

**Connecticut Conservation & Load Management:   
Potential “Next Measures” (X2227)   
Final Report**

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**Connecticut Energy Efficiency Board**

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# Abstract

Connecticut holds a strong position with its energy efficiency programs, and utilities had considerable success in reducing energy consumption through their successive triennial Conservation and Load Management Plans. Recent market trends however have increased the challenges of continuing to grow energy efficiency impacts in the state, with increased building standards, more stringent energy efficiency equipment standards, and broad market adoption of efficient lighting technologies.

**Project Summary:**

There were three main efforts in this project, each of which produced a product for use by PAs. The products are included in the embedded Excel™ workbook and this report.

1. **Exhaustive List of 200+ potential “Next” Measures across all sectors, assembled and assessed for on-going consideration / monitoring by PAs.** These near and longer-term measures were culled from regional and nation-wide potential studies, technical studies, and other sources. About 90 measures each were identified in the residential and C&I sectors, and two dozen related to the agricultural sector.
2. **High Interest measure subset of 39 measures, ranked by six key metrics, and re-prioritizable / re-sortable by users**. These measures focused on the nearer-term measures, and those that were deemed most relevant near-and mid-term to Connecticut. Information on 14 residential, 22 C&I, and 3 agricultural measures is included. Detailed information on the measures is included, prioritized based on six criteria: Measure Applicability; Market Breadth and Applicability; Time Horizon to market; Track Record with other PAs; Cost Effectiveness; and Lifetime Energy Savings.
3. **Drill-down on 8 “focus” measures, assessing characteristics, applicability, and potential in Connecticut in more detail**. Eight measures were selected for more detailed analysis, focusing on Connecticut savings potential, market conditions, concerns or barriers, opportunities for the measures, and high-level reviews of cost-effectiveness and program potential.

Each measure at each level includes extensive information, in increasing levels of detail on topics. Because the amount of information on measures at the first two levels is extensive, the report focuses on the eight drill-down measures. However, the spreadsheet tool allows PAs to review the information aggregated from scores of sources on measures for consideration in program refinements in the near and mid-term.

**Study Objectives and Approach**

The objective of the study is to identify and study candidate technologies for the next cycle of Connecticut’s Conservation and Load Management Plan which can support sustained growth in energy efficiency achievements. The study focused on emerging technologies already available - although at an early stage of commercialization - in order to identify potential utility interventions in the next 1-5 years required to support increased adoption in Connecticut.

The study involves the identification of candidate technologies, a multi-stage screening process based on increasingly detailed information, and finally an in-depth review of key technologies relevant to Connecticut. Through a multi-stage disposition process, the study started with a broad inventory list of 204 measures, refined to identify high-potential measures (39 measures). Measures already promoted in several other jurisdictions have not been included in the high-potential measure list since information is readily available from other sources.

Six key metrics were used to assess each candidate measure, and a combined final score based on the weighted metrics was used to identify the final list of measures and includes 8 high-potential opportunities for Connecticut. The selected measures were subjected to a deep dive analysis, incorporating both qualitative and quantitative assessments to estimate their cost-effectiveness and savings potential.

The final ranking of measures is based on a comprehensive evaluation of each parameter, resulting in an objective indication of their potential relevance to Connecticut's energy efficiency programming. Among the targeted measures identified, several show significant promise.

The study has not conducted a detailed cost-effectiveness analysis and utilities should complete this assessment and define appropriate incentives before integrating the measures into programs.

**Study Recommendations**

The recommendations below address findings on eight drill-down measures.

1. **Review Measures Periodically** - It is strongly recommended that the PAs periodically review the list of measures in Table 1 and Table 2 of the companion workbook for measures that may have the potential for meeting specific program portfolio or savings needs.
2. **Aerosol Sealant to Reduce Multi-Unit Dwelling Envelope Air Leakage** **– Residential** (Score: 4/5):targeting multi-family buildings, this measure offers a novel approach to sealing air leaks, potentially achieving significant reductions in air exchange rates and energy savings. We recommend that this measure should be promoted by the utilities for multi-family buildings undergoing a major retrofit.
3. **Displacement Ventilation Technology – C&I** (Score: 3.8/5, target sector: C&I): providing efficient delivery of clean air to occupant breathing zones, displacement ventilation technology offers energy savings and non-energy benefits such as improved indoor air quality and thermal comfort. As lack of knowledge of the technology appears to be a significant barrier to adoption, we recommend raising awareness bypublishing use cases and communications to professionals and building owners.
4. **High-Temperature Heat Pump - Industrial** (Score: 3.75/5): focusing on industrial processes, this measure explores the potential of high-temperature heat pumps to deliver significant energy savings by efficiently transferring heat from low to high temperatures, thereby reducing reliance on conventional heating systems. On a 1-3-year timeline, we recommend developing relationships with international suppliers to back local projects and large-scale demonstrations within the United States to highlight the benefits of the technology and convince international and local stakeholders to develop the domestic market.
5. **Cold Climate Commercial Rooftop Units – C&I** (Score: 3.65/5): replacement of conventional rooftop units with cold climate capable heat pump units presents an opportunity to reduce fossil fuel reliance for heating in commercial buildings, especially in colder climates. Commercial-sized cold climate Air Source Heat Pumps are beginning to be introduced in the market and represent a short-term opportunity for Connecticut. As the economics are more promising for partial displacement measures than full displacement measures, we recommend promoting this option as a starter.
6. **Advanced Buildings Control** **– C&I** (Score: 3.5/5): by integrating HVAC and lighting systems and implementing pre-emptive controls based on occupancy forecasting, this measure aims to optimize energy usage in buildings, enhancing efficiency and comfort. For the first 1-3 years horizon, as the extent of the market readiness of the technology is not clear yet, we recommend a trial using C&LM existing Retro-Commissioning program.
7. **Fault Detection and Diagnostic (FDD) for Existing HVAC Systems – Residential and Small Commercial** (Score: 3.15/5): utilizing embedded sensors and analytic tools to identify and address faults in HVAC systems, this measure offers opportunities for early fault detection, preventing waste and optimizing system performance. As behavioral outcomes are unknown, we recommend a pilot study to inform how the Connecticut market responds to fault detection and what additional costs may be incurred with training contractors on FDD.
8. **Performance-Based Duct Renovation** **– Residential and Small Commercial** (Score: 3.00/5): this measure addresses inefficiencies in HVAC distribution systems, offering benefits such as improved system efficiency, comfort, and energy cost savings through systematic testing and renovation procedures. Due to the high site-dependent costs and savings potential, we recommend investigating the approach prescribed in ASHRAE Standard 221 to tap into this savings potential.
9. **Plug-In Space Heating Heat Pumps (Micro Heat Pumps) – Residential Multifamily** (Score: 2.50/5): with easy installation and operation, micro heat pumps offer an alternative to conventional space heating systems, potentially replacing inefficient heaters in multi-family dwellings. In the short term, we recommend considering incentives for mild-climate heat pump products paired with a robust education campaign to displace windows/portable AC units and portable room heaters and monitor cold-climate technology availability in the coming 1-3 years/

These 8 measures are particularly interesting for Connecticut based on their ranking and variety, but are not the only measures of interest identified in the study. **The utilities should consider the other measures presented in the companion workbook based on specific sectoral needs or preferences.**

In addition to these targeted measures, emerging program concepts such as Smart Building Electrification, Residential Staged Retrofit, and Grid Interactive Efficient Buildings are discussed, highlighting innovative approaches to further enhance energy efficiency in Connecticut.

# Executive Summary

Connecticut holds a strong position in its energy efficiency programs, and utilities had considerable success in reducing energy consumption through their Triennial Conservation and Load Management Plans. Recent market trends however have increased the challenges of continuing to grow energy efficiency impacts in the state, with increased building standards, more stringent energy efficiency equipment standards, and broad market adoption of various efficient technologies.

The pursuit of the next most promising energy efficiency measures to implement in Connecticut requires a comprehensive approach that considers a range of parameters from the suitability of technologies for the local market to their potential impact on lifetime energy savings. This report presents the outcome of a rigorous screening process that evaluated various energy efficiency measures based on key metrics, including in order of weighting: lifetime savings, market breadth and applicability, measure applicability in Connecticut, measure cost-effectiveness, time horizon to market and track record with other program administrators.

**Project Summary:**

There were three main efforts in this project, each of which produced a product for use by PAs. The products are included in the embedded excel workbook and this report.

1. **Exhaustive List of 200+ potential “Next” Measures across all sectors, assembled and assessed for on-going consideration / monitoring by PAs.**
   * The project compiled a comprehensive list of potential “next” measures that might be considered as new opportunities in Connecticut. This list of more than 200 measures was identified and classified according to market condition / status. These near and longer-term measures were culled from regional and nation-wide potential studies, technical studies, and other sources. About 90 measures each were identified in the residential and C&I sectors, and two dozen related to the agricultural sector, with the largest number related to HVAC. This is included in the embedded (and attached) Excel™ workbook, and information sources are provided.
2. **High Interest measure subset of 39 measures, ranked by six key metrics, and re-prioritizable / re-sortable by users**.
   * These measures focused on the nearer-term measures, and those that were deemed most relevant near-and mid-term to Connecticut. Information on 14 residential, 22 C&I, and 3 agricultural measures is included, with an emphasis on the higher-saving HVAC end-use. The table includes measure description, range of savings, estimated useful life, range of measure costs, suitability in CT’s area, level of market development, GHG avoidance and market availability and other information. The six criteria are: Measure Applicability; Market Breadth and Applicability; Time Horizon to market; Track Record with other PAs; Cost Effectiveness; and Lifetime Energy Savings. Users may revise the weights on any / all criteria to provide rankings most suited to their purposes. This is included in the (embedded and attached) Excel™ workbook, and information sources are provided.
3. **Drill-down on 8 “focus” measures, assessing characteristics, applicability, and potential in Connecticut in more detail**.
   * A list of 8 measures was selected from the 39 for more detailed analysis. The measures were selected as highly ranked, and providing options across the array of sectors. This analysis examined savings potential and market conditions related to Connecticut in more detail, examined concerns or barriers, and opportunities for the measures, and provided high-level reviews of cost-effectiveness and program potential. This is included in the Excel™ workbook and detailed in this report.

Each measure at each level includes extensive information, in increasing levels of detail on topics. Each one of these three products-in-a-workbook provides information useful to the PAs in the near and longer-term.

The first two items are included in the project’s “X2227 Next Measures Tool”, an embedded spreadsheet. Each of the measures can be reviewed, and can be sorted for sectors for consideration as specific program revisions occur, and sorted by end-uses to refine program offerings. The priority and interest / potential of the measures can be sorted and re-sorted going forward under differing conditions by modifying criteria weights.

Because the amount of information on measures at the first two levels is extensive, the report focuses on the eight drill-down measures. However, readers responsible for programs, now and in the future, will want to become very familiar with the spreadsheet and the information it has aggregated from scores of sources on measures the PAs may want to consider for program refinements in the near and mid-term.

**Level 1 Spreadsheet – Comprehensive List – Basic Information on Potential and Market Status**

| End Use | **Residential** | **C&I** | **Industrial** | **Agriculture** | **Total** |
| --- | --- | --- | --- | --- | --- |
| **Agriculture** |  |  |  | 16 | 16 |
| **Appliances** | 10 |  |  |  | 10 |
| **Food Service** | 1 | 4 |  |  | 6 |
| **Hot Water** | 14 | 1 |  |  | 15 |
| **HVAC** | 33 | 40 |  | 2 | 75 |
| **Lighting** | 1 | 8 |  | 2 | 11 |
| **Motors and Drives** |  | 2 |  | 2 | 4 |
| **Other** | 18 | 18 |  |  | 36 |
| **Plug Load** | 2 | 1 |  |  | 3 |
| **Process** |  |  | 10 |  | 10 |
| **Refrigeration** |  | 6 |  | 2 | 8 |
| **Weatherization** | 10 | 1 |  |  | 11 |
| **Total** | 89 | 81 | 10 | 24 | 205 |

**Level 2 Spreadsheet – High Interest Measures – Spreadsheet with Extensive Information and Weighted Scoring**

| End Use | **Residential** | **C&I** | **Industrial** | **Agriculture** | **Total** |
| --- | --- | --- | --- | --- | --- |
| **Agriculture** |  |  |  | 1 | 1 |
| **Hot Water** | 1 |  |  |  | 1 |
| **HVAC** | 9 | 15 | 1 |  | 25 |
| **Lighting** |  |  |  | 1 | 1 |
| **Motors and Drives** |  | 1 |  | 1 | 2 |
| **Other** | 2 | 2 |  |  | 4 |
| **Process** |  |  | 1 |  | 1 |
| **Refrigeration** |  | 2 |  |  | 2 |
| **Weatherization** | 2 |  |  |  | 2 |
| **Total** | 14 | 20 | 2 | 3 | 39 |

**Level 3 Spreadsheet – 8 Drill-down Measures**

| End Use | **Residential** | **C&I** | **Industrial** | **Total** |
| --- | --- | --- | --- | --- |
| HVAC | 3 | 3 |  | 6 |
| Process |  |  | 1 | 1 |
| Weatherization | 1 |  |  | 1 |
| **Grand Total** | **4** | **3** | **1** | **8** |

**Study Objectives and Approach**

The objective of the study is to identify and study candidate emerging technologies for the next cycle of Connecticut’s Conservation and Load Management Plan which can support sustained growth in energy efficiency achievements.

The study involves the identification of candidate technologies, a multi-stage screening process based on increasingly detailed information, and finally an in-depth review of key technologies relevant to Connecticut. The outcome of each step is fully documented in a companion workbook to this report.

The screening process focused on identifying emerging energy efficient measures where additional research was required to provide a reasonable understanding of promising technologies and steps the utilities could take in the next 1-5 years to support their successful introduction in Connecticut – now and later - in order to unlock additional energy savings in the future. The study only considered measures providing **energy savings**, as such, demand-response only measures have not been considered in the study.

Figure ES- 1: Screening Process

**Stage 1** provides an initial assessment of the status of the maturity of the technology in the market to focus the assessment on relatively new measures but still likely available in the market. Keeping with the study objectives, measures already promoted in several other jurisdictions have not been prioritized for a more detailed analysis beyond the initial categorization as additional details can be readily obtained from other jurisdictions' DSM documents (technical reference manuals and/or evaluation reports notably). Stage 1 is a preliminary disposition to focus the study effort on candidate measures recently introduced or considered in North America. The companion spreadsheet provides more detailed information on those measures as well as relevant sources for additional information.

**Stage 2** scores the measures based on the Dunsky Team’s expertise (in consultation with the Evaluation Administrator) and easily accessible information. [[1]](#footnote-2)For each measure considered in stage 2, additional data sources and analysis are provided in the companion workbook.

**Stage 3** involves a more detailed assessment of the technology to refine the individual scores and calculated energy impacts.

The screening process is based on 6 different metrics, individually weighted to provide a final score used to rank candidate technologies. Table ES- 1 presents the metrics used and their weight in the final score. The metrics weight in the final score was developed by the Study team in consultation with the Evaluation Administrator. Reasonable variations on the metrics weight were conducted to assess sensitivity, and results remained consistent throughout the range assessed.

The companion workbook can be used to adjust the metrics weights to reflect changing priorities on the final score and relative ranking of the measures.

Table ES- 1: Scoring Metrics

|  |  |  |
| --- | --- | --- |
| Metric | Weight | Description |
| Measure Applicability | 15% | Indicate whether the measure is appropriate in CT given its climate and economy. (Consider relevance for a cold, humid climate, and CT's business practices (e.g., farming is less irrigation intensive than in the West). |
| Market Breadth and Applicability | 25% | Indicates how widely this measure could be adopted in the medium term (1-5 years) future within the applicable sector |
| Time Horizon to market | 10% | Reflects product maturity and when the technology can be available in Connecticut. |
| Track Record with other PAs | 5% | A qualitative assessment of the degree to which the measure is offered by other states and PAs currently. |
| Cost Effectiveness | 10% | Reflect the expected cost-effectiveness of the measure in the absence of any incentives |
| Lifetime Energy Savings | 35% | This metric is based on a per unit lifetime energy savings. It is ranked based on percentile against the other measures scaled from 1 (bottom of the group – lowest savings) to 5 (top of the group – biggest savings)[[2]](#footnote-3)[[3]](#footnote-4) |

**Outcomes of the Screening Process**

The study provides an initial inventory of 204 measures, 39 of which were scored for each metric. Of these, 25 measures[[4]](#footnote-5) were considered as candidates for a more in-depth review and analysis. Eight of the candidate measures were considered as high-priority opportunities needing additional analysis conducted in this study. Figure ES- 2 illustrate the progression of measure count through the different steps of the process.

Figure ES- 2: Screening Progression

**Recommendations**

The final ranking of measures included in the Deep Dive is based on a comprehensive evaluation of each parameter, resulting in an objective indication of their potential relevance to Connecticut's energy efficiency programming. Among the targeted measures identified, several show significant promise, and the recommendations below address findings on eight drill-down measures:

1. **Review Measures Periodically** - It is strongly recommended that the PAs periodically review the list of measures in Table 1 and Table 2 of the companion workbook for measures that may have the potential for meeting specific program portfolio or savings needs.
2. **Aerosol Sealant to Reduce Multi-Unit Dwelling Envelope Air Leakage** **– Residential Multifamily** (Score: 4/5): targeting multi-family buildings, this measure offers a novel approach to sealing air leaks, potentially achieving significant reductions in air exchange rates and energy savings. We recommend that this measure should be promoted by the utilities for multi-family buildings undergoing a major retrofit, such as a semi-prescriptive approach with an incentive proportional to the reduction in ACH (translated to cfm). The program should prohibit the use of hazardous chemicals; this can be ensured by requesting the use of UL Greenguard Gold certified air sealant or similar certification. Although this measure is more relevant for multi-family buildings, it can also be used for other building topologies such as single-family and small C&I buildings.
3. **Displacement Ventilation Technology – C&I** (Score: 3.8/5): providing efficient delivery of clean air to occupant breathing zones, displacement ventilation technology offers energy savings and non-energy benefits such as improved indoor air quality and thermal comfort. This technology can be deployed in new and existing buildings. As lack of knowledge of the technology appears to be a significant barrier to adoption, we recommend raising awareness bypublishing use cases and communications to professionals and building owners, with notable highlights on building owner satisfaction with the technology. Considering the variability of the savings, this measure is best promoted through a custom program. Follow-up studies to develop design and operational guides would help deploy this measure in a cost-efficient way.
4. **High-Temperature Heat Pump - Industrial** (Score: 3.75/5): focusing on industrial processes, this measure explores the potential of high-temperature heat pumps to deliver significant energy savings by efficiently transferring heat from low to high temperatures, thereby reducing reliance on conventional heating systems. On a 1-3-year timeline, we recommend developing relationships with international suppliers to back local projects and large-scale demonstrations within the United States to highlight the benefits of the technology and convince international and local stakeholders to develop the domestic market. On long term, we recommend offering incentives through a program or rates aimed at prompting end users to adopt Integrated Heat Pumps (IHPs) by offsetting the cost difference between electricity and natural gas.
5. **Cold Climate Commercial Rooftop Units – C&I** (Score: 3.65/5): replacement of conventional rooftop units with cold climate capable heat pump units presents an opportunity to reduce fossil fuel reliance for heating in commercial buildings, especially in colder climates. Commercial-sized cold climate Air Source Heat Pumps are beginning to be introduced in the market and represent a short-term opportunity for Connecticut. As the economics are more promising for partial displacement measures than full displacement measures, we recommend promoting this option as a starter. If full displacement measures are to be integrated into a program, we recommend emphasizing greenhouse gas (GHG) reduction benefits as they are significant, which helps to convince potential buyers to make the switch to hit their decarbonization targets. We also recommend furthering the research on estimating energy savings specific to a broader range of building types.
6. **Advanced Buildings Control** **– C&I** (Score: 3.5/5): by integrating HVAC, lighting systems, and implementing pre-emptive controls based on occupancy forecasting, this measure aims to optimize energy usage in buildings, enhancing efficiency and comfort. For the first 1-3 years horizon, as the extent of the market readiness of the technology is not clear yet, we recommend a trial using C&LM existing Retro-Commissioning program. For the 3+ years horizon, we recommend launching a separate program to promote advanced Occupancy-Centric Controls (OCC) and gather data to better refine the program along the way. We also recommend keeping an eye on the whole pre-emptive controls using control strategies driven by artificial intelligence (AI) in the coming years. It just emerged in the building industry and is moving very fast; staying afloat demonstrations, pilots and papers on the topic in the coming months is paramount to strategically shape this measure to generate the most impact possible in the short and medium term.
7. **Fault Detection and Diagnostic (FDD) for Existing HVAC Systems – Residential and Small C&I** (Score: 3.15/5): utilizing embedded sensors and analytic tools to identify and address faults in HVAC systems in real time, this measure offers opportunities for early fault detection, preventing waste and optimizing system performance. As behavioral outcomes are unknown, we recommend a pilot study to inform how the Connecticut market responds to fault detection and what additional costs may be incurred with training contractors on FDD. As an alternative to FDD, smart diagnostic tools are available and have been integrated into other quality maintenance utilities programs to address the same system deficiencies during routine service calls; we recommend considering providing training for this tool, and incentives could be offered for their purchase.
8. **Performance-Based Duct Renovation – Residential and Small C&I** (Score: 3.00/5): this measure addresses inefficiencies in HVAC distribution systems going beyond duct leakage, offering benefits such as improved system efficiency, comfort, and energy cost savings through systematic testing and renovation procedures. It can also support wider adoption of Air Source Heat Pump more sensitive to duct system deficiencies. Due to the high site-dependent costs and savings potential, we recommend investigating the approach prescribed in ASHRAE Standard 221 to tap into this savings potential. The proposed approach would involve conducting a diagnostic involving pre and post-measurements, combined with an automated analysis, to estimate the potential savings. Through the Energize CT Contractor Portal, we recommend promoting training resources for HVAC Distribution System Performance testing and Optimization and providing subsidized training on relevant topics.
9. **Plug-In Space Heating Heat Pumps (Micro Heat Pumps) – Residential Multifamily** (Score: 2.50/5): with easy installation and operation, micro heat pumps offer an alternative to conventional space heating systems, potentially replacing inefficient heaters in multi-family dwellings. In the short term, we recommend considering incentives for mild-climate heat pump products paired with a robust education campaign to displace windows/portable AC units and portable room heaters. In the mid-term, once products suitable for cold climate conditions are available on the market, we recommend launching a pilot to confirm savings, usability, and market constraints. Education will be key to program design to differentiate this higher-cost model from comparable window AC units and room heaters. Depending on distribution channels for cold-climate portable heat pumps, a point-of-sale or midstream rebate approach might be appropriate.

These 8 measures are particularly interesting for Connecticut based on their ranking and variety but are not the only measures of interest identified in the study. The utilities should consider the other measures presented in the companion workbook based on specific sectoral needs or preferences. Additional data sources are presented in the workbook for all measures included in Stage 2.

**Emerging Program Concepts**

The North American landscape with regards to energy efficiency and conservation has changed in the last five years with significant impacts on utility’s programs and initiatives. Improved building energy codes and equipment energy efficiency standards have moved prior energy efficiency opportunities to the baseline characteristics of technologies, climate policies are having profound impacts on energy systems and consumption patterns, new communicating technologies are installed in homes and buildings, multiple stakeholders are intervening in order to support GHG reductions, affordability and equity, corporations are integrating environmental, social and governance metrics including Net Zero commitments, and Demand-Side Management initiatives are also not being considered as tools to support broader goals, including economic development and customer retention.

The study also conducted a qualitative assessment of the C&LM portfolio to identify emerging program design trends addressing these new issues. The study presents 3 new program trends addressing several of these issues.:

**Smart Building Electrification**: can be defined as including three components:

* Combining building electrification with demand-reduction strategies (energy efficiency and demand management)
* Preference for building electrification technologies efficient at peak
* Consideration for hybrid (multi-fuel) heating systems to mitigate significant peak growth depending on the energy system constraints – although this consideration is more appropriate for colder climates than Connecticut

Different Program Administrators have implemented the following approaches to support Smart Building Electrification:

* Combine Electrification incentives with other energy efficiency programs
* Mitigate winter peak impacts through DR/DER and dual-fuel systems

**Residential Staged Retrofit:** an emerging approach is for program administrators to maintain on a long-term relationship with homeowners through an Energy Coach or concierge service developing a personalized roadmap to support homeowners on their renovation journey over an extended period (10-20 years if needed). The roadmap is a home-improvement plan that considers the homeowners’ needs and circumstances and avoids obstructing future energy efficiency solutions due to a lack of foresight.

**Grid Interactive Efficient Buildings (GEB):** are energy-efficient buildings with smart technologies characterized by the active use of DERs to optimize energy use for grid services, occupant needs and preferences, climate mitigation, and cost reductions in a continuous and integrated way. Several initiatives are underway in the U.S. to maximize the grid benefits of GEB, and utilities can now start to adjust their portfolio to fully leverage GEBs in the medium future.

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# Introduction

Connecticut holds a strong position in its energy efficiency programs, and utilities had considerable success in reducing energy consumption through their Triennial Conservation and Load Management (CL&M) Plans. Recent market trends however have increased the challenges of continuing to grow energy efficiency impacts in the state, with increased building standards, more stringent energy efficiency equipment standards, and broad market adoption of various efficient technologies.

**Study Objectives and Approach**

The objective of the study is to identify and study candidate technologies for the next cycle of Connecticut’s Conservation and Load Management Plan which can support sustained growth in energy efficiency achievements.

The study involves the identification of candidate technologies, a multi-stage screening process based on increasingly detailed information, and finally an in-depth review of key technologies relevant to Connecticut. The outcome of each step is fully documented in a companion workbook to this report.

The study is limited to energy efficiency and electrification measures only and does not cover Demand-Reduction only measures or other Distributed Energy Resources.

# Disposition Process

The study applied a multi-stage process to identify, assess and select a list of candidate technologies of interest to expand the CL&M programs and achieve higher energy efficiency impacts. Each subsequent step in the process builds and refined information gathered previously, and the key information of each step is documented in the companion workbook in Appendix B.

Figure 1: Overview of Study Assessment Process

**Stage 1** provides an initial assessment of the status of the maturity of the technology in the market to focus the assessment on new measures but still likely available in the market.

**Stage 2** scores the measures based on expertise and easily accessible information.

**Stage 3** involves a more detailed assessment of the technology to refine the individual scores and calculated energy impacts.

## Stage 1: Inventory List and Categorization

The study has collected a comprehensive list of technologies through multiple sources, including:

* Several energy efficiency potential studies
* Emerging Technology Programs in CA, MN, MA, and others
* Industry Sponsored Research Institute
* Industry Associations
* Other Jurisdictions DSM Portfolios

Each measure was further categorized based on its maturity status by professional judgment. The objective at this stage was to identify measures of interest for which information was available but are not commonly found in DSM portfolios across North America.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **1​** | **2​** | **3​** | **4​** | **5​** |
| “Not new and already in CT”​ | “Not that new”​ | “Somewhat new”​ | “Fairly new”​ | “Space Age”​ |
| *Measures that are widely adopted in transformed markets.*​ | *Common measures.*​ | *Established measures, technologies, and approaches that may not be widely used or have some upward potential.*​ | *Not commonly used, but available measures.*​ | *Less widely available or understood.*​ |

Measures in **categories 1 and 2** are mature, and additional information on these measures is readily available and would not require additional research. These measures were not considered for the next stages.

**Category 3** measures represent good candidates but are considered well-established in DSM programs, although more recently than those in lower categories. Except for specific exceptions, these measures do not proceed to the next stage.

**Category** **4** regroups relatively new measures that have been introduced recently in DSM programs – the measures are considered available to the market.

Finally, technologies insufficiently mature are in **Category 5.** These measures are not considered ready for the short and mid-term but could become good candidates in the future.

The Study has inventoried 204 measures for consideration, of which 39 have proceeded to Stage 2: Preliminary Assessment and Ranking. Figure 2 below presents the result of the categorization process.

Figure 2: Stage 1 Results

## Disposition Stage 2 – Measure Scoring

The 39 candidate technologies have been assessed against 8 distinct metrics to assess their respective relevance for Connecticut. For Stage 2, the study used categorical metrics converted to a scale of 1 to 5. Each category was assigned a weight to estimate the total Stage 2 score for each measure. Below is a description of each metric used for the ranking.

Table 1 presents each metric weight used to calculate the final score as well as potential values for each metric.

**Measure Applicability**: Indicate whether the measure is appropriate in CT given its climate and economy. (Consider relevance for a cold, humid climate, and CT's business practices (e.g., farming is less irrigation intensive than in the West).

**Market: Availability**: Indicates the degree to which the technology and expertise exist for this solution.

**Market Breadth and Applicability**: Indicates how widely this measure could be adopted in the medium-term future within the applicable sector

**Time Horizon to market**: Reflects product maturity and when the technology can be available in Connecticut[[5]](#footnote-6).

**Track Record with other PAs:** A qualitative assessment of the degree to which the measure appears to be offered by other states and PAs currently. This metric does not seek to assess if the measure is well established with other PAs, but to identify existing program concept in at least one jurisdiction to inform program design.

**Cost-Effectiveness**: Reflect the expected cost-effectiveness of the measure in the absence of any incentives

**Energy Savings:** Provide a high-level assessment of the unitary annual energy savings.

**Estimated Useful Life:** The metric represents the expected measure useful life

**Lifetime unitary energy savings**: Provides the total unitary savings over the full estimated life of the measure. The measures are ranked based on percentile against the other measures scaled from 1 (bottom of the group – lowest savings) to 5 (top of the group – biggest savings)[[6]](#footnote-7)

Table 1: Scoring Metrics, Weight, and Categories

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Metric | Weight | 1 | 2 | 3 | 4 | 5 |
| Measure Applicability | 15% | Good fit |  | Possible Fit |  | Limited or no fit |
| Market Breadth and Applicability | 25% | Niche Application |  | Subset of Buildings or customers |  | Broad Application |
| Time Horizon to market | 10% | 7+ years |  | 3-6 years |  | 1-3 years |
| Track Record with other PAs | 5% | Known Offering |  | Related Offering |  | None Identified |
| Cost Effectiveness | 10% | Expected to be challenging |  | Unknown |  | Expected to be cost-effective |
| Lifetime Energy Savings | 35% | Ranked based on percentile against the other measures scaled from 1 (bottom of the group – lowest savings) to 5 (top of the group – biggest savings | | | | |
| Energy Savings[[7]](#footnote-8) | 0% | Small  (0-500 ekWh) |  | Medium  (500-5000 ekWh) |  | Large (5000+ ekWh) |
| Estimated Useful Life | 0% | Unknown | 1-5 years | 6-10 years | 10-15 years | 16-20 years |
| Market Availability | 0% | Not readily available |  | Could be developed | Believed to be available | Available |

Six metrics have been assigned a weight to calculate the individual measure core, with 3 additional metrics (energy savings, estimated useful life and Market availability) also included in the companion workbook but are not used in the overall score since they are implicitly or explicitly accounted for in other metrics.

Following the individual scoring, all measures were screened to exclude for further analysis any measure already promoted in Connecticut or if it can be considered as equivalent to another measure.   
  
Out of the 39 measures included in Stage 2 scoring, 25 have been assigned a score indicating relevance for CT. 8 measures were selected for a more detailed analysis based on their relevance for Connecticut and potential impacts. Table 2 presents the weighted score of those measures with final disposition for Stage 3.

Table 2: Stage 2 Scoring

|  |  |  |
| --- | --- | --- |
| Measure name | Total Weighted Score of Measures | Included in Stage 3 |
| Aerosol sealant to reduce multi-unit dwelling envelope air leakage | 3.50 | YES |
| Displacement ventilation technology | 3.40 | YES |
| High-Temperature Heat pump (industrial) | 2.91 | YES |
| Integrated heat pump controllers | 2.90 | NO |
| FDD for existing HVAC systems | 2.85 | YES |
| Horticulture lighting fixtures | 2.83 | NO |
| Aerofoils for Open Display Cases | 2.81 | NO |
| Structural color coating | 2.80 | NO |
| Cold-climate commercial rooftop units | 2.80 | YES |
| Nanowire mesh air filters | 2.75 | NO |
| Self-correcting controls for air handling units | 2.70 | NO |
| R-717-based refrigeration systems | 2.65 | NO |
| Integrated building control retrofit package | 2.65 | YES |
| HVAC distribution system renovation | 2.60 | YES |
| Commercial building automation | 2.55 | YES |
| Dedicated Outdoor Air System (DOAS) | 2.50 | NO |
| Gas absorption heat pumps | 2.48 | NO |
| Solar air heaters (Active Solar Heating) | 2.43 | NO |
| Advanced controls for residential HVAC fan | 2.36 | NO |
| Plug in space heating heat pumps (micro heat pumps) | 2.20 | YES |
| T-Studs | 2.15 | NO |
| Commercial IAQ | 2.15 | NO |
| Auto milker | 2.15 | NO |
| Integrated PTHP, ERV, Filter and toilet exhaust | 2.01 | NO |
| Non-REM brushless DC motor technology | 1.95 | NO |

The detailed results of Stage 2 are available in the accompanying workbook under the Stage 2 – Measure Scoring Tab.

The commercial building automation and integrated building control retrofit package have been combined in a unique measure for stage 3.

## Recommendation

The study provides insights into several additional measures not considered for the deep dive analysis. The utilities should review the comprehensive measure list for additional measures of interest, notably the 25 measures scored during Stage 2 of the disposition process.

# Targeted Measures

High potential candidate measures identified through the disposition process have been assessed in greater detail, and the outcome of this analysis is presented in the following section. Each parameter used during the disposition process has been revised and used to conduct the final ranking of the measures.

The deep dive of each measure consisted of reviewing the initial assumption and adding layers of research to it to better assess their relevance to be pulled into a program in Connecticut. On top of a qualitative assessment, a quantitative analysis was performed to estimate the cost-effectiveness and the high-level savings potential at a project scale as well as the market level.

Appendix A presents global inputs used for the cost-effectiveness analysis.

## Scoring Summary

Table 3 presents the score for each parameter used in the study. The measures are ranked based on the Final Score – providing a relative indication of their potential relevance to Connecticut Energy Efficiency Programs. Figure 3 presents the detailed score per measure and the relative contribution of each metric considering the weighting assigned.

Table 3: Final Score and Ranking of Measures

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Measure | Final Score | Applicability | Track Record | Time Horizon | Market Breadth | Cost-Effectiveness | Lifetime savings |
| Aerosol sealant to reduce multi-unit dwelling envelope air leakage | **4.00** | 5 | 4 | 5 | 3 | 4 | 4 |
| Displacement ventilation technology | **3.80** | 5 | 3 | 5 | 2 | 5 | 4 |
| High-Temperature Heat pump (industrial) | **3.75** | 5 | 2 | 4 | 1 | 5 | 5 |
| Cold-climate commercial rooftop units | **3.60** | 5 | 2 | 5 | 4 | 2 | 3 |
| Advanced buildings control (replaces 55 and 154) | **3.50** | 5 | 1 | 4 | 3 | 5 | 3 |
| FDD for existing HVAC systems | **3.15** | 5 | 2 | 4 | 5 | 3 | 1 |
| Performance-based Duct renovation | **3.00** | 5 | 2 | 4 | 3 | 3 | 2 |
| Plug in space heating heat pumps (micro heat pumps) | **2.50** | 5 | 1 | 3 | 3 | 3 | 1 |

Figure 3: Detailed Score per Measure

The details about each measure are presented in the following sections. For each measure, a summary of the data collected is presented, followed by a more detailed discussion related to each metric.

### Cost-Effectiveness and Lifetime Energy Savings Score

The scoring for cost-effectiveness in stage 3 is based on a simplified Utility Cost Test (UCT), accounting only for energy and GHG related impacts, and applying incentives varying between 50% and 75% of incremental costs. Incentives would use the lower band of the range only when a higher incentive value would lead to a benefit-cost ratio lower than one. The simplified cost-effectiveness calculations are meant to provide a preliminary indication of the cost-effectiveness of measures under the framework used for the C&LM Plan Assessment.

Impacts of alternatives incentive level can be assessed using the companion spreadsheet.  
  
The simplified UCT does not account for other impact factors, non-energy impacts or program administration costs – all included in the modified UCT applied in Connecticut.

UCT Benefits (Total Avoided Costs) are estimated using the levelized avoided costs over the estimated useful life of the measure. Appendix A presents the values used for the economic analysis and references.

The companion workbook also provides a simplified Participant Cost Test (PCT) calculation only accounting for energy impacts.

Lifetime Unit Energy Savings are scored using a ranked scaling with the top score for the highest unitary savings. This approach – used in conjunction with the Market Breadth metric - recognize the value of high unitary savings measures, while not over-penalizing measures with lower unitary savings but high market volume potential.

## Performance-Based Duct Renovation

### Measure Summary

**Final Score: 2.65**

**Target Sector:** Residential and Light Commercial

**End-Use:** HVAC

**Decision Type:** Retrofit

**Applicability to Connecticut:** Good fit

**Market Readiness:** Could be developed – knowledge and capabilities exist but would benefit from a structured approach and support.

**Market Breadth/Applicability:** Subset of buildings – high opportunity when paired with HVAC electrification.

**Lifetime unit energy savings: ​**On average, 15 % of total HVAC energy and demand for residential and light commercial.

* Electric: 4,140 kWh
* Natural Gas: 180 MMBtu

**Incremental Costs:** Costs can vary significantly depending on the issues identified. Costs can range from $200 to conduct a diagnostic with minimal corrections to $15,000 for a large home complete ductwork replacement project.  
For the analysis, we assumed an incremental cost of $3,000.

**Estimated useful life:** 18 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time horizon to market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 2.65 | 5 | 2 | 4 | 3 | 3 | 1 |

### Measure Description

This measure consists of identifying the source of an improperly sized/designed HVAC distribution system through basic measurements and analysis and performing the required work while allowing to quantify the energy savings through a detailed methodology.

Distribution system designs are based on multiple factors, including delivered volumes, fan power, required airflow velocity, and duct types, amongst others. An improperly sized/designed HVAC distribution system can:​

* **Reduce the HVAC system efficiency** through increased system cycling and run times​ and lower equipment efficiency at low flow rates.
* **Impact comfort** because of uneven temperatures throughout the home/building, insufficient moisture removal in AC mode​, increased noise with undersized ductwork due to high air velocity.
* **Impact fan performance** due to increased pressure drop in the system.
* **Shorten the lifespan** of the equipment​.
* **Increase energy costs** ​due to lower system efficiency.
* **Lead to operational problems**: low airflow can lead to equipment trip on high temperature, coil freezing in cooling mode and low suction pressure.

The measure includes a systematic testing procedure of the forced air system to identify previously undetected deficiencies and provide a standard system performance score. ASHRAE Standard 221 (ASHRAE2020) provides a uniform industry-supported standard to conduct the required testing and field data collection and the methodology to estimate the equipment performance score[[8]](#footnote-9).

The process starts with a complete analysis of the duct system – which results in a remediation plan to address the HVAC distribution inefficiencies. Remediations can range from:

* Duct sealing[[9]](#footnote-10).
* Resizing and replacing the return airdrop.
* Replacing an individual duct run.
* Adding additional parallel duct runs.
* Replacing the whole home/building ductwork​.

The measure provides a systematic and uniform approach to assess system performance before and following the duct renovation project, allowing to estimate energy savings from each project.

### Applicability to Connecticut

**Score: 5**

The measure is applicable to all US residential and light commercial buildings with forced-air distribution systems, independent of the location. Based on the 2020 Residential Appliance Saturation Survey, 40% of CT single family households used forced air heating systems or central air conditioning.

A 2018 DOE Meta Study (DOE2018) indicates that at least 50 to 65% of households in different US regions experience airflow-related faults in the distribution system – in addition to most homes experiencing some level of duct leakage.

### Track Record with Other Program Administrators

**Score: 2**

No evidence of energy efficiency programs supporting duct renovations (outside of duct sealing) for residential and light commercial buildings has been identified. In California, program administrators (PAs) are subsidizing contractor training on distribution system testing, diagnostics, and optimization to support the industry. The training is provided through the [National Comfort Institute](https://nationalcomfortinstitute.com/pro/index.cfm?pid=8615#online).

Southern California Edison integrated a similar measure (test-in test-out duct renovation) for light commercial in a preliminary program design in 2017, but the program was not introduced to the market.

The National Comfort Institute (NCI) has been supporting and testing the approach over the years in various markets.

### Technology Readiness

The measure requires typical HVAC training and qualifications for implementation. For this measure, HVAC distribution measurements are required to properly assess existing conditions: it consists of gathering nameplate data of the HVAC equipment and of taking simple measurements (pressure, temperature, flow rate) at the return and supply sides of the air handler and at the end of the various legs of the HVAC distribution system.   
  
Contractors in CT already providing duct balancing are prime candidates to adopt the measure.

### Market Availability

NCI offers training on duct system optimization and residential & commercial system performance for HVAC contractors. A list of certified professionals is available at <https://www.myhomecomfort.org/find-a-contractor/>

While there are many NCI Certified professionals listed in other states, none is presently listed in Connecticut.

The required expertise is, however, not exclusive to NCI-certified professionals. Some contractors, building on their own experience and/or on training from other associations possess the expertise to optimize duct systems.

ASHRAE Standard 221 provides a robust framework to conduct the required site evaluation and system performance measurement to support the estimation of energy savings.

### Energy Savings and Cost-effectiveness

**Cost-effectiveness score: 3**

**Lifetime Energy Savings score: 1**

Simplified UCT B/C ratio: 2.06

Total cost: $3,000

Energy Avoided costs : $3,077

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | 230 |
| Lifetime | 4,140 |
| Natural Gas (MMBtu) | Annual | 10 |
| Lifetime | 180 |
| Greenhouse Gas (tCO2e) | Annual | 0.6 |
| Lifetime | 10.7 |

This measure is applicable to any energy sources. Calculations for other fuels should be conducted separately as part of a detailed assessment.

The following assumptions have been used to perform the cost-effectiveness analysis:

* Highly site-dependent
* Average of 15% of HVAC energy use
* Assumed cooling load: 1,530 kWh[[10]](#footnote-11)
* Assumed heating load: 67 MMBtu[[11]](#footnote-12)
* Incremental Costs: Assumed $3,000[[12]](#footnote-13). Incremental costs are project specific and can range from $600 for a simple diagnostic and replacement of the return air drop to $15,000 for whole home ductwork replacement
* Incentive Amount: 50% of incremental costs
* Estimated Useful Life: 18 years

For the magnitude of potential impact, potential savings were assumed to represent 15% of HVAC system energy consumption and demand for residential and light commercial units with HVAC ducts. Also, 72% of residential units in CT are assumed to have HVAC ducts and assumed 50%[[13]](#footnote-14) of prevalence of significant issues.

|  |  |  |
| --- | --- | --- |
| **Market scale savings** | | |
| Electricity (GWh) | Lifetime | 650 |
| Natural Gas (MMBtu) | Lifetime | 14,000,000 |
| GHG (tCO2e) | Lifetime | 215 |

### Recommendations

Significant energy and demand savings could be generated from duct system renovation in the residential and light commercial market segments in Connecticut. Another benefit of this activity is to prepare existing duct systems for full-displacement heat pumps that are generally larger and require higher airflow capacity than the existing systems[[14]](#footnote-15).

Due to the high site-dependent costs and savings potential, it could be worthwhile to **investigate the approach prescribed in ASHRAE Standard 221** to tap into this savings potential: the proposed approach would involve conducting a diagnostic involving pre and post-measurements, combined with an automated analysis, to estimate the potential savings.

Through Energize CT Contractor Portal, **promote training resources** for HVAC Distribution System Performance testing and Optimization, and consider providing subsidized training on relevant topics – including on the application of ASHRAE Standard 221.

As further research, the demonstration and feasibility of a performance-based duct retrofit program could be demonstrated through a few pilot projects – potentially in conjunction with a full electrification displacement with an air-source heat pump. Based on the outcome of the research, performance-based incentives could be provided.

Criteria for qualifying contractors to quantify the potential savings and implement the measure.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| NCI, 2017a | B. Libscomb, *Performance-Based HVAC Energy Savings,* 2017. |
| NCI, 2017b | M. Johnson, *Stranded HVAC Performance Potential,* 2017. |
| CPUC, 2017 | California Public Utilities Commission, *Advice Letter SCE 3463-E-B,* 2017. Accessed at: <https://edisonintl.sharepoint.com/teams/Public/TM2/Shared%20Documents/Forms/AllItems.aspx?ga=1&id=%2Fteams%2FPublic%2FTM2%2FShared%20Documents%2FPublic%2FRegulatory%2FFilings%2DAdvice%20Letters%2FApproved%2FElectric%2FELECTRIC%5F3463%2DE%2DB%2Epdf&parent=%2Fteams%2FPublic%2FTM2%2FShared%20Documents%2FPublic%2FRegulatory%2FFilings%2DAdvice%20Letters%2FApproved%2FElectric> |
|  | J. Rodriguez, Fire & Ice Heating & Air Conditioning, Inc. *Cost of HVAC Ductwork Modification, 2024*. Accessed at: <https://indoortemp.com/resources/ductwork-modification-cost> |
|  | B. Lipscomb, Director, National Comfort Institute. Email exchanges. |
| DOE, 2001 | Walker et al. *Simulation of residential HVAC System Performance,* 2001. Accessed at: <https://www.osti.gov/servlets/purl/785278-tSflhr/native/> |
| DOE2018 | US Department of Energy, *Residential HVAC Installation Practices: A Review of Research Findings*, 2018. Accessed at: <https://www.energy.gov/eere/buildings/articles/residential-hvac-installation-practices-review-research-findings> |
| ASHRAE,2020 | ASHRAE, *ANSI/ASHRAE Standard 221-2020 Test Method to field-Measure and Score the Cooling and Heating Performance of an Installed Unitary HVAC System*. Available for purchase at: <https://store.accuristech.com/ashrae/standards/ashrae-221-2020?gateway_code=ashrae&product_id=2185614> |

## High-Temperature Heat pump (industrial)

### Measure Summary

**Final Score: 3.75**

**Target Sector:** Industrial

**End-Use:** Industrial Processes (140-392F)

**Decision Type:** Retrofit or New Construction

**Applicability to Connecticut:** Good fit – industrial sectors with processes involving temperatures below 320 F.

**Market Readiness:** Technology is mature outside of the U.S. Access to technology in the US is challenging.

**Market Breadth/Applicability:** Niche set of buildings or customers as only a portion of the industrial facilities can run entirely or partly on IHPs​.

**Lifetime energy savings: ​**Highly dependent on the process, but generally 26-32% of the source energy is used for process heat generation. It represents about 566,406 MMBtu of natural gas for a chemical facility.​

**Incremental Costs:** 350-650 $/kW (based on the temperature of the process heat sink). The cost only expresses the Capex as the maintenance cost is assumed to be similar to the baseline. The Capex of the baseline, an industrial gas boiler, is estimated at 150 $/kW.**​**

**Estimated useful life:** 20 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 3.75 | 5 | 2 | 4 | 1 | 5 | 5 |

### Measure Description

A heat pump is a device that moves heat from a lower temperature (heat source) to a higher temperature (heat sink). Heat sources can be air, water, geothermal, waste heat from an industrial process, or recycled wastewater. The heat sink can be used for space heating, water heating, process heating, and so on.​

The measure focuses on Industrial Heat Pumps (IHP) delivering medium (175-212°F) to high temperatures (212-320°F), which represent 35% of industrial heat processes in the U.S. Different technologies of IHPs are entailed within the measure:​

* Mechanical Vapor Compression (**MVC**)​: completely closed refrigerant loop maintains the working fluid’s pressures and temperatures.
* Mechanical Vapor Re-compression (**MVR**)​: takes advantage of recompressing waste low-pressure steam or hydrocarbon vapor that would otherwise be vented or condensed with heat rejected to the ambient air.
* Thermal Vapor Re-compression (**TVR**)​: most common in industry today, has no moving parts, but it is restricted to compressing low-pressure (waste) steam (heat source) to a medium pressure steam header (heat sink) using high-pressure steam (IHP driver).
* Heat Activated (**HA**): uses various chemical processes, such as absorption, adsorption, or a reversible chemical reaction to transfer the heat from the source to the sink.

**HA** IHPs will be discussed but will not be the focus of the measure as they are still at the late development / early commercialization stage.

**MVC** and **MVR** heat pumps can be configured in **two stages compression** which almost double the temperature lift; the figures in this presentation are reflective of these technologies configured this way.​

Multiple refrigerants are used in industrial heat pump applications – ranging from natural refrigerant (water, Ammonia and Carbon dioxide) to different hydrofluoroolefins /hydrocholrofluoroolefins (HFOs/HCFOs), each with unique characteristics and temperature application range. The International Energy Agency (IEA) Heat Pumping Technologies Technology Collaboration Programme (HPT TCP) maintains a list of supplier technologies and characteristics, and most systems documented are using natural refrigerants or HFOs/HCFOs based refrigerant.

The baseline condition are industrial facilities using a conventional process heating system using natural gas (e.g.: hot water boiler, boiler steam or fired process heater).

### Applicability to Connecticut

**Score: 5**

IHPs are particularly suitable for the **chemicals, food, and paper** sectors as a significant proportion of their heating processes are done at relatively low temperatures (140-392°F). The combined shares of these sectors in Connecticut represent 22% of the entire industrial sector’s total GDP, chemicals being the second-biggest industry in the State.​

​In addition, manufacturing, notably automobile manufacturing, also involves processes that could be served by IHPs. For example, IHPs can be used to provide process hot water at temperatures at 122°F for washing applications, to preheat feed water to 194°F for steam generation or to heat air to 81°F for welding and painting. The aerospace and transportation manufacturing sectors are the most prominent ones in Connecticut, representing 37% of the sector’s GDP. ​

​IHPs are well suited for the manufacturing landscape of Connecticut, even though the impact is limited as the most promising sectors for the measure only represent less than 1/4 of the industries, based on GDP, in the State.​

### Track Record with Other Program Administrators

**Score: 2**

Our research did not identify any specific program to support adoption of industrial heat pumps in North America – however, the measure can be supported through utility’s custom energy efficiency programs. For instance, Mass Save, in Massachusetts, received one application for an IHP in mid-2022 as part of a manufacturing facility expansion in Fall River (Mass Save, 2022).

From a technological development perspective, the Department of Energy (DOE) is issuing R&D grants for HP, with a focus on the decarbonization of industrial drying applications through innovative IHP technology ($900,000 was granted in 2023).

### Technology Readiness

Several IHP technologies have been proven in operational environments and are used in facilities in different regions of the world, although with limited penetration in the U.S. The following table presents the Technology Readiness Level of different technologies as of 2023.

|  |  |
| --- | --- |
| **IHPs type (ACEEE, 2023)** | **Technology Readiness Level** |
| **Heat Activated (HA)** | 4-7  (4: technology validated in lab, 7: system prototype demonstrated in operational environment) |
| **Mechanical Vapor Compression (MVC)** | 9 (actual system proven in operational environment) |
| **Mechanical Vapor Re-compression (MVR)** | 9 |
| **Thermal Vapor Re-compression (TVR)** | 9 |

### Market Availability

The domestic supply of IHPs is currently limited in the US. Manufacturers such as Nyle Corporation are US-based, but they develop IHPs with capabilities capping at 162°F and are hence mostly suited for food dehydration and water heating applications. Johnson Controls, with headquarters in Wisconsin, develops products with higher temperature ranges, but they are manufactured overseas and tailored to the European market. No local vendor currently develops IHPs with sink temperatures above 176°F, but several vendors in Japan and Europe have products on the market able to reach temperatures as high as 320°F. However, foreign manufacturers are quoting a 52-week lead time on products*.*

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 5**

**Lifetime Energy Savings Score: 5**

The project scale results are related to a chemical facility with the following heating processes: ethylene debutanizer, process water stripper reboiler, ethanol dry mill distillation of ethanol-water mixture. These applications are very well suited for IHPs and are showing the most promising results of all industries.

Simplified UCT B/C ratio: 17.2 (assuming a COP of 6 – COPs as low as 3 demonstrates positive simplified UCT results

Total costs: $17,197,070

Avoided costs: $147,917,306

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | *-41,387,000 (increase)* |
| Lifetime | *-827,734,000 (increase)* |
| Natural Gas (MMBtu) | Annual | *988,281* |
| Lifetime | *1,976,563* |
| Greenhouse Gas (tCO2e) | Annual | *39,274* |
| Lifetime | *785,474* |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Process heating load of the facility: 1,218,056 MMBtu/hr
* COP: ~6
* Natural Gas savings (as a percentage of the heating load): 81.1%
* Unit Incremental Cost: 650 $/kW
* Incentive: 75% of incremental costs
* Estimated Useful Life: 20

Not all processes, however, show results as aggressive as the above. For example, the opportunities to use IHPs for process load are more limited in the food processing industry and the performance is reduced; the savings are about ¼ of the ones in the example above.

The total market techno-economic potential is very dependent on the industry landscape and the heating processes involved. Therefore, a more exhaustive potential study is required to quantify the impact of this measure at the market level for Connecticut.

Assuming 28 chemical facilities (26 MW heating capacity per facility) and 148 food processing facilities (7 MW heating capacity per facility), market-level potential would be as follows:

|  |  |  |
| --- | --- | --- |
| **Market scale savings** | | |
| Electricity (GWh) | Annual | -3,555 (increase) |
| Lifetime | -71,105 (increase) |
| Natural Gas (Tbtu) | Annual | 66 |
| Lifetime | 1,312 |

### Recommendations

On a 1-3 year timeline, we recommend enhancing a local market for IHPs by **working with international suppliers** to back local projects and large-scale demonstrations within the United States. By fostering vendors' awareness of these U.S.-based use cases, it will pave the way for **establishing a domestic supply** by highlighting the technology’s capabilities and market opportunities. In addition, the creation of **knowledge clusters** with the local leading heat pump manufacturers to share project learnings is a way to stimulate the market and increase the supply capabilities. CT Utilities can work with industry organizations such as ACEEE, NEMA and the Renewable Thermal Collaborative through the Industrial Heat Pump Alliance to promote the adoption of industrial heat pumps in manufacturing plants.

On a 3+ year timeline, we recommend stimulating the development of the local market for IHPs and offer **incentives** through a program or rates aimed at prompting end users to adopt Integrated Heat Pumps (IHPs) by **offsetting the cost difference between electricity and natural gas**. Currently in Connecticut, electricity is estimated to be about 3 times more expensive than natural gas to generate the same amount of heat. Most industrial heat pumps with COPs above 3 should provide a cost-effective solution for utilities and customers alike – although individual cases should be assessed.[[15]](#footnote-16)

We also recommend keeping an eye on technological development of IHPs with higher temperature capabilities and their cost projections, as HA technologies are promising but currently expensive. While the technology gains maturity, food, chemicals and paper industries are the initial target market as their processes don’t require a high lift temperature. Current IHPs technologies can achieve COPs ranging from 2.5 to 6, but next generations will likely evolve towards the higher end of the range – considering current technologies are already available with COPs well above 4.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| ACEEE, 2023 | E. Rightor et al. (ACEEE), *Industrial Heat Pumps: Electrifying Industry’s Process Heat Supply,* 2022. Available at: <https://www.aceee.org/sites/default/files/pdfs/ie2201.pdf> [accessed February 27th, 2024] |
| CalNext, 2023 | C. Lee, D. Baroi & A. Karasawa, *Industrial Heat Pump Market Study,* 2023. Available at CalNext: <https://calnext.com/wp-content/uploads/2023/12/ET23SWE0036_Industrial-Heat-Pump-Market-Study_Final-Report.pdf> [accessed March 8th, 2024] |
| Transform CT, 2022 | Transform CT, *Connecticut Manufacturing Report*, 2022. Available at: <https://www.cbia.com/wp-content/uploads/2022/11/CT-Mfg-Report_22.pdf> [accessed March 14th, 2024] |
| NASA, 2023 | C. G. Manning (NASA), *Technology Readiness Level*, 2023. Available at: <https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/> [accessed March 25th, 2024] |
| EPA, 2013 | G. McNeil (EPA), *Fact Sheet: CHP as a boiler replacement opportunity,* 2013. Available at: <https://www.epa.gov/sites/default/files/2015-07/documents/fact_sheet_chp_as_a_boiler_replacement_opportunity.pdf> [accessed March 22nd, 2024] |
| Mass Save, 2022 | Mass Save, *Massachusetts Energy Efficiency Program Administrators Quarterly Report ǀ Third Quarter, 2022*. Available at: <https://ma-eeac.org/wp-content/uploads/Final-Third-Quarter-2022-Report-11.18.22.pdf> |
| IEA2023 | International Energy Agency. *Annex 58 about HTHP Task 1: Technologies – State of the art and ongoing developments for systems and components*. Available online at: <https://heatpumpingtechnologies.org/annex58/task1/> |

## Advanced buildings control

### Measure Summary

**Final Score: 3.5**

**Target Sector:** Commercial

**End-Use:** HVAC and lighting

**Decision Type:** Retrofit and new construction

**Applicability to Connecticut:** Good fit

**Market Readiness:** Broadly available in the US, although the more advanced controls of the optimal spectrum are still in an early stage of market commercialization

**Market Breadth/Applicability:** Existing commercial buildings equipped with a Building Management System (BMS) and occupancy sensors – more suited for recent constructions with multiple closed zones, such as offices and schools

**Lifetime energy savings: ​**

* Electricity: 59,959-191,406 kWh
* Natural gas: 446-1,888 MMBtu

(15-40% of end-use consumption for HVAC, and 15-60% for lighting)

**Incremental Costs:** $9,000-$12,250

**Estimated useful life:** 10 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 3.5 | 5 | 1 | 4 | 3 | 5 | 3 |

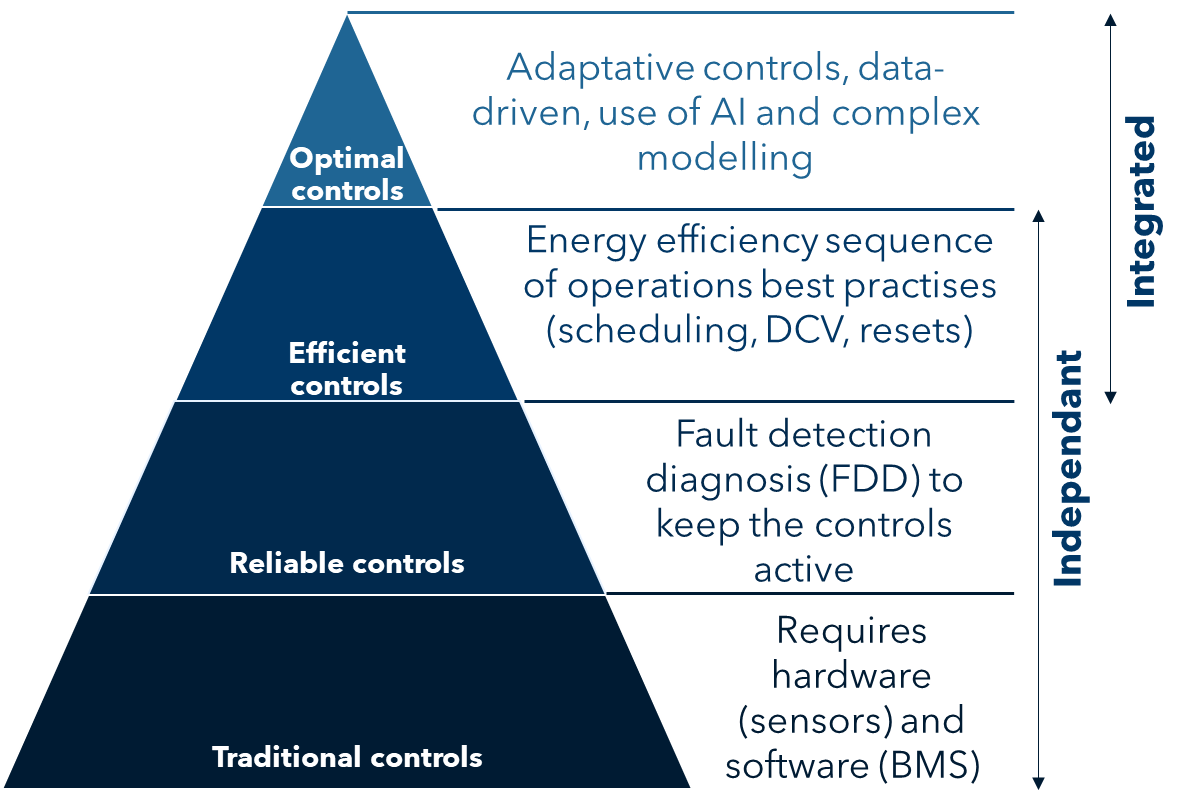
### Measure Description

This measure combines different efficient sequence of operations of HVAC or lighting systems to **integrate** them together by reacting to the same occupancy input in a coordinated fashion. This approach is referenced as **Occupancy-Centric Control (OCC) –** and can be implemented with minimal disturbances to building operations.

The measure relies on distributed technologies able to **detect occupancy**. Although not the base efficient case, emerging technologies to detect occupancy will be presented.

The measure also discusses forecasting data-driven techniques to achieve optimal **pre-emptive controls,** defined as holistic controls based on a forecast, as opposed to reactive controls based on real-time reading of measurement points.

The measure **baseline** is a building with a BMS system and occupancy sensors, but no integration between lighting (interior and exterior) and HVAC (heating, cooling, and ventilation) system operation.



### Applicability to Connecticut

**Score: 5**

This measure can generate savings in all climates and all types of buildings that have multiple rooms/zones and a varying occupancy rate. For example, **offices, schools, institutional** buildings equipped with digital occupancy sensors and a central building management system are well suited for this measure.

**Only 17% of commercial buildings** in New England reported having a BMS, and 19% reported being equipped with occupancy sensors (source: EIA, 2018)[[16]](#footnote-17). This limits the potential of the measure in Connecticut or would increase its cost as its implementation would require hardware installation to make it operational (potentially through other PA programs).

### Track Record with Other Program Administrators

**Score: 2**

Integrated Building Controls and Multivariable predictive Building Controls are typically eligible in utilities’ Custom Energy Efficiency Program.

Certain US utilities, such as Xcel, PG&E, and Duke Energy, have participated in studies or pilot projects on advanced OCC.

No evidence of dedicated programs for Advanced Building Controls was found.

### Technology Readiness

The measure has **been tested in a building** of the University of California Davis to demonstrate its technical feasibility and potential. At the cost of $5,474, it was estimated using real tests and simulations that the measure could generate 11% savings, over the total energy consumption baseline, by adding building systems control integration hardware to an existing code-compliant building and implementing temperature and ventilation setbacks based on occupancy signals from the lighting controls (CLTC, 2023). On top of the consideration of thermal comfort for HVAC OCC controls, the integration of ventilation for air quality, through demand-control ventilation, has also been demonstrated using simulations in different locations, notably Colorado and Vermont (LBNL, 2022).

**Lower-Cost Enabling Alternatives (still under development):** Passive infrared sensors integrated into lightingare the most prevalent in commercial buildings in the US and have been around for a while. CO2 sensors have also proven to be accurate for a long time to detect occupancy but are more expensive (100 $/unit). New occupation sensing technologies that do not rely on occupancy sensors are also emerging, but they have important challenges (NREL, 2020):

* Inaccuracy in the proxy needing constant recalibration (i.e., derived analysis using room temperature or humidity data)
* Still at the early research phase (i.e., WIFI detection – using Wi-Fi traffic data and statistical methods to predict patterns of building occupancy (Alishahi, 2021))
* Facing data privacy issues (i.e., integration with online calendars or smartphone position)

### Market Availability

Overall, the measure is available in Connecticut’s market to do advanced OCC and achieve the lower bound of the savings range. The higher bound requires more advanced controls, which still is at the pilot or early market stage.

OEMs have integrated HVAC and lighting in a centralized system for years using BACnet. For instance, Metasys by Johnson Controls, or Tracer Ensemble by Trane.

* **1995**: BACnet Standard is published as an ANSI/ASHRAE Standard
* **2004**: BACnet Standard becomes worldwide as an ISO standard (ISO 16484-5)

Startups are emerging with innovative solutions; OEMs are starting to invest; the market remains very nascent.

* **2022**: launch of Efficiency AI, powered by Brainbox AI, to do predictive controls using artificial intelligence.
* **2024**: launch of Advance Control for buildings, in partnership with NXP Semiconductors, to leverage machine learning.

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 5**

**Lifetime Energy Savings Score: 5**

Simplified UCT B/C ratio: 14.35

Total cost: $9,000

Avoided cost (over 15 years): $96,829

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | 59,959 |
| Lifetime | 599,588 |
| Natural Gas (MMBtu) | Annual | 44.6 |
| Lifetime | 446 |
| Greenhouse Gas (tCO2e) | Annual | 22.6 |
| Lifetime | 227 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Commercial building size: 50,000 ft2
* Estimated useful life: 10 years
* HVAC electricity energy use intensity: 4.84 kWh/ft2
* Lighting electricity energy use intensity: 3.15 kWh/ft2
* HVAC gas energy use intensity: 1.74 ekWh/ft2
* Unit energy savings: 15% of lighting end-use, 15% of HVAC end-use
* Unit incremental cost: 0.18 $/ft2
* Incentive amount: 75% of incremental cost

To estimate the market potential magnitude, we relied on the assumption that 19% of commercial buildings in New England reported being equipped of a BMS system and/or occupancy sensors, which represents 12,331 commercial buildings in Connecticut. Their combined electric load is assumed to be 1.52 TWh and gas consumption for heating is 3.29 Tbtu. The total market techno-economic estimated potential is as follows.

|  |  |  |
| --- | --- | --- |
| **Market scale savings** | | |
| Electricity (GWh) | Annual | 227.8 |
| Lifetime | 2,278 |
| Natural Gas (Tbtu) | Annual | 0.49 |
| Lifetime | 4.9 |

### Recommendations

**For the first 1-3 years horizon**, as the extent of the market readiness of the technology is not clear as of now, we recommend **a trial using C&LM existing Retro-Commissioning program**. It would allow to assess the state of the market, which providers are able to deploy at scale in Connecticut and define robust baseline approach to assess impacts with Industry Standard Practices. The advanced OCC trial could also inform a future program design by testing program strategies applied at different market segments and appropriate incentive design strategy. This trial can also inform the required communication strategies to increase awareness of the technology and its benefits.

**For the 3+ years horizon**, we recommend **launching a separate program to promote advanced OCC** and gather data to better refine the program along the way. Once the technology is commercially ready, a **trial using alternative data-driven occupancy detection techniques** to test it would allow to increase the market breadth of the program.

We also recommend keeping an eye on the whole pre-emptive controls using AI scene in the coming years. It just emerged in the building industry and is moving very fast; staying afloat demonstrations, pilots and papers on the topic in the coming months is paramount to strategically shape this measure to generate the most impact possible in the short and medium term.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| EIA, 2018 | U.S. Energy Information Administration, *Commercial Buildings Energy Consumption Survey (CBECS),* 2018. Available at: [https://www.eia.gov/consumption/commercial/data/2018/#b3-b5](https://www.eia.gov/consumption/commercial/data/2018/) [accessed March 8th, 2024] |
| CLTC, 2023 | K. Graeber, A. Harper and P. Von Erberich (CLTC), *Pilot-Scale Evaluation of Integrated Building Control System for Commercial Buildings,* 2023*.* Available at: <https://www.energy.ca.gov/sites/default/files/2023-06/CEC-500-2023-039.pdf> [accessed February 12th, 2024] |
| LBNL, 2022 | Xcel Energy and Lawrence Berkeley National Laboratory, *LEDs with Advanced Lighting Controls and Occupancy Sensor-based Demand Control Ventilation*, 2022*.* Available at: <https://buildings.lbl.gov/sites/default/files/2023-10/BW_Phase_2_Program_Manual.pdf> [accessed March 5th, 2024] |
| NREL, 2020 | M. Deru (NREL) et al., *Innovations in Sensors and Controls for Building Energy Management,* 2020. Accessed at: [*https://www.nrel.gov/docs/fy20osti/75601.pdf*](https://www.nrel.gov/docs/fy20osti/75601.pdf)[accessed February 15th, 2024] |
| ASHRAE 62.1 | ASHRAE, ANSI/ASHRAE Standard 62.1-2013 *Ventilation for Acceptable Indoor Air Quality,* 2013. Accessed at: <https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/62_1_2013_p_20150707.pdf> [accessed March 7th, 2024] |
| Alishahi, 2021 | N. Alishahi, M. Nik-Bakht and M. Ouf, *A framework to identify key occupancy indicators for optimizing building operation using WiFi connection count data,* 2021. Accessed at: <https://www.sciencedirect.com/science/article/abs/pii/S0360132321003401> [accessed March 6th, 2024] |

## Fault Detection and Diagnostic for existing HVAC systems

### Measure Summary

**Final Score: 3.15**

**Target Sector:** Residential and Light Commercial

**End-Use:** HVAC

**Decision Type:** Retrofit / Lost Opportunity

**Applicability to Connecticut:** Good fit.

**Market Availability:** Limited – Embedded FDD available on higher-end CAC/ASHP. Add-on FDD not readily available.

**Market Breadth/Applicability:** Broad Application: central air conditioners and air-source heat pumps.

**Lifetime energy savings:**

* Central AC: 588 kWh
* ASHP: 2,622 kWh

Estimated savings are based on an approximate 9% improvement in system performance over the life of the equipment, taking into consideration that only 50% of fault detection would result in a service call and remediation.

**Incremental Costs:** $375 plus contractor training and installation

**Estimated useful life:** 12 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 3.15 | 5 | 2 | 4 | 5 | 3 | 1 |

### Measure Description

**Fault Detection and Diagnostic** (FDD) is an **analytic tool that identifies faults in HVAC systems** and provides advice about how to address those problems.

**FDD for economizers**While the proposed measure focuses on CAC and ASHP, FDD technologies are also relevant for economizers and are a requirement for systems with cooling capacity about 54,000 Btu/hr as per Connecticut 2022 Building Code.

After market economizer control packages from different vendors include FDD capabilities for economizers of any size.

The measure can be implemented as a **retrofit through the addition of sensors onto an existing HVAC unit** to help the user identify system faults sooner to prevent waste and aid in tune-ups or repair, or when installing **new HVAC equipment that includes FDD**.

The measure **targets refrigerant-based systems** (CAC, central ASHP and GSHP) considering higher performance impacts of undiagnosed faults compared to other HVAC systems.

### Applicability to Connecticut

**Score: 5**

This measure applies to **existing residential and light commercial HVAC systems**. It is estimated that poor HVAC installation results in **at least one fault in 70 – 90% of homes** (inadequate refrigerant charge, insufficient evaporator airflow, improper sizing, conduction losses) in the U.S. The following points also reinforce the applicability of the measure in the State:

* 33% of CT homes have air conditioning (excluding multifamily buildings with chillers), penetration of ASHP estimated at 8% – expected to grow in the near future through electrification and enhanced utility program support.
* CT also has many older homes and small commercial buildings, likely with older HVAC equipment/configurations.
* Retrofitting existing HVAC systems with an add-on FDD would be mostly applicable to homes/businesses with relatively new HVAC systems without FDD, considering the incremental costs and remaining useful life of the system[[17]](#footnote-18).
* The new HVAC equipment + FDD measure would be mostly applicable to homes/businesses looking to replace older equipment, and this could be an add-on feature or — eventually — a requirement for an HVAC equipment incentive.

The measure is limited to refrigerant-based central systems (AC and ASHP).

### Track Record with Other Program Administrators

**Score: 2**

No evidence of retrofit programs with specific incentives for FDD sensors or FDD-embedded HVAC equipment were found[[18]](#footnote-19).

Many PAs, including CT, offer HVAC measures, such as heat pumps, air handlers, duct sealing, and thermostats, but we did not find evidence that these programs are contingent on installing FDD-embedded units[[19]](#footnote-20).

Two programs employ smart diagnostic tools through HVAC Tune Ups and an installation verification incentive for contractors but do not provide incentives for FDD monitoring or FDD-embedded HVAC equipment specifically. (Mass Save, Entergy Mississippi).

### Technology Readiness

FDD technology has been demonstrated and is available for some applications:

* At least **13 HVAC manufacturers** currently offer **onboard FDD.**
* **Non-embedded options are new to the market**, one notable product, Sensi Predict – with indoor and outdoor sensors - **was recently discontinued.**
* **Smart Diagnostic Tools are available** for HVAC contractors. DOE is promoting adoption through its STEP (Smart Tool for Efficient HVAC Performance) campaign. Considering non-embedded options are not currently available, expanding the use of Smart Diagnostic Tools to facilitate Fault Detection and Diagnostics by field technicians can provide some of the benefits of FDD technology.

However, the measure is facing technical and market barriers:

* **Product cost**: embedded FDD (CAC and ASHPs) are only available in high-end models.
* **Lack of contractor training**: most HVAC contractors are unfamiliar with FDD and would require training and certification.
* **Lack of knowledge**: customers may not understand the potential benefits of ongoing fault detection and diagnostics or be aware that HVAC equipment performance can degrade over time.

### Market Availability

Onboard FDD is currently only available in high-end products.

Smart Diagnostic Tools are available, although adoption by HVAC Contractors in CT is unknown, but probably relatively low.

Non-embedded FDD options are not readily available with the recent discontinuation of the Sensi Predict product – limiting the applicability of the measure to lost opportunities for the time being.

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 3**

**Lifetime Energy Savings Score: 1**

Simplified UCT B/C ratio: 1.69

Total cost: $475

Avoided cost: $604

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | 268 |
| Lifetime | 4020 |
| Natural Gas (MMBtu) | Annual | Not applicable |
| Lifetime | Not applicable |
| Greenhouse Gas (tCO2e) | Annual | 0.09 |
| Lifetime | 1.36 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Baseline: 3.6%/yr performance degradation – translates to 75% of rated efficiency over 15 years.
* Improved: FDD results in a service call when performance goes below 85%
* Average lifetime performance: 93%
* 50% of fault detection leads to service calls: average impact = 9% performance improvement
* 50%/50% of the market split between CAC and ASHP
* CAC annual energy consumption (3 tons): 1,086 kWh
* ASHP annual energy consumption (3 tons): 4,870 kWh
* Unit Costs: $475 installa 2022 DOE study (DOE2022) estimated the incremental hardware cost of embedded FDD to be $116$ - excluding increased markup or labor costs on the assembly line.
* Estimated useful life: 15 years

Regarding the magnitude of potential impact, it was assumed that 33% of households have central AC and 8% of households have ASHP. Going forward, the expected annual installation of ASHP is assumed to evolve to a 50/50 distribution. The total technical potential in the residential sector is as follows:

|  |  |  |
| --- | --- | --- |
| **Market scale savings** | | |
| Electricity (GWh) | Annual | 49.8 |
| Lifetime | 747.3 |

### Recommendations

Although FDD technologies are mature and available in high-end equipment, non-embedded systems are still nascent with limited market availability[[20]](#footnote-21). The technology is not sufficiently mature today to support a broad incentive program in Connecticut, although rebate programs could provide bonuses or require embedded FDD to receive CAC or ASHP equipment incentives.

As an alternative, smart diagnostic tools are available and have been integrated into other quality maintenance utilities program to address the same system deficiencies and provide tools and expertise to properly identify equipment faults by field technicians. CT could provide training on the appropriate use of smart diagnostic tools and incentives for their purchase, similar to other programs, and leverage material from PNNL’s [STEP Campaign](https://www.pnnl.gov/projects/step-campaign).

As further research, we recommend a pilot study to inform how the CT market responds to fault detection and what additional costs may be incurred with training contractors on FDD as behavioral outcomes are unknown (e.g., do participants call for service or do nothing after the system detects a fault?).

In our research, we only found one non-embedded system, Sensi Predict – which has since discontinued its product. As the market develops, it would be useful to identify other manufacturers of FDD systems/sensors.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| PNNL, 2020 | Pacific Northwest National Laboratory, *Automated Fault Detection & Diagnostics: Residential Market Analysis,* 2020. Available at: <https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-30077.pdf> |
| ESource, 2022 | B. Dronkers, S. Patanaude, *3 innovative technologies that can benefit utilities and their customers,* 2022*.* Available at: <https://www.esource.com/blog/436221kjon/three-innovative-technologies-can-benefit-utilities-and-their-customers> |
| CASE, 2022 | Frontier Energy Inc., *Single Family HVAC Fault Detection and Diagnosis Research Report*, 2020, <https://title24stakeholders.com/wp-content/uploads/2020/08/Final-2022_T24_CASE_Report_SF-FDD_Future-Cycle.pdf> |
| Winkler, 2020 | J. Winkler (NREL) et al., *Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage,* 2020. Accessed at:  [*https://www.sciencedirect.com/science/article/am/pii/S030626192031045X*](https://www.sciencedirect.com/science/article/am/pii/S030626192031045X) |
| DOE, 2022 | J. Winkler (NREL) et al., *Barriers to Broader Utilization of Fault Detection Technologies for Improving Residential HVAC Equipment Efficiency,* 2022. Accessed at: <https://www.nrel.gov/docs/fy22osti/82024.pdf> |

## Cold climate commercial rooftop units

### Measure Summary

**Final Score:** 3.6

**Target Sector:** Commercial

**End-Use:** HVAC

**Decision Type:** Retrofit and new construction

**Applicability to Connecticut:** Good fit

**Market Readiness:** Some models are available

**Market Breadth/Applicability:** Commercial buildings already equipped with RTUs. Replacement on burnout, new construction

**Lifetime energy savings: ​**

* Electricity: -11,800 kWh (increase)
* Natural gas: 138.9 MMBtu

(*69%-70% of the baseline consumption of energy used for heating[[21]](#footnote-22)*)

**Incremental Costs:** $4,900

**Estimated useful life:** 15 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 3.6 | 5 | 2 | 5 | 4 | 2 | 3 |

### Measure Description

Replacement on burnout of gas-fired rooftop units (RTUs) with *cold climate capable[[22]](#footnote-23)* heat pump RTUs (ccHP RTUs) with auxiliary gas or electric heat.

*Cold climate capable* HP RTUs can operate at a temperature below 17oF (standard AHRI rating) while keeping a COP above 1; certain models show a COP of 2.15 at 17oF and 1.3 at -8oF. Their use can therefore help reduce reliance on fossil fuels for heating commercial buildings equipped with RTUs.

The heating capacity of HP RTUs, however, decreases as the outside temperature decreases. Hence, to avoid dimensioning the HP RTU based on the heating load, *cold climate capable* HP RTUs are often combined with some auxiliary electric or gas heat (dual-fuel RTUs).

### Applicability to Connecticut

**Score: 5**

Connecticut has a cold climate and could benefit from commercial size ccHP RTUs, and even standard ASHPs as the temperature is mild most of the year. Several types of commercial buildings in Connecticut rely on RTUs to meet their HVAC needs, for instance, the retail segment. The target market for the measure is therefore commercial buildings equipped with gas-fired RTUs.

### Track Record with Other Program Administrators

**Score: 2**

Our research did not yield any findings specifically for ccHP RTUs for large commercial buildings, although some smaller HPs designed for the residential sector can be used for small commercial buildings.

Regarding HP RTUs, several different programs in the US are promoting them.

### Technology Readiness

There are several RTU manufacturers offering an HP option:

* York
* Aaon
* Daikin
* Transom
* Lennox
* Trane
* Carrier

Some models also offer the dual-fuel option (HP and gas heat auxiliary)[[23]](#footnote-24). However, only a few of the above are claiming *cold climate capable* operations. Although many commercial heat pumps are already meeting the cc-ready specifications, the ccHP RTUs are still in the deployment stage, with independent field trials beginning.

### Market Availability

The major manufacturers now offer HP RTUs, and these manufacturers are active in Connecticut.

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 2**

**Lifetime Energy Savings Score: 3**

Simplified UCT B/C ratio: 0.58

Total cost: $5,000

Avoided cost: $2,158

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | -11,786 |
| Lifetime | -176,790 |
| Natural Gas (MMBtu) | Annual | 138.9 |
| Lifetime | 2082.9 |
| Greenhouse Gas (tCO2e) | Annual | 3.37 |
| Lifetime | 50.6 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Incremental Costs: 500 $/ton
* Savings (heating only): calculated using temperature bin analysis
* The auxiliary heating system is powered by natural gas (partial displacement)
* Balance temperature: 55F
* COP @ 20F = 2.25
* Capacity Derate Factor @ 20F = 0.48
* Aux Lockout temperature: 20F (based on discussion with Trane)
* Estimated Useful Life: 15 years
* Average RTU capacity: 10 tons
* Incentives of 75% of incremental costs

### Recommendations

As the economics are more promising for partial displacement measures (with a natural gas auxiliary system) than full-displacement measures (with an electric auxiliary system), we recommend promoting this option as a starter. If full displacement measures are to be integrated into a program, we recommend putting emphasis on GHG benefits as they are significant, which helps to convince potential buyers to make the switch in order to hit their decarbonisation targets. More aggressive performance curves already show better economics close to cost-effectiveness for these measures, meaning that the efficiency does not need to increase by a lot to also make the product more attractive from a financial standpoint.

Additional research is required to refine the savings and the cost estimates to quantify the benefits more accurately. The cost for most models is expected to decrease which would result in a lower payback period and hence a better cost-effectiveness.

With lower payback periods, standard and “cold climate capable” HP RTUs could be promoted by the utilities. This could be done as a 2-tiered measure, with Tier 1 for standard HP RTUs and Tier 2 for “cold climate capable” HP RTUs. Following Maine’s example, the measure could be prescriptive with an incentive expressed in terms of the RTUs’ heating capacity.

As energy savings were evaluated from load profiles estimated for an average commercial building in CT (NREL, 2024) and using conservative performance curves for HP RTUs, further research should focus on estimating energy savings specific to a broad range of building types. In addition, available results from field trials, if any, could be used to validate these refined energy savings estimates.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| NEEP, 2024 | Northeast Energy Efficiency Partnerships, *Emerging Heat Pump Technologies,* 2024. Available at: <https://neep.org/sites/default/files/media-files/neep_emerging_heat_pump_tech_brief_final.pdf> |
| NREL, 2024 | National Renewable Energy Laboratory, *Comstock Analysis Tool.* Available at: <https://www.esource.com/blog/436221kjon/three-innovative-technologies-can-benefit-utilities-and-their-customers> |
| Trane, 2024 | Trane, *Precedent® Rooftop Units*, 2024. Accessed at: <https://www.trane.com/commercial/north-america/us/en/products-systems/packaged-units-and-split-systems/rooftop-units/precedent.html> |
| Rheem, 2024 | Rheem*, Packaged Heat Pumps,* 2024. Accessed at:  <https://www.rheem.com/products/commercial/heating-and-cooling/package_hp/> |

## Aerosol sealant to reduce multi-unit dwelling envelope air leakage

### Measure Summary

**Final Score: 4.0**

**Target Sector:** Multi-Family Residential

**End-Use:** Envelope

**Decision Type:** Retrofit / New Construction

**Applicability to Connecticut:** Good fit

**Market Availability:** Potentially Limited – single supplier, network of authorized partners.

**Market Breadth/Applicability:** Existing Multi-Family building undergoing a major renovation.

**Lifetime energy savings: ​** Electric Space heating: 2,272,440 kWh

Natural Gas heating: 9,750 MMBtu

**Incremental Costs:** $75,000

**Estimated useful life:** 20 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 4.0 | 5 | 4 | 5 | 3 | 4 | 4 |

### Measure Description

An aerosol sealant is used to seal cavities in multi-family buildings that are hard to reach with conventional methods. Multi-family buildings have additional air leakage paths through shared walls and other cavities that are difficult to air seal with conventional techniques. The sealant application goes as follows:

* The building or unit must first be prepared by covering floors, windows, and openings such as return and supply vent openings. Although it is technically feasible to use this measure with furniture in place, costs would be significantly increased due to the additional effort required to protect belongings.
* The unit or building is then pressurized. Sealing stations spread an atomized sealant fog that follows air currents through air leaks and seals them.
* This technique can achieve an air exchange rate of 3ACH50 or even lower. Results and savings are project-specific.

The baseline used to assess the measure is an existing multi-family building with an air leakage rate to be determined using a blower door test[[24]](#footnote-25).

A room with a vacuum cleaner and a vacuum hose

Description automatically generated with medium confidence

While more relevant to multi-family buildings considering their unique construction characteristics increasing challenges in the reduction of air leakages, the measure is also applicable to other building types such as residential single-family or other commercial facilities.

### Applicability to Connecticut

**Score: 5**

Connecticut has multiple multi-family buildings; space heating energy loss through air leakage can represent 25% of the energy requirements. 19% of housing units in Connecticut are in multifamily buildings (more than 5 units), with a third of those in buildings with more than 50 units.

More superficially, the target market is existing multi-family buildings that are undergoing a major renovation as the measure requires that the targeted units be empty and undergo a pre and post air leakage measurement.

### Track Record with Other Program Administrators

**Score: 4**

The measure is documented in Minnesota and Illinois’s TRM. There is no program specifically targeting this measure. Incentives for the measure are available through other performance-based air sealing[[25]](#footnote-26).

**Minnesota TRM: MF Aerosol Air Sealant**

* New measure in TRM v 3.0 (effective Jan.1, 2020)
* Energy savings characterization updated in v 4.0 to modify EFLH values.

**Illinois TRM: 5.6.10 MF Whole Building Aerosol Sealing**

* New measure in 2023 (TRM v.11.0), reconducted in 2024 (TRM v.12.0)
* Based on MN TRM with savings adjusted to IL as a function of HDDs and CDDs

### Technology Readiness

The technology uses similar techniques as typical duct aerosol sealing project.

It is provided commercially and many case studies are available from one sealant manufacturer, AEROSEAL.

### Market Availability

The measure is available in Connecticut, although with a limited delivery network.   
AEROSEAL Manufacturer has a partner in Connecticut, Daniels Caulking, who performs the application of the AeroBarrier air sealant for Retrofit and New Construction.

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 4**

**Lifetime Energy Savings Score: 4**

Simplified UCT B/C ratio: 3.43

Total cost: $75,000

Avoided cost: $193,030

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | 34,088 |
| Lifetime | 681,750 |
| Natural Gas (MMBtu) | Annual | 341.2 |
| Lifetime | 6825 |
| Greenhouse Gas (tCO2e) | Annual | 28.9 |
| Lifetime | 577.6 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Space Heating baseline is 70% NG / 30% Elec heat
* Heating Savings:
  + Elec: 1.515 kWh/sq.ft.
  + NG: 0.0065 MMBtu/sq.ft
* Reducing from 7 ACH50 to 3 ACH50[[26]](#footnote-27),[[27]](#footnote-28),[[28]](#footnote-29),[[29]](#footnote-30)
* Cost: 1 $/ sq.ft. floor area[[30]](#footnote-31)
* Incentive amount: 75% of incremental costs
* Estimated useful life: 20 years
* Assumed building size: 75,000 square feet (70 units).

The measure is applicable irrespective of the fuel source used for space heating. Calculations for other fuels should be conducted separately as part of a detailed assessment[[31]](#footnote-32).

Market technical potential is considerable given that 55% of multifamily housing units are in buildings with more than 20 units (target market). However, considering the requirement for the measure (empty building, envelope retrofit, significant disturbances) it is not expected this measure will represent a high volume of activity in any given year. New Construction may see interest in this measure, although code requirements will significantly reduce potential savings.

### Recommendations

This measure should be promoted by the utilities for multi-family buildings undergoing a major retrofit and as another approach to achieve high air tightness in new construction.

A performance approach with an incentive proportional to the reduction in ACH (translated to cfm) could be used. If a specific incentive for this technology is not warranted, the measure benefits should be communicated to potential participants in a custom performance-based multifamily retrofit program.

The program should prohibit the use of hazardous chemicals. This can be ensured by requesting the use of UL Greenguard Gold certified air sealant[[32]](#footnote-33) or similar certification.

One manufacturer, AEROSEAL, who produces the AEROBARRIER, a UL Greenguard Gold certified air sealant, and has a local partner in CT has been identified. There may be other products available on the CT market – to be confirmed.

AEROSEAL’s AEROBARRIER is UL Greenguard Gold certified. A program should define a minimum level of Greenguard certification (or other) required as product eligibility criteria. The study did not research health-related requirements.

Any code minimum leakage requirements for major renovation of multi-family buildings would affect the baseline. A code analysis is required to confirm the baseline leakage rate.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| MNCEE, 2016 | Center for Energy and Environment, 2016. *Demonstrating the Effectiveness of an Aerosol Sealant to Reduce Multifamily Envelope Air Leakage,* 2016. Accessed at: <https://wcec.ucdavis.edu/wp-content/uploads/2018/07/card-cee-aerosol.pdf> |
| CLTC, 2023 | K. Graeber, A. Harper and P. Von Erberich (CLTC), *Pilot-Scale Evaluation of Integrated Building Control System for Commercial Buildings,* 2023*.* Available at: <https://www.energy.ca.gov/sites/default/files/2023-06/CEC-500-2023-039.pdf> [accessed February 12th, 2024] |
| ILSAG, 2022 | Illinois Stakeholder Advisory Group, 2023*. 2024 Illinois Statewide Technical Reference Manual for Energy Efficiency, Version 12.0. Volume 3: Residential Measures* Available at: <https://www.ilsag.info/wp-content/uploads/IL-TRM_Effective_010124_v12.0_Vol_3_Res_09222023_FINAL_clean.pdf> |
| NRDC, 2022 | V. Singla (NRDC) et al., *Insulation and Air Sealing in Low-Income Multifamily Energy Efficiency Programs: Current State, Challenges, and Opportunities to Use Safer Materials,* 2022. Accessed at: <https://healthybuilding.net/uploads/files/NRDC-HBN-EEFA%20Insulation%20Air%20Sealing%20Report%202022.pdf> |
|  | AEROSEAL, *Builder Adoption of Aerobarrier continues*. Web: <https://aeroseal.com/air-duct-sealing-blog/builder-adoption-of-aerobarrier-continues/> |

## Displacement Ventilation Technology

### Measure Summary

**Final Score: 3.8**

**Target Sector:** Commercial

**End-Use:** HVAC

**Decision Type:** Mostly New Construction and niche opportunity for Retrofit

**Applicability to Connecticut:** Good fit.

**Market Availability:** Limited availability for displacement ventilation due to professional knowledge and awareness.

**Market Breadth/Applicability:** Niche set of buildings or customers (schools, hospitals, offices)​

**Lifetime energy savings: ​**2,272,500 kWh, 9,750 MMBtu for a prototypical office building of 50,000 ft2. The measure can lead to whole-building energy use intensity savings of 16% with significant variability.

**Incremental Costs:** $56,250 - average incremental costs are 1 - 2 $/ft2

**Estimated useful life:** 30 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 3.8 | 5 | 3 | 5 | 2 | 5 | 4 |

### Measure Description

Displacement ventilation (DV) technology provides ventilation air directly to occupant breathing zones using low air velocity and moderate delivery temperatures. It is not designed to heat or cool the entire volume of the room, just the occupied or “breathing” zones at high ventilation effectiveness. Sensible loads from lighting are above the occupied zones and do not need to be considered.

The intended benefits of DV, however, are direct, efficient delivery of clean air to occupants and reductions in fan energy. Diagram of a room with a ventilator and a person standing

Description automatically generated

*Image Source: Price Industries*

The measure is particularly well suited to buildings and areas with high occupancy density (restaurants, schools, meeting rooms), high ventilation requirements (healthcare), or specific building characteristics such as high ceilings (significant volumes outside of the occupied zones) or high lighting power density.

The most prevalent application of displacement ventilation in North America is using raised floors for ventilation distribution, although this is mostly limited to new construction. Horizontal distribution, however, can be used in retrofit applications with floor-standing diffusers – either free-standing or wall-integrated. Horizontal flow distribution is the most common type of DV in Europe.

In addition to the increased energy efficiency provided by the improved ventilation efficiency, displacement ventilation also provides significant additional non-energy benefits through increased Indoor Air Quality improved acoustics, and potentially improved thermal comfort compared with typical mixing ventilation design.

### Applicability to Connecticut

**Score: 5**Connecticut has mild summer months that could benefit from the cooling properties of DV technology. Improved air distribution can reduce ventilation air heating requirements in colder climates due to very high ventilation effectiveness.

In regions with lower outdoor humidity, DV can increase the number of economizer hours that can be used to save air conditioning energy. Considering the temperature stratification resulting from DV, increased economizer hours can also be expected in high-humidity regions through an increase in return air temperature.

Price Industries, an HVAC supplier, identified regions in the Midwest and Northwest as having significant energy savings potential for DV.

### Track Record with Other Program Administrators

**Score: 3**

No evidence of dedicated programs supporting displacement ventilation has been identified in the US. However, the measure is currently eligible to various PAs’ custom energy efficiency programs. Also, programs are common in Europe.

### Technology Readiness

Technology is readily available in the U.S. and has been demonstrated in different applications. Adoption of distribution ventilation in Nordic countries is reported to be significant for several decades, estimated to be 25% for new office buildings in Scandinavia as early as 1989.

### Market Availability

A survey of Minnesota building professionals found that lack of exposure and knowledge is the key barrier to this technology. Most professionals report having used this measure (two-thirds) few report using the technology frequently (13%).

### Energy Savings and Cost-effectiveness

**Cost-Effectiveness Score: 5**

**Lifetime Energy Savings Score: 4**

Simplified UCT B/C ratio: 5.26

Total cost: $75,000

Avoided cost: $295,935

|  |  |  |
| --- | --- | --- |
| **Project scale savings** | | |
| Electricity (kWh) | Annual | 11,700 |
| Lifetime | 351,000 |
| Natural Gas (MMBtu) | Annual | 616 |
| Lifetime | 18,480 |
| Greenhouse Gas (tCO2e) | Annual | 35.8 |
| Lifetime | 1075 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Estimated useful life: 30 years, same as ductwork.
* Savings:
* Electric: 5% EUI savings annually
* Natural Gas: 22% EUI savings annually
* Electric EUI:4.68 kWh/ft2/yr
* Natural Gas EUI: 56 kBTU/ft2/yr
* Incremental costs: $1 – 2/square foot more than traditional VAV systems
* Incentive amount: 75% of incremental costs
* Prototype building size: 50,000 ft2

### Recommendations

Displacement ventilation has been found to provide air quality and comfort benefits. The findings on savings due to efficiency gains have been demonstrated although with significant variability. The key barrier to adoption: increased awareness and market penetration **should be addressed through published use cases and communications to professionals and building owners**, with notable highlights on building owner satisfaction with the technology. Considering the variability of the savings, this measure is best promoted through a **custom program**.

In addition, there was significant variability in savings from the MN CARD study, which indicates that there may be savings impacts based on operation and design. Follow-up studies to develop design and operational guides would help deploy this measure in a cost-efficient way.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| CARD, 2016 | Sustainable Engineering Group LLC, prepared for the Minnesota Department of Commerce. *The Energy Conservation Potential of Displacement Ventilation Technology in Minnesota Climate Conditions – Conservation Applied Research & Development (CARD)*, 2016. Available at: <https://www.cards.commerce.state.mn.us/documents/%7B3FCD4351-2555-4F64-A813-3DBA3479C769%7D/download?documentClass=ENERGY_DATA_AND_REPORTS&contentSequence=0> |
| PRICE, 2016 | Price Industries, *Engineering Guide Displacement Ventilation*, 2016*.* Available at: <https://www.priceindustries.com/content/uploads/assets/literature/engineering-guides/displacement-ventilation-engineering-guide.pdf> |
| HANS, 2020 | B. Hans et al. *Displacement Ventilation Provides Cornerstone of Hospital Design*, 2020*.* ASHRAE Journal, Vol. 62, no. 10, Oct. 2020. Available at: <https://www.ashrae.org/technical-resources/ashrae-journal/featured-articles/displacement-ventilation-provides-cornerstone-of-hospital-design> |

## Plug in space heating heat pumps (micro heat pumps)

### Measure Summary

**Final Score:** 2.50

**Target Sector:** Multifamily Residential[[33]](#footnote-34),

**End-Use:** HVAC

**Decision Type:** Retrofit / Lost Opportunity

**Applicability to Connecticut:** Good fit

**Market Readiness:** Limited. Expected to increase with new models and interest from other manufacturers.

**Market Breadth/Applicability:** Multi-family dwellings,

**Lifetime energy savings: ​**214 kWh (blended baseline)

8,560 kWh (electric resistance baseline)

21.7 MMBtu (gas furnace baseline)[[34]](#footnote-35)

**Incremental Costs:** 600 $ / unit[[35]](#footnote-36)

**Estimated useful life:** 10 years​

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Final Score** | **Applicability** | **Track Record** | **Time Horizon to Market** | **Market Breadth** | **Cost-Effectiveness** | **Lifetime Savings** |
| 2.50 | 5 | 1 | 3 | 3 | 3 | 1 |

### Measure Description

A white square object with a black background

Description automatically generatedMicro heat pumps offer **space heating ability without the need for a contractor** or permit – the device **operates on a shared 15A 120V circuit**, comes factory-charged, and is easy to install.   
Note: the technology has multiple form factors, such as portable, saddle, window[[36]](#footnote-37).

This technology is most appropriate for units with in-suite heating systems. There is potential to replace small gas-fired furnaces or inefficient electric resistance space heaters commonly used in multi-family.

**This measure is emerging and currently undergoing testing and data collection** for potential by CalMTA, NEEA, NYPA, and Cal ETP.

Actual performance at this stage is not documented, but a recent NEEP Report (NEEP2024) expects efficiencies to be slightly less than cold climate mini-splits system.

Like other plug-in devices, the persistence of energy savings will need to be monitored and assessed since the equipment can be removed from the buildings.

### Applicability to Connecticut

**Score: 5**

Connecticut has a healthy MF market that could benefit from heat pumps that eliminate cost barriers associated with design, installation, and permitting required for systems requiring 240V services .

There are some concerns with operation under 40 degrees which need to be studied further. Cold climate versions will likely become available soon and NEEA has a study planned to review performance. Similarly, NYPA is conducting a monitoring pilot of cold-climate micro heat pumps. Results for the NYPA pilot are not yet available but should be reviewed once made available.

### Track Record with Other Program Administrators

**Score: 1**

There is no program in the US offering this measure as of now. However, [NYPA in partnership with NYC Housing Authority announced](https://www.nypa.gov/news/press-releases/2023/20230920-heat) the installation of 72 cold-climate packaged window heat pump units for the 2023/24 winter season. This is an initial monitoring pilot which will be followed by a more widespread installation of 30,000 units in the coming years. (NYSERDA2023).[[37]](#footnote-38)

### Technology Readiness

**Units are available** on the market. However, there is a **limited number of manufacturers** active in this technology, and models available are **targeting milder climates** than Connecticut. New models designed for cold-climate applications are **expected to become available soon**.

### Time Horizon to Market

**Score: 3**

Mild climate units are currently available from several manufacturers. Micro heat pumps efficient at lower temperatures still need to be tested for heating capability below 40°F. At least two manufacturers are committed to cold-climate capable micro heat pumps ([Midea](https://www.midea.com/us) and [Gradient](https://www.gradientcomfort.com/)) and indicate on their websites broader availability of their product in 2024.

Market awareness is quite low, and customers are unaware of the benefits. There are no ENERGY STAR labels nor performance standards for these products yet to help market and communicate benefits to customers, although NEEP reports ENERGY STAR and the Consortium for Energy Efficiency (CEE) are considering developing specifications for this technology (NEEP2024).

### Energy Savings and Cost-effectiveness

Considering the existing opportunities for micro heat pumps, Cost-effectiveness calculations are presented for lost opportunity – when replacing a window air conditioning unit, and for a retrofit application.

**Use case: Lost Opportunity – blended baseline**

**Cost-Effectiveness Score: 3**

**Lifetime Energy Savings Score: 1**

Simplified UCT B/C ratio: 1.1

Total cost: $300

Avoided cost: $334

|  |  |  |
| --- | --- | --- |
| **Project scale savings – blended electric resistance/gas baseline** | | |
| Electricity (kWh) | Annual | 21.4 |
| Lifetime | 214 |
| Natural Gas (MMBtu) | Annual | 2.2 |
| Lifetime | 22 |
| Greenhouse Gas (tCO2e) | Annual | 0.12 |
| Lifetime | 1.22 |

|  |  |  |
| --- | --- | --- |
| **Project scale savings – electric resistance baseline** | | |
| Electricity (kWh) | Annual | 856 |
| Lifetime | 8560 |
| Natural Gas (MMBtu) | Annual | 0 |
| Lifetime | 0 |
| Greenhouse Gas (tCO2e) | Annual | 0.3 |
| Lifetime | 2.9 |

|  |  |  |
| --- | --- | --- |
| **Project scale savings – natural gas furnace baseline** | | |
| Electricity (kWh) | Annual | -336.3 |
| Lifetime | -3363 |
| Natural Gas (MMBtu) | Annual | 3.1 |
| Lifetime | 31 |
| Greenhouse Gas (tCO2e) | Annual | 0.05 |
| Lifetime | 0.5 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Incremental Costs $400 - $800 for market available units (mild climate – operating to 40 F) – baseline condition: window AC unit ($500)  
   Cold climate unit costs are not available yet – The estimated cost for Midea is $3,000, for Gradient $2,800.
* Savings in a CalMTA study estimated average energy savings per unit of 856[[38]](#footnote-39) kWh (replacing ER) and 3.1 MMBtu (displacing gas furnace).
* Estimated Useful Life unknown but assumed to be the same as portable AC equipment (10 years).
* Baseline assumes cooling already used – no increased consumption due to new cooling load.
* Space Heating baseline is 70% NG / 30% Elec heat. The measure is suitable for any heating fuel source but considering the low penetration of in-suite oil furnaces, delivered fuel savings have not been assessed.
* Incentives of 50% of incremental costs.

Measure cost-effectiveness is challenging considering the benefits and avoided costs. Benefit-cost ratios are more favorable for the electric baseline (estimated at 4.3) versus a natural gas furnace baseline (deemed not cost-effective due to increased electric consumption).   
  
**Use-case: Retrofit – electric resistance baseline**

**Cost-Effectiveness Score: 3**

**Lifetime Energy Savings Score: 1**

Simplified UCT B/C ratio: 2.4

Total cost: $550

Avoided cost: $1,294

|  |  |  |
| --- | --- | --- |
| **Project scale savings – electric resistance baseline** | | |
| Electricity (kWh) | Annual | 856 |
| Lifetime | 8560 |
| Natural Gas (MMBtu) | Annual | 0 |
| Lifetime | 0 |
| Greenhouse Gas (tCO2e) | Annual | 0.3 |
| Lifetime | 2.9 |

The following assumptions have been used to perform the cost-effectiveness analysis:

* Full Costs $900 - $1,300 for market available units (mild climate – operating to 40 F) –Cold climate unit costs are not available yet – Estimates for Midea $3,000, Gradient $2,800.
* Savings in a CalMTA study estimated an average energy savings per unit of 856 kWh (replacing ER) and 3.1 MMBtu (displacing gas furnace).
* Estimated Useful Life unknown but assumed to be the same as portable AC equipment (10 years).
* Baseline assumes cooling already used – no increased consumption due to new cooling load.
* Space Heating baseline is 70% NG / 30% Elec heat.
* Incentives of 50% of incremental costs.

### Recommendations

In the short term, we recommend considering moderate **incentives for mild-climate heat pump products** paired with a robust **education campaign** to displace windows/portable AC units and portable room heaters.

Once products suitable for cold climate conditions are available on the market (expected for 2024), we recommend launching a pilot to confirm costs, savings, useability and market constraints, and cost-effectiveness – targeting electric resistance heating.

Education will be key to program design to differentiate this higher-cost model to comparable window AC units and room heaters. The appropriate delivery channel should be assessed once manufacturers' distribution channels for cold-climate capable units are known, and could include point-of-sale rebates (if products are available at common retailers) or promotion to building owners/property managers.

We also recommend furthering the research by monitoring the completion of studies from [NEEA](https://neea.org/product-council-documents/micro-heat-pump-field-study-results-product-council), [CalMTA](https://calmta.org/window-portable-heat-pumps/), ETCC ([project ET23SWE0034](https://www.etcc-ca.com/reports/emerging-micro-heat-pumps-testing-and-heating-performance-metrics)), and NYPA/NYC Housing to confirm savings for products suitable for cold climate, estimated in 2024/2025. In addition, cold-climate implications similar to considerations for ASHPs and DHPs are to keep an eye on.

### Sources

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| NEEA, 2023 | Northwest Energy Efficiency Alliance (NEEA)*,* *Micro HP Field Study – Data Analysis Slides* 2023. Available at: <https://neea.org/img/documents/Micro-Heat-Pump-Field-Study-Presentation-Product-Council.pdf> |
| CalMTA, 2024 | California Market Transformation Advisory Board (CalMTA), *Portable/Window Heat Pumps Market Transformation Advancement Plan,* 2024*.* Available at: <https://calmta.org/wp-content/uploads/sites/263/MTI-Advancement-Plan-Portable-Heat-Pumps.pdf> |
| VEIC2023 | Vermont Energy Investment Corporation, *ET22SWE0035 Market and Technical Evaluation of Multifamily In-Unit Heat Pumps, Final Report.* 2023 Accessed at:<https://www.veic.org/Media/Default/Reports/ET22SWE0035%20-%20Multifamily%20In-Unit%20Heat%20Pumps_Final%20Report.pdf> |
| NEEP2024 | Northeast Energy Efficiency Partnership (NEEP), *Emerging Heat Pump Technologies*, 2024. Available at: <https://neep.org/sites/default/files/media-files/neep_emerging_heat_pump_tech_brief_final_sm.pdf> |
| NYSERDA2023 | New York State Energy Research and Development Authority (NYSERDA). *Window Heat Pump Unit installed in Public Housing as Part of Clean Heat Challenge*. 2024. Available at: <https://www.nyserda.ny.gov/About/Newsroom/2023-Announcements/2023-09-20-Governor-Hochul-Announces-Installation-Of-Window-Heat-Pumps-For-New-York-City> |

# Emerging Program Concepts

The North American landscape with regard to energy efficiency and conservation has considerably changed in the last 5 years with significant impacts on utility’s programs and initiatives. Improved building energy codes and equipment energy efficiency standards have moved prior energy efficiency opportunities to the baseline characteristics of technologies, climate policies are having profound impacts on energy systems and consumption patterns, new communicating technologies are installed in homes and buildings, multiple stakeholders are intervening in order to support GHG reductions, affordability, and equity, corporations are integrating environmental, social and governance metrics including Net Zero commitments, and Demand-Side Management initiatives are also being considered as tools to support broader goals, including economic development and customer retention.

These new issues and drivers for energy efficiency are presented in the following table – and their relevance to the residential or commercial and industrial sectors is identified.

**New Issues and Drivers for Demand-Side Management**

|  |  |  |
| --- | --- | --- |
|  | Residential | C&I |
| EE goals steady or increasing | P | P |
| Post-lighting era | P | P |
| Goals/policies for DSM broadening | P | P |
| Equity | P | P |
| Climate | P | P |
| Affordability | P |  |
| Economic development |  | P |
| Customer retention |  | P |
| Electrification | P | P |
| Greater focus on load flexibility/ demand | P | P |
| More players/ crowded program market | P |  |
| Smart homes & devices | P |  |
| Consumer à prosumer | P |  |
| Corporate ESG, including Net Zero commitments | P | P |

The study also conducted a qualitative assessment of Energize CT portfolio to identify emerging program design trends addressing these new issues. The study presents 4 new program trends addressing several of these issues.

## Smart Building Electrification (residential and commercial)

Building Electrification is one of the key pillars to achieving Connecticut’s 2050 greenhouse gas emission reduction targets – and electric heat pumps and heat pump water heaters provide an efficient solution to achieve this goal. These technologies can be paired with other approaches to mitigate their impacts on the electricity grid.

Smart Building Electrification can be defined as including three components:

* Combining building electrification with demand-reduction strategies (energy efficiency and demand management)

New York Public Service Commission has recently introduced a [Smart Building Electrification Earning Adjustment Mechanism](https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BC03E9087-0000-C0B4-9AD2-4AA7A90C31A0%7D) for the 2023-2025 Plan cycle. This new EAM includes the following measure categories: improvement to the building envelope, ground source heat pumps, waster heat recovery, and advanced controls and applies to both electric and natural gas utilities.   
Bringing those categories together under the Smart Building Electrification EAM underscores the role of increased building shell performance in building decarbonization.

NY [PUC’s decision](https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7bE0F27489-0000-CF14-9DBB-3BE183AC4793%7d) also introduced a new framework to assess DSM priorities – and only initiatives supporting the Smart Building Electrification will be considered as strategic.

* Preference to building electrification technologies efficient at peak
* Consideration for hybrid (multi-fuel) heating systems depending on future peak constraints and grid expansion requirements – although this component is specific to colder climates than Connecticut – and not recommended considering the availability of technologies with lower peak impacts than auxiliary heating resistance strips.

Program strategies supporting Smart Building Electrification will go beyond pure technology-based rebates, integrate into existing energy efficiency programs, and will be able to provide tailored solutions to individual buildings’ needs. Different Program Administrators have implemented the following approaches to support Smart Building Electrification.

**Combine Electrification incentives with other energy efficiency programs**

This approach can take different forms:

Require building shell improvements in combination with space and water heating electrification technologies. This is mostly seen in income-qualified programs, where all costs are covered by the program. [Massachusetts Mass Save program](https://www.masssave.com/residential/rebates-and-incentives/heating-and-cooling/heat-pumps/air-source-heat-pumps)[[39]](#footnote-40) also requires homes to be sufficiently weatherized to access higher incentives through the Whole-home heat pump program

Encourage building shell improvements through increased incentives or targeted marketing. In the residential sector, this is seen through bonus incentives when electrification is done in conjunction with weatherization or increased insulation. For its Partial Electrification incentive, Mass Save offers a $500 bonus for homes sufficiently weatherized. Some programs limit their approach to a strong marketing campaign to convince participants to also undertake building shell improvements in addition to the electrification project.

Combining energy efficiency and electrification incentives can also reduce the required heat pump capacity and lead to lower costs for participants.

**Mitigate winter peak impacts through DR/DER and dual-fuel systems**

The building electrification project is a unique opportunity to implement other solutions to reduce winter peak impacts due to the new electric load.

DR-enabled control devices (connected thermostats and water heater controllers, BAS/BMS integration) can be promoted through the electrification program (or specified as part of the program criteria). Electrified buildings can be strongly encouraged to enroll in DR programs.

Other technologies pairing heat pumps with thermal storage can also be used to mitigate peak impacts.

Hybrid (dual-fuel) heating systems can also provide up to 80% of the emission reduction benefits while avoiding their peak impact on the grid. These systems can provide 80% of the emission reduction benefits while avoiding the peak impacts generated by the new heating load.

Program Snapshot: Hydro-Québec Efficient Homes Program

Hydro-Quebec is the main electric utility in the province of Quebec, providing electric distribution services to the vast majority of homes and businesses in the province. Hydro-Québec’s [*LogisVert Efficient Homes Program*](https://www.hydroquebec.com/residential/energy-wise/financial-assistance/logisvert.html) provides a good example of several components of a Residential Smart Building Electrification program. The program notably includes the following:

* Participants can access a 5% bonus incentive for multiple measures in a project. While this is not specific to electrification, most program participants install a heat pump, thus providing an opportunity to engage participants on other measures
* Bundled measure: air source heat pump and weatherization. The program does not have a specific incentive for weatherization but will provide a 17% incentive increase when combining a heat pump installation with professional weatherization
* Differentiated incentives for performance during peak: Incentives for ground-source heat pumps are 625% that of cold-climate air-source heat pumps. The program also has a generous incentive for thermal energy storage paired with an air-source heat pump
* Participants can access a 25% incentive bonus if they enroll in the utility automated demand-response program

The study has not identified any specific Commercial Smart Building Electrification programs, although several utilities have account managers and DSM specialists promoting energy efficiency in conjunction with electrification and demand response initiatives. The approaches and concepts presented here can be applied to all building sectors.

**Recommendations:**

* Consider increased building shell incentives when participants install a heat pump
* Consider increased incentives for a communicating thermostat when installing a central air source heat pump or a ground source heat pump
* Increase the incentive for ground source heat pump to reflect increased system benefits and limited peak impact
* Promote utility’s DR program – consider a DR enrollment bonus for new participants installing heat pumps with a connected thermostat

**Sources**

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| ACEEE2022 | Cohn C, and N.W. Esram. 2022. *Building Electrification: Programs and Best Practices.*American Council for an Energy-Efficiency Economy. Accessed at: aceee.org/researchreport/b2201 |
| ACEEE2021a | Specian, M., C. Cohn, and D. York. 2021. *Demand-Side Solutions to Winter Peaks and Constraints*. Washington, DC: ACEEE. [www.aceee.org/research-report/u2101](http://www.aceee.org/research-report/u2101) . |
| ACEEE2021b | Amann, J., R. Srivastava, and N. Henner. 2021. Pathways for Deep Energy Use Reductions and Decarbonization in Homes. Washington, DC: American Council for an Energy-Efficient Economy.  [www.aceee.org/research-report/b2103](http://www.aceee.org/research-report/b2103) |
| ACEEE2024 | Nadel, Steven, and Lyla Fadali. 2024. *Options for Decarbonizing Space Heating in Cold Climates*. Washington, DC: ACEEE. [www.aceee.org/research-report/b2404](http://www.aceee.org/research-report/b2404) |
| ELEC2022 | Electrifying Canada 2022. *Electrifying Heating in Commercial and Institutional Buildings.* Accessed at: https:// [www.iisd.org/system/files/2022-05/electrifying-heating-commercial-institutionalbuildings-en.pdf](http://www.iisd.org/system/files/2022-05/electrifying-heating-commercial-institutionalbuildings-en.pdf) |
| BOMA2023 | Boma International 2024. *Electrification in Commercial Buildings.* Accessed at: <https://www.bomaconvention.org/BOMA2023/custom/BOMA%20Electrification%20Study%20Draft%202023-06-22.pdf> |

## Residential Staged Retrofit

Multiple studies have underscored the need to retrofit a considerable proportion of existing buildings in order to reach 2050 GHG emission reduction goals. According to The Advanced Building Construction (ABC) Collaborative, close to 85% of residential single-family homes in Connecticut need whole-building retrofit – including envelope improvements - to meet those goals. This requires a significant increase in the rate at which residential homes in Connecticut undergo energy efficiency improvements, and to achieve deeper savings for each home. Connecticut also has a legislated goal that 80% of housing units are weatherized[[40]](#footnote-41) by 2030 – and increases in the pace and depth of residential retrofit would support progress toward that goal.[[41]](#footnote-42)

There are, however, several well-documented barriers to achieving deeper energy retrofits, notably:

* Lack of Awareness and Energy Literacy: homeowners lack knowledge and are uncertain about energy efficiency benefits, and lack knowledge about prioritizing and planning retrofits
* Difficulty managing projects: there are significant complexity and disruption involved in the process
* Difficulty accessing capital: Energy efficiency retrofits represent high upfront costs; homeowners have limited access to capital and competing capital priorities

Utility programs can address several of these barriers, and develop solutions to support homeowners along their deep energy retrofit journey.   
  
One such emerging approach is for program administrator to maintain a long-term relationship with homeowners through an Energy Coach or concierge service[[42]](#footnote-43) developing a personalized roadmap to support homeowners on their renovation journey over an extended period (10-20 years if needed). The roadmap is a home-improvement plan that considers the homeowners’ needs and circumstances and avoids obstructing future energy efficiency solutions due to a lack of foresight.

Multiple stakeholder consultations in different jurisdictions have confirmed the preference for many homeowners to stage retrofits over time. This approach would require a central database to track and monitor the progress of participants over time.

**Recommendation:**

Assess the opportunity of expanding Home Energy Solutions to include access to an Energy Coach who can develop a personalized roadmap to deep retrofit. Additional support can be included related to project management and additional consulting services.

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| ABC2024 | Webster et al. 2024. Accelerating Residential Building Decarbonization: Market Guidance to Scale ZeroCarbon-Aligned Buildings. Accessed at: <https://advancedbuildingconstruction.org/wp-content/uploads/2024/03/ABC_Industry-Guidance-Report_2023_v6.pdf> |
| ACEEE2021 | Amann et al. 2021. Pathways for Deep Energy Use Reductions andDecarbonization in Homes. Washington, DC: American Council for an Energy-Efficient Economy. Accessed at: aceee.org/research-report/b2103 |
| GUIDEHOUSE2024 | Buccitelli et al. Guidehouse. *CT R2221 Concierge Programs – Final Report.* 2024. |

## Grid Interactive Efficient Buildings

Buildings across North America are increasingly integrating a multitude of smart technologies and various Distributed Energy Resources, partly in response to utility programs, partly on their own merits and services provided to building owners and managers. At the same time, grid operation is increasingly more complex due to the increased integration of variable energy grid resources, as well as increased customer-sited generation and/or storage.  
  
Utilities have leveraged customers' assets to reduce energy consumption through energy efficiency programs, and increasingly to reduce peak demand at specific periods.

The DOE, in its National Roadmap for Grid-Interactive Efficient Buildings (GEB), defines a GEB as “an energy-efficient building with smart technologies characterized by the active use of DERs to optimize energy use for grid services, occupant needs and preferences, climate mitigation, and cost reductions in a continuous and integrated way.” The figure below presents the key GEB characteristics according to the DOE.

A diagram of a smart home

Description automatically generated The report further defines the services GEBs can provide to the electricity system: efficiency and demand flexibility (reduce, shed, shift, modulate, or generate electricity). The DOE estimates that services provided by GEBs to the grid could represent between $8 billion and $18 billion annually by 2030. Although there are still technical barriers to achieving the full value of those benefits, and no specific GEB Program is currently in market, several DSM/DR program types are promoting aspects of GEBs.

The ACEEE presents different program types that can leverage different value streams of GEBs, on a scale leading to an integrated GEB program capable of fully utilizing buildings as grid assets. Figure 4 presents the evolution path towards a full-fledged GEB program.

A diagram of energy efficiency

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Figure 4: Scaling up to GEB Programs   
Source: ACEE2019

The DOE and other actors are actively engaged in addressing some of the technical challenges around interoperability of systems and cybersecurity challenges, but this does not prevent utilities from preparing the stage for future integrated GEB programs. In its roadmap, a specific recommendation the DOE puts forward a specific recommendation to “Improve and Expand Innovative Customer Demand Flexibility Program Offerings” directly targeted to utilities and program administrators.

**Recommendation:**

Based on the DOE’s Pillar 2, Recommendation 1, Energize CT should review its energy efficiency and DR programs to identify opportunities to evolve towards an integrated GEB program when technology has sufficiently matured.

|  |  |
| --- | --- |
| **Short reference** | **Long reference** |
| SEPA2022 | Smart Electric Power Alliance. *Accelerating Coordinated Utility Programs for Grid-Interactive Efficient Buildings,* 2022. Accessed at: <https://sepapower.org/resource/accelerating-coordinated-utility-programs-for-grid-interactive-efficient-buildings-practitioners-perspectives/> |
| ACEEE2019 | Perry et al. Grid-Interactive Efficiency Building Utility Programs: State of the Market. Washington, DC: American Council for an Energy-Efficient Economy. Accessed at: <https://www.aceee.org/sites/default/files/pdfs/gebs-103019.pdf> |
| DOE2021 | U.S. Department of Energy. *A National Roadmap for Grid-Interactive Efficient Buildings,* 2021. Accessed at: <https://gebroadmap.lbl.gov/A%20National%20Roadmap%20for%20GEBs%20-%20Final.pdf> |

APPENDIX

# Appendix A

## Global Input

The table below presents the different assumptions we used for the high-level cost-effectiveness analysis of the measures included in the deep dive. Although the AESC 2024 study has been released and constitutes the most recent data source in the State, we recommend using the same assumptions as the 2022-2024 C&LM Plan for the economic inputs. However, since the 2022-2024 C&LM Plan does not provide any assumptions related to avoided GHG emissions, we recommend using the AESC 2024 study.

Table 0‑1: Global Input for Cost-effectiveness Analysis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Component** | **Item** | **Units** | **Value** | **Source** |
| Avoided Energy Costs | Electricity – Levelized 15 years | $/kWh (2021) | 0.111 | [2022-2024 Conservation & Load Management Plan](https://portal.ct.gov/-/media/DEEP/energy/ConserLoadMgmt/Final-2022-2024-Plan-to-EEB-1112021.pdf) Includes energy, energy DRIPE, and Non-embedded emissions |
| Natural Gas – Levelized 15 years | $/MMBtu (2021) | 7.65 | [2022-2024 Conservation & Load Management Plan](https://portal.ct.gov/-/media/DEEP/energy/ConserLoadMgmt/Final-2022-2024-Plan-to-EEB-1112021.pdf) Includes natural gas and DRIPE |
| Fossil Emission | $/ton CO2 (2021) | 125 | [2022-2024 Conservation & Load Management Plan](https://portal.ct.gov/-/media/DEEP/energy/ConserLoadMgmt/Final-2022-2024-Plan-to-EEB-1112021.pdf) |
| Energy Retail Rate[[43]](#footnote-44) | Electricity – residential | $/kWh (2021) | 0.159 | <https://energizect.com/rate-board/compare-energy-supplier-rates?customerClass=1201&monthlyUsage=750&planTypeEdc=1191> |
| Electricity – commercial | $/kWh (2021) | 0.160 | <https://energizect.com/rate-board/compare-energy-supplier-rates?customerClass=1201&monthlyUsage=750&planTypeEdc=1191> |
| Natural gas | $/cf (2021) | 0.015 | <https://portal.ct.gov/DEEP/Energy/Energy-Price-and-Supply-Information> |
| Discount Rate | Real Discount Rate | % | 1 | [2022-2024 Conservation & Load Management Plan](https://portal.ct.gov/-/media/DEEP/energy/ConserLoadMgmt/Final-2022-2024-Plan-to-EEB-1112021.pdf) Based on a 3% nominal discount rate and 2% inflation. |
| Emission Factor | Natural Gas | Ton CO2e/MMBtu | 0.053 | <https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references> |
|  | Electricity | Ton CO2e/MWh | See table below – varies by year | [Avoided Energy Supply Components in New England: 2024 Report](https://www.synapse-energy.com/sites/default/files/AESC%202024.pdf) |

Table 0‑2: Electricity Marginal CO2 Emission Rate from 2025 to 2050

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Marginal CO2 Emissions Rate | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| Electricity (Ton CO2e/MWh) | 0.332 | 0.345 | 0.331 | 0.225 | 0.176 | 0.162 |

# Appendix B – Detailed Spreadsheet





**“No Disclaimers” Policy**

This report was prepared by Dunsky Energy + Climate Advisors, an independent firm focused on the clean energy transition and committed to quality, integrity and unbiased analysis and counsel. Our findings and recommendations are based on the best information available at the time the work was conducted as well as our experts' professional judgment.   
**Dunsky is proud to stand by our work.**

1. The scoring process conducted in Stage 2 and 3 is not meant to identify the measures with the highest potential for CT, but as a decision aid to inform the selection of technologies warranting a more in-depth analysis based on their future potential. The disposition process and scoring conducted in this study should not be considered as an alternative to an Energy Efficiency Potential Study providing a broader view and in-depth analysis of the market potential of multiple measures. [↑](#footnote-ref-2)
2. The scoring process distinguishes between project-level savings (Lifetime Energy Savings) and potential CT-wide volume (Market Breadth and Applicability). This approach allows to assign weight to the metric of interest. Where possible, the study has provided insights into the market-level potential of the measure. [↑](#footnote-ref-3)
3. For the study, only electricity and natural gas energy savings were estimated, although several measures are also applicable to delivered fuels. [↑](#footnote-ref-4)
4. Stage 2 of the disposition process included a more refined analysis to remove measures already promoted in Connecticut, or measures that were essentially the same but with different names. [↑](#footnote-ref-5)
5. This metric provides a refinement of the Stage 1 process – and reflects additional data collected as part of Stage 2 and 3. This metric is critical to identify measures not prime for deployment in CT. [↑](#footnote-ref-6)
6. The scoring process distinguishes between project-level savings (Lifetime Energy Savings) and potential CT-wide volume (Market Breadth and Applicability). This approach allows to assign weight to the metric of interest. Where possible, the study has provided insights into the market-level potential of the measure – although a detailed market-level assessment was outside the scope of this study. [↑](#footnote-ref-7)
7. Total energy savings were converted to ekWh only for scoring purposes. Lifetime energy savings are reported in kWh for electricity and MMBtu for natural gas. [↑](#footnote-ref-8)
8. The extent to which contractors in CT have the required skill sets is unknown, but contractors providing Duct Testing and Balancing services are prime candidates to provide these new services. Utilities can provide training support to the industry to achieve the required competency level and potential certification for this measure. [↑](#footnote-ref-9)
9. Duct sealing is one of the potential remediation steps already supported in CT and other states. Contractors providing duct sealing are focused on one strategy and may not have the skills to do a full system analysis. Additional tools and training will be required. [↑](#footnote-ref-10)
10. Based on Massachusetts Baseline Load Shape Study. Navigant, 2018 – available online at: https://ma-eeac.org/wp-content/uploads/RES-1-FINAL-Comprehensive-Report-2018-07-27.pdf [↑](#footnote-ref-11)
11. Adapted from Massachusetts Technical Reference Manual annual heating load values. – available online at: https://www.masssavedata.com/TRL/Technical%20Reference%20Manual%202023%20Plan%20-%20010323.pdf [↑](#footnote-ref-12)
12. Based on professional judgement considering the range and type of projects involved. [↑](#footnote-ref-13)
13. DOE2018 – Residential HVAC Installation Practices: A Review of Research Findings [↑](#footnote-ref-14)
14. The purpose of the system analysis is to identify if the existing system is adequate to handle a full displacement heat pump. If the system is too small, the heat pump replacement project will likely run into problems. The frequency of undersized duct systems in full displacement heat pump projects is not known but doing the system performance analysis ahead of the system replacement project will identify and remediate problems ahead of time. [↑](#footnote-ref-15)
15. The assumptions used for the Energy Savings and Cost-effectiveness calculations represent the most efficient technology available and is based on a real-life data. Most IHPs documented by the IEA achieve COPs higher than 4 and should be considered as cost-effective for utilities and participants. [↑](#footnote-ref-16)
16. Market shares to be updated once the DNV Group study, *C2201 – Commercial Baseline and Database,* is published in 2024 with updated CT market characterisation data. [↑](#footnote-ref-17)
17. Although add-ons FDD are technically suitable and relevant for any existing AC or ASHP – irrespective of vintage, cost-effectiveness considerations may warrant limitation of the measure to system installed before a certain period (to be assessed). [↑](#footnote-ref-18)
18. Eversource CT states they launched a monitoring-based commissioning demonstration to identify and analyze HVAC energy strategies leveraging FDD systems in 2023. The results of the demonstration (expected to be available in late 2025), which will be compiled after installations are complete, will assess the market potential, implementation challenges, and savings impact of using FDD technologies. [↑](#footnote-ref-19)
19. California is now required FDD enabled economizer controllers on RTUs and Air Handling Units. Although not targeted at the same technologies, this may lead to further advances for FDD embedded technologies in the future. [↑](#footnote-ref-20)
20. The only non-embedded systems identified was recently discontinued by its manufacturer. As of May 2024, no non-embedded system for residential applications has been identified. The utilities could conduct a technology watch to identify new market actors which may introduce new FDD add-on products. [↑](#footnote-ref-21)
21. Assuming 81% thermal efficiency for baseline [↑](#footnote-ref-22)
22. The *cold climate* attribute is for residential HPs that operate at 5oF with a COP>=1.75. There is no *cold climate* for commercial heat pumps serving larger buildings, hence the term *cold climate capable*. Some ccHPs designed for residential have been reported to be used in the commercial space for smaller buildings. [↑](#footnote-ref-23)
23. NEEP Emerging Heat Pump Technologies, Feb. 2024. [↑](#footnote-ref-24)
24. Current market availability of large multifamily whole building air leakage testing in Connecticut has not been assessed during this study. [↑](#footnote-ref-25)
25. Actual adoption of this measure by program participants in MN and IL is unknown at this stage. [↑](#footnote-ref-26)
26. 7ACH50 assumed typical in retrofit – achieved airtightness based on communication with AEROSEAL provider. [↑](#footnote-ref-27)
27. Using energy savings per cfm from CT 2024 PSD, 3.2.7. Blower Door Test (Small C&I) p. 143, assuming 8 ft ceiling height. [↑](#footnote-ref-28)
28. Energy savings must be adjusted for other sources of heating. [↑](#footnote-ref-29)
29. Energy savings should be reevaluated if assumptions and algorithms used for to estimate weatherization savings in CT PSD are revised, considering declining trends in weatherization across New England. [↑](#footnote-ref-30)
30. Email exchange with a commercial air sealing contractor active in New England. [↑](#footnote-ref-31)
31. The measure, while applicable to single units – is more appropriate for whole building applications. Actual impacts on energy savings when not treating whole buildings has not been documented. [↑](#footnote-ref-32)
32. UL Greenguard Gold includes health-based criteria to ensure that products are acceptable for use in environments such as schools and healthcare facilities. [↑](#footnote-ref-33)
33. Multifamily buildings with in-suite heating systems are the primary target market for this measure. The measure is applicable to any building type using window units – although alternative solutions such as ductless heat pumps are best suited for SFD and 2-4 units buildings. [↑](#footnote-ref-34)
34. For natural gas furnaces baseline, this is a fuel switching measure leading to increased electricity consumption. Details are provided in section 3.9.7 [↑](#footnote-ref-35)
35. For mild-climate micro heat pumps, compared to a windows A/C unit. Additional background and details can be found in the companion workbook. [↑](#footnote-ref-36)
36. To achieve the stated heating savings, installation must be properly weatherized to avoid heat losses through window opening – in particular for window units. [↑](#footnote-ref-37)
37. Outreach to NYPA to gather additional insights from the pilot have not been successful. [↑](#footnote-ref-38)
38. For references – a ductless heat pump of 9,000 Btu/hr and rated HSPF of 9 provides 876 kWh of savings for an electric resistance baseline based on CT PSD algorithms and assumptions. [↑](#footnote-ref-39)
39. Program details are available at: https://www.masssave.com/residential/rebates-and-incentives/heating-and-cooling/heat-pumps/air-source-heat-pumps. [↑](#footnote-ref-40)
40. A draft definition of weatherization is available at: <https://portal.ct.gov/-/media/deep/energy/weatherization/definitionofweatherizationinconnecticutaugust32015pdf.pdf> [↑](#footnote-ref-41)
41. ABC’s analysis (2023) based on NREL Residential Building Stock Analysis has categorized 75% of the existing residential buildings as requiring envelope upgrade at least equivalent to the draft definition of weatherization used in CT. [↑](#footnote-ref-42)
42. Of specific interest to Connecticut is the recent Guidehouse Report (CT R2221 Concierge Programs) exploring specific recommendations in-line with the approach presented. [↑](#footnote-ref-43)
43. Energy Retail Rates are used to estimate a simplified PCT ratio. For the analysis, only the energy components have been included. [↑](#footnote-ref-44)