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Review of Market Share Forecast and Key Assumptions for VHE DOAS

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Introduction

NEEA contracted with Cadmus to review its approach to developing a naturally occurring baseline market share forecast for very high efficiency dedicated outside air systems (VHE DOAS). NEEA's definition of a VHE DOAS includes an energy/heat recovery ventilator (E/HRV) paired with an electric high-efficiency HVAC system. There are also two required design practices: fully or partially decoupling ventilation and heating/cooling ducts and downsized heating/cooling equipment (because standard sizing calculations do not factor the reduced heating/cooling load provided by the HRV/ERV).

The key research questions for this task are the following.

Naturally Occurring Baseline Market Share Forecast Review

- Is NEEA's forecast appropriate and credible?

Key Assumptions Review

- Is NEEA's approach to estimating the number of very efficient HRVs/ERVs shipped to locations in the Northwest prior to the program's intervention reasonable? Is there a better way to establish the starting point for NEEA's naturally occurring baseline market share?
- Has NEEA captured the primary market drivers influencing market adoption to date? Are there other market drivers that NEEA should factor into its naturally occurring baseline market share?
- Will NEEA's approach for tracking unit sales and market share provide realistic and credible estimates of market adoption?
- Are the data and methods used to determine unit energy savings and market size reasonable and sufficient for credible accounting of energy savings?

This report summarizes Cadmus' review findings and recommendations.

Naturally Occurring Baseline Market Share Forecast Review

NEEA provided Cadmus with a memo (see *Appendix*) describing its proposed naturally occurring baseline market share forecast for VHE DOAS. Accompanying the memo was an Excel file with calculations and other key assumptions, such as NEEA's methods for estimating energy savings and market size. NEEA also provided several market research reports that spanned decades.

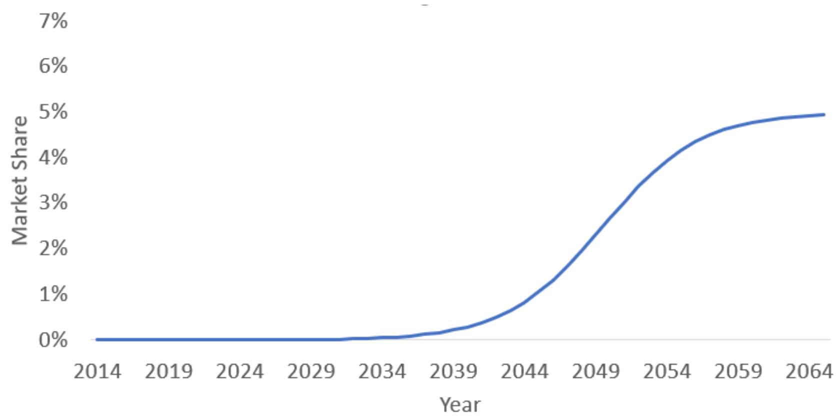
The proposed naturally occurring baseline market share forecast for VHE DOAS is based on a top-down approach. The forecast uses the following equation, which is a simplified S-curve according to its original developer.[1]

$$Market\ Penetration\ (Year) = Initial\ Condition + \frac{Saturation}{1 + Factor^{\left(\frac{Hypergrowth + \frac{Takeover}{2} - Year}{Takeover}\right)}}$$

[1] Wikipedia. September 10, 2007. "Diffusion of innovations." Accessed March 2022. https://www.immagic.com/eLibrary/ARCHIVES/GENERAL/WIKIPEDI/W070910D.pdf

Figure 1 shows the proposed naturally occurring baseline market share forecast calculated with NEEA's parameters.

Figure 1. Proposed Naturally Occurring Baseline Market Share Forecast



The benefit of a top-down approach using an S-curve is that only a few parameters need to be specified. The limitation is that the S-curve still requires holistic interpretation of the market research data to make an informed estimate of the proper parameter values.

Cadmus' feedback on NEEA's proposed naturally occurring baseline market share forecast is summarized in Table 1. Recommendations are in **bold**.

Table 1. Feedback on Proposed Naturally Occurring Baseline Market Share Forecast

Element	Cadmus Assessment
Graph	There is a disconnect between market share (installed VHE DOAS/all major renovations and new construction in applicable buildings for that year) shown on the y-axis of Figure 1 and the equation for market penetration, which is a cumulative function (total installed VHE DOAS/applicable building stock since time=0). **The figure and equation should refer to the same measurement unit (either cumulative or annual). If NEEA is interested in tracking annual market share then a different equation may be used (e.g., the derivative of the market penetration).**
Market penetration equation	It is unclear from the documentation what types of VHE DOAS installations are included. **NEEA should clarify if only best practice designs (e.g., fully decoupled system design and right-sized HVAC system) are included or if good practice also counts (e.g., partially decoupled systems and right-sized HVAC).**
Initial Condition = 0% in 2014	NEEA's efforts started in 2015, so the start year of 2014 is appropriate. NEEA's justification for the 0% market penetration in that year is that there were no qualifying high efficiency ERVs in the U.S. market prior to 2015. Cadmus agrees that a VHE DOAS (as specified by NEEA) would not have been feasible in 2014, so the 0% penetration is appropriate.

Element	Cadmus Assessment
Saturation = 5%	NEEA describes multiple **barriers** to adoption of VHE DOAS: • Without NEEA's efforts, it is unlikely the market would have identified which equipment and design elements would lead to maximized savings, and without a defined VHE DOAS approach, the benefits from high-efficiency HVAC projects would have been more difficult to characterize and transfer to other projects. • High upfront cost and bidding practices that discourage specifiers to include any DOAS to win the bid. • VHE DOAS are not a great fit for emergency replacement scenarios. • Equipment often must be sourced from multiple vendors. Specifiers may not be willing to take a risk with unfamiliar vendors. • The high cost and niche market for VHE DOAS equipment means it may not be in stock or must be special ordered from the factory. • Multiple project team members (architects, engineers, and contractors) must all be willing to try a VHE DOAS approach. • Building owners and operators with a long history with legacy systems may be reluctant to try something new. Reasons for natural market **adoption**: • Decarbonization policies • Improved indoor air quality • Passive building design trends • Adoption of variable refrigerant flow (VRF) systems Considering the barriers and drivers of adoption, a small number of naturally occurring installations seems feasible and, as such, a maximum saturation of 5% is reasonable.
Hypergrowth = 2042	The year NEEA assumes market share growth accelerates is a few years after the Washington 2036-2039 building code cycle. In NEEA's absence, the WA code may begin to offer compliance options with a VHE DOAS. Cadmus agrees that the major drivers for adoption would be from building codes or other energy efficiency policies.
Takeover = 15	NEEA proposes a takeover period, or the amount of time needed for the product to catch on, of 15 years. The rationale for this is that there will only be one opportunity to choose an efficient option throughout the usable life of an HVAC system. We agree the takeover period should be over a long period because (1) existing buildings are renovated after decades of service and (2) because market actors need experience designing and installing VHE DOAS to be comfortable with the technology.
Factor = 81	This factor affects the shape of the curve, with larger values resulting in a sharper rise to the maximum market share. With the other parameters set, a value of approximately 81 forces the curve through 2029 to stay at or under 0.1%, which is NEEA's proposed maximum natural market adoption in the near term. Cadmus agrees that in the near term there is unlikely to be significant natural market adoption. Despite NEEA's efforts to promote and observe the implementation of VHE DOAS, several did not succeed. Interview findings indicate many near-term barriers: cost, complexity, code, and contractor capability. With VHE DOAS not necessary for code and a lack of contractor awareness, these systems will take significant time to catch on.

The rationale provided by NEEA for these parameters is reasonable and is supported by the general market research findings reviewed. Ultimately, it appears there could be natural adoption of VHE DOAS for niche applications in the short term and possibly more adoption if market actors experience success and become more familiar with these systems on a longer timeframe.

Alternative Approaches to Naturally Occurring Baseline Market Share Forecasting/Validation

Validation with market feedback: In addition to validating parameters, NEEA could also gather naturally occurring adoption forecasts from other market experts via a Delphi panel to see if NEEA's proposed naturally occurring baseline market share forecast aligns with other market perspectives. Also, note that the naturally occurring baseline market share forecast of buildings installing 82% sensible recovery efficiency E/HRVs would provide the maximum bound for VHE DOAS.

Bottom-up approach: NEEA has implemented a bottom-up approach for other products in the past. This would require setting up a new model, either summing up adoption rates from naturally occurring decision-making pathways or, if the naturally occurring baseline market share forecast of 82% sensible recovery efficiency E/HRVs is known, an assumed conversion rate to qualified VHE DOAS can be applied. Though a bottom-up approach can support transparency, it is not a good fit if any of the critical data sources are proprietary.

Key Assumptions Review

Is NEEA's approach to estimating the number of very efficient VHE DOAS shipped to locations in the Northwest prior to the program's intervention reasonable? Is there a better way to establish the starting point for NEEA's naturally occurring baseline market share forecast?

NEEA's starting point (2014) for naturally occurring baseline market share forecast and estimate of the number (zero) of VHE DOAS prior to program intervention are reasonable. The forecast begins in the year (2014) prior to NEEA's VHE DOAS program activities. The market research documents NEEA supplied do not mention any qualifying elements of a VHE DOAS in the market prior to the 2014 start date.

Has NEEA captured the primary market drivers influencing market adoption to date? Are there other market drivers that NEEA should factor into its naturally occurring baseline market share forecast?

By using a top-down model, the overall interaction of all market drivers and barriers is captured. The major market drivers and barriers (e.g., cost, complexity, and challenges in actual implementation) are reflected in the near-term and maximum saturations.

Will NEEA's approach for tracking unit sales and market share provide realistic and credible estimates of market adoption and savings estimates?

To be considered a facility with a VHE DOAS requires more than a single high-efficiency widget to be installed; rather, it is a specific set of equipment (E/HRV sensible recovery effectiveness >=82% and high-performance heating/cooling unit) and design practices that work together to decrease energy consumption in commercial buildings.[2]

NEEA provided a three-step process for estimating market adoption and a list of various data sources. Table 2 lists these steps and Cadmus' assessment. Recommendations are in **bold**.

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[2] BetterBricks. February 2022. "Very High Efficiency Dedicated Outside Air System: Equipment Design Best Practices for Optimal Efficiency." https://betterbricks.com/uploads/resources/VHE-DOAS_Requirements-Summary.pdf

Table 2. Market Adoption Estimation Process Review

Process	Cadmus Assessment
Step 1: Count qualifying E/HRV sales	Since there are currently only five manufacturers that produce qualifying models, it may be possible to obtain and maintain data agreements with all manufacturers to share Northwest sales of qualifying E/HRVs. However, if the number of manufacturers grows, then it becomes more challenging to have data for the entire market.
Step 2: Observe VHE DOAS installs for a sample of projects	Assuming there is a way to inspect a representative sample of building designs using data from ConstructConnect, energy-efficiency program data, or other studies, NEEA would need to develop a method to determine whether minimum or best design practices were followed. Using permit building drawings, equipment schedule and cutsheets, NEEA should be able to accomplish the following: • Determine the E/HRV sensible recovery effectiveness: should be 82% or higher • Determine heating and cooling system efficiency • Verify the supply, return, and exhaust fans are variable speed • Verify the fans airflow and horsepower and estimate W/CFM • Verify if the system is partially coupled or completely decoupled • Verify the supply air temperature (as the energy savings assume the supply air temperature is around 70°F) It may not be possible or practical to verify if the system is oversized or right-sized without access to building energy models or heating and cooling load sizing calculations. **If NEEA detects a potential VHE DOAS installation, NEEA could make a specific request to the building owner or engineer to determine if the system if right or oversized. This should minimize the level of effort and burden on building owners/engineers.** The Commercial Building Stock Assessment (CBSA) that NEEA listed as a measurement methodology data source is also an opportunity to detect VHE DOAS **but will require targeted sampling and VHE DOAS specific data collection and analysis protocols (e.g., low adoption rates will require larger samples to detect, HVAC right sizing, and decoupled or coupled ventilation systems).**
Step 3: Extrapolate to eligible building population	Extrapolation should be done in a way that can inform calculation of energy savings. Modeled energy savings are on a per-square-foot basis, by climate zone and building type and level of adherence to best practice. NEEA proposes to create, from the sample, a weighted average Unit Energy Savings (UES) at the building level for each year. The proportion of buildings with DOAS in the sample may then be applied to the population of eligible buildings. Additional information on extrapolation is discussed in the next sections.

NEEA's proposed approach is feasible, but may not be practical to update every year depending on the resources required for taking a sample (the CBSA is not done annually although the other data sources are available annually).

Another approach is to conduct annual interviews with design firms capable of specifying a VHE DOAS. A professional engineer (PE) must sign off on building plans for all VHE DOAS installations. As such, if NEEA has a good estimate of the number of capable design firms, number of projects these firms complete each year, and relationships with these firms**, NEEA could interview a sample of firms each year to determine how many qualified systems were installed; whether the project followed good vs. best design practice; and obtain estimated energy savings, energy models or HVAC sizing calculations.** NEEA could incentivize design firms to participate in a longitudinal study to ensure the necessary data will be tracked throughout the years.

Cadmus considered using VRFs as a simplifying indicator of VHE DOAS adoption, but since VRF systems can be ducted or ductless in configuration, no simplifying assumptions can be made on whether these systems by default are compliant with all or part of NEEA's VHE DOAS specifications.

Are the data and methods used to determine unit energy savings and market size reasonable and sufficient for credible accounting of energy savings?

Unit Energy Savings

NEEA used energy modeling simulation results developed by RedCarAnalytics to determine the kWh/sqft savings achieved by installing a VHE DOAS instead of a roof-top unit (RTU) heat pump system. The savings (Table 1 on the "Savings rates" tab of NEEA's VHE DOAS baseline and model assumptions workbook) vary based on the VHE DOAS system configuration, building type, heating zone, and vintage. For a complex system such as VHE DOAS that primarily targets new construction or substantial renovation markets, energy modeling is the best approach to estimate savings.

NEEA then proposes multiplying the savings per square foot by the building prototypical floor area to get a "unit energy savings" (per building) then calculating the weighted average unit energy savings (UES) across all buildings for the year based on observed installations (from a sample of the market) among the different combinations of vintage, climate zone, system configuration, and building type.

Instead of prototypical floor area, which Cadmus assumes comes from the CBSA or other data source that includes the entire building stock, Cadmus suggests using actual conditioned floor area, which should be readily available from building designs for the sample. New construction or major renovations may differ in characteristic floor area than the existing building stock. Also, since regular updates to the UES will be calculated, NEEA can monitor the stability of the UES over time, and if it is stable, could decrease the frequency of updates.

Figure 2 shows the proposed calculation of various weighted UES from the individual buildings that make up the sample. It is unnecessary to develop weighted UES for different building vintages and heating zones. Only the annual All-UES is needed (yellow highlighted row).

Figure 2. Example Weighted UES and aMW

Table 2. Example Weighted UES and aMW in Year X

Building vintage	Heating zone	Weighted UES (kWh/sqft)	Observed installs	Extrapolated total installs	aMW
New	1	26,093	11	110	0.33
	2	54,473	7	70	0.44
	3	61,440	7	70	0.49
Existing	1	59,199	6	60	0.41
	2	38,891	6	60	0.27
	3	67,102	3	30	0.23
All		47,206	40	400	2.16

Source: NEEA VHE DOAS baseline and model assumptions workbook

Extrapolation to the Market

On the "Savings rates" tab of its VHE DOAS baseline and model assumptions workbook, NEEA proposes in Table 2 to proportionally extrapolate the UES to the whole market based on "Total E/HRV Sales in Year X." Cadmus assumes NEEA meant "Total 82% or higher sensible recovery effectiveness E/HRV Sales in Year X." However, this assumes that each E/HRV sale would result in a qualifying VHE DOAS. If NEEA is tracking qualifying E/HRV sales, some fraction of those E/HRV installations will not be part of a VHE DOAS. **To estimate the fraction that are part of a VHE DOAS, NEEA should study a sample of qualifying E/HRV sales and apply that fraction to the total qualifying E/HRV sales.**

Cadmus suggests the following equation for extrapolated installations:

$$Annual\ Extrapolated\ Installations = \frac{Buildings\ with\ Observed\ Installations\ of\ VHE\ DOAS}{Total\ Buildings\ in\ Sample\ with\ Qualifying\ E/HRV} \times \#\ of\ Total\ Qualifying\ E/HRV$$

Also, Table 2 in the workbook should be corrected to the following:

"Weighted UES (kWh/sqft)" should say "Weighted UES (kWh/building)."

Market Size

The proposed market size forecast (2019-2042) is calculated in NEEA's workbook under "Table 3" on the "Market Size" tab. NEEA proposes to track the market size based on square footage of new construction and renovations of existing buildings. The new construction market is based on new construction starts; however, the renovation rate is assumed to be 0.10% of existing floorspace[3] (to account for buildings that change heating fuel to electricity). Decarbonization policies may push the rate of renovation/ electrification up, so **Cadmus recommends revisiting this assumption of 0.10% and aligning with decarbonization plans in the region.** For example, WA State's 2021 Energy Strategy[4] specifies the following action item: "To reach building electrification targets, an electrification program should be developed and implemented. The program should provide funding generated from all building energy end uses, including electric, gas and liquid petroleum through a public benefits charge, carbon fee or economy-wide cap and trade program."

Currently the "Annual combined market size growth" is in square feet while the energy savings and the naturally occurring baseline market share forecast is based on number of buildings with qualifying installations. **NEEA should add a column to the market size forecast that calculates the annual number of buildings from the square feet forecast. The market size forecast can be converted to number of new or renovated buildings based on average square footage of sampled eligible buildings. For additional measurement accuracy, NEEA could evaluate the market size forecast against actual construction activity. For example, NEEA could examine data from sources such as Co-Star, which contains the year a building is built or renovated, building size, number of floors, etc. Permit data may**

3 NEEA's workbook states this value is the "Annual percentage of existing floorspace entering the VHE DOAS market due to changing primary heating fuel to electricity."

4 Accessed 3/30/2022. https://www.commerce.wa.gov/wp-content/uploads/2021/01/WA_2021SES_Chapter-D-Buildings.pdf

be challenging to use for identifying major renovations since permits may be required for relatively minor alterations. If looking at permit data, NEEA could establish a permit fee cutoff or other simplifying criteria to signify projects that are unlikely to be for major renovations.

Appendix: NEEA Naturally Occurring Baseline Memo

Memorandum

February 23, 2022

TO: NEEA Market Research and Evaluation

FROM: Havala Hanson, Ph.D., Manager of Planning and Analysis, Northwest Energy Efficiency Alliance

SUBJECT: Proposed naturally occurring baseline for High-Performance HVAC market share projection

In 2014, NEEA's High-Performance HVAC Program developed a counterfactual naturally occurring baseline market share projection for very high efficiency dedicated outside air systems (DOAS). Developed the year before NEEA activities began, the estimate forecasts the market share among HVAC installations in both new construction and existing building renovations if NEEA were to not intervene with the high-performance HVAC program. The baseline estimation is grounded in market research as there is no reliable historical sales data, or other tracking data, available to support the estimation of current market adoption. This is related to the complexity of the system's design whereby multiple discreet components, integrated using specific design practices, are required. Given these unique challenges, this memo explains the rationale for the baseline and presents the results to be evaluated by a third party.

High-Performance HVAC

A very high efficiency dedicated outside air system is an approach to commercial high-performance HVAC that includes four system attributes, including both equipment and design elements. Very high efficiency DOAS must include two equipment components: 1) a very-high efficiency energy or heat recovery ventilator (ERV/HRV) to serve the ventilation load, and 2) an ENERGY STAR® high-efficiency heating and cooling system to serve the heating and cooling load. Very high efficiency DOAS must also exhibit two design practices: 1) partially or fully decoupled ventilation air (i.e., the ventilation air is controlled and delivered independently from the heating/cooling air, which implies that the ducting for each is independent), and 2) a rightsized heating and cooling system. When compared to a code-minimum system replacement,[5] this approach has been demonstrated to reduce commercial building energy use by an average of 48%. And, when compared to conventional HVAC systems, very high efficiency DOAS has been demonstrated to reduce HVAC energy use by an average of 69%.[i]

[5] Code-minimum equipment on NEEA demonstration projects have often been a packaged rooftop unit (RTU).

Market conditions prior to NEEA's involvement

In 2015, NEEA began working with a manufacturer to bring a high efficiency commercial ERV to the U.S. Prior to these efforts, the absence of qualifying equipment made it impossible to design and install a system that met NEEA's minimum efficiency requirements for very high efficiency DOAS. Another major barrier at the time was that none of the four states in the Northwest region encouraged DOAS in their commercial building code. NEEA's High-Performance HVAC Program activities from 2015 onward aimed to influence market transformation by changing these conditions.

NEEA's High Performance HVAC Program market interventions, 2015–2021

In 2015, NEEA encouraged a manufacturer to introduce a high efficiency ERV/HRV in the U.S. Today, four additional manufacturers sell ERV/HRVs that meet the program's efficiency standards. Without NEEA's involvement, it is likely that the technology would have remained solely overseas for many years.

NEEA's High-Performance HVAC Program additionally conducted eight field studies and provided technical support to 20 projects to evaluate this system approach. Field testing and energy modeling studies helped identify the most important equipment and design elements needed to maximize energy savings for a commercial HVAC system that includes an ERV/HRV. The resulting very high efficiency DOAS approach would not have been defined without NEEA's support.

Moreover, NEEA provided energy modeling data to inform Washington State's 2015 commercial code development process in a successful effort to support an HRV requirement (Washington State Energy Code (WSEC) Section C403.5.1). NEEA further supported increasing the number of additional efficiency package options from one to two (WSEC 2015, Section C406), which include the provision of a DOAS and more efficient HVAC performance overall. NEEA staff, contractors and Washington State Department of Commerce staff collaborated to improve and gain buy-in for the code proposal that was ultimately adopted in WSEC 2015. Demonstrative of NEEA's influence on this development, the resulting code requires DOAS in the same building types (schools, small offices and small retail buildings) that were featured in NEEA's very high efficiency DOAS energy modeling.

Following these successes, NEEA continued providing technical expertise and field study data to support the inclusion of very high efficiency DOAS technology in state codes, including the 2018 WSEC and California's 2019 Title 24 Energy Code for Nonresidential Buildings.[6] NEEA also used the energy modeling data for International Energy Conservation Code (IECC) commercial code proposals, although an HRV requirement has not yet been included in IECC commercial code. Without further support, barriers to code and market adoption are likely to persist.

Market research suggests that code advancements are the primary driver of practice change.[ii,x] Since Washington and California building codes include high efficiency heat pumps and ERV/HRVs in commercial code, specifiers are likely to become more familiar with these technologies.[v] "Anecdotally, I

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[6] See https://www.energy.ca.gov/sites/default/files/2020-05/04_MechanicalSystems.pdf

can say that [Washington] code has pushed everyone into a very efficient system with DOAS and heat recovery," one engineer commented (Specifier, p. 33). However, interviewees in the study often thought of adding heat recovery to a typical RTU system rather than the 100-percent-outdoor-air approach of very high efficiency DOAS. Similarly, the 2018 Washington State Energy Code for a DOAS system requires ERV/HRVs to have a minimum efficiency of 60 percent sensible recovery efficiency (SRE), and only for some building types (C.403.3.5, WSEC 2018). This is lower than NEEA's specification of 82 percent SRE. However, there is an option for energy efficiency credits that requires an ERV/HRV with at least 80 percent SRE (C.406.7).

Some quantitative evidence has captured this momentum. The WSEC Commercial Compliance Documentation Website Year End Data Report (2021) indicated that several buildings have installed DOAS where they were not required. Some of these installed high efficiency DOAS to get energy efficiency points. DOAS installations had a 99 percent code compliance rate.[7]

In addition to its work with manufacturers, field studies, technical support projects and building codes, NEEA's High-Performance HVAC Program team commissioned research to learn about market actor awareness of very high efficiency DOAS, and to document best practices for designing and installing them. The resulting findings, delivered between 2017 and 2021, contribute to the development of the naturally occurring baseline.

Primary market barriers

Without intervention, formidable barriers hinder market adoption of very high efficiency DOAS. These include cost, equipment availability, complexity of the design and installation process, and risk aversion among market actors.

Cost was consistently cited as the foremost barrier among research literature.[iii, iv, x] However, the issue is more complex than a simple difference in payback period for higher efficiency equipment that can be overcome with a value proposition for the consumer. In competitive bidding for major renovation and new construction, the lowest bid often wins. Since HVAC systems are "invisible" in buildings, they are often among the first items market actors identify to reduce project costs.[v,ii] For instance, one interviewed engineer remarked, "When the owner says, 'I want a really cheap option,' we start trying to eliminate the DOAS" (p. 20).[v] If building owners make high efficiency HVAC a priority, specifiers (i.e., architects, engineers and contractors) will propose a DOAS. However, to remain competitive, they typically propose the least expensive, least efficient ERV/HRV and heating and cooling system. Tight budgets further limit market actors' ability to apply best practices in system design, resulting in sub-optimal systems.[ii] Additionally, market research estimates that half of HVAC system replacements are emergency replacements.[viii,vi] In these situations, first cost is a significant consideration.

Information gaps contribute to the emphasis on cost as a major barrier to market adoption. Property investors and building owners have little awareness of the reduction in net operating costs and increase in capitalization rates that high efficiency HVAC systems like very high efficiency DOAS can provide.[vii]

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[7] At the time of writing, this report is unpublished. The sample for this data is nonrandom and excludes Seattle.

Lacking a clear understanding of how very high efficiency DOAS can provide immediate benefits to their business perpetuates building owners' low prioritization of HVAC efficiency.

Equipment availability poses another significant barrier to market adoption, as building owners value product availability for both planned and emergency replacements.[viii] When NEEA began working with market actors in 2014, ERV/HRVs that met NEEA's product specification (at least 82 percent SRE) were virtually unknown in the U.S. As recently as 2019, only one U.S. manufacturer produced qualifying ERV/HRVs. With NEEA's engagement, that number has increased to five manufacturers in 2022.

Nevertheless, it is insufficient to simply improve the availability of qualified ERV/HRVs, as they must also be paired with an ENERGY STAR heating and cooling system. Exclusive relationships between specifiers and manufacturer representatives and distributors mean that specifiers rarely consider mixing and matching equipment from different suppliers. Specifiers who have exclusive relationships with manufacturer representatives or distributors that do not offer both are unlikely to pair a qualifying ERV/HRV with a qualifying heating and cooling system in a DOAS.

Furthermore, manufacturers and distributors are in sync with the bidding process that awards the lowest-cost proposal for planned replacements. They also cater to the large market for emergency replacement situations where low first costs are a top priority.[v] Combined, these conditions can result in small markets for high efficiency equipment. In turn, manufacturers and distributors have little incentive to produce and stock qualifying very high efficiency DOAS equipment.

Risk aversion, driven by specifiers' lack of familiarity and experience with designing and installing very high efficiency DOAS, is another inhibitor of market adoption.[viii] Financiers and developers of commercial properties are hesitant to invest in projects that lack a proven track record of profitability.[Error! Bookmark not defined.] When the market value of new technologies and approaches is unproven, it adds uncertainty rather than value to a project requesting funding.[Error! Bookmark not defined.] Property investors and developers prefer models that have a history of return on investment. Risk is likewise a concern among public-building decisionmakers who need proof of system reliability and longevity.

Lack of familiarity with designing and installing very high efficiency DOAS increases specifiers' risk of installing systems with sub-optimal performance that, in turn, result in unsatisfied customers.[ii,viii,x] Interviews with specifiers demonstrated a range of ability to identify the components of very high efficiency DOAS, along with a large degree of unfamiliarity with the holistic approach that incorporates best design practices.[ii] The specifiers expressed a "fear of failure when venturing into uncharted territory to try something new" (p. 31).[ii] Moreover, since architects, engineers and contractors must work in close collaboration, one specifier who is unwilling to risk trying something new can derail the opportunity of pursuing the very high efficiency DOAS approach. According to one interviewee:

> *"It's not that the equipment isn't available, it's more if a contractor or installer isn't familiar with the technology, they aren't going to make it the first time they install it. VRF is an example—when it first started, I wasn't going to recommend it if contractors hadn't installed it before.*

Everybody knows what it is now. Early days it was different. The contractor needs to know what they are doing, we were burned by VRF early on" (p. 20).[v]

Likewise, building operations and management contractors can resist new technology adoption because they are unable to support it.[ix] As with contractors, the preference for older technology can represent the perception of "sunk costs" in training, relationships or hardware.[Error! Bookmark not defined.] Building owners with large portfolios or multiple prior projects also expressed preferences for equipment and manufacturers that remove options and latitude for innovation.[x]

The complexity of the commercial HVAC decision-making process in new construction and major renovations further hinders adoption of very high efficiency DOAS. Successful HVAC system design and installation depend on good communication, project planning and work that is completed on time and on budget among all specifiers throughout the process. A complex approach such as very high efficiency DOAS requires a higher standard of communication, planning, and coordination to perform on-time and on-budget tasks. Collecting information about various options and systems while addressing concerns about reliability can discourage architects and engineers from advocating for a specific system.[ii]

Further, HVAC systems are either "the caboose of a project," as one engineer declared, or the responsibility of a single market actor, most often the engineer (p. 31).[ii] Typically, architects design space for mechanical systems, but leave the system design up to engineers. Then, engineers attempt to use existing equipment and may encounter constraints, such as electrical panels that do not support additional load.[ii] Further, for engineers to risk designing complex systems that involve new technology, they require contractors who are familiar with the system and can install it properly.[ii] This siloed decision-making, in which HVAC design and installation is done independently of the overall building design, means simple systems are more likely to be selected. "Eventually, the system gets simplified down to the level of whoever is maintaining it," one engineer remarked (p. 20).[v]

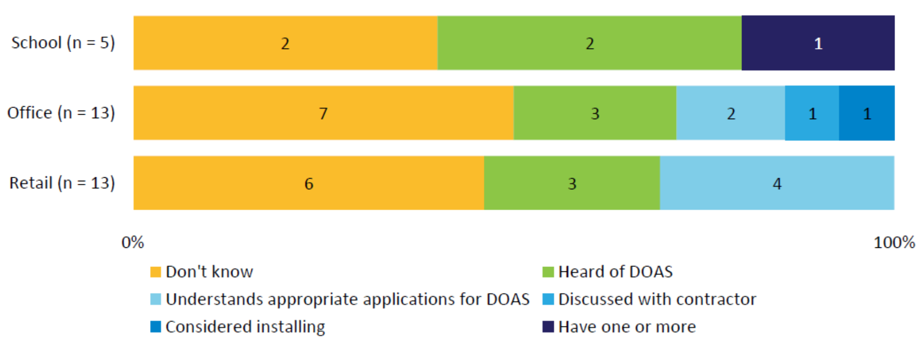
Finally, the **absence of customer demand** is a significant barrier to market adoption, as customer demand is typically a primary driver of specifiers' design and installation choices.[ii] As noted above, risk aversion, cost, and acceptance of inefficient infrastructure inhibit demand. Even for building owners who prioritize energy efficiency, HVAC system design is likely the first area of compromise when project budgets must be trimmed. Further, their ability to conduct a deep energy retrofit that includes a higher performance HVAC system can be curtailed by several additional factors, including a) difficulty in securing approval from financial backers; b) lack of capital to invest; c) uncertainty about which equipment to buy; and d) the belief that tenants are unwilling to pay for energy efficiency upgrades even though they stand to benefit from them the most.[xi]

Market momentum

Despite the above barriers, there are certain indicators that the market may be more open to the very high efficiency DOAS approach in the future. These include increased public interest in better ventilation and indoor air quality (IAQ), growing specifier and customer awareness of DOAS options, and responses to sustainability goals and policies that promote electrification.

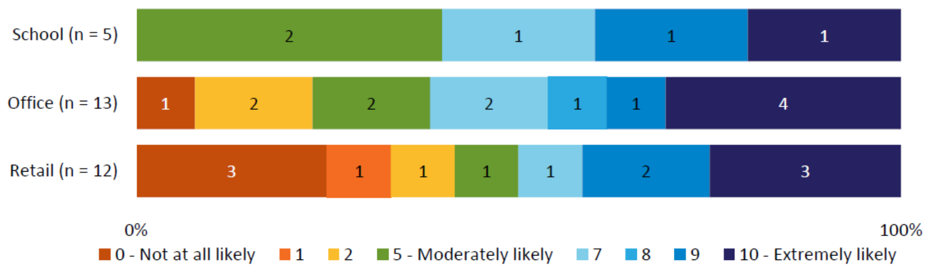
Better IAQ is a key non-energy benefit of very high efficiency DOAS. The COVID-19 pandemic has raised public awareness of and interest in better ventilation and IAQ.[ii] When interviewed, many market actors said they received requests for solutions to improve ventilation in existing buildings and saw very high efficiency DOAS as a vehicle to meet those requests.[ii] Demand for improving IAQ has recently increased across a wide range of constituents, particularly those representing public buildings and healthcare facilities. These audiences, as well as commercial property investors, value comfort and public image when replacing HVAC systems.[viii] Very high efficiency DOAS can meet demands for comfort and IAQ[xii] while improving the public image and brand perceptions of building owners who invest in their tenants' wellbeing and safety.[x]

Even before COVID-19, DOAS awareness was increasing among market actors and consumers. In a 2019 report, McClaren and colleagues found that all specifiers and most manufacturers and distributers had some familiarity with systems they termed DOAS.[viii] While DOAS awareness existed in general, research in 2020 showed that market actors did not know of the range of DOAS configuration options, including very high efficiency DOAS.[ii] Likewise, about half of surveyed building owners and managers in the school, office and retail sectors had awareness of DOAS and were willing to discuss them with a contractor (see figures 2 and 3). Among respondents, those representing the school sector were most likely to plan HVAC replacements, least sensitive to first cost, and most willing to invest in highly efficient systems and systems with non-price benefits, such as IAQ. Representatives of retail buildings were least willing to invest in very high efficiency DOAS, as they were less concerned about occupant health and safety, highly budget conscious, and their buildings were rarely owner occupied.



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.]

Figure 2. About half of building owners had some familiarity with DOAS.
Reproduced from McClaren et al., 2019.



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.]

Figure 3. More than half of building owners were at least moderately likely to discuss DOAS with a contractor or building professional.
Reproduced from McClaren et al., 2019.

Interest in comfort and efficiency. As early as 2016, commercial building HVAC distributors noted a shift away from gas RTUs to heat pumps with variable refrigerant flow (VRF).[v,xiii] One report notes that "VRF systems are especially attractive in large commercial buildings with higher operating costs and energy usage" (p. 22),[v] and this attraction only strengthens when energy prices increase (BetterBricks, 2020). The preference for VRF systems is further reinforced by the ability to configure settings for individual spaces within a building and simultaneously heat and cool different parts of a building.[xiii] Evergreen Economics' 2017 findings implied that building owners may shift their preference from gas-powered RTUs to high efficiency HVAC systems that are powered by electricity. As one manufacturer representative noted, "Heat pumps in general provide better efficiency than gas RTUs. Straight gas heating is declining, and the market is trending towards heat pumps of all kinds" (p. 22).

Finally, local and state **sustainability goals and policies** could influence building owner decision-making when selecting an HVAC system. While very high efficiency DOAS is not the only efficient HVAC solution and is not the optimal choice for every building, increased consumer awareness and demand incited by such goals and policies may lead to an increase in the availability of its system elements. Several initiatives, building codes and policies already exist in the Northwest that support high efficiency HVAC solutions, including the Boise Climate Action Roadmap (ID), the Billings 2030 Energy & Conservation Commission Roadmap (MT), the City of Bend Strategic Energy Management Plan (OR), and the Pierce County Sustainability 2030: Greenhouse Gas Reduction Plan (WA). Additionally, Washington State is a national leader in state-level decarbonization policy, including its Clean Buildings Act (HB 1257, 2019–20), and Oregon has followed suit with a recent policy on decarbonizing its grid (100% Clean Energy for All Act, HB 2021, 2020–2021). These policies and initiatives foreshadow a shift to more efficient technologies across the board, including applications of very high efficiency DOAS.

Additionally, there is evidence of an emerging shift in practice and priorities (p. 16):[x]

> *[Building] owners who independently prioritize sustainability (net zero, zero carbon, achieving a building label) or who are required to meet statutory or policy objectives (common among institutional buildings) will weight a system's overall contribution to these goals higher.*

Interestingly, several architects who reported working with clients like this discussed an overall objective of reducing mechanical systems completely by integrating natural ventilation and night flushing, and by getting agreement to allow wider temperature fluctuations.

Consumer decision influencers

The consumer path to purchase is complex for commercial HVAC systems. There are several junctures where different market actors influence decisions about system design and installation. This section provides a conceptual overview of the decision-making process and discusses factors within the process that could help or hinder very high efficiency DOAS market adoption.

In a simplified model, mechanical contractors and engineers get information about innovations, best practice, or new equipment from manufacturers and ASHRAE (figure 4).[x] This model emphasizes the importance of manufacturers and ASHRAE as gatekeepers on the path to purchase. For example, if ASHRAE and major manufacturers do not embrace very high efficiency DOAS, most mechanical contractors and engineers (and by extension, architects and owners/developers) are unlikely to consider installing very high efficiency DOAS.

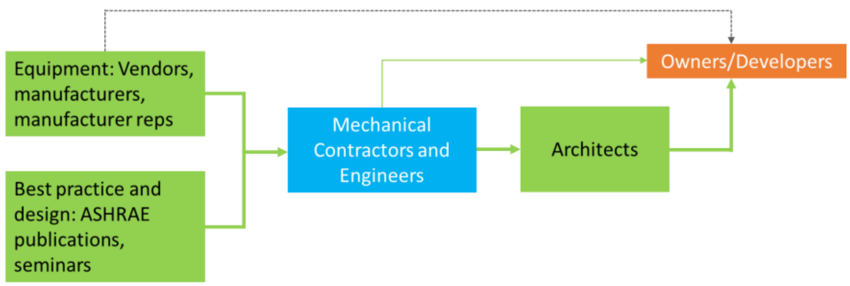


Figure 4. Typical HVAC design information flow
Reproduced from Moran et. al, 2020.

However, the path to purchase is more complex than the flowchart above suggests. To begin with, it omits financial decisionmakers despite the fact that new construction and major renovations begin with financiers. Risk aversion is paramount for providers of capital who prefer to fund proven models rather than innovations.[Error! Bookmark not defined.] Information gatekeepers, including building engineers and trusted vendors, have a significant influence on financial decisionmakers. Their information networks, priorities and personalities influence what information is passed along to financial decisionmakers. In small organizations, financial decisionmakers may interact directly with vendors and third-party engineers, but in larger organizations, information from building engineers may be diluted through intermediaries, such as building managers and building owners.[xiv] The messages financial decisionmakers receive, and who they receive them from, are important factors in the securement of funding for high-ticket projects.

Furthermore, decisionmakers and decision influencers vary across building types. There are six primary types of commercial investment building clusters,[vii] each of which is briefly described below along with factors that may make each of them more or less likely to adopt high-performance HVAC technology:

Table 1. Decisionmakers, motivators, and paths to purchase constraints vary by building type.

Commercial building cluster	Key decisionmakers	Motivation	Path to purchase constraints
Small commercial and industrial (<$5 million)	Small business owner, design charettes	Cost, net operating income (NOI), long-term business viability, financial incentives and tax credits	• Securing financing • Competing demands for capital • Lack of facilities staff to identify needs and maintain equipment • Lack of information and bandwidth • Sensitivity to lead times
Medium commercial and industrial ($5–20 million)	Large owner-user, part owner-user, local investor, principal, external parties	Cost, NOI, capitalization rate, long-term business viability, property value, public image, financial incentives, tax credits	• Competing demands for capital • Return on investment (ROI) requirements
Large commercial and industrial (multi-tenant leased, >$20 million)	CEO, owner/partners, project manager, board of directors, energy managers, engineers, building operators, facilities managers	Cost, NOI, capitalization rate, property value, occupancy, tenant turnover, rent, usable space, public image, financial incentives, tax credits, IAQ	• ROI requirements • Value engineering • Competitiveness of rental market
Multifamily (includes medium-to-large buildings, affordable and market value, investor-grade apartments, condos, etc.)	Property investor, energy managers, engineers, building operators, facilities managers		• ROI requirements • Value engineering • Competitiveness of rental market
Special purpose (assembly, fast food, hotels, gas station, etc.)	Owner, property investor (local, regional or national)	Cost, NOI, capitalization rate, property value, public image, financial incentives, tax credits, IAQ	Varies, with constraints including financing, ROI requirements and competing demands for capital
Municipal, university, school and hospital (MUSH) buildings	Governing body (legislature, school board, board of regents, etc.), building operators, facilities managers, general services administrators	Cost, durability, financial incentives, tax credits, IAQ	• Skilled third-party contractors often needed to raise issues • Financing relies on bonding, grants and incentives • Project approval typically requires political will and public buy-in • Competing demands for capital

Sources: McCabe, M. (2022). *Commercial building decision makers market research.* Bigfork, MT: Hayden + Tanner.; Merit. (2018). *BetterBricks and Commercial real estate audience research* [Unpublished Research Report]. Portland, OR: Merit.; Dopfel, E., Effinger, J., Crowe, E., & Frank, M. (2015). *Commercial sector analysis*. Portland, OR: CLEAResult.; Navigant Consulting, Inc. (2014). *Northwest commercial buildings deep energy retrofit market characterization and twenty-year market baseline assessment*. Boulder, CO: Navigant Consulting, Inc.

Across all building types, **timing** is a major path to purchase consideration.[vii,xv] For example, decisions to invest in HVAC improvements are more likely to occur under certain conditions, depending on the building type. For MUSH buildings, funding and election cycles play a role. For owners and investors, the ideal timing is when capital is on hand, interest rates are low, and/or the market for tenants or real estate is competitive (i.e., a buyer's market). For all building types, planned major renovations—whether they include HVAC systems or not—are a good time to integrate HVAC system upgrades.

The path-to-purchase complexities in the commercial property market lead to two major implications. First, the large majority of the market is comprised of small commercial and industrial customers. Eighty-seven percent of structures are less than 25,000 sq. ft. and small business firms own 84 percent of these. These owners represent myriad values, financial situations and business types. As described above, without intervention they are likely to face formidable barriers to adopting very high efficiency DOAS, including cost, lack of familiarity, system complexity, competing demands for capital, and unawareness of the need for and benefits of efficient HVAC systems. This suggests minimal adoption among this group in a naturally occurring baseline.

Second, although improved IAQ may have a slight influence on large commercial, industrial, multifamily, and MUSH building owners and managers to invest in a DOAS, market research indicates that IAQ remains a small decision-making factor in comparison to cost, ROI and property value. Additionally, even though public image motivates commercial property owners to invest in efficiency upgrades, it does not draw them specifically to very high efficiency DOAS. Without a compelling business case, adoption of very high efficiency DOAS among these building types would remain low without intervention.

Policies and building codes that require or incentivize high-efficiency HVAC systems can add some momentum to the adoption of very high efficiency DOAS. Without NEEA's intervention to codify the specifications of high-efficiency DOAS in code, it is unlikely that the market would naturally arrive at the model as a go-to choice for complying with policy and code when there are alternatives that are less complex and less costly.

Market adoption rate

The evidence above suggests that without intervention, the market adoption rate and ultimate market share for very high efficiency DOAS would be limited. The near- and long-term adoption rates are described below. Note that there are two reasons market share is not expected to reach 100 percent—with or without interventions. First, it is not feasible to meet the highest standard of all design principles in all buildings. Second, small projects such as emergency and planned like-for-like replacements of one RTU are unlikely to consider very high efficiency DOAS as a solution to their HVAC needs. This reduces the share of the market that may be willing to adopt very high efficiency DOAS. The 2021 Power Plan sets the maximum feasible adoption at 8–31 percent of existing floorspace among buildings in the target market.[xvi] However, this refers to an optimum version of very high efficiency DOAS that includes top efficiency equipment and best practices, such as fully decoupled ventilation. NEEA's updated product definition includes flexibility to design systems that are expected to be feasible in a larger percentage of buildings. Based on NEEA's discussions with designers, allowing systems to be up to 20 percent oversized (ASHRAE 90.1) and allowing for partial decoupling adds up to a 50 percent increase in the number of projects that meet the very high efficiency DOAS specification.

Near-term market adoption (2014–2029)

Absent interventions that improve awareness, availability and cost-effectiveness (including introducing high-efficiency ERV/HRV technology to the U.S., encouraging the articulation of the approach in state code, and providing design and installation technical support), the near-term adoption of very high efficiency DOAS would be negligible. The proposed baseline in this memo and in the 2021 Power Plan both start at zero percent with a slow, "lost opportunity" ramp rate.[xvi] NEEA proposes that a naturally occurring adoption of very high efficiency DOAS would achieve a maximum of 0.1 percent market share, on average, for new construction and major renovation projects in the region.

Long-term maximum market share (2030–2065)

In the long term, local, state and national initiatives and building codes are likely to require stricter efficiency standards and incentivize decarbonization or net-zero buildings. For example, Washington State's energy strategy includes building equipment efficiency as a core element in scenarios for achieving its 2050 zero emissions goal.[xvii] Very high efficiency DOAS might be identified as an approach for market actors to meet incremental decarbonization goals in Washington and other states outside the Northwest with similar goals. This, in turn, could lead to a gradual increase in product availability and familiarity. In addition, interest in improving IAQ could increase demand for ERV/HRVs.

However, this does not guarantee the very high efficiency DOAS approach would naturally catch on in the market for several reasons, including:

- There are many options in the commercial HVAC market. Alternatives to very high efficiency DOAS are likely to become more efficient to keep up with code. Simpler, cheaper, commonplace and code-minimum alternatives will likely dominate market shares until code requirements catch up with the product specification for ERV/HRVs and rooftop heat pumps.
- Without intervention, building owners, managers and property investors are not likely to become aware of the very high efficiency DOAS approach. This means they are unlikely to be able to articulate an accurate level of risk to financiers. Importantly, since HVAC system improvements are "invisible" relative to aesthetic and common space renovations, they are often eliminated from projects with budget constraints.
- Lacking demand, interest will remain low for manufacturers to produce necessary equipment and for distributors to stock it. When the winning bid is almost always the lowest one, code-minimum equipment will continue to be the most reliably available.
- Compared to commonplace HVAC solutions, very high efficiency DOAS requires better collaboration and communication among engineers, architects and installation contractors. Without demand from building decisionmakers, there will be little motivation for engineers, architects and installers to gain the necessary skills and improve their collaboration to design and install very high efficiency DOAS according to best practices.

In sum, although policy and code are expected to increase the pressure on buildings to become more efficient, lack of awareness and risk aversion among building decisionmakers, financiers and market actors throughout the supply chain will stunt the market-share growth of very high efficiency DOAS and product availability will remain low. Moreover, without training and technical support, very high efficiency DOAS installations will demonstrate subpar performance due to the lack of skill and effort required to learn and implement best practices.

NEEA proposes a maximum market share of five percent with a 2042 hypergrowth year (i.e., the year in which market share growth accelerates). This corresponds with the implementation of Washington's 2036–2039 building code cycles, which could, in a baseline scenario, begin to offer options for meeting code with very high efficiency DOAS. Assuming there will only be one opportunity to choose an efficient option throughout the usable life of an HVAC system, NEEA proposes a 15-year takeover period (i.e., the length of time it takes for the product to catch on).

Naturally occurring baseline estimation

The naturally occurring baseline estimation shown below is calculated with the following formula:

$$Market\ Penetration\ (Year) = Initial\ Condition + \frac{Saturation}{1 + Factor^{\left(\frac{Hypergrowth + \frac{Takeover}{2} - Year}{Takeover}\right)}}$$

Table 2 presents the counterfactual market baseline between 2014 and 2057. Below, figure 5 illustrates the data presented in table 2.

Table 2. Very high efficiency DOAS counterfactual market baseline (2014–2057)

Year	Very High Efficiency DOAS Counterfactual Market Baseline	Year	Very High Efficiency DOAS Counterfactual Market Baseline
2014	0.00%	2040	0.29%
2015	0.00%	2041	0.38%
2016	0.00%	2042	0.50%
2017	0.00%	2043	0.65%
2018	0.00%	2044	0.83%
2019	0.00%	2045	1.06%
2020	0.00%	2046	1.32%
2021	0.00%	2047	1.62%
2022	0.00%	2048	1.96%
2023	0.00%	2049	2.32%
2024	0.00%	2050	2.68%
2025	0.00%	2051	3.04%
2026	0.01%	2052	3.38%
2027	0.01%	2053	3.68%
2028	0.01%	2054	3.94%
2029	0.01%	2055	4.17%
2030	0.02%	2056	4.35%
2031	0.02%	2057	4.50%
2032	0.03%	2058	4.62%
2033	0.04%	2059	4.71%

2034	0.05%	2060	4.78%
2035	0.07%	2061	4.83%
2036	0.09%	2062	4.87%
2037	0.13%	2063	4.91%
2038	0.17%	2064	4.93%
2039	0.22%	2065	4.95%

Source: Author's estimation.

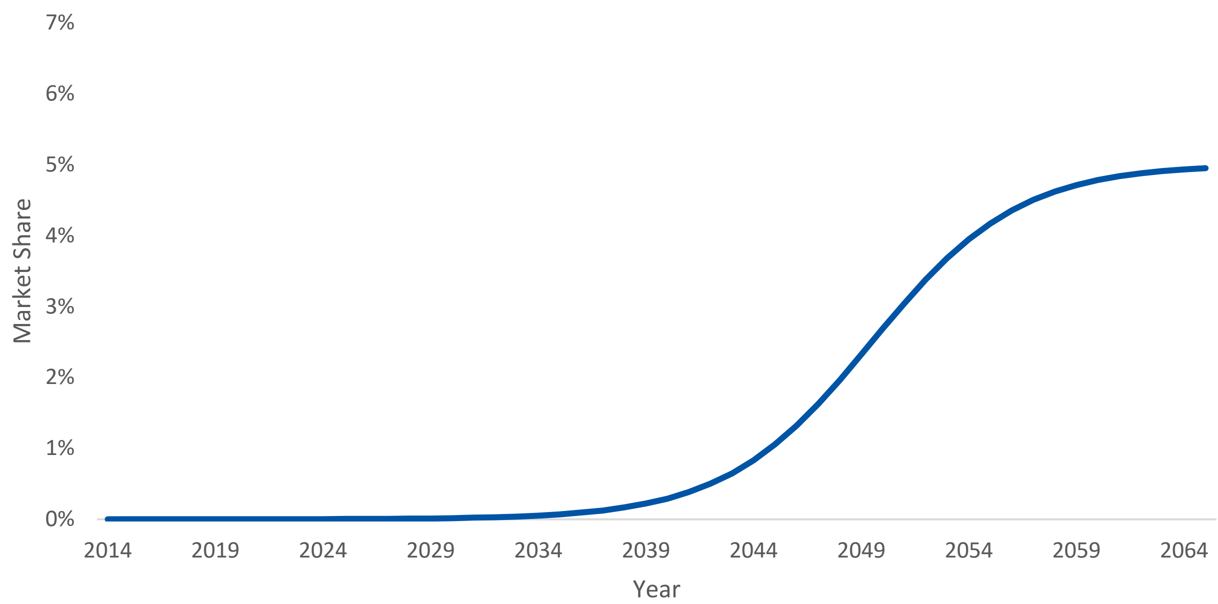


Figure 5. Very high efficiency DOAS counterfactual market baseline (2014–2057)

Source: Author's estimation.

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