peak design day, reduce the heat pump's size which is often the more expensive component, and purchase a thermal hot water storage tank. The tank however is often very large and in addition to the area, most require some form of seismic restraints, which can be challenging to design into buildings or, in retrofits, often impossible.

Increased Heat Pump Reliability

Smaller thermal buffer tanks, which are a form of thermal storage, can be used in combination with hydronic heat pumps to maintain thermal setpoint for cooling and heating, assuming one tank for each thermal loop, and allow the heat pump to operate across a wider range of temperatures to maintain the refrigerant cycle and compressor operations. Unlike chillers where only one side of the refrigerant cycle is required to maintain a chilled water setpoint, heat pumps can maintain heating and cooling setpoints at the same time.

Electrical Sizing

Depending on the climate and the building's peak thermal heating and cooling load, using thermal storage may reduce the size of a hydronic heat pump at peak conditions. By specifying and installing smaller-sized heat pumps with a primary thermal storage tank, the designer can directly reduce the size of the electrical infrastructure required. In retrofit conditions, this is particularly important where electrical infrastructure can be limited.

Challenges

Complexity Challenges

Using thermal storage in an engineered system can be more complicated than a standard design where heat pumps or chillers are directly serving a building's load in real time. One designer noted that as a result, thermal storage is not commonly used due to the complexities of creating custom controls and systems which can adjust their operation based on loads when charging or discharging the thermal storage tank.

Energy Code Considerations

Through the perspective of those interviewed and the authors' knowledge of the current energy code and the code change process, several informational gaps were identified that could serve as areas for further study relating to thermal energy storage.

1. What thermal storage products exist today for mid-sized thermal storage applications, and do they come with any built-in or manufacturer-recommended controls?
2. What types of thermal storage insulation or active heating elements are used to maintain hot water thermal storage tanks when directly configured to serve the building's thermal loads?
3. What is the market cost trajectory of thermal storage for non-residential buildings with heat pump plants, assuming a secondary ambient storage tank solution?
4. What is the peak load reduction potential of using thermal storage in non-residential buildings?
5. What efficiency improvement can a 4-pipe air-to-water heat pump system gain by using an ambient thermal storage tank for condenser cooling rather than outdoor air?

VENTILATION HEAT RECOVERY

TECHNOLOGY OVERVIEW

Heat recovery ventilators (HRV) or energy recovery ventilators (ERV) technology were mentioned several times by design engineers when discussing space heating with all-electric systems. HRV/ERV systems recover heat from exhaust air leaving the building, conditioning the incoming ventilation air by either heating or cooling. HRV and ERV systems work best when the outdoor temperatures are at their extremes, where heating or cooling from the building exhaust air stream can be recovered into the incoming outdoor air stream, which would otherwise be lost to the outside environment.

HRV and ERV technology ranges from rotating wheels exchanging heat across air streams to fixed plate heat exchangers.

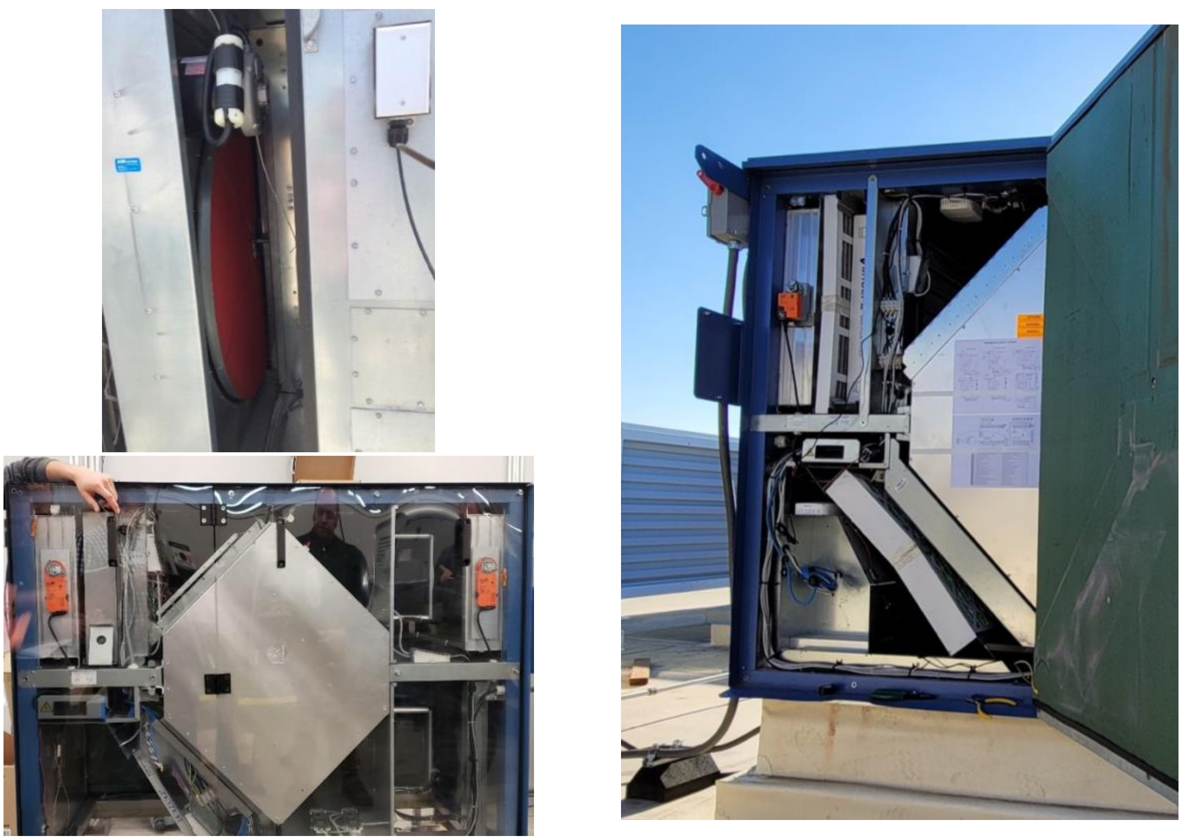


FIGURE 12: EXAMPLE ERV WITH ROTATING WHEEL (LEFT) AND HRV WITH FIXED PLATE HEAT EXCHANGER (RIGHT)

OPPORTUNITIES

Reduced Peak Load

ERV and HRV technologies can reduce building peak heating and cooling loads, reducing the size of active heat pumps or thermal storage systems depending on the building design and engineering. While this may not work in all buildings or for all levels of risk and reliability, it can be used in many buildings to further reduce mechanical equipment.

Reduced Heating Energy

Several designers noted the ability to reduce annual energy by using ERV and HRV technologies in California climates. In market research by NEEA, several technologies are readily available at 70% effectiveness levels, with leading technologies capable of recovering 85% of the thermal energy and installed in low-pressure configurations to maintain low fan energy.

Challenges

System Ducting Requirements

In several instances, designers mentioned the challenge of routing supply and return duct work to the same location to use an ERV or HRV.

Energy Code Considerations

Through the perspective of those interviewed and the authors' knowledge of the current energy code and the code change process, several informational gaps and questions were identified that could serve as areas for further study relating to HRV/ERV units.

1. To what degree can HRV/ERV units be used to reduce peak thermal heating loads to make electrification more cost-effective?
2. In multi-zoned VAV systems with limited supply air reset capability of 5°F (often 55°F to 60°F), what levels of heat/energy recovery effectiveness achieve similar levels of heating and cooling energy savings in systems with 10 or 15°F of reset, such as DOAS? Can both system types be enhanced in the Title 24, Part 6 energy code to reduce energy use?
3. Can HRV or ERV technologies complement thermal energy storage and shoulder season energy shifting between morning heating and afternoon cooling?

CONCLUSIONS

Although this report contains interviews from a relatively small sample of engineers, those surveyed have more experience with electrification than typical design engineer working in California at the time the interviews were conducted, and the ideas they expressed are indicative of the type of collective learning taking place in the mechanical design industry. The goal of 100% electrification of space heating includes both the technical challenge of fundamentally shifting how building heating systems are engineered, installed, and operated, as well as a regulatory challenge to ensure consumer confidence and to protect California residents, businesses, utilities, and grid operators from the potential impacts of poorly functioning and inefficient electric space heating equipment.

Natural gas furnaces and boilers provided a means of low-cost, high-density heat, available on demand, with operational efficiency independent of the outdoor environment. The lower cost of natural gas can result in masking the true energy use fluctuation of a building between its design intention and actual operations. Often, a change in heating energy of 200% to 300% would result in only a minor change in a buildings overall energy costs given the low relatively cost of gas for heating. Conversely, heat pumps, the primary solution for electrifying heat in most buildings, rely on the ability to pull heat out of the outdoor environment causing their operational efficiency to vary with outdoor conditions. That characteristic; combined with the risk of buildings requiring substantially more heat than estimated; can dramatically change annual energy costs, peak grid impacts, and public perception of building heating electrification technologies.

Quickly scaling appropriate solutions will require changes in both engineering practices and statewide policy. On the engineering side, just as the air conditioning industry has established a methodology for peak cooling with compressor-based systems to ensure operational flexibility (while minimizing oversizing and excessive costs), a similar level of effort will be needed to develop sizing, control, and operational strategies for space heating heat pumps. On the policy front, it will be necessary to develop requirements to ensure a minimum level of system efficiency for robust systems that can be easily maintained. To support technical and policy efforts, it may also be necessary to educate building designers, owners, and operators about the benefits of all-electric buildings and the difference in energy costs vs. mixed-fuel buildings.

In the results section of this report, there are specific energy code considerations for each technology evaluated, including recommendations for further research and development. The following are the top 10 recommendations from the individual technology findings.

KEY RECOMMENDATIONS FOR RESEARCH TO SUPPORT CODE DEVELOPMENT

1. For electric resistance heating technologies, identify what the energy costs are from operating electric resistance heating systems today, even in buildings with high-performance envelopes. What is the gap between how electric resistance and building loads are simulated versus how they operate given the low efficiency and potential market risk of electric heat?

2. How would the proliferation of resistance heating impact electrical demand at the grid scale, and how might that impact electricity rates and the future cost to operate electric resistance and other electric heating systems? How would it impact grid infrastructure, generation, and energy storage costs required to support the connected load?
3. For VRF systems, what types of refrigerant piping fixtures and fittings can be used to support low leakage VRF systems? Is there an incremental first cost or skill requirement to accomplish low leakage VRF system installation?
4. For air-to-air heat pumps, are electric resistance or natural gas backup heating elements being used for cold climate conditions? What is the impact and/or added load of backup heating, and how often are new or existing buildings relying on this component?
5. For hydronic heat pump technologies, what level of simultaneous heating and cooling is necessary for different building types to cost-effectively justify 4-pipe heat pumps vs. 2-pipe heat pumps?
6. For hydronic heat pump technologies, how much power do heat pumps use during peak heating loads, including backup heating element power? What is the impact on the electric grid, and how can the resulting grid infrastructure costs be minimized?
7. Is system oversizing a barrier to deploying hydronic heat pumps? How can system sizing calculations be modified to be more accurate?
8. What thermal storage products exist today for mid-sized thermal storage applications, and do they come with any built-in or manufacturer-recommended controls?
9. For thermal energy storage technologies, what efficiency improvement can a 4-pipe air-to-water heat pump system gain by using an ambient thermal storage tank for condenser cooling rather than outdoor air?
10. To what degree can HRV/ERV units be used to reduce peak thermal heating loads to make electrification more cost-effective?

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