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Commercial High-Performance HVAC Market Characterization

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is working on transforming the heating, ventilation, and air-conditioning (HVAC) market in the Northwest by accelerating adoption of high efficiency HVAC systems and components, which provide substantial energy and non-energy benefits. Presently, NEEA has focused on the Very High Efficiency Dedicated Outside Air System (VHE DOAS) technology. VHE DOAS as proposed in the Initiative is a system comprising two separate components: 1) a heat recovery ventilation (HRV) system with 85% or better sensible heat recovery efficiency and 2) a highly efficient heating and cooling system with a minimum heating seasonal performance factor (HSPF) of 9.5, a minimum coefficient of performance of 3.0, and a minimum cooling energy efficiency ratio (EER) of 11.0 or integrated energy efficiency ratio (IEER) of 18.0

NEEA's initial focus is buildings in the schools, office and retail sectors less than 50,000 square feet, which NEEA estimates to be about 50% of the buildings in these sectors in NEEA's territory.

Research Questions

This study explores the market conditions, adoption barriers, and decision-making relevant to VHE DOAS adoption in Washington, Oregon, Idaho, and Montana. Specifically, the study:

1. Explores HVAC installation decision-making
2. Explores potential market barriers to VHE DOAS
3. Estimates factors that inform market opportunity (drivers of replacement, replacement cycle)
4. Reviews and validates initiative assumptions

Methods

Study methods included:

1. Literature review (20 documents),
2. Telephone interviews with 35 HVAC manufacturer representatives, distributors, specifiers, and installers (typically 45 to 60 minutes in length),
3. Web survey of 31 building owners/managers responsible for HVAC installations at schools, offices, and retail establishments, and
4. Two work sessions with NEEA Initiative staff during which the research team shared findings with staff, staff debated possible interpretations and implications, and the research team obtained additional Initiative background information.

Conclusions

Barriers Review: Impediments to Rapid Uptake of VHE DOAS

The study focused on three of four potentially strong barriers to transforming the commercial HVAC market identified in the Initiative logic model: lack of VHE DOAS system *awareness*, the system's *first cost* (in many applications is anticipated to exceed the alternative equipment cost; in addition, installation entails design fees, as it's a custom technology), and the unwillingness of market actors to change the way they do business – *market inertia*. The research indicates that no barrier presents an insurmountable obstacle to Initiative efforts.

1. The market is aware of and experienced with what may be termed standard "DOAS." However, DOAS systems are not comprehensively understood across all market actor group or consistently defined. The only market actors reporting experience with "VHE DOAS" were those that had been directly involved in NEEA's pilot.

2. First cost is a significant consideration in HVAC replacement and selection decisions for approximately half of the target market. It is one of many considerations for the rest of the market. The replacement context and sector in which the system is to be installed determines the relative influence of first cost.
    - First cost, design complexity, and immediate availability are the key drivers for most emergency replacements.
    - Planned replacements, even the systems planned to be replaced the next time they break, use broader selection criteria than first cost.
    - Among planned replacements, the following non-first-cost factors affect system selection: occupant comfort, public image, life cycle costs, product availability, specification, installation, trouble-shooting support offered from distributors/manufacturer representatives, and capabilities of facilities management staff.

3. Market inertia (established ways of doing business) and lack of experience designing/ implementing VHE DOAS will likely impede progress to transforming this market.
    - Market inertia dominates the (roughly estimated) half of the market comprised of HVAC systems replaced on an emergency basis.

Planned/Emergency Replacement Dichotomy Oversimplifies Installation Context

The study found three HVAC system replacement contexts:

- Planned (more than six months in advance for more than half of planning respondents),
- Plan to replace next time it breaks (with replacement times ranging from immediate to six months), and

- Emergency replacements (one week or less for more than half of respondents engaging in emergency replacement).

Roughly speaking, the research team estimates the HVAC market is approximately evenly divided between planned installations and emergency replacements. The study findings suggest a more nuanced characterization of roughly 40% planned installations (including new construction/renovation and replacements), 20% plan to replace it next time it breaks, and 40% emergency replacements. (Note: these estimates should be confirmed with additional research over time as this study contained primarily qualitative information and may not be generalizable).

System Influencers and Supply Chain Relationships Vary by Installation Context

System influencers differ by installation context.

- Planned replacements are most commonly influenced by specifiers who typically work for mechanical engineering firms, architecture firms, or independently.
- Plan-to-replace-it-next-time-it-breaks replacements are most commonly influenced by field staff and specifiers who typically work for the HVAC installation/service firm that has been maintaining the equipment.
- Emergency replacements are most commonly influenced by the installation salesperson. In-house specifiers are involved in all sales to ensure the proper quantities of equipment are purchased, but this specifier typically influences the equipment selection only if called on by the salesperson to advise.

Specifiers and contractors often have exclusive relationships with distributors/manufacturer representatives and use the equipment that the latter offer, rarely if ever considering equipment from different suppliers. These exclusive relationships limit avenues for VHE DOAS systems to enter the market because of the upstream relationships the distributors/ manufacturer representatives have with manufacturers.

- Specification, installation, and trouble-shooting support offered by distributors/manufacturer representatives strongly influence choices of specifiers and installers in brands of equipment offered to their customers.
- Currently, one manufacturer produces an HRV that meets the requirements for that component of VHE DOAS. Multiple manufacturers produce heating and cooling systems that meet VHE DOAS requirements, but no single manufacturer provides both components of the VHE DOAS system.
- Given that supply-chain relationships are relatively stable and individuals in the chain may work with the products of only one or a few manufacturers, the VHE DOAS market is currently limited due to a variety of factors: lack of qualifying HRV products, lack of a single manufacturer for both components of the system or established relationships between HRV and heating/ cooling system manufacturers, distributor reach, and confidence in the market to commit to the system.

Market Opportunity Exists for VHE DOAS

A near-term market opportunity for VHE DOAS appears to exist based on findings that roughly 40% to 50% of HVAC system installations in schools, office, and retail buildings are planned, and that VHE DOAS attributes align with common planned system selection criteria.

- VHE DOAS benefits and features align well with many HVAC selection decision criteria for the (roughly estimated) half of the market comprised of planned HVAC installations (examples of aligning features: lifetime cost, system size, comfort, controllability, IAQ, and low noise).
- The current state of the supply chain (a single HRV manufacturer, with consequent limited support available from the distributors and manufacturing relationships with which specifiers work) will limit this market opportunity.

A long-term market opportunity for VHE DOAS appears to exist based on findings that roughly 20% of HVAC system installations occur in a context of "replace it next time it breaks," that the servicing HVAC contractor has specifiers on staff, and that perhaps a quarter or more of these installations take longer than three weeks from system failure, a longer term market appears to exist for VHE DOAS.

- As installers gain experience with VHE DOAS planned installations, they will consider VHE DOAS systems for "replace it next time it breaks" contexts.
- As distributors/manufacturer representatives gain experience with VHE DOAS (assuming expansion in the number of HRV manufacturers), they will support contractors installing this system and thereby increase contractor willingness to specify.
- Although not explicitly investigated by the study, NEEA might anticipate that the primary opportunity for VHE DOAS in this context would be where owners/managers with multiple rooftop HVAC units on one building are replaced systematically as they fail.

Recommendations

The research team offers the following recommendations to NEEA's High-Performance HVAC Initiative team as it further develop it approach to transforming this market.

- First wave of VHE DOAS efforts should target installations planned via budgeting and upgrade cycles – schools, large office property management, and new construction/renovation. Building owners/managers use specifiers for these installations.
- Emphasize VHE DOAS benefits as they align with each sector to minimize first-cost thinking.
- Align Initiative terminology with common industry terms whenever possible.
- Educate distributors/manufacturer representatives on NEEA's VHE DOAS specifications and how to source VHE DOAS components from the manufacturers they work with.
- Explore resources (beyond education) NEEA could provide suppliers to support increases in VHE DOAS sales.

1. Background

The Northwest Energy Efficiency Alliance (NEEA) is working on transforming the heating, ventilation, and air-conditioning (HVAC) market in the Northwest by accelerating adoption of high efficiency HVAC systems and components, which provide substantial energy and non-energy benefits. The study team refers to this effort as the "High-Performance HVAC Initiative" or the "Initiative." As part of this effort, NEEA plans to promote several high efficiency HVAC technologies over time. Presently, NEEA has focused on delivering a system called Very High Efficiency Dedicated Outside Air System (VHE DOAS). NEEA is targeting replacements of existing equipment in commercial (non-residential) buildings and the new construction market. This market study supports NEEA's efforts to understand barriers and opportunities in its early-stage initiative program structure by providing insight into market landscape, potential market size, adoption barriers, and decision-making relevant to VHE DOAS adoption in Washington, Oregon, Idaho, and Montana.

VHE DOAS as proposed in the Initiative is a system comprising two *separate* components: 1) a heat recovery ventilation (HRV) system with 85% or better sensible heat recovery efficiency and 2) a highly efficient heating and cooling system with a minimum heating seasonal performance factor (HSPF) of 9.5, a minimum coefficient of performance of 3.0, and a minimum cooling energy efficiency ratio (EER) of 11.0 or integrated energy efficiency ratio (IEER) of 18.0 (see Appendix A).

1.1. Research Objectives

NEEA recognizes that buildings designed for use as schools, offices and retail that are less than 50,000 square feet (sf) and under four stories are an important target for commercial HVAC market transformation. Buildings with these characteristics represent both the most appropriate size range and the most appropriate building layout for the proposed system. In addition, this target represents a large portion of the existing building stock in this segment.[1]

This study provides findings on the following research objectives:[2]

1. **Estimate the market opportunity:** What is the market size of in terms of the potential replacement market for VHE DOAS, considering how frequently are HVAC systems replaced? What proportion of replacements are planned versus emergency? What factors limit adoption of VHE DOAS system and for whom?
2. **Explore potential barriers to adoption of VHE DOAS:** What is the level of awareness of and experience with highly efficient HVAC technologies for building owner and market actors,

[1] *High Performance HVAC Briefing Slides Market Characterization*, Microsoft PowerPoint file provided by NEEA to the study team on July 9, 2018.

[2] Appendix A provides NEEA's verbatim research questions.

including for DOAS and HRV? To what degree do perceptions about new technologies, high upfront cost, product quality, product availability, and entrenched HVAC design and installation practices act as barriers to VHE DOAS technology adoption?

3. **Explore HVAC installation decision-making:** What triggers decisions to replace HVAC? What are decision-making criteria used by building owners and (supply side) market actors in selecting a replacement HVAC system? How do owners and market actors interact in making decisions about HVAC purchase and replacement decisions?

4. **Review and validate initiative assumptions:** Are NEEA's assumptions about the market opportunity, awareness, resistance to change, limited supply base, and decision-making consistent with the current state of the market? Are the assumptions reasonable to ensure initiative savings estimates are robust? How can NEEA use the knowledge of HVAC replacement decisions and sale processes to encourage market actors to sell VHE DOAS?

1.2. Research Approach

Several data collection activities informed this research study; see a summary of these activities in Table 1. The research team also conducted two work sessions with NEEA staff to review key findings and discuss levers they might use to encourage adoption of VHE DOAS technology.

Table 1. Summary of Data Collection Approaches

Target Groups	Secondary Data	Primary Data Collection		
		Method	Sample Frame [a]	Sample
Commercial HVAC / HRV manufacturer reps or distributors	Lit. review papers	Phone in-depth interviews	~30	Purposive: 8
Specifiers (mechanical engineers, architects, HVAC design consultants)	Lit. review papers	Phone	~1,200 [b]	Purposive: 14
Commercial HVAC installers	Lit. review papers	Phone		Purposive: 13
Commercial office, retail, and school building owners/ managers	Lit. review papers	Web survey	~12,400 [c]	Stratified Random

[a] A sample frame is a list of all those within a population who can be sampled. Target group lists came from NEEA, D&B Hoovers, Dunhill International List Co. (Dunhill) and State Education Offices. D&B Hoovers and Dunhill maintain databases of many U.S. businesses and provide samples for market research companies.

[b] The study team identified during the interview which firms and contacts fall under specifier or installer category.

[C] The research team purchased a list of emails for 4,200 office, 4,200 retail, and 3,600 school building owners/managers from Dunhill. The team also received a list of 500 school facility managers from the Washington State Office of Public Instruction. The purchased contacts were randomly selected.

2. Target Market Landscape

This section synthesizes study findings to describe the market landscape for VHE DOAS in the existing commercial buildings market of schools, offices, and retail establishments less than 50,000 square feet in the Pacific Northwest. The section also introduces terms and concepts used throughout this report.

2.1. The DOAS Technology Opportunity

The options for configuring energy efficient HVAC are plentiful. Study findings touch on multiple technologies, as summarized in Table 2-1.

Regarding DOAS, the research team found most study contacts were experienced with dedicated outdoor air systems, as the systems "have become a staple" during the last 20 years. However, the market has not settled on a specification or system configuration that represents the "standard" for energy efficient DOAS technology – that is there is no market consensus around which components and technologies should be configured to optimize the delivery of energy efficient heating, cooling and ventilation. Nor is there even consensus around a minimum efficiency level.

Table 2. Technologies Addressed by Study Findings

Technology	Description	Recap of Findings
VHE DOAS Very high efficiency dedicated outdoor air system	Comprises two parallel, separate systems: 1) high-efficiency HRV (see below) to pre-condition outside/intake air; 2) highly efficient heating and cooling system [a]	▪ NEEA developed this terminology and technology specification; as of 2018, a very high efficiency HRV, which is the enabling technology for this system, was only available in the US is from Ventacity ▪ As NEEA's VHE DOAS initiative is in its infancy, the only study contacts familiar with this term and its specification had been involved in a 2018 NEEA VHE DOAS pilot
DOAS Dedicated outdoor air system	A ventilation system that delivers outside air independently of the heating and cooling equipment; it delivers air without using the blowers associated with the heating and cooling equipment	▪ All manufacturing reps, distributors, and specifiers in study were familiar with DOAS and all but one was experienced with DOAS ▪ Half of installation contractors in the study were experienced with DOAS, although some with very limited experience ▪ Study interviews and web searches suggest the term DOAS encompasses many types of equipment and configurations, including both with and without heat recovery. As examples: ▪ one manufacturer's DOAS webpage focuses on moisture control;[b] ▪ one specifier stated "DOAS is another acronym for ERV [see below] or HRV" ▪ Contacts agreed that common Northwest DOAS practice includes an ERV or HRV.
HRV Heat recovery ventilator	Building exhaust air is used as a heat source (or heat sink) to pre-heat (or pre-cool) fresh air prior to it entering the conditioned space.	▪ All study contacts were experienced with HRV
ERV Energy recovery ventilator	Building exhaust air is used as a source of heat and moisture transfer (that is, moisture in supply air is retained or jettisoned as needed)	▪ All study contacts were experienced with ERV

Technology	Description	Recap of Findings
VAV Variable air volume	A combined heating/cooling and ventilation system capable of delivering a variable percentage of conditioned outside air	▪ All study contacts were experienced with VAV
VRF Variable refrigerant flow	Uses refrigerant, conditioned by a variable capacity compressor and sent through a condenser, as the cooling and heating medium; the refrigerant is circulated to two or more indoor units[c]	▪ All study contacts were experienced with VRF

[a] NEEA defines the VHE DOAS as a system comprising two components: 1) a separate heat recovery ventilation (HRV) system with 85% or better sensible heat recovery efficiency and 2) a highly efficient heating and cooling system with a minimum heating seasonal performance factor (HSPF) of 9.5, a minimum coefficient of performance of 3.0, and a minimum cooling energy efficiency ratio (EER) of 11.0 or integrated energy efficiency ratio (IEER) of 18.0 (see Appendix A).

[b] Trane. *https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/unitary/dedicated-air-solutions/OAU-SLB004-EN_2016_WEB.pdf*

[c] Heat pump VRFs are most common. Heat recovery VRFs (less common) can simultaneously provide heating and cooling to different indoor units and transfers heat between the spaces for increased efficiency. Source: http://digital.bnpmedia.com/publication/?i=113979&article_id=1079986&view=articleBrowser#{%22issue*id%22:113979,%22view%22:%22article Browser%22,%22article_id%22:%221079986%22}*

2.2. Framework for Decision Making

This section provides a description of the backdrop against which HVAC installation decisions are made using a variety of perspectives – project type, market actors and building type.

NEEA's Initiative team had recognized that planned replacements are potentially a more viable target of the Initiative than emergency replacements, as the latter need to occur very quickly and other research suggests such systems are typically replaced "like for like;" for example, a roof top unit that failed suddenly is most likely to be replaced by another roof top unit. The study found that this planning dichotomy did not sufficiently capture how the market works. Instead HVAC installation decisions are made on a spectrum of advance planning, as illustrated in Figure 1a.

The findings suggest that perhaps 40% of the targeted market has planned installations (both new and replacement installations), perhaps 20% of the market has "replace it next time it breaks" planning (see further discussion below), and perhaps 40% of the market has emergency replacements. As this section describes, schools are most likely and retailers are least likely to be planners, to consider attributes other than first cost, and to use specifiers.

The study team found that new HVAC system installations (that is, new construction and major renovation) in the target market of schools, offices, and retail less than 50,000 SF are planned months or years in advance of new construction or renovation projects (shown on the left in Figure 1a). Replacement system installations comprise the remainder of the spectrum (from capital planning projects through emergency replacements) shown in Figure 1a.

Specifiers design the HVAC systems for new construction and renovation projects (Figure 1b). The specifiers work for mechanical engineering firms or by design-build firms, which employ the gamut of architects, engineers, and general contractors. All target sectors (schools, offices, retail) use specifiers to plan for new installations (new construction and renovations; Figure 1c).

The sectors vary in the degree of planning they typically engage in, driven by differing objectives they need to achieve.

Schools are comparatively more interested in a variety of HVAC system benefits, including indoor air quality, noise, and life-cycle costs. Schools may start planning several years in advance of construction, working with mechanical engineering firms. **Offices** are next most likely to consider a variety of system characteristics (depending on the intended occupant or target market) and engage in a longer planning cycle, with offices managed as part of a real estate portfolio typically engaging in greater planning than other offices. Offices use specifiers employed by mechanical engineering firms and design-build firms. New HVAC installations in the **retail** sector are more likely to be driven by first costs, design complexity, and immediate availability than are new installations in other sectors and to use design-build firms.

Figure 1a. Spectrum of Equipment Installations: Some Planning, including Replace When It Breaks

Figure 1b. Trade Allies Influencing Equipment Installations across Spectrum

Figure 1c. Sectors Conducting Installations across Spectrum

Turning now to a discussion of decision making to replace existing systems, the research found that some owners/managers have established capital expenditures on budget cycles or upgrade cycles and plan for HVAC system replacements (Figure 1a). As with new construction, these owners/managers engage specifiers that work for mechanical engineering firms (Figure 1b) and typically consider a variety of system characteristics. These owners/managers include most schools and most offices that are held and managed as part of a real estate portfolio (Figure 1c). Owner planning is part of an on-going business process, likely to occur over much of a year, tied to established budget cycles and used to support equipment maintenance and upgrades. HVAC installation and service contractors commonly tell owners/managers to expect a 20-year equipment life; of course, owners/managers commonly tie replacement planning to the condition of the equipment and whether they need functionality or performance that the existing system cannot deliver.

The replacement spectrum includes a transition area (shown in the central portion of the figures where the color transitions from light to dark) that some contacts apparently considered as within the realm of planned replacements and others considered as emergency replacements (Figure 1a). These installations are planned to the extent that owners/managers plan to “replace it next time it breaks,” while being unplanned and occurring on an emergency basis because the next failure date is unknown.

These owners/managers include a minority of schools, offices that are not managed according to budgeting or upgrade cycles, and retailers (Figure 1c).

Planning in the transition area may be limited to an intention to replace the system with something similar (likely with low first cost; these installations are reflected in the darker shading on the right of the diagrammed transition zone) to be determined at the time of failure or may include a deliberate investigation of alternatives and their attributes, including operation and maintenance costs and possibly non-cost considerations (installations in the lighter shading on the left). The more deliberate the investigation, the more likely a dedicated specifier is involved, although for these replacements the specifier is most likely employed by the HVAC installation and service firm that has been maintaining the equipment (Figure 1b). Contacts reported that system failures are most common within 15 to 25 years, although certainly there are outliers, with a very small minority failing more rapidly and a more substantial minority lasting more than 25 years.

Emergency replacements entail no planning and comprise the end of the planning spectrum (the far right of Figure 1a). Emergency replacements occur when it is not feasible or not cost-effective to repair the equipment. Although owners/managers may anticipate their equipment may fail in the next few years, they have not planned for a replacement. They most typically select the replacement equipment based on first-cost and availability. All HVAC equipment needs to be specified in the loose sense of the word and the contractor's sales manager will involve the firm's specifier, although the role is mainly to ensure the right pieces of equipment are ordered, at the right sizes, and with the right type and amount of ancillary equipment, such as piping and conduit. Again, system failures occur most commonly between 15 and 25 years, with most contacts agreeing that 20 years is a good point estimate.

Distributors/manufacturer representatives support both specifiers and HVAC contractors. Contacts reported that specifiers and contractors have existing relationships with distributors/manufacturer representatives and use the equipment that the latter offer, rarely if ever considering equipment from different suppliers. Specifiers and installation contractors also reported that the quality of support they receive from distributors/manufacturer representatives influences their equipment recommendations.

3. Market Awareness of and Experience with DOAS and Other High Efficiency HVAC Systems

While DOAS has been available in the market for many years now, awareness of and experience with DOAS, HRV, and VRF, varies among specifiers, manufacturer representatives, installers, and building owners/managers. Section 2.1 (above) provides technology definitions, an overview of the study's technology-related findings, and suggests that market actors employ a variety of definitions of DOAS. This section elaborates on that overview, describing the extent and type of awareness and experience with DOAS and related technologies among each group of market actors addressed by the study.

This and subsequent chapters provide experiences and opinions endorsed by more than one interview contact due to the exploratory nature of the research and per the direction of NEEA's study evaluation manager. This report distinguishes findings by type of market actor when relevant to a complete understanding of the topic.

3.1. Supply-Side Market Actors

Table 3 summarizes study findings on the awareness of and experience with technology they termed DOAS reported by interviewed supply-side market actors; the study found high awareness and experience with what might be considered "standard" DOAS (see the distinctions made among DOAS in Table 2).

Table 3. Market Actor Awareness and Experience with DOAS

	Aware of DOAS	Experienced with DOAS	Type of Experience
Specifiers	14 of 14	14 of 14	▪ Design DOAS (14)
Distributors/Manufacturer representatives	7 of 8	6 of 8	▪ Sell and offer DOAS to customers (6)
Installers	6 of 13	6 of 13	▪ Install DOAS (6) ▪ Install DOAS with VRF (2) ▪ Install only when asked by customer (2) ▪ Experience in institutional settings like hospitals, but not schools, office, or retail sectors (1)

While all but one interviewed specifiers and distributors/manufacturer representatives were aware of DOAS and all but two had some DOAS experience, there is a lack of consistency in how contacts defined DOAS, often equating it with one component or a specific service it delivers. For example, three contacts directly equated DOAS with HRV or ERV, as illustrated by the following comment from a specifier with a

design and installation firm: “DOAS is another acronym for ERV or HRV.” Other market actors defined DOAS as a “decoupled system,” that is, separate systems for ventilation and temperature control, as illustrated by the comment of one manufacturer representative: “I think a more proper terminology is decoupled system. We build DOAS equipment but it’s not always a part of a decoupled system. It’s a bit of a nuance.” As the Initiative is still in its infancy and NEEA has introduced the term “VHE DOAS” to only selected market partners, the only interviewed contacts familiar with NEEA’s definition of VHE DOAS had been involved with NEEA’s VHE DOAS pilot.

Both specifiers and manufacturer representatives readily expressed the benefits of the systems they term DOAS, including better air quality, greater efficiency, and ability to meet code.

All (14) interviewed specifiers had some experience designing systems they termed DOAS. Three-quarters (6 of 8) Interviewed distributors/manufacturer representatives said they either sold or offered DOAS to their customers. Both specifiers and manufacturer representatives described that their experience involves pairing DOAS (which according to contacts always includes HRV or ERV, with the selection dependent on the climate) with VRF.

Most interviewed specifiers and distributors/manufacturer representatives were also aware of HRV or ERV. Specifically, all (14) interviewed specifiers were familiar with HRV or ERV and all but two explained its benefits, primarily as a necessary component of a high efficiency DOAS. All but one (7 of 8) of the interviewed distributors/manufacturer representatives were aware of and had experience with HRV or ERV.

Interviewed specifiers (11 of 14 discussed) and distributors/manufacturer representatives (5 of 8 discussed) were also aware of and experienced with VRFs in the context of DOAS. Interviewed market actors specifically touted the superior efficiency of using VRF and its conformance with energy codes and standards.

Similar to specifiers and manufacturer representatives, installers who expressed they were aware of DOAS varied in how they define it. Two installers, for example, explained that they and their colleagues call DOAS “MAUs” (makeup air units). An additional installer equated DOAS with HRV and ERV saying “DOAS are either labelled as heat or energy recovery units” and another equated DOAS with VRF saying “VRF is the DOAS. It could be any technology that brings in outside air.”

About half of interviewed installers (6 of 13) were aware of what they termed DOAS; the sole installer familiar with VHE DOAS had involvement with NEEA’s VHE DOAS pilot. Consistent with the literature review findings, interviewed installers aware of DOAS noted primarily the benefit of improved air quality.

About half of interviewed installers (6 of 13) had any level of experience with DOAS, and that experience was varied. For example, one installer of the six said he was experienced with DOAS in institutions like hospitals but not in the retail, office, or school sectors. Another installer said his company just started offering and installing DOAS. The two installers who had more experience discussed that they install DOAS with VRF, HRV or ERV, and economizers. Importantly, two installers specifically noted that they

install DOAS when customers ask for them, indicating that currently installer experience rests on whether the specifiers and building owners request DOAS.

Most interviewed installers (11 of 13) also expressed that they are aware of and had experience with HRV or ERV and 5 of 13 installers mentioned VRFs.

Interviewed specifiers and distributors/manufacturer representatives (13 mentions) suggested that a lack of familiarity with DOAS among installers and building owners/managers constitutes a prominent barrier, consistent with the literature review.

> **"A lot of the smaller contractors aren't educated about the technology. We need to get exposure to those types of people and educate them about those types of benefits. If they have a relationship with an end user, they are trusted. The other equipment might not be considered."**

The literature review indicated there are numerous competing technologies that address ventilation and energy efficiency, which from the perspective of some market actors, may serve as a substitute for DOAS and limit its adoption. Alternative heating and cooling technologies mentioned in interviews with specifiers and distributors/manufacturer representatives included:

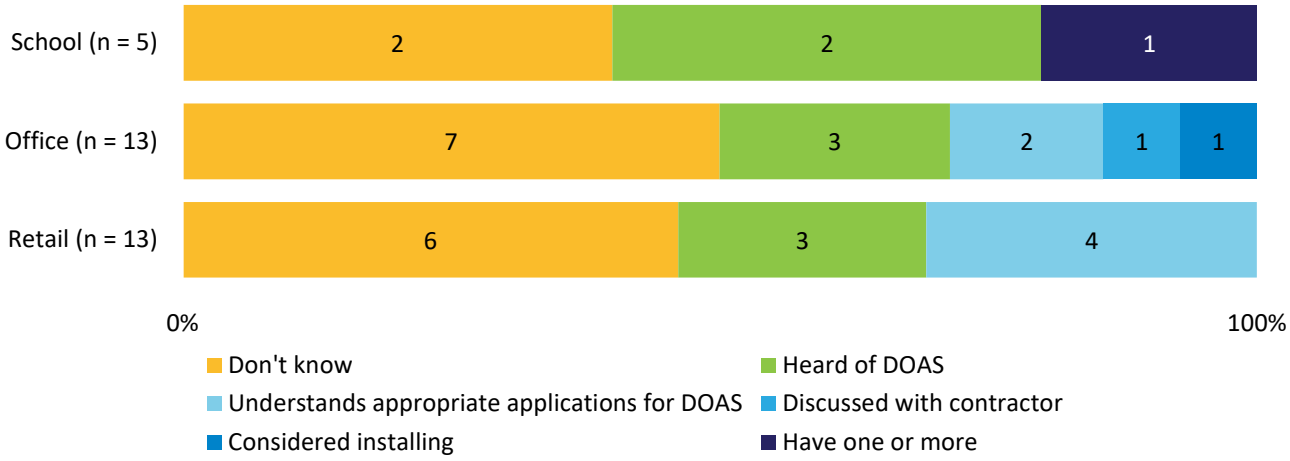
- Heat pumps (13 mentions),
- Boilers (7 mentions),
- Split systems (6 mentions),
- Fan coils (4 mentions), and
- Chillers (3 mentions).

The study also briefly explored awareness of systems powered by natural gas, to support NEEA's team in developing subsequent initiatives. Supply-side market actors generally had limited awareness of gas condensing roof top units (CRTUs). For example, four interviewees (1 manufacturer rep, 1 installer, and 2 specifiers) explicitly stated they were not aware of this technology. Those experienced with gas condensing roof top units included: 3 installers, 1 specifier, and 1 manufacturer representative. Lastly, one installer also mentioned having installed combined heat and power (CHP) systems in commercial buildings.

3.2. Building Owners/Managers

Surveyed building owners/managers had varying levels of awareness of and experience with DOAS, ranging from having heard of DOAS to having one or more installed in their facilities (Figure 2). The majority of building owners/managers, however, selected "don't know", indicating a lack of DOAS awareness.

Figure 2. Building Owner Awareness of and Experience with DOAS, by Sector

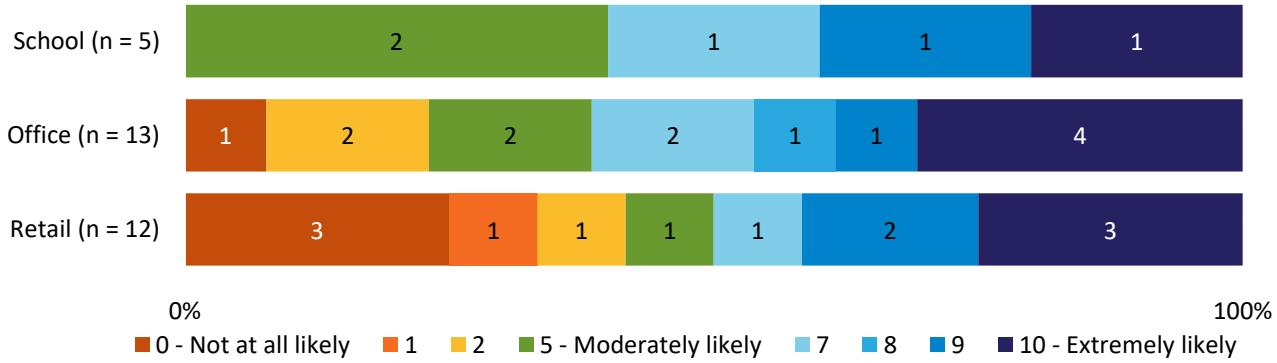


Source: Owners/Managers Survey Q9: A dedicated outdoor air system (DOAS) is an HVAC unit that is installed outside to bring fresh air into interior spaces independently from heating or cooling efforts. Addressing ventilation and air conditioning separately can save fan energy while improving indoor air quality. Coupled with a heat recovery system on the air conditioning equipment, the system also saves heating and cooling energy. Please describe your experience with DOAS technology by checking all that apply. [Response categories shown in graph.]

Surveyed building owners/managers varied according to sector in their likelihood to discuss DOAS with a contractor or building professional and in their likelihood to seek a bid for DOAS installation (Figure 3 and Figure 4, respectively).

All school sector building managers (100%, 5 of 5) indicated at least a moderate likelihood to discuss DOAS with a contractor or building professional, followed by 77% (10 of 13) of office sector building owners/managers, and 60% (7 of 12) retail sector building owners/managers.

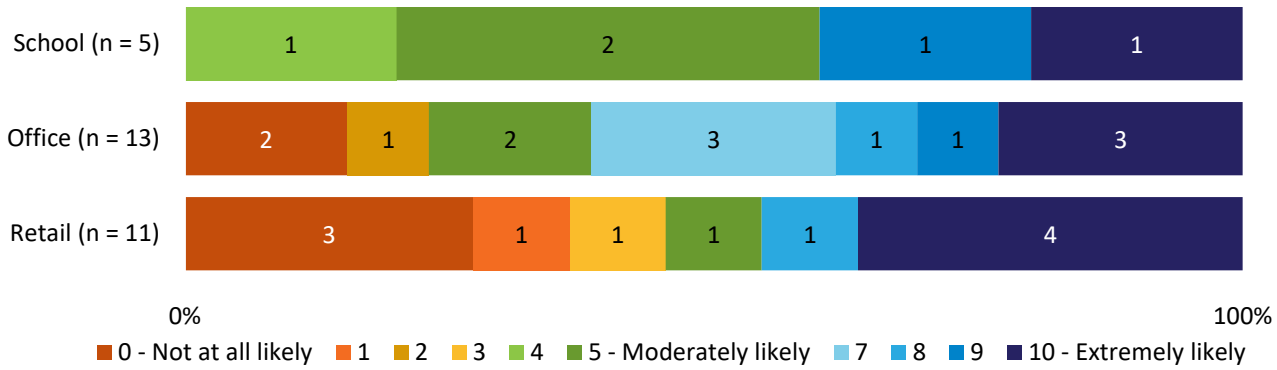
Figure 3. Building Owner Likelihood to Discuss DOAS with a Contractor or Building Professional



Source: Owners/Managers Survey Q10: Imagine that you are planning to replace an HVAC system and you've heard that a DOAS system can be installed at the same price as a system similar to what you now have. How likely are you to: (a) Discuss DOAS with your contractor or building professional? [Response categories: 0-10 scale where 0=Not at all likely, 5=Moderately Likely, and 10=Extremely likely.]

Almost all (80%; 4 of 5) school sector building managers indicated at least a moderate likelihood to seek a bid for DOAS installation, followed by 77% (10 of 13) of building owners/managers in the office sector and 55% (6 of 11) in the retail sector.

Figure 4. Building Owner Likelihood to Seek a Bid for DOAS Installation



Source: Owners/Managers Survey Q10: Imagine that you are planning to replace an HVAC system and you've heard that a DOAS system can be installed at the same price as a system similar to what you now have. How likely are you to: (b) Seek a bid for a DOAS installation? [Response categories: 0-10 scale where 0=Not at all likely, 5=Moderately Likely, and 10=Extremely likely.]

4. HVAC Installations Occur on a Spectrum of Advance Planning

4.1. Replacement Context Overall

As discussed in Section 2.2, HVAC installations occur along a broad spectrum of planning, from highly planned to moderately planned to unplanned. Highly planned installations include new construction and renovations (the Initiative's secondary market), and replacement installations included in capital planning (per budget or upgrade cycles). Moderately planned installations occur when building owners/managers discuss with their HVAC contractors their intention to replace the system the next time it breaks. Unplanned installations occur in the context of emergency replacement (see Figure 2-1).

The HVAC installation market is characterized by related factors: the commercial sector installing the system (such as schools), where the installation falls on the spectrum of advance planning, importance of first cost/immediate availability, and willingness to invest in highly efficient systems. This section elaborates on these factors.

For scenarios found in the highly planned portion of the spectrum, owners/managers have the opportunity to think more broadly about their needs and preferences, bringing multiple decision criteria to the selection, more than can be accommodated in response to an end-of-life equipment failure. Owners/managers planning replacements are less likely to be concerned with first cost than are owners/managers needing emergency replacements. Further, installations planned as part of new construction or renovations face fewer limitations on their size and system footprint than replacement of existing equipment, for which the system must fit within the space available. Planned replacements often have budgets that often can support an upgrade in system quality or performance.

Emergency replacements are typically funded through operations and maintenance budgets, in contrast to new construction or planned replacements, which typically are funded through capital budgets. With replacements outside of capital budgeting, owners/managers focus on cost minimization. However, even in emergency replacements, some market actors (2) noted that owners/managers whose existing systems have performed poorly may, budget-allowing, choose a more expensive unit that will cost them less over its lifetime.

Table 4 illustrates the planning context among surveyed building owners/managers.

Table 4. Planning Context of Previous HVAC System Replacement, per Building Owners

	Surveyed Building Owners	
Planning Context	**Number**	**Percent**
Capital planning	11	37%
Planned to replace on next failure	7	23%
Emergency replacement	12	40%

Source: Owners/Managers Survey Q4: Thinking of the last HVAC system you replaced, was the replacement planned or in response to an emergency? [Response options: Planned, emergency, other (specify), don't know.] Q6: In general, is your or your organization's HVAC planning driven by an established budget cycle or upgrade cycle? [Response options: Budget cycle, upgrade cycle, both, neither, other (specify), don't know.]

The study team notes that the scenario "plans to replace the system next time it breaks" was not anticipated in the instrument design and was developed by the team through triangulation of the data. The seven respondents categorized as "planned to replace on next failure" described their last installations as planned but also reported they do not replace HVAC equipment on a budget or upgrade cycle. Four of these seven owners/managers provided open-ended comments consistent with this interpretation. The 11 respondents categorized as "capital planning" reported both that their last installation was planned and that their HVAC planning is driven by a budget or upgrade cycle. The 12 respondents categorized as "emergency replacement" said both that their last installation was on an emergency replacement and that they do not engage in budget or upgrade cycle planning.

Consistent with these findings (40% of owners/managers engage in emergency replacements), interviewed market actors indicated that about half of HVAC system replacements occur on an emergency basis. Numerous interviewed market actors (12) reported that HVAC systems are typically replaced because of system failure for which it is no longer financially reasonable to repair the system or components compared to replacing the system.

Table 5 provides the same building-owner survey data as Table 4-1 organized by building type. Market actors consistently reported that office replacements were variable; the preponderance of emergency replacements for sampled offices may be an artifact of our small sample.

Table 5. Planning Context by Sector, per Building Owners

	Sector		
	School (n = 5)	Office (n = 13)	Retail (n =12)
Capital planning	60%	31%	33%
Plan to replace on next failure	20%	15%	33%
Emergency replacement	20%	54%	33%

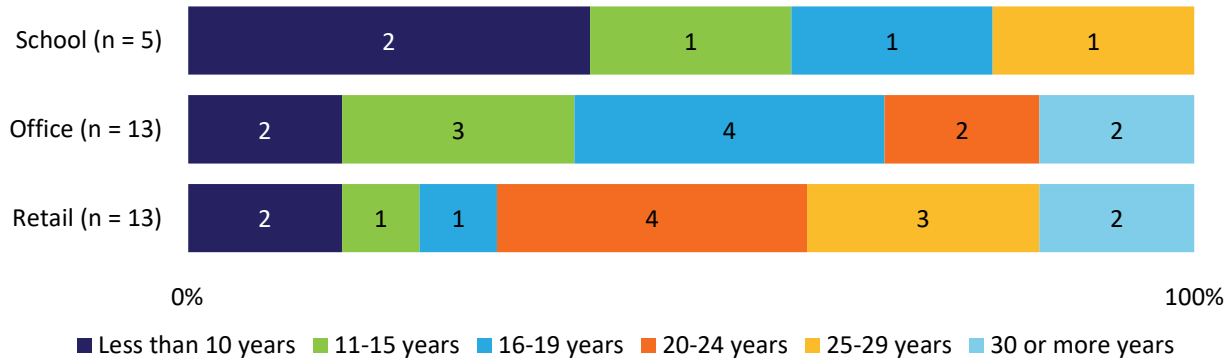
Source: Owners/Managers Survey Q4: Thinking of the last HVAC system you replaced, was the replacement planned or in response to an emergency? [Response options: Planned, emergency, other (specify), don't know.] Q6: In general, is your or your organization's HVAC planning driven by an established budget cycle or upgrade cycle? [Response options: Budget cycle, upgrade cycle, both, neither, other (specify), don't know.]

4.2. Frequency of HVAC Replacement

HVAC system replacements, as described by the greatest proportion of interviewed market actors (22), occur approximately every 20 years. Market actors' estimates of replacement age generally ranged from 15 to 25 years, which some described as depending on how well the unit has been maintained and the location of the system. Indoor units, market actors explained, have a longer useful life than outdoor units and are therefore replaced less frequently.

Building owner survey data suggest that the school sector has the shortest replacement cycle, with perhaps half of replacements occurring at equipment lifetimes less than 20 years (Figure 5). The office sector's apparent HVAC replacement cycle is more varied and somewhat longer than for schools, yet even so most replacements appear to occur less than every 20 years. Retail has the longest replacement cycle, with a majority of reported replacements occurring at measure lives of 20 years or more.

Figure 5. Age of Last HVAC Replacement, per Building Owners/Managers by Sector



Source: Owners/Managers Survey Q1: Thinking of the last HVAC system you replaced, how old was it at the time of replacement?

Notably, the one study the research team identified in the literature review on replacement cycle (conducted in Minnesota) discussed the average age of an HVAC commercial unit as 13 years, a significantly shorter period than indicated by market actor interviews and owner surveys.

For capital planning replacements, building owners/managers typically take longer than six months to move from identifying the need to installation. Responses between owners/managers replacing on an emergency basis and those that plan to replace on failure did not differ; half of these replacements occur within one week (Table 6).

Table 6. Length of Time from Identifying HVAC Need to HVAC Install, per Building Owners

	Planned (n = 11)	Emergency or Plan to Replace on Failure (n = 19) [a]
Less than one week		58%
One week		16%
Two weeks		
Three weeks		11%
One up to 2 months	18%	5%
2 to 6 months	9%	11%
7 to 12 months	27%	
More than 12 months	45%	

[a] Includes both owners/managers stating they replace equipment on failure and those categorized by the study team as "plan to replace the next time it fails."

Source: Owners/Managers Survey Q7: For planned replacements, about how long does it typically take you or your organization to move from identifying the HVAC need to installing the system? [Open-ended response, don't know,] Q8: For emergency replacements, about how long does it typically take you or your organization to move from identifying the HVAC need to installing the system? [Open-ended response, don't know,] One respondent in the "emergency or plan to replace on failure" category did not indicate a time and was excluded from analyses.

4.3. Replacement Context by Sector

The school sector typically plans its HVAC replacements, is least sensitive to first cost, and is the most willing to invest in highly efficient systems and systems with non-price benefits, according to interviewed market actors (Table 7). This finding is consistent with the research team's literature review, which indicated that schools are a prime market; schools value improved indoor air quality (IAQ) and are driven by codes and standards affecting IAQ that are more stringent for many school buildings than they are for other structures, given schools' occupancy levels and other characteristics.

The office sector commonly engages in both planned and emergency replacements. Professionally managed office buildings, such as those in real estate portfolios, are more likely to engage in planned

replacements governed by upgrade cycles. Among those, office buildings that serve the high-end segment of office occupants are most likely to consider non-price benefits such as controllability, occupant comfort, and (depending on the sub-segment) energy efficiency. Offices without professional asset managers, such as single offices (not held within a portfolio), and offices most concerned with minimizing costs, such as those serving the mid- and lower-end segment of office occupants, are most likely to "replace it next time it breaks" and to replace on an emergency basis.

The retail building owners/managers are least likely to plan their HVAC replacements, least likely to occupy their buildings or pay the utility bills, least likely to have high levels of occupancy most sensitive to first cost/immediate availability, and least willing to invest in highly efficient systems. Retail owners/managers engage in "replace it next time it breaks" and replace on an emergency basis.

Table 7. Interest in Highly Efficient HVAC Systems Varies by Sector (Source: Market Actor Interviews, n=35)

Sector	Typical Installation Context	Importance of First Cost (Number of Mentions)	Willingness to Invest in Highly Efficient Systems (Number of Mentions)	Characteristics Influencing Replacement Decisions
Schools	Planned installations/ replacements (planning often in two-year increments)	Non-first-cost criteria of equal or greater importance (4)	Most willing (10)	▪ High occupancy by repeat occupants ▪ Concern for occupant health and comfort, including superior IAQ and low noise ▪ Owner occupied; pay utility bills ▪ Lengthy ownership, concern for operation and maintenance (O&M) costs, total cost of ownership ▪ Stringent ventilation codes applicable to many ▪ Taxpayer-funding allows broader performance objectives (ex: public stewardship)
		"For schools, operating and maintenance cost concerns often supersedes first costs concerns."		
Offices	Planned replacements more likely among a portfolio of buildings; otherwise, planning typically limited to "replace it next time it breaks;" plus planned installations in new construction, renovation	First cost varies in importance by owner characteristics	Variable willingness (5)	▪ Medium occupancy by repeat occupants ▪ May have concern for occupant health and comfort if owner-occupied or target market demands it ▪ May be owner occupied and pay utility bills ▪ If lengthy ownership anticipated, may have concern for total cost of ownership ▪ May have dedicated facilities manager ▪ May vary by type and size of business
		"For offices, importance of first cost really depends on the owner and what his priorities are. You get everything with office buildings from down and dirty cheap to super high end. It really depends on what types of clients they're trying to lease to and how they advertise."		
Retail	Planned installations limited to new construction, renovation, and a plan to replace it next time it breaks	First cost typically most important criteria (8)	Least willing (3)	▪ Low occupancy, short occupancy periods for most occupants, limited repeat occupants ▪ Little concern for occupant health and comfort ▪ Seldom owner occupied; owner seldom pays utility bills ▪ Seldom concerned with total cost of ownership ▪ Owners highly budget-conscious
		"Retail, more than any other sector, waits until it breaks." **"Retail is typically cheap: just keep it warm or cool… and spend as little money as you can."**		

4.4. Other Factors Affecting Replacement Decisions

Market actors (9) described ownership characteristics in addition to those included in Table 4-3 above that influence interest in highly efficient HVAC systems (Table 8).

Table 8. Interest in Highly Efficient HVAC Systems Varies by Ownership Characteristics

Characteristic	Higher Interest in Highly Efficient HVAC Systems (Number of responses)	Detail
Payment of utilities	Owner pays (5)	Schools pay utility costs; owners of offices may or may not pay; owners of retail seldom pay
Duration of ownership	Long duration (3)	Institutional organizations and investors and established firms more likely to own buildings for the long-term
Public image	Positioning as a "green" organization (3)	Schools and offices may publicize they have highly efficient buildings, for prestige or to appeal to a target market
Maintenance staff	Have dedicated staff; have staff with greater capabilities (2)	Operating and trouble-shooting highly efficient HVAC systems typically requires more capable staff as systems are complex and have sophisticated controls
Number of properties	Multiple properties owned (2)	Owners of multiple properties accrue more savings than single-building owners (market actors did not elaborate on the relationship)

> **"Owners that anticipate occupying the building for long time will invest more than investors who will be flipping the building quickly."**

In addition to sector and ownership characteristics, market actors described factors such as availability of incentives, the cost of energy, building codes and standards, and benchmarking requirements that determine owner interest in high efficiency HVAC systems.

Numerous (8) market actors pointed out that evolving building codes and standards drive the adoption of highly efficient HVAC systems, a finding that is consistent with the research team's literature review. These codes and standards have particularly changed the market for DOAS in Washington, leading to an increase in the adoption of high efficiency systems. The research team notes that Washington's requirements for DOAS system efficiency nonetheless fall short of NEEA's anticipated VHE DOAS specifications, providing opportunity for NEEA to further move the market (even in Washington).

"In the state of Washington, we have seen a significant growth in HRV and ERV in a market that has not been conducive to a cost justification for efficient products because the climate is temperate. But we've seen growth in that market due to some of the codes that have gone into place."

Several interviewed market actors (4) stated that available incentives and rebates are a major factor in owners' likelihood to choose highly efficient systems. The cost of electricity and natural gas is also a determinant, and owners/managers in locations with inexpensive electricity or natural gas are less inclined to invest in energy efficiency (2).

Two market actors also noted that City of Portland benchmarking requirements influence the adoption of efficient systems. Though not mentioned by contacts, Seattle and Washington state also have benchmarking requirements. One manufacturer representative speculated "As that information becomes more public, it might educate more consumers who are looking to rent."

5. HVAC Selection Criteria

Study findings confirm all the decision-making criteria the Initiative team had identified and articulated to the study team. The most prominent barrier to adoption of DOAS and other high efficiency HVAC products, according to interviewed supply-side market actors, is building owners' concerns about first cost/immediate availability.

Market actors (24) discussed first cost more often than other factors as important in driving HVAC system choice, and the majority (16) stated that first cost is the predominant driver for most building owners, as illustrated by the following comments. However, the importance of first cost varies across the system planning scenarios (Figure 2-1a) and by commercial sector (Table 3-1).

> **"First cost usually ends up being the driving factor…. We're involved on larger scale projects with general contractors because we do multiple rounds of budgeting. In the end, the final say is first cost."**

> **"I think probably the top factors would be: cost – getting a cost-effective way to condition their space both first cost and operating cost – and comfort – to get a stable temperature and also the ability to create zones within the building for unique temperature controls. Then long-term service and operating cost."**

Although the market actors identified first cost/immediate availability as typically most important to building owners/managers (as mediated by planning context and sector), the specifiers, distributors/manufacturing representatives, and installers often consider a range of factors.

Some market actors described that when recommending HVAC systems, they balance first cost with quality and reliability, which translates to improved ability to manage operating and maintenance costs. As one specifier (design and install) noted, systems with lower first cost may be of too low quality or reliability for them to recommend to customers, and lower first cost often does not mean lower cost over the lifetime of the system.

"Even if the budget is tight, we tell building owners it will pay for itself in five years. We advise them to forego finishes in the building so they can make this investment. Fancy flooring is not an investment for example; maybe a durable floor but not fancier looking flooring. We tell them to forego that and invest in a better HVAC system."

Although according to some interviewed contacts as well as Initiative staff a VHE DOAS may need the same or less space than an RTU-based system, understanding of VHE DOAS was limited among interviewed contacts. Perhaps as a consequence of this limited understanding, numerous interviewed market actors (12) explained that the types of systems they can install or recommend depends on the space available in the building and/or on the roof and the potential need for additional ductwork. For example, one installer noted:

"The only reason [I might be hesitant to recommend a high efficiency DOAS to my customers] would be the allowable space to install equipment, especially if it's a large renovation job."

Consistent with the criteria of both first cost and space availability, most market actors (24) described like-for-like replacement as the most common type of replacement, especially in emergency situations. As one interviewee noted, even a like-for-like replacement on a system that is 20 years old is an upgrade; newer systems are built to higher efficiency specifications and have added features (often with added complexity).

Notably, the desire for and frequency of like-for-like replacements found in the supply-side market actor interviews is consistent with the literature review, which identified like-for-like replacement as influence in HVAC replacement decisions. However, among surveyed building owners, 100% (4 of 4) of school, 75% (9 of 12) of office, and 50% (6 of 12) of retail contacts described their most recent HVAC system installation as having different equipment than the previous system, and not as a like-for-like replacement.

Several interviewed market actors reported they specialize in high efficiency equipment, which is generally costlier. This indicates that that first-cost concerns and selling the cheapest product on the market is not a consideration to the supply-side market actors who specialize in premium products.

Market actors mentioned other factors in addition to cost, size constraints, and like-for-like replacement. These additional considerations include quality and reliability of the equipment (16), comfort (13), manufacturer/supplier/distributor support (9), ease of maintenance (9), especially in relation to staff ability to deal with added complexity (4), controllability (6), indoor air quality (IAQ; 5), noise reduction (4), and product availability (3).

"You can't go beyond the ability of their staff when choosing a system. You can't take an expensive system with features and controls not found on lower-price systems and turn it over to unprepared staff. They will turn things off if they don't understand."

A few specifiers and manufacturer representatives discussed manufacturer and distributor support in-depth, explaining that the extent of specification, installation, and trouble-shooting support offered strongly influences system selection. One specifier, for example, explained that they specify equipment more often from distributors that provide better service. Another explained that manufacturer and distributor support allow them to respond quickly to maintenance issues, ultimately fostering better customer relationships and reputation to establish new customers.

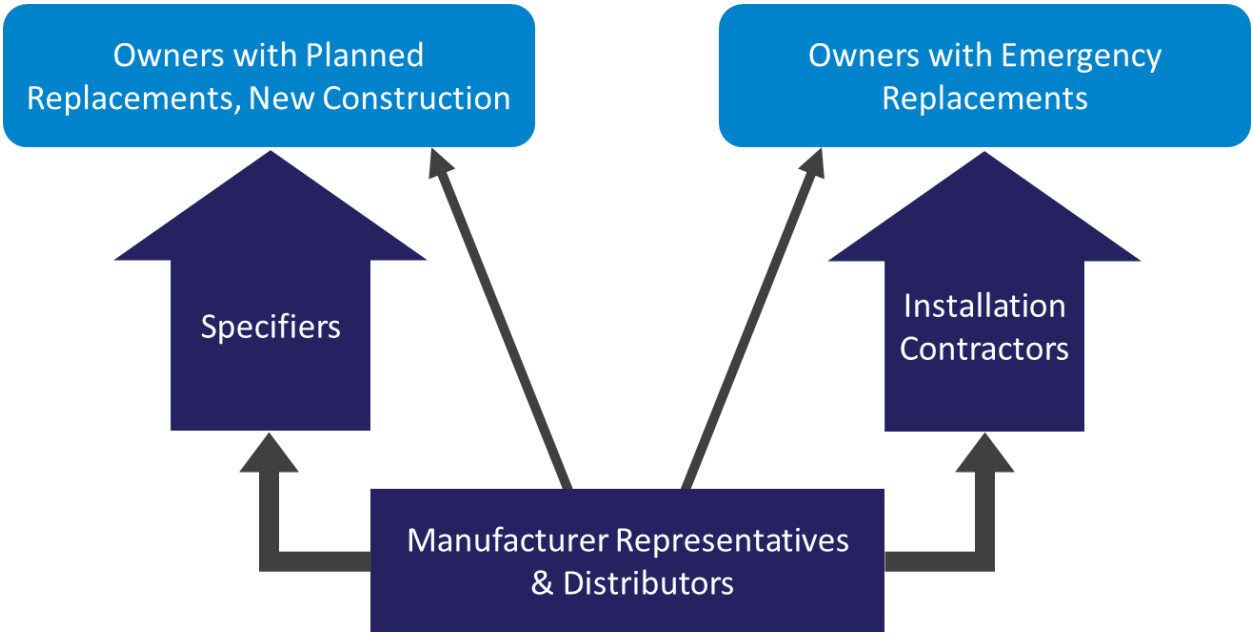
"A lot of the barriers can be overcome and addressed through relationships we [distributors] have with contractors. For example, I had a contractor who had not done VRF [Variable Refrigerant Flow] but because we had done work together and because we were confident in the product and that it was the right fit, it helped his confidence level with the product. He went with VRF and the project turned out very well."

6. Role of Supply-Side Market Actors

The owner is always the final decision maker and may have priorities or constraints that lead to the selection of a system other than the specifier's or installer's first recommendation.

Specifiers influence owners' HVAC system selection for planned installations ranging from new construction to replacements included in capital planning (see Figure 6; see Table 7 for the prevalence of planned installations by sector). Specifiers are comprised of mechanical engineers (most frequently), HVAC design specialists (typically a role within an installation contractor firm, but possibly independent), and architects. Mechanical engineers' clients may then include architects, who call upon the engineers to design the systems (2 mentions). In circumstances when specifiers are not required, including for most smaller remodels and retrofits, the owner or installer may call on specifiers to consult on projects.

Figure 6. Market Actor Influence on HVAC Selection



In planned scenarios, specifiers have greater influence on the type of HVAC system installed (8 mentions), yet they influence a fewer number of installations than installers do because they work on fewer systems (see Figure 2-1b). Installers influence system selection for replacements planned for the next time the system breaks and for emergency replacements. For emergency replacements, installers are likely making a recommendation to install for the same type of system as previously installed (like-for-like replacement).

Installers may also "educate" the building owner about the most suitable type of HVAC system and offer advice (2 mentions). Installers will have greater influence on the selection process when the building owner does not have a specific system in mind and is not rigidly prioritizing first costs. For planned

replacements, installation contractors install the specified equipment and have limited or no contact with the building owner. These installers are often hired by the architect or engineer and are selected for the installation work, 8 installers explained, typically because they had the lowest bid for the project. One installer explained that they also provide advice about design to other market actors, including the designer and engineers.

Distributors/manufacturer representatives support and influence specifiers and installers. Manufacturer representatives include internal (or in-house) manufacturer representatives, who represent a single manufacturer, and independent representatives, who represent single or multiple manufacturers. Similarly, distributors differ as to whether they carry the products of a single manufacturer or multiple manufacturers. Distributors work directly with manufacturers or their representatives, as well as with their clients.

One distributor explained that both distributors and manufacturer representatives are contacted at times by specifiers for high-efficiency solutions. One installer noted the influence of distributors (he termed it their vendor) on the roll-out of new products saying, “The technology will come into the market and one of our vendors would buy into it. Then the representative or the vendor itself might come and do some training on it, give the installers some pricing, tell them the pluses and minuses and hope they might try it.”

Specifiers, installers, and owners/managers of large real estate holdings have long-standing and often exclusive relationships with distributors/manufacturer representatives. The range of systems and products that specifiers and installers can recommend to their clients depends on whether their distributors/manufacturer representatives carry the products of a single manufacturer or multiple.

Building owners, the ultimate decision maker, may also communicate with various parties including building maintenance staff and tenants to select the HVAC system. Several market actors (5) explained that the building’s maintenance staff often has an influence. One interviewed installer added that the tenant might communicate with the building owner and occasionally the owner and tenant will work together to select the most appropriate system.

6.1. Currently, One Manufacturer Produces an HRV that Meets VHE DOAS Criteria

Currently, one manufacturer produces an HRV that meets the requirements for that component of VHE DOAS. The VHE DOAS pilot conducted by the Initiative team used this manufacturer’s system. Multiple manufacturers produce heating and cooling systems that meet VHE DOAS requirements, but no single manufacture provides both components of the VHE DOAS system.

Given that supply-chain relationships are relatively stable and individuals in the chain may work with the products of only one or a few manufacturers, the VHE DOAS market is currently limited in product

availability, distributor reach, and confidence in the market to commit to the system, as well as by the lack of a single manufacturer for both components of the system.

"From our manufacturer perspective, our hand is not forced, we [the four main manufacturers] are still selling equipment into small buildings. In terms of what will force our hand, as a manufacturer, it would be regulation or another manufacturer taking business away from us. If we saw our competitor getting specifications on everything because they always offer DOAS, then that would get our attention."

7. Conclusions and Recommendations

7.1. Conclusions

7.1.1. Barriers Review: Impediments to Rapid Uptake of VHE DOAS

The study focused on three of four potentially strong barriers to transforming the commercial HVAC market identified in the Initiative logic model: lack of VHE DOAS system *awareness*, the system's *first cost* (in many applications is anticipated to exceed the alternative equipment cost; in addition, installation entails design fees, as it's a custom technology), and the unwillingness of market actors to change the way they do business – *market inertia*. The research found that no barrier presents an insurmountable obstacle to Initiative efforts.

- The market is *aware* of what may be termed standard DOAS. However, DOAS systems are not comprehensively understood across all market actor group or consistently defined. Interviewed market actors…
  - Are aware of and typically have experience with DOAS (most interviewed specifiers and distributors/manufacturer representatives; about half of interviewed installers and surveyed building owners/managers);
  - Consistently couple HRV/ERV with DOAS in Pacific Northwest installations; (most interviewed specifiers and distributors/manufacturer representatives);
  - Describe DOAS inconsistently – varying in terminology, components, energy efficiency, and features and benefits; and
  - Lack experience with VHE DOAS unless had prior involvement in the Initiative's pilot.
- *First cost* is a significant consideration in HVAC replacement and selection decisions for a roughly estimated half of the market. It is less so, but one of many considerations, for the rest of the market.
  - The replacement context and sector in which the system is to be installed determines the relative influence of first cost.
    - First cost, design simplicity, and immediate availability are the key drivers for most emergency replacements.
      - Owners/managers that choose not to plan (that is, the emergency replacements other than early unanticipated failure) are implicitly choosing to continue with their existing systems and are looking for the least-cost installation.
      - Emergency replacements occur quickly after failure (more than half in a few days and three-quarters within one week, per surveyed owners/managers), leaving no

time to select anything other than the existing system type, for which owners/managers want the least-cost installation.

- Planned replacements, even the systems planned to be replaced the next time they break, use broader selection criteria than first cost.
- Among planned replacements, the following non-first-cost factors affect system selection:
  - Tenant and occupant comfort, including superior IAQ and low noise (for high-occupancy buildings, owner-occupied buildings, non-retail commercial buildings, government buildings, etc.);
  - Target market niche or tax-payer objectives (sustainability positioning, certification, policy governing public facilities);
  - Building codes governing the space type;
  - Operations and maintenance costs, including who pays the utility bills;
  - Life cycle costs (includes O&M, expected duration of ownership, expected system lifetime);
  - Product availability;
  - Specification, installation, and trouble-shooting support offered from distributors/manufacturer representatives; and
  - Capabilities of facilities management staff.

- *Market inertia* (established ways of doing business) and lack of experience designing/ implementing VHE DOAS impede progress to transforming this market.
  - Market inertia dominates the (roughly estimated) half of the market comprised of HVAC systems replaced on an emergency basis.
  - The study found that what may be termed standard DOAS went from relatively new to a mainstream technology in the past two decades, suggesting that market inertia can be overcome.
  - The study found that both interviewed supply-side market actors and the reviewed literature suggest the predominance of like-for-like HVAC replacements. However, surveyed building owners did not support this conclusion: 100% (4 of 4) of school, 75% (9 of 12) of office, and 50% (6 of 12) of retail contacts described their most recent HVAC system installation as having different equipment than the previous system, and not as a like-for-like replacement.

7.1.2. Planned/Emergency Replacement Dichotomy Oversimplifies Installation Context

- The study found three HVAC system replacement contexts:
  - Planned (more than six months in advance for more than half of planning respondents),
  - Plan to replace next time it breaks (with replacement times ranging from immediate to six months), and
  - Emergency replacements (one week of less for more than half of respondents engaging in emergency replacement).
- Very roughly speaking, the study estimates the HVAC market is roughly evenly divided between planned installations and emergency replacements; at a greater level of refinement, study findings suggest a more nuanced characterization of roughly 40% planned installations (including new construction/renovation and replacements), 20% plan to replace it next time it breaks, and 40% emergency replacements. Study limitations preclude more refinement than provided by these very rough estimates.

7.1.3. System Influencers and Supply Chain Relationships Vary by Installation Context

- System influencers differ by installation context.
  - Planned replacements are most commonly influenced by specifiers who typically work for mechanical engineering firms, architecture firms, or independently.
  - Plan-to-replace-it-next-time-it-breaks replacements are most commonly influenced by field staff and specifiers who typically work for the HVAC installation/service firm that has been maintaining the equipment.
  - Emergency replacements are most commonly influenced by the installation salesperson. In-house specifiers are involved in all sales to ensure the proper quantities of equipment are purchased, but this specifier typically influences the equipment selection only if called on by the salesperson to advise.
- Specifiers and contractors often have exclusive relationships with distributors/manufacturer representatives and use the equipment that the latter offer, rarely if ever considering equipment from different suppliers. These exclusive relationships limit avenues for VHE DOAS systems to limit the market because of the upstream relationships the distributors/manufacturer representatives have with manufacturers.
  - Distributors/manufacturers' representatives vary by whether they support/ supply the equipment of a single manufacturer or multiple manufacturers.
  - Among manufacturer representatives, the internal or in-house representatives, as well as some independent representatives, work with the products of a single manufacturer. The remaining independent representatives work with the products of multiple manufacturers.

- Support offered by distributors/manufacturer representatives strongly influences choices of specifiers and installers in brands of equipment offered to their customers.
  - Distributors/manufacturer representatives provide support for specification, installation, and troubleshooting both to specifiers and HVAC contractors, as well as occasionally advising building owners/managers.
  - Interview respondents described specifying equipment more often from distributors/manufacturer representatives that provide better service and enable them to respond quickly to maintenance issues, ultimately fostering better customer relationships and reputation to establish new customers.
    - Currently, one manufacturer produces an HRV that meets the requirements for that component of VHE DOAS. Multiple manufacturers produce heating and cooling systems that meet VHE DOAS requirements, but no single manufacture provides both components of the VHE DOAS system.
    - Given that supply-chain relationships are relatively stable and individuals in the chain may work with the products of only one or a few manufacturers, the VHE DOAS market is currently limited in product availability, distributor reach, and confidence in the market to commit to the system, as well as by the lack of a single manufacturer for both components of the system.

7.1.4. Market Opportunity Exists for VHE DOAS

- A near-term market opportunity for VHE DOAS appears to exist based on findings that roughly 40% to 50% of HVAC system installations in schools, office, and retail buildings are planned, and that VHE DOAS attributes align with common planned system selection criteria.
  - VHE DOAS benefits and features align well with many HVAC selection decision criteria for the (roughly estimated) half of the market comprised of planned HVAC installations (examples of aligning features: lifetime cost, system size, comfort, controllability, IAQ, and low noise).
  - The current state of the supply chain (a single HRV manufacturer, with consequent limited support available from the distributors and manufacturing relationships with which specifiers work) will limit this market opportunity.
- A long-term market opportunity for VHE DOAS appears to exist based on findings that roughly 20% of HVAC system installations occur in a context of “replace it next time it breaks,” that the servicing HVAC contractor has specifiers on staff, and that perhaps a quarter or more of these installations take longer than three weeks from system failure, a longer term market appears to exist for VHE DOAS.
  - As installers gain experience with VHE DOAS planned installations, they will consider VHE DOAS systems for “replace it next time it breaks” contexts.

- As distributors/manufacturer representatives gain experience with VHE DOAS (assuming expansion in the number of VHE DOAS manufacturers), they will support installation contractors in VHE DOAS and thereby increase contractor willingness to specify.
- Although not explicitly investigated by the study, NEEA might anticipate that the primary opportunity for VHE DOAS in this context would be where owners/managers with multiple rooftop HVAC units on one building are replaced systematically as they fail.

7.2. Recommendations

The research team offers the following recommendations to NEEA's High-Performance HVAC Initiative team as it further develops a VHE DOAS effort.

- First wave of VHE DOAS efforts should target installations planned via budgeting and upgrade cycles – schools, large office property management, and new construction/renovation. Building owners/managers use specifiers for these installations.
- Emphasize VHE DOAS benefits as they align with each sector to minimize first-cost thinking.
- Align Initiative terminology with common industry terms whenever possible.
- Educate distributors/manufacturer representatives on NEEA's VHE DOAS specifications and how to source VHE DOAS components from the manufacturers they work with.
- Explore resources (beyond education) NEEA could provide suppliers to support increases in VHE DOAS sales.

Appendix A. Very High Efficiency DOAS System

According to Northwest Energy Efficiency Alliance (NEEA) staff at the outset of this study (2018):

Very High Efficiency Dedicated Outside Air System (VHE DOAS) is a system using the highest efficiency equipment available. The system is made up of two major components, (1) a very high efficiency ventilation system (85% or better sensible heat recovery efficiency) and (2) a heating and cooling system typically provided by very high efficiency heat pump-based system, including variable refrigerant flow (VRF) equipment. [The heating and cooling system must meet or exceed the following criteria:] minimum heating seasonal performance factor (HSPF) 9.5, COP 3.0+, and minimum cooling energy efficiency ratio (EER) 11.0, integrated energy efficiency ratio (IEER) 18.0. The heating and cooling system could also be a ducted or ductless mini-split heat pump, or a ceiling radiant heating and cooling system if the system meets the minimum efficiency levels specified. Both the heat recovery ventilation (HRV) and heating/cooling components have high efficiency fans (0.5 watts/cfm or less). VHE DOAS can be included in new construction or in converting an existing heating, ventilation, and air-conditioning (HVAC) system. System design (zoning, ducting, controls) varies from traditional systems and is critical to achieve full efficiency.

Per NEEA staff, the following do not meet NEEA's VHE DOAS specification:

- *Conventional DOAS that uses heat or cooling energy from the primary system to condition the ventilation air,*
- *Systems that use heating/cooling delivery airstream to meet ventilation requirements (same ducts to deliver heat/cool and ventilation),*
- *HRVs that have lower sensible heat recovery than 85% or energy recovery efficacy below 75%.*
- *HRVs that use wheel heat exchangers (due to high cross flow leakage),*
- *Variable air volume (VAV) systems with heat recovery, or any system with variable percentage of outside air, and*
- *Systems using supplemental conditioning of ventilation air (that is, terminal reheat or simultaneous heating and cooling).*

Appendix B. Summary of Findings Pertinent to NEEA's Market Assumptions

This section summarizes the extent to which the current study confirms the Initiative's market assumptions market (Table 9).

Table 9. Confirmation of NEEA's Market Assumptions

Assumption	Explanation
Confirmed	
Decision makers default to replacement systems with the same fuel type	Normally
Product selection process differs by building type	True: different building types serve different owner, manager and tenant needs, which can drive decision makers to value similar HVAC systems differently Also, selection differs by planned versus emergency, which differs by building type/sector
HE HVAC like the VHE DOAS solution will not be selected in an emergency replacement situation	True, as VHE DOAS is a system that requires design However, it *might* be specified when the market is sufficiently established that HVAC installation and service contractors are experienced with VHE DOAS and suggest it to customers engaged in "replace it next time it fails" planning
Market has confusion over DOAS, does not think of it as NEEA does	True; "varying in components, functionality, and efficiency
Who makes or influences HVAC installation decisions differs by project type and replacement scenario	Yes, the decision makers/influencers vary by degree of planning, which varies by sector Examples: School replacements typically planned; system selection influenced by designer (and designer typically works for a mechanical engineering firm). Retail replacements typically on an emergency or basis or a plan to replace next time it breaks; system selection influenced by HVAC installation firm (which includes some design capability)

Assumption	Explanation
Confirmed	
Project specifiers are not a narrowly defined group.	All systems are specified. To bring functionality to the market actor "specifier," NEEA should think of (define) specifiers as mechanical engineers (most frequently) and HVAC design specialists (typically a role within an installation contractor firm, but possibly independent). Specifiers work on planned replacements. Installers identify the equipment for emergency replacements and someone in their firm determines the exact specification, including sizing and ancillary equipment needed. Distributors/manufacturer representatives provide support to specifiers and installers but do not specify equipment (see section 5)
If a HE HVAC system (as VHE DOAS would be) is specified, there is a good chance it will be 'value-engineered' out?	There is pressure on specifiers to find efficiency solutions in HVAC that are less than optimal. One specifier did describe recommending a higher-cost DOAS system over another alternative yet selecting a lower-cost (lower-efficiency) HRV to keep total costs down.
Somewhat Confirmed	
Replacement is usually one-for-one project (not part of a larger building overhaul or an add-on to another project).	Planned replacements may be part of a larger building overhaul or an add-on to another project; replace-when-it-next-fails and emergency replacements are one-for-one.
Decision makers don't think about HVAC replacement until near failure, and they generally use equipment beyond typical life span.	Owners/managers that eschew planning use the equipment until it is no longer feasible to repair, which may be beyond the typical life span.
Not Supported	
Decision makers/influencers vary by project size.	Differs by planned versus emergency, which differs by building type/sector; the owners on the planning side of the continuum generally have larger buildings, and thus larger projects, yet project size is a more of a correlate than a driver
Not Addressed by Interviews	
Assumption: There is a trend toward electrification because of carbon goals, codes	

Appendix C. Literature Review Parameters

The literature search focused on the commercial adoption of the following technologies in the Northwest and elsewhere: Dedicated Outside Air System (DOAS), Very High Efficiency (VHE) DOAS, Heat Recovery Ventilation (HRV), and high-efficiency cooling and heating Roof Top Units (RTUs).

Table 10 outlines the literature review topics and target sectors.

Table 10. Literature Review Parameters

Research Objectives	Secondary Literature Review Parameters	Larger Goals (NEEA Will Use Findings to…)
Estimate market opportunity	**Topics:** DOAS, VHE DOAS, HRV, and high-efficiency RTU market adoption and trends, including anything on replacement cycles. **Sectors:** New construction and existing building commercial sectors.	Devise a program and/or marketing strategy to target supply actors and potential VHE DOAS adopters
Assess barriers to adoption	**Topics:** Barriers and solutions to adopt technologies referenced above, including if others are implementing initiatives to encourage adoption of the above technologies. **Sectors:** New construction and existing building commercial sectors.	
Document decision-making	**Topics:** How are capital improvement and HVAC replacement decisions made? **Sectors:** New construction and existing building commercial sectors.	

C.1. Research Questions

The study investigates the following research objectives:

1. **Estimating the market opportunity:** What is the frequency of HVAC replacements in the target market and what is the share of emergency versus planned replacements? What factors limit adoption of VHE DOAS system and a qualitative assessment of the proportion of the estimated 20,000 buildings in the target market that would be affected by these factors? What proportion might do so in a given period, based on the likelihood of a planned replacement during that period and the willingness to adopt this new technology for planned replacements?
2. **Assessing market barriers:** What is the level of building owner and market actor awareness of highly efficient HVAC technologies, including VHE DOAS and HRV, and its benefits? To what extent do market actors lack experience and knowledge in designing and selling VHE DOAS systems? To what degree do beliefs or concerns about high upfront cost, product quality, and product availability (i.e., a few manufactures producing highly efficient HRV component of the system) prevent other actors from considering VHE DOAS as a feasible technology? To what extent is there resistance to new technologies due to entrenched HVAC design, installation, and

other practices? To what extent do market actors see the value of the technology but are limited by their conviction that building owners will not see its value?

3. **Explicating the relevant decision-making processes:** What triggers decisions to replace HVAC? What are the criteria owners and market actors use to assess the value of an HVAC system (initial cost, energy efficiency, maintenance costs, building use, or complexity)? How do specifiers, distributors and manufacturer representatives, installers, and building owners interact in making decisions about HVAC purchase and replacement decisions? How does that vary by building type, ownership structure, and whether it is a new construction or retrofit project? How might it depend on other factors, such as building size or property or energy management model? Who are the market influencers? What can NEEA do (provide tools, market the product, show data, offer incentives) to encourage market actors to offer VHE DOAS?
4. **Reviewing and validating assumptions:** To what degree do NEEA's understanding and assumptions about the market opportunity, awareness, resistance to change, limited supply base, and decision-making reflect the current state of the market? Are NEEA's assumptions reasonable to ensure savings estimates are robust? How can NEEA use the knowledge of HVAC replacement decisions and sale processes to encourage market actors to sell VHE DOAS?

C.2. Sources Investigated

The study team reviewed several energy efficiency and building technology conference proceedings (some dating back to 2015), publication sites from Northwest agencies involved in administering energy efficiency programs (NEEA, Bonneville Power Authority, and Energy Trust of Oregon), and heating and cooling specialty publications and sites. The following list documents the sources the study team investigated:

- Efficiency Exchange Conference Publications, 2016 - 2018
- American Council for an Energy-Efficient Economy (ACEEE) Publications, 2015 - 2018
- Association of Energy Service Professionals (AESP) Conference Proceedings, 2015 - 2018
- ASHRAE Winter Conference/Journal Publications
- Air Conditioning, Heating and Refrigeration (ACHR) News
- Energy Trust of Oregon Commercial Buildings Research Literature
- New Buildings Institute Research Literature
- National Renewable Energy Laboratory (NREL) Publications
- NEEA's Commercial Building and HVAC Research
- Bonneville Power Administration Commercial Building and HVAC Research

From these sources, the study team identified 14 papers or publications relevant to this study. The next section provides the publication title, authors, year of publication, and the source of publication (URL).

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Appendix D. In-depth Interviews

D.1. Manufacturer Representatives/Distributors

D.1.1. Screening [ASK ALL]

S1. Does any of the equipment you sell go into the office, retail, or school sector? [If no, thank and terminate]

S2. [If distributor] Do you distribute HVAC systems that are 125-tons or smaller? [If no, thank and terminate]

S2. [If manufacturer rep] Okay thanks for that information. Does your company manufacture HVAC systems that are 125-tons or smaller? [If no, thank and terminate]

S3. [If distributor] About how many years have you been working with commercial HVAC equipment?

S4. [If distributor] And about how many employees work for your company on commercial HVAC equipment?

D.1.2. Introduction

Thanks for taking the time to talk today. We'd like to get your insights on what building owners need and want when choosing HVAC systems and better understand how you work with your customers about satisfying the goals of their customers, the building owners.

I'll be taking notes as we talk, but I would like to record this interview to ensure the accuracy of my notes. Would that be okay with you?

And please note, nothing you say will be identified with your company or your name in our reports.

[*Interviewer: If permission granted, record the interview*.]

D.1.3. Role in the Market

Q1. Many of my questions today concern the schools, office, and retail markets. As we begin our conversation, I'd like to know, who are your typical customers, and I'm thinking of possibly the designer/specifier, the contractor/installer, the building owner.

1. [If not addressed] How frequently are you called on to help craft solutions for specific buildings with systems no larger than 125 tons?

D.1.4. Equipment Familiarity

[To Interviewer: Note what sectors contact works in. For contacts that only work in one of the target sectors, omit follow-ups asking for differences between the sectors. For contacts that work in two sectors, follow up only on those two sectors.]

Q2. NEEA is initially considering the market for HVAC systems of about 125-tons or smaller going into schools, offices, and retail facilities. What are the different types of HVAC systems you've sold into this market, including some of your more innovative systems?

Q3. If one of your customers is interested in high efficiency equipment (again, 125 tons or smaller), what types of equipment do you think of as suited to this need? Anything else?

Q4. [IF CONDENSING ROOF TOP UNIT (CRTU) OR DOAS NOT MENTIONED; AND BROADEN TO ANY CUSTOMER; DON'T LIMIT TO TARGET MARKET]

1. [CRTU] What is your experience with gas condensing rooftop units?
2. [DOAS] And dedicated outdoor air systems or DOAS? [IF NEEDED, AND NOTE IF UNFAMILIAR] Roughly speaking a DOAS is an HVAC system with ventilation supply that relies solely on outside air?
3. [IF FAMILIAR WITH DOAS] And what is your experience with a high efficiency DOAS, which is a dedicated outdoor air system in tandem with a heat or energy recovery ventilator?

D.1.5. Drivers – Client and Self

Q5. In this market, what are the key factors that influence your recommendations for HVAC system type? For example, what problems are clients trying to solve? What are customers typically seeking when they consider HVAC systems?

1. What about: [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:] First cost, reliability, operating costs, maintenance, like-for-like replacement, comfort
2. [IF NOT ADDRESSED] How about energy efficiency? What types of customers might be looking for efficiency?

3. [IF NOT ADDRESSED AND MULTIPLE SECTORS] Do these concerns vary by customer type – office, retail, or school, and if so, how?
4. [IF NOT ADDRESSED] Do these concerns vary the installation context – new construction vs major renovations vs planned end-of-useful-life replacement?

Q6. And in this market, what considerations do you bring to your thinking, beyond that which the customer specifies. I am thinking of possible factors such as your familiarity with a system type, your experience with installer support, or a desire to minimize the back-and-forth needed with clients.

1. Anything else? [PROBE TO FULLY UNDERSTAND]

Q7. At what age are HVAC systems typically replaced in these markets (that is schools, office and retail), and about how long far in advance do organizations start planning?

D.1.6. Decision Makers

Q8. We understand there can be a lot of people that influence the final equipment selection, including multiple decision makers on the customer side and different professionals and building trades on the supply side. Can you sketch out who typically has some influence on equipment selection in this market (schools, offices, retail, 125 tons or less) and their roles in the process?

1. Again, do these considerations vary by customer type or by installation context? [Installation context is new construction, major renovation, end-of-life replacement]
2. [IF NOT ADDRESSED] Under what conditions, if any, are you one of the principal people influencing the choice of equipment type?

Q9. What types of customers use the services of a system designer or specifier, or what circumstances lead customers to engage a specifier?

1. In your experience with schools, offices, or retail seeking units of 125-ton or less, how common is it to use a specifier? [IF NOT STATED] About what proportion of the time?

D.1.7. Decision Making

Q10. NEEA is interested in the potential for DOAS systems, especially high efficiency systems that include heat recovery. NEEA has identified both cost and non-cost benefits, such as potentially lower operating costs, need for less rooftop square footage, improved indoor air quality and compliance with IAQ standards, lower noise, good controls, and a more sustainable approach to HVAC. Hypothetically, say you proposed such a system to your customers in this target market. What would be their likely? What would they like about this, if anything, and what would their concerns be?

Q11. And from your perspective, what are reasons you might be hesitant or reluctant to recommend a high efficiency DOAS to your customers in this market?

Q12. So, to recap and perhaps touch on some additional ideas, how important is the following in limiting your potential interest in DOAS for your customers? [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:]

… Your comfort with the DOAS technology, your familiarity and expertise
… Upfront cost

[FOLLOW UP: Is it your perception that a DOAS system is more expensive? By about how much, would you say?]

… Product quality
… Product availability
… Inertia (resistance to new technologies by customer or other market actors)
… Building owners are unlikely to see high-efficiency HVAC value

Q13. From your perspective are there any design or specification challenges or concerns issues associated with the DOAS technology?

Q14. And the same question for an HRV or ERV. From your perspective are there any design or specification challenges or concerns issues associated with the heat or energy recovery technologies?

D.1.8. Closing [ALL]

That's it! Thank you so much. I really appreciate your insights and your sharing your experience. Is there anything else you would like to mention before we end our conversation? Finally, if I need to follow-up with you on something we discussed, would it be okay with you if I reached out?

D.2. Specifiers

D.2.1. Screening – ASK WHEN SCHEDULING INTERVIEW

S1. Do you have any clients in the office, retail, or school sector? [If no, thank and terminate; If yes, record what.]

S2. We are interested in the HVAC market for systems 125 tons or less. Do you have any clients with systems of this size? [If no, thank and terminate]

S3. About how many years have you been working with commercial HVAC equipment?

S4. And about how many employees work for your company on commercial HVAC equipment?

D.2.2. Introduction

Thanks for taking the time to talk today. We'd like to get your insights on what building owners need and want when choosing HVAC systems and better understand how you help to satisfy those goals.

I'll be taking notes as we talk, but I would like to record this interview to ensure the accuracy of my notes. Would that be okay with you?

And please note, nothing you say will be identified with your company or your name in our reports.

[*Interviewer: If permission granted, record the interview*.]

D.2.3. Equipment Familiarity

[To Interviewer: Note what sectors contact works in. For contacts that only work in one of the target sectors, omit follow-ups asking for differences between the sectors. For contacts that work in two sectors, follow up only on those two sectors.]

Q1. NEEA is initially considering the market for HVAC systems of about 125-tons or smaller going into schools, offices, and retail facilities. In this market, what are the different types of HVAC systems you've designed, including some of your more innovative system designs.

Q2. If one of your clients is interested in high efficiency equipment (again, 125 tons or smaller), what types of equipment do you think of as suited to this need? Anything else?

Q3. [IF CRTU OR DOAS NOT MENTIONED; AND BROADEN TO ANY CLIENT; DON'T LIMIT TO TARGET MARKET]

1. [CRTU] What is your experience with gas condensing rooftop units?
2. [DOAS] And dedicated outdoor air systems or DOAS? [IF NEEDED, AND NOTE IF UNFAMILIAR] Roughly speaking a DOAS is an HVAC system with ventilation supply that relies solely on outside air.
3. [IF FAMILIAR WITH DOAS] And what is your experience with a high efficiency DOAS, which is a dedicated outdoor air system in tandem with a heat or energy recovery ventilator?

D.2.4. Drivers – Client and Self

Q4. In this market, what are the key factors that influence your recommendations for HVAC system type? For example, what problems are clients trying to solve? What are clients typically seeking when they consider HVAC systems?

1. What about: [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:] First cost, reliability, operating costs, maintenance, like-for-like replacement, comfort
2. [IF NOT ADDRESSED] How about energy efficiency? What types of clients might be looking for efficiency?
3. [IF NOT ADDRESSED AND MULTIPLE SECTORS] Do these concerns vary by client type – office, retail, or school, and if so, how?
4. [IF NOT ADDRESSED] Do these concerns vary across the installation context – new construction vs major renovations vs planned end-of-useful-life replacement?

Q5. And in this market, what considerations do you bring to your thinking, beyond that which the client specifies. I am thinking of possible factors such as your familiarity with a brand or a system type, your experience with distributor support, or a desire to minimize the back-and-forth needed with clients.

1. Anything else? [PROBE TO FULLY UNDERSTAND]

D.2.5. Replacement

Q6. At what age are HVAC systems typically replaced in these markets (that is schools, office and retail), and about how long far in advance do organizations start planning?

1. [IF NOT ADDRESSED] Again, do these considerations vary by client type?

Q7. Is it typical that facilities replace like-for-like in emergency situations such as equipment failure?

Q8. [IF KNOWLEDGEABLE] About what proportion of replacements are in emergency situations?

D.2.6. Decision Makers

Q9. We understand there can be a lot of people that influence the final equipment selection, including multiple decision makers on the client side and different professionals and building trades on the supply side. Can you sketch out who typically has some influence on equipment selection in this market (schools, offices, retail, 125 tons or less) and their roles in the process?

1. Again, do these considerations vary by client type or by installation context? [Installation context is new construction, major renovation, end-of-life replacement]

2. [IF NOT ADDRESSED] Under what conditions, if any, are you one of the principal people influencing the choice of equipment type?

D.2.7. Decision Making

Q10. NEEA is interested in the potential for DOAS systems, especially high efficiency systems that include heat recovery. NEEA has identified both cost and non-cost benefits, such as potentially lower operating costs, need for less rooftop square footage, improved indoor air quality and compliance with IAQ standards, lower noise, good controls, and a more sustainable approach to HVAC. Hypothetically, say you proposed such a system to your clients in this target market. What would be their likely? What would they like about this, if anything, and what would their concerns be?

Q11 And from your perspective, what are reasons you might be hesitant or reluctant to recommend a high efficiency DOAS to your clients in this market?

Q12. So, to recap and perhaps touch on some additional ideas, how important is the following in limiting your potential interest in DOAS for your clients? [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:]

… Your comfort with the DOAS technology, your familiarity and expertise
… Upfront cost

[FOLLOW UP: Is it your perception that a DOAS system is more expensive? By about how much, would you say?]

… Product quality
… Product availability
… Inertia (resistance to new technologies by client or other market actors)
… Building owners are unlikely to see high-efficiency HVAC value

Q13. From your perspective are there any design or specification challenges or concerns issues associated with the DOAS technology?

Q14. And the same question for an HRV or ERV. From your perspective are there any design or specification challenges or concerns associated with the heat or energy recovery technologies?

D.2.8. Closing [ALL]

That's it! Thank you so much. I really appreciate your insights and your sharing your experience. Is there anything else you would like to mention before we end our conversation? Finally, if I need to follow-up with you on something we discussed, would it be okay with you if I reached out?

D.3. Installers

D.3.1. Screening – ASK WHEN SCHEDULING INTERVIEW

S1. Do you have any customers in the office, retail, or school sector? [If no, thank and terminate; If yes, record what.]

S2. We are interested in the HVAC market for systems 125 tons or less. Do you have any customers with systems of this size? [If no, thank and terminate]

S3. About how many years have you been working with commercial HVAC equipment?

S4. And about how many employees work for your company on commercial HVAC equipment?

D.3.2. Introduction

Thanks for taking the time to talk today. We'd like to get your insights on what customers need and want when choosing HVAC systems and better understand how you work with building owners to satisfy those goals.

I'll be taking notes as we talk, but I would like to record this interview to ensure the accuracy of my notes. Would that be okay with you?

And please note, nothing you say will be identified with your company or your name in our reports.

[*Interviewer: If permission granted, record the interview*.]

D.3.3. Equipment Familiarity

[To Interviewer: Note what sectors contact works in. For contacts that only work in one of the target sectors, omit follow-ups asking for differences between the sectors. For contacts that work in two sectors, follow up only on those two sectors.]

Q1. NEEA is initially considering the market for HVAC systems of about 125-tons or smaller going into schools, offices, and retail facilities. In this market, what are the different types of HVAC systems you've installed, including some of your more innovative installations.

Q2. If one of your customers is interested in high efficiency equipment (again, 125 tons or smaller), what types of equipment do you think of as suited to this need? Anything else?

Q3. [IF CRTU OR DOAS NOT MENTIONED; AND BROADEN TO ANY CUSTOMER; DON'T LIMIT TO TARGET MARKET]

1. [CRTU] What is your experience with gas condensing rooftop units?
2. [DOAS] And dedicated outdoor air systems or DOAS? [IF NEEDED, AND NOTE IF UNFAMILIAR] Roughly speaking a DOAS is an HVAC system with ventilation supply that relies solely on outside air?
3. [IF FAMILIAR WITH DOAS] And what is your experience with a high efficiency DOAS, which is a dedicated outdoor air system in tandem with a heat or energy recovery ventilator?

D.3.4. Drivers – Client and Self

Q4. In this market, what are the key factors that influence your recommendations for HVAC system type? For example, what problems are clients trying to solve? What are customers typically seeking when they consider HVAC systems?

1. What about: [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:] First cost, reliability, operating costs, maintenance, like-for-like replacement, comfort
2. [IF NOT ADDRESSED] How about energy efficiency? What types of customers might be looking for efficiency?
3. [IF NOT ADDRESSED AND MULTIPLE SECTORS] Do these concerns vary by customer type – office, retail, or school, and if so, how?
4. [IF NOT ADDRESSED] Do these concerns vary the installation context – new construction vs major renovations vs planned end-of-useful-life replacement?

Q5. And in this market, what considerations do you bring to your thinking, beyond that which the customer specifies. I am thinking of possible factors such as your familiarity with a brand or a system type, your experience with distributor support, or a desire to minimize the back-and-forth needed with clients.

1. Anything else? [PROBE TO FULLY UNDERSTAND]

D.3.5. Replacement

Q6. At what age are HVAC systems typically replaced in these markets (that is schools, office and retail), and about how long far in advance do organizations start planning?

1. [IF NOT ADDRESSED] Again, do these considerations vary by client type?

Q7. Is it typical that facilities replace like-for-like in emergency situations such as equipment failure?

Q8. [IF KNOWLEDGEABLE] About what proportion of replacements are in emergency situations?

D.3.6. Decision Makers

Q9. We understand there can be a lot of people that influence the final equipment selection, including multiple decision makers on the customer side and different professionals and building trades on the supply side. Can you sketch out who typically has some influence on equipment selection in this market (schools, offices, retail, 125 tons or less) and their roles in the process?

1. Again, do these considerations vary by customer type or by installation context? [Installation context is new construction, major renovation, end-of-life replacement]
2. [IF NOT ADDRESSED] Under what conditions, if any, are you one of the principal people influencing the choice of equipment type?

Q10. What types of customers use the services of a system designer or specifier, or what circumstances lead customers to engage a specifier?

Q11. In your experience with schools, offices, or retail seeking units of 125-ton or less, how common is it to use a specifier? [IF NOT STATED] About what proportion of the time?

D.3.7. Decision Making

Q12. NEEA is interested in the potential for DOAS systems, especially high efficiency systems that include heat recovery. NEEA has identified both cost and non-cost benefits, such as potentially lower operating costs, need for less rooftop square footage, improved indoor air quality and compliance with IAQ standards, lower noise, good controls, and a more sustainable approach to HVAC. Hypothetically, say you proposed such a system to your customers in this target market. What would be their likely? What would they like about this, if anything, and what would their concerns be?

Q13. And from your perspective, what are reasons you might be hesitant or reluctant to recommend a high efficiency DOAS to your customers in this market?

Q14. So, to recap and perhaps touch on some additional ideas, how important is the following in limiting your potential interest in DOAS for your customers? [DO NOT READ ALL, EXPLORE ACROSS INTERVIEWS:]

… Your comfort with the DOAS technology, your familiarity and expertise
… Upfront cost

[FOLLOW UP: Is it your perception that a DOAS system is more expensive? By about how much, would you say?]

… Product quality
… Product availability
… Inertia (resistance to new technologies by customer or other market actors)

… Building owners are unlikely to see high-efficiency HVAC value

Q15. From your perspective are there any design or specification challenges or concerns issues associated with the DOAS technology?

Q16. And the same question for an HRV or ERV. From your perspective are there any design or specification challenges or concerns issues associated with the heat or energy recovery technologies?

D.3.8. Closing [ALL]

That's it! Thank you so much. I really appreciate your insights and your sharing your experience. Is there anything else you would like to mention before we end our conversation? Finally, if I need to follow-up with you on something we discussed, would it be okay with you if I reached out?

Appendix E. Web Survey

E.1. Building Owners, Managers, or Superintendents

E.1.1. Screening Questions

S1. Do you own or manage any buildings that are **50,000 square feet or less**?

1. Yes
2. No – [TERMINATE AND SKIP TO TERMINATION SCRIPT FOR S1]
98. Don't know - [TERMINATE AND SKIP TO TERMINATION SCRIPT FOR S1]

S2. Thinking of your building's **last HVAC replacement**, are you familiar with: (select all that apply)

[MULTIPLE RESPONSE]

- How old the system was at replacement
- The approximate size (tonnage) of the replaced or installed heating and cooling system
- Whether the replacement was planned or an emergency
- None of the above [EXCLUSIVE RESPONSE; TERMINATE AND SKIP TO TERMINATION SCRIPT FOR S2]

[THEY QUALIFY FOR THE SURVEY IF THEY SELECT 1 OR 3, OTHERWISE SKIP TO TERMINATION SCRIPT FOR S2]

[ASK IF OFFICE AND/OR RETAIL]

S3. Please select the types of buildings that your either own or manage.

[MULTIPLE RESPONSE]

1. Office
2. Retail
3. Office/Retail
4. Other, please describe: [OPEN-ENDED RESPONSE]

[IF THEY SELECT OPTION "4" (Other) AND NOTHING ELSE, SKIP TO TERMINATION SCRIPT FOR S3] [IF THEY SELECT OPTION "5" (NONE OF THE ABOVE) SKIP TO TERMINATION SCRIPT FOR S3]

E.1.2. Replacement Cycle

[DISPLAY TO THOSE WHO PASS OUR SCREENING QUESTIONS]

You qualify for our survey!

Please think about buildings that are less than 50,000 square feet in size when you provide answers.

[ASK ALL]

Q1. Thinking of the last HVAC system you replaced, how old was it at the time of replacement?

1. Less than 10 years
2. 11-15 years
3. 16-19 years
4. 20-24 years
5. 25-29 years
6. 30 or more years
98. Don't know [MAKE ANSWER EXCLUSIVE]

[ASK IF Q2=98 (DON'T KNOW)]

Q2. Was the last HVAC System you replaced older or younger than 15 years?

[SINGLE RESPONSE]

1. Older than 15 yrs.
2. Younger than 15 yrs.
3. About 15 yrs.
98. Don't know

[ASK ALL]

Q3. Thinking again of the last HVAC system you replaced, would you consider it a like-for-like replacement?

[SINGLE RESPONSE]

1. Yes, it was a like-for-like replacement
2. No, the new system has different equipment than the previous system
96. Not sure, please describe: [OPEN-ENDED RESPONSE]
98. Don't know

[ASK ALL]

Q4. Thinking again of the last HVAC system you replaced, was the replacement planned or in response to an emergency?

[SINGLE RESPONSE]

1. Planned
2. Emergency
96. Other, please specify: [OPEN-ENDED RESPONSE]
98. Don't know

[IF Q5=2, EMERGENCY]

Q5. What prompted the emergency replacement? Please select all that apply.

[MULTIPLE RESPONSE]

1. Unrepairable failure
2. Costly to repair
3. Took too long to repair
4. Unreliable
5. Other [OPEN-ENDED RESPONSE]
98. Don't know [PROGRAMMER MAKE THIS EXCLUSIVE RESPONSE]

[ASK ALL]

Q6. In general, is your or your organization’s HVAC planning driven by an established budget cycle or upgrade cycle?

[SINGLE RESPONSE]

1. Budget cycle
2. Upgrade cycle
3. Both
4. Neither
96. Other, please specify: [OPEN-ENDED RESPONSE]
98. Don't know

[ASK ALL]

Q7. For planned replacements, about how long does it typically take you or your organization to move from identifying the HVAC need to installing the system?

1. [OPEN-ENDED RESPONSE]

98. Don't know

[ASK ALL]

Q8. For emergency replacements, about how long does it typically take you or your organization to move from identifying the need to installing the system?

1. [OPEN-ENDED RESPONSE]
98. Don't know

E.1.2.1. DOAS

[ASK ALL]

Q9. A dedicated outdoor air system (DOAS) is an HVAC unit that is installed outside to bring fresh air into interior spaces independently from heating or cooling efforts. Addressing ventilation and air conditioning separately can save fan energy while improving indoor air quality. Coupled with a heat recovery system on the air conditioning equipment, the system also saves heating and cooling energy. Please describe your experience with DOAS technology by checking all that apply.

[MULTIPLE RESPONSE]

1. I have heard of DOAS
2. I have a general understanding of appropriate applications for a DOAS
3. I have discussed DOAS with a contractor or other building professional
4. I have considered installing a DOAS
5. I have one or more DOAS in my buildings
98. Don't know [PROGRAMMER MAKE THIS EXCLUSIVE RESPONSE]

Q10. Imagine that you are planning to replace an HVAC system and you've heard that a DOAS system can be installed at the same price as a system similar to what you now have. How likely are you to:

a. Discuss DOAS with your contractor or building professional [INSERT 0-10 scale where 0=Not at all likely, 5=Moderately Likely, and 10=Extremely likely]
b. Seek a bid for a DOAS installation [INSERT THE SAME SCALE AS ABOVE]

E.1.3. Closing

All done! Thank you very much for sharing your experiences with us.! We will email you a **$50** Amazon e-gift card in the next few days. If the email address below is not correct, then please provide the correct email address.