Memorandum

To: Massachusetts Program Administrators and Energy Efficiency Advisory Council

From: Decker Ringo and Theo Kassuga; Navigant Consulting Inc.

Date: March 2, 2020

Re: Energy Optimization Model Updates (MA19R16-B-EO)
Task 1: Update Energy Optimization Measures and Assumptions

This memo summarizes the evaluation team's work to update the Energy Optimization Model (EOM) per the requests of the Massachusetts Program Administrators (the PAs) and the Energy Efficiency Advisory Council (EEAC) consultants. The evaluation team initially developed the EOM in October 2018 to estimate the costs and benefits associated with a variety of energy efficiency measures that use electric heat pumps and natural gas heating equipment to displace the consumption of delivered fuels. The PAs have used this model to develop prescribed savings values used for energy efficiency measures that involve fuel switching. This memo describes updates implemented in the model, including revised input values, new installation parameters, and new measures covering ground-source heat pumps (GSHPs). In addition, this memo describes further improvements implemented in the model as part of the C&I Energy Optimization Study (MA19C04-E-EO) conducted for the Massachusetts commercial PAs.

Summary

This study updated the previously-developed Energy Optimization Model (EOM) for residential energy optimization measures in Massachusetts. New data has become available since the publication of the original EOM in October 2018, and new features have been requested by the PAs. In addition, a parallel C&I EOM development project led to improvements in the residential EOM.

This study was divided into five sub-tasks:

1. **Introduce Pre- and Post-Weatherization Loads:** in this sub-task, the evaluation team added the capability of selecting between pre- and post-weatherization heating and cooling loads. The heating and cooling loads for pre- and post- weatherization scenarios were determined based on the findings of the 2018 RES 34 Home Energy Services (HES) Impact Evaluation study.
2. **Update Efficiency Levels and Performance Curves for Heat Pumps:** in this sub-task, the evaluation team updated the efficiency levels for heat pumps based on the latest rebate requirements from the Mass Save program. In addition, the evaluation team updated the heat pump performance curves that support the EOM calculations based on recently-published product performance data.
3. **De-Rate Heat Pump Performance:** in this sub-task, the evaluation team reviewed the existing literature describing *in situ* performance of cold climate heat pumps and developed a de-rating factor to better estimate real-world heating system performance based on lab-rated performance data.

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4. **Revise Inputs per RES 1 Baseline Study:** in this sub-task, the evaluation team reviewed the data from the ongoing RES 1 Baseline Study and introduced up-to-date inputs into the EOM. The team also reviewed the latest version of the Massachusetts Technical Reference Manual for up-to-date input values.
5. **Add Ground-Source Heat Pump (GSHP) Measures to the Model:** in this sub-task, the evaluation team gathered cost and performance data for open-loop and closed-loop GSHP systems and added new measures to the EOM to characterize the costs and savings associated with GSHP measures.

In addition to the sub-tasks listed above, the evaluation team applied the following three improvements derived from our development of a model for small commercial energy optimization measures.

1. The October 2018 version of the EOM allowed users to input a single switchover temperature for each fuel type, representing the temperature at which a dual-fuel heating system would switch from heating by heat pump to heating by a backup fuel-fired system. Dual-fuel systems often allow for overlap between heat pump heating and backup fuel heating, so we updated the model to allow users to specify two switchover temperatures that define a transition range between a heat pump and the back-up heating system (or built-in resistance heat);
2. The October 2018 version of the EOM calculated peak electric demand for heat pump systems using the heat pump's rated Heating Seasonal Performance Factor (HSPF). However, the peak demand of a heat pump system is driven by the heat pump's full load power demand instead of the seasonal power demand. We revised the peak demand calculations to use the heat pump's rated coefficient of performance (COP), which represents peak demand better than the HSPF rating.
3. The October 2018 version of the EOM calculated source energy consumption based on the mix of fuels used to generate electricity in Massachusetts. Since Massachusetts customers take electricity from the broader ISO NE electric grid, we revised the fuel mix assumed for electric generation to reflect the ISO NE fuel mix.

Background

The goal of this study is to update the existing EOM with more recent data sources and to implement additional features of interest to the PAs and EEAC consultants. The original EOM was developed in 2018 and allowed users to estimate the savings, costs, peak demand, and lifetimes for a focused group of energy optimization measures for space heating and water heating end uses.

Data Sources

The evaluation team used the following publicly-available data sources throughout the analyses conducted for the EOM update:[1]

- **Massachusetts Technical Reference Manual (TRM), 2019-2021 Plan Version**
  Link: https://www.masssavedata.com/Public/TechnicalReferenceLibrary
  The Massachusetts TRM describes the efficiency of different residential equipment at the baseline, code, and high efficiency levels of performance. The team referenced the 2019-2021 plan version of the TRM to determine equipment performance at the different efficiency levels considered in this study.

- **Residential Evaluation Studies Conducted on Behalf of the EEAC**
  Link: http://ma-eeac.org/studies/residential-program-studies/
  The team referenced pre- and post-weatherization heating loads in the RES 34 HES Impact Evaluation and ductless mini-split heat pump (DMSHP) performance from the Ductless Mini-Split Heat Pump Impact Evaluation. The team referenced equivalent full-load hours (EFLH) for cooling and peak load coincidence factors (CFs) from the RES 1 Baseline Study.

- **Northeast Energy Efficiency Partnerships (NEEP) Cold Climate Air-Source Heat Pump Database**
  Link: http://www.neep.org/initiatives/high-efficiency-products/emerging-technologies/ashp/cold-climate-air-source-heat-pump
  NEEP publishes a Cold Climate Air-Source Heat Pump (ccASHP) Specification and a database of products that meet the specification. NEEP's ccASHP Product List provides performance data at outdoor test temperatures of 47 °F, 17 °F and 5 °F. The team used this data to revise the performance curves that inform our energy consumption calculations.

- **ISO-NE Electricity Generation Fuel Mix**
  Link: https://www.iso-ne.com/about/key-stats/resource-mix/
  ISO-NE publishes data on the regional electricity generation mix for its service region, which includes Massachusetts. The team used this data to estimate the electric generation fuel mix used to calculate source energy consumption in the model.

- **Massachusetts Clean Energy Center (MassCEC) GSHP Rebate Data**
  Link: https://www.masscec.com/ground-source-heat-pumps
  The MassCEC offers rebates for residential installations of GSHPs. MassCEC publishes a database with installation parameters and costs of over 375 residential and small-scale GSHP projects that have been installed since 2015. The team used this data to estimate the typical installation costs of GSHP installations.

[1] For conciseness, only the data sources used for the purposes of the EOM update are included in this list. The original list of data sources used in the EOM but not updated during this EOM update can be found in the RES 21 Energy Optimization Study memo, available at: http://ma-eeac.org/wordpress/wp-content/uploads/RES21_Energy-Optimization-Study_09OCT2018.pdf.

Methodology and Assumptions

Introduce Pre- and Post-Weatherization Loads

The October 2018 version of the EOM assumed average values for heating and cooling loads, and it did not distinguish between homes that had or had not undergone weatherization. In this sub-task, the evaluation team implemented the ability to select between pre- or post-weatherization heating and cooling loads in the model and developed estimates for those loads based on the findings from the RES 34 HES Impact Evaluation.

The evaluation team obtained the following data points from the RES 34 study:

- Average heating consumption for non-weatherized Massachusetts homes in the study
- Average heating energy consumption savings from weatherization
- Average cooling energy consumption savings from weatherization
- Estimated heating equipment efficiency for homes in the study

In addition, the evaluation team used previously determined values for non-weatherized cooling load and cooling equipment efficiency.[2] Based on this information, the team estimated the average cooling and heating loads pre- and post-weatherization for homes in Massachusetts. This was done using the following mathematical relationships:

$$Load = Consumption \times Efficiency$$
$$Savings = Consumption, pre - Consumption, post$$

Table 1 summarizes the results of this analysis.

Table 1. Pre- and Post-Weatherization Loads[3]

Data Type	Pre-Weatherization (MMBtu/yr)	Post-Weatherization (MMBtu/yr)
Cooling Load	18.2	17.8
Heating Load	77.2	67.1

These results are included in a new tab in the model called *Building Characteristics – RES*. Users can select the applicable set of loads (pre- or post-weatherization) from the *Inputs – RES* tab via a dropdown list, as shown in Figure 1. Users can also select “Average Customer” for scenarios where the customer’s weatherization status is not known.

[2] See the RES 21 memo for details. Available at: http://ma-eeac.org/studies/residential-program-studies/.
[3] The cooling loads were additionally affected by an update from RES 1, leading to the pre-weatherized value of 18.2 MMBtu/yr. See the “Revise Inputs per RES 1 Baseline Study” section of this memo for details.

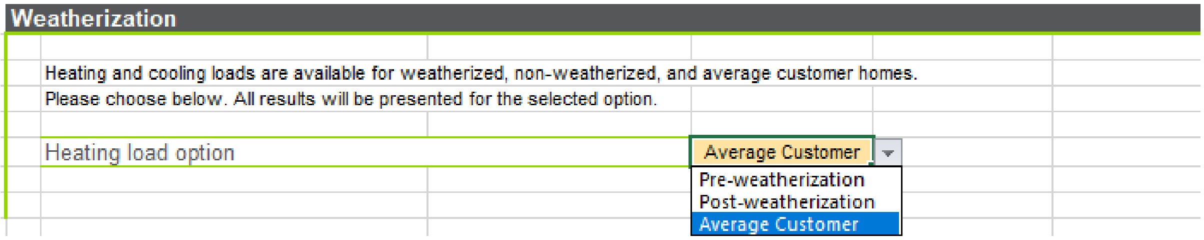

Figure 1. User interface to select weatherization scenario.

Update Efficiency Levels and Performance Curves for Heat Pumps

Since the release of the October 2018 EOM, Mass Save has updated its efficiency requirements for rebate-eligible heat pumps. The evaluation team revised the model to match the current Mass Save requirements.[4] This change involved updates to the energy, demand and cost calculations, as applicable to reflect the new Mass Save requirements. Table 2 shows the previous requirements and the current requirements in the model.

Table 2. Previous and Current Mass Save Requirements for Air-Source Heat Pumps

Tier	Previous Requirements Modeled in the October 2018 EOM			Revised Requirements	
	Central HP	Ductless MSHP	→	Central HP, Ducted MSHP, Multi-Split	Ductless MSHP
Low Measure	16 SEER 8.5 HSPF	18 SEER 10 HSPF	→	15 SEER 9 HSPF	15 SEER 10 HSPF (as of 2019)†
High Measure	18 SEER 9.6 HSPF	20 SEER 12 HSPF	→	16 SEER 9.5 HSPF (as of 2020)	18 SEER 10 HSPF (as of 2020)

† In 2019, Mass Save required that DMSHPs must be rated in the NEEP ccASHP Product List to qualify for rebates. The SEER and HSPF requirements shown here are the same requirements of the NEEP ccASHP Specification.

In addition, NEEP recently updated their ccASHP Product List, which provides performance data for commercially available heat pumps at different outdoor temperatures. The October 2018 version of the EOM uses heat pump performance curves that the team developed based on data from the October 2018 version of NEEP's ccASHP Product List. The evaluation team reviewed the November 13, 2019 version of the NEEP ccASHP Product List (the "Nov/2019 Product List") to determine if the performance curves had changed as a result of NEEP's updates to the Product List. The team created a linear fit through the COP values available in the Nov/2019 Product List (outdoor test temperatures of 47 °F, 17 °F and 5 °F) using the same method used for the October 2018 EOM and compared the results to the performance curves used in the October 2018 version of the EOM. We examined the performance of central heat pumps (CHP) and ductless mini-split heat pumps (DMSHP) separately. The results are shown in Figure 2.

[4] Mass Save requirements for rebate-eligible products are available at https://www.masssave.com/en/saving/residential-rebates/electric-heating-and-cooling/.

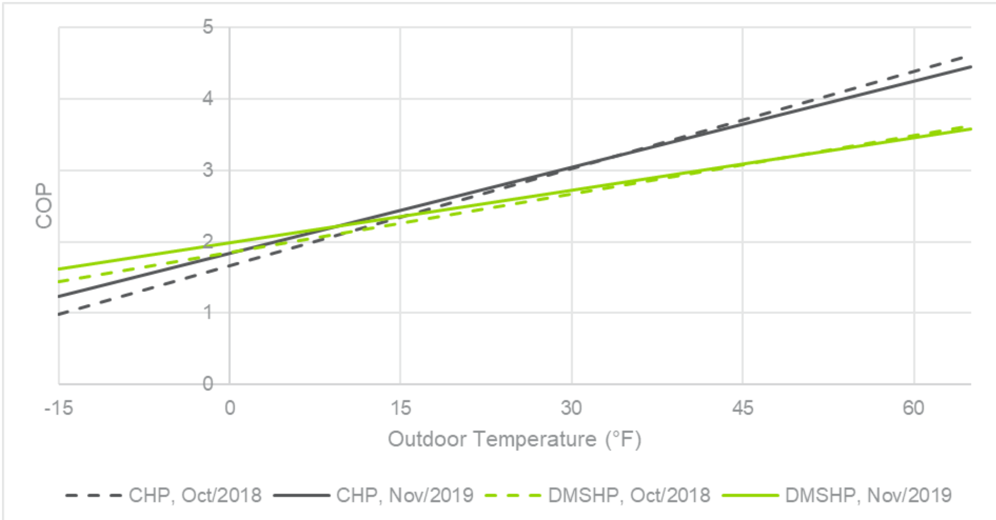

Figure 2. Estimated COP as a Function of Outdoor Temperature, Based on NEEP ccASHP Product List Data

As shown in Figure 2, the COP curves derived from the NEEP ccASHP Product List have changed somewhat since October 2018. For both CHP and DMSHP, the performance curves fit to NEEP's October 2019 Product List showed slightly better performance at outdoor dry bulb temperatures below 20ºF, compared to the curves fit to NEEP's October 2018 ccASHP Product List. The evaluation team updated the COP curves in the EOM to match the most recent data provided by the Product List.

De-Rate Heat Pump Performance

Heat pumps are usually rated in a controlled environment at various temperature levels to simulate real-world operation. However, the efficiency metric for heat pump performance, the Heating Seasonal Performance Factor (HSPF), is calculated at temperatures that may not accurately represent the reality of usage in Massachusetts. The evaluation team examined data from *in situ* performance measurement studies to develop a correction factor that accounts for differences between rating temperatures and typical operation temperatures in Massachusetts.

The evaluation team examined the results from the 2016 Ductless Mini-Split Heat Pump Impact Evaluation and compared the COP curves from the study with the COP curves derived from the NEEP ccASHP Product List.[5] All COP curves shown here are based on linear fits over the available data and pertain only to cold-climate DMSHPs (non-cold-climate DMSHPs were also investigated by Cadmus, but were excluded from this analysis to allow for direct comparison across COP curves). Figure 3 shows the COP curves constructed from the NEEP November 2019 Product List, the NEEP October 2018 Product List, and the Cadmus group study.

[5] The Ductless Mini-Split Heat Pump Impact Evaluation, which was published by the Cadmus Group, is available at: http://ma-eeac.org/wordpress/wp-content/uploads/Ductless-Mini-Split-Heat-Pump-Impact-Evaluation.pdf.

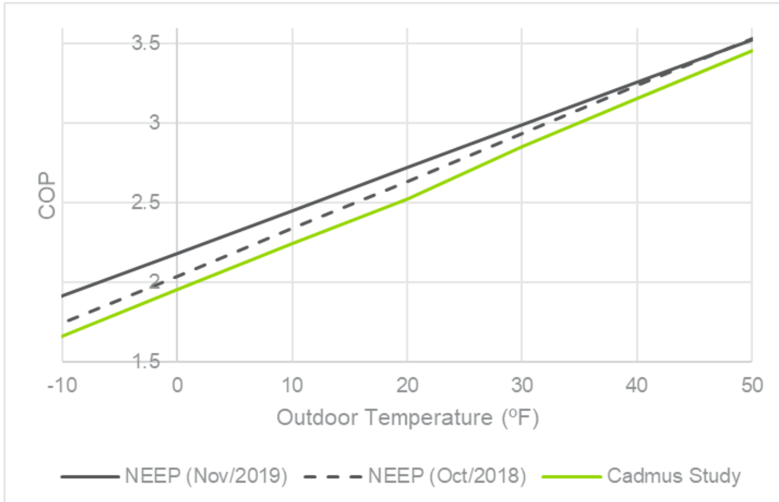

Figure 3. COP Curves Based on NEEP Product Lists and on the Cadmus Study.[6]

The Cadmus study was conducted in 2015 and 2016 with heat pumps designed and sold prior to 2015. Therefore, the technology available in the units Cadmus studied more closely resembles the technology available in the Oct/2018 NEEP-listed models than the Nov/2019 NEEP-listed models (the latter being much newer and potentially with more advanced technology). Based on those considerations, the evaluation team assumed that the differences between the Cadmus study and the Oct/2018 NEEP PL COP curves are due to the loss of performance in the field, while the differences between the Oct/2018 NEEP PL and the Nov/2019 NEEP PL COP curves are due to technological improvement. This assumption is summarized in Figure 4.

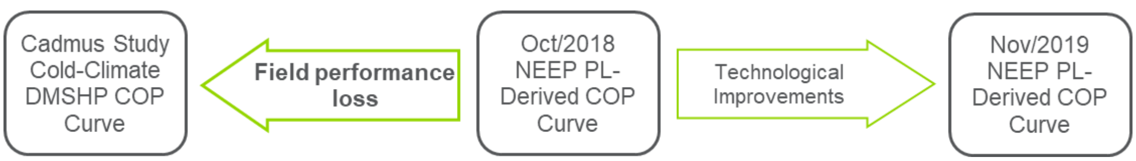

Figure 4. Assumptions for the Field Performance Loss Analysis.

Based on the assumption shown in Figure 4, the evaluation team estimated the performance loss of DMSHPs in the field, when compared to their rated performance. The evaluation team compared the COP curve from the Cadmus study to the COP curve based on the Oct/2018 NEEP PL. This showed that the real-world performance of the heat pumps was between 94 and 98% of the rated performance within the range of temperatures expected in a normal heating season, as shown in Figure 5.

[6] The average HSPF for the Cadmus study heat pumps was 11; the NEEP curves were derived based on 10 HSPF models and then scaled to 11 HSPF, therefore allowing for direct comparison. The Cadmus data for 2016 was used in this analysis. (Cadmus also reported data for 2015, but that winter was particularly snowy, which led to the condensers being buried under snow for a significant amount of time, which in turn affected the measured performance significantly.)

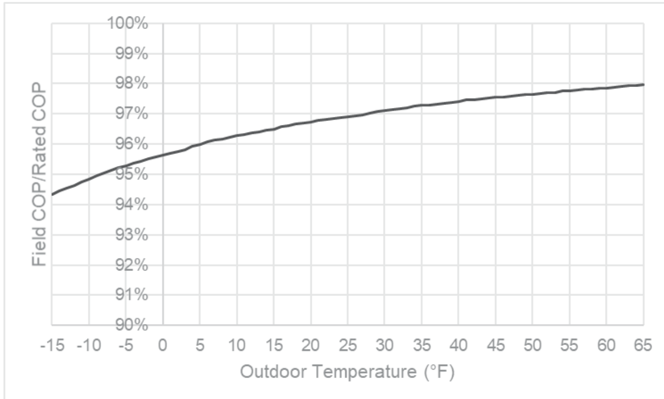

Figure 5. Ratio of Field COP to Rated COP.

The evaluation team calculated the average efficiency factor using the following relationship:

$$Average\ efficiency\ factor = \frac{1}{[65°F - (-15°F)]} \int_{T=-15°F}^{T=65°F} \frac{COP_{Field}(T)}{COP_{Rated}(T)} dT$$

where T is the outdoor temperature and a factor less than 1 indicates that the heat pump loses efficiency when operating in the field, when compared to its rated efficiency.

The evaluation team performed numerical integration and rounded the result down to the nearest percent, obtaining an efficiency factor of 96%. In other words, the team estimated that a DMSHP delivers on average 96% of its rated COP when installed in the field in Massachusetts. The team assumed that the same factor would apply to central heat pumps given that they operate under the same climatic conditions as DMSHPs. Consequently, the efficiency factor was introduced in the model using the Overall Heat Pump Efficiency Factor input, which can be viewed and adjusted by users in the *General Inputs* tab of the model.[7]

Revise Inputs per RES 1 Baseline Study

The ongoing RES 1 Massachusetts Baseline Study regularly publishes data on the energy consumption patterns of Massachusetts homes.[8] The evaluation team reviewed the most recent data from RES 1 to determine if an update to the inputs in the model was necessary. Based on that review, the inputs listed in Table 3 were updated in the model.

[7] The October 2018 version of the EOM included a “Overall Heat Pump Efficiency Factor” equal to 100%. This input value had no effect on the calculated results in the October 2018 version, and it was included as a placeholder value. Compared to the October 2018 version, the new efficiency factor input of 96% effectively reduces the estimated heat pump efficiency and slightly increases the electric consumption calculated for heat pump scenarios.

[8] See RES 1 publications at http://ma-eeac.org/studies/residential-program-studies/ for details.

Table 3. Updated Inputs per RES 1

Input Type	Input Value (RES 1)	Input Unit
Cooling Load	18.2	MMBtu/year
Room AC Equivalent Full Load Hours (EFLH)	338	hours/year
Room AC Summer Coincidence Factor	0.42	dimensionless
Central AC/HP Summer Coincidence Factor	0.47	dimensionless
DMSHP Summer Coincidence Factor	0.32	dimensionless

Considering that the average cooling load reported by RES 1 represents a large sample of homes in Massachusetts of various building vintages and build qualities, the evaluation team assumed that the average cooling load reported by RES 1 more closely represents non-weatherized homes than weatherized homes. Thus, the evaluation team assigned a cooling load of 18.2 MMBtu/year to non-weatherized homes and calculated the cooling load for weatherized homes by subtracting the estimated cooling savings from weatherization (as described previously in the section titled *Introduce Pre- and Post-Weatherization* Loads).

In addition to the input updates based on RES 1, the evaluation team revised the winter coincidence factors for various equipment based on the latest version of the Massachusetts Technical Reference Manual.[9]

Add Ground-Source Heat Pump (GSHP) Measures to the Model

The PAs requested that the EOM be updated to include measures involving installations of GSHPs in place of oil- and propane-fired heating systems. To characterize the cost and configuration of GSHP measures, the team analyzed a database of residential GSHP projects published by MassCEC.[10] This database describes more than 375 residential and small-scale GSHP projects that have been installed in Massachusetts since 2015. Our analysis found the following:

- The majority of GSHP installations (294 out of 379 records in the MassCEC database) used forced air heat distribution.
- There is a large difference in installation cost between closed-loop GSHP systems and open-loop GSHP systems. Closed loop systems circulate fluid through a hydronic circuit that is buried underground, with a median installation cost of $888 per kBtu/hour of capacity. Open loop GSHP systems circulate fluid from a proximate pond, lake, or aquifer, with a median installation cost of $572 per kBtu/hour of capacity.
- There is a difference in installation cost between installations that replace a prior GSHP system and installations that add a new GSHP system.

Based on these findings, we conclude that the typical energy optimization replacement would install a forced-air GSHP in place of an oil- or propane-fired furnace. Since the costs of closed-loop and open-loop systems vary widely, we added separate measures to the EOM for closed- and open-loop systems. Since the EOM models the savings resulting from a fuel switch, we limited our cost analysis to consider systems that installed a new GSHP system where no prior GSHP system existed.

[9] Available at https://www.masssavedata.com/Public/TechnicalReferenceLibrary.
[10] Available at http://files-cdn.masscec.com/get-clean-energy/govt-np/clean-heating-cooling/ResidentialandSmallScaleGSHPProjectDatabase.xlsx

To characterize the energy consumption of GSHP systems, we defined a code-level efficiency based on the U.S. Department of Energy's minimum efficiency requirements for water-source heat pumps. The DOE has established minimum EER efficiency levels for heat pumps rated in a water-loop heat pump (WLHP) configuration. We correlated product ratings from the AHRI Directory of Certified Product Performance to determine the typical minimum performance for a ground-loop heat pump configuration (GLHP, representing a closed-loop installation) and a ground water heat pump configuration (GWHP, representing an open-loop installation).

Mass Save does not currently rebate GSHPs, but the team assumed that Mass Save could define GSHP measures using ENERGY STAR specifications for GSHPs. With this assumption, the team defined a measure-level efficiency equivalent to the ENERGY STAR specification for GSHPs.[11] The team also observed that many systems on the market exceed ENERGY STAR levels, indicating that more savings could be achievable from a higher measure threshold. The team defined a high efficiency level that corresponds with the median efficiencies rebated through the MassCEC's GSHP Program. Table 4 summarizes the efficiency levels modeled for GSHP measures added to the EOM.

Table 4. GSHP Efficiency Levels

Loop Configuration	Code Level (Based on Federal Standards)	Measure Level (ENERGY STAR)	High Efficiency (Typical rebate by MassCEC)
Closed Loop	3.2 COP, 14.0 EER	3.6 COP, 17.1 EER	4.3 COP, 23.5 EER
Open Loop	3.8 COP, 18.0 EER	4.1 COP, 21.1 EER	4.9 COP, 28.5 EER

The team added four new measures to the EOM, detailed in Table 5.

Table 5. GSHP Measures Added to the Energy Optimization Model

Measure ID	Baseline	Replacement
MEASR34	Baseline A/C Blend + Oil Furnace	Closed Loop GSHP
MEASR35	Baseline A/C Blend + Propane Furnace	Closed Loop GSHP
MEASR36	Baseline A/C Blend + Oil Furnace	Open Loop GSHP
MEASR37	Baseline A/C Blend + Propane Furnace	Open Loop GSHP

GSHP product performance ratings have several nuances that must be considered when estimating the energy consumption of GSHP systems. First, GSHP systems are installed with a circulator pump (also referred to as a "flow center") that circulates a working fluid through the ground loop, and the EER and COP ratings of GSHPs do not account for the pump energy consumed for ground loop circulation. Second, GSHPs with forced air distribution use a blower fan to circulate air to the conditioned space, and the EER and COP ratings do not account for the fan energy consumed for air

[11] ENERGY STAR product criteria for geothermal heat pumps are available at: https://www.energystar.gov/products/heating_cooling/heat_pumps_geothermal/key_product_criteria

circulation.[12] Therefore, an accurate estimate of GSHP system consumption should account for (1) the energy used by a circulator pump to move the working fluid, (2) the energy used by the indoor unit fan to circulate air in the home, and (3) the energy used by the GSHP to move heat between the working fluid and the circulated air.

1. Energy consumption of the circulator pump: The International Ground Source Heat Pump Association publishes GSHP system pump power benchmarks that show a range of acceptable pump power ratings, the midpoint of which is 75 W per ton of GSHP capacity.[13] This predicts a "pump penalty" of 300 Watts for the 4-ton system modeled in this analysis. We calculated annual pump consumption by multiplying an assumed pump power of 300 Watts by the sum of the equivalent full load hours (EFLH) for cooling (419 hours) and heating (1,200 hours) reported for central heat pumps in 2019-2021 MA TRM.[14]
2. Energy consumption of the indoor fan: We referenced product literature for heat pump air handler products, which showed power draw of 328 W to 385 W for a 4-ton air handler unit.[15] We calculated annual fan consumption by multiplying an assumed average fan power of 356 Watts by the total EFLH of 1,619 hours noted above.
3. Energy consumption of the GSHP unit: The efficiency of GSHP units depends on the temperature of the working fluid that enters the GSHP, which in turn depends on the soil temperature of the buried circulation loop. There is some seasonal fluctuation in soil temperatures, but we assumed the effects of this fluctuation would be small, and that the product ratings accurately represent GSHP unit performance. We calculated the heating consumption of the GSHP unit by dividing the heating load by the rated efficiency (in COP) for each efficiency level. We calculated the cooling consumption of the GSHP unit by dividing the cooling load by the rated efficiency (in EER) for each efficiency level.

The total annual energy consumption for the GSHP system was calculated as the sum of the energy consumption of the pump, fan, and GSHP unit.

Additional Improvements via the C&I EOM Adaptation

The EOM was recently adapted on behalf of the Massachusetts Commercial PAs to characterize energy optimization measures installed in small commercial buildings. During this adaptation, the team added new measures and input tabs to the model. We also implemented the following features in both the residential and the commercial sections of the model.[16] Those features are listed below:

[12] GSHP performance is rated using ISO Standard 13256-1 "Water-source heat pumps — Testing and rating for performance — Part 1: Water-to-air and brine-to-air heat pumps." Ratings to ISO 13256-1 only include pump power to overcome internal resistance (e.g., pressure drop inside the condenser unit), not pump power to overcome external resistance from the ground loop. Similarly, on the air side, the rating only includes power to overcome the internal pressure drop rather than being based on a minimum ESP that is supposed to be representative of ductwork in the field, as is the case for ratings of central ASHP products.

[13] IGSHPA (2017). "Closed-Loop/Geothermal Heat Pump Systems: Design and Installation Standards." Table 3.1. Available at: https://igshpa.org/wp-content/uploads/2019/01/2017_IGSHPA_Standards-restricted.pdf

[14] Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures 2019-2021 - Plan Version. Measure "RES-HVAC-ASHP"

[15] See, for instance, Trane (2017). "Product Data: Convertible Air Handlers 1.5 to 5 Ton." Tables 7 & 8 for 4-ton units at Normal speed setting and 0.5 External Static Pressure. Available at: https://api.ferguson.com/dar-step-service/Query?ASSET_ID=4551767&USE_TYPE=PARTS&PRODUCT_ID=5146588

[16] For a detailed discussion of the C&I EOM adaptation, refer to the memo associated with MA C&I study number MA19C04-E-EO.

- A switchover temperature band was introduced in the heat pump analysis. This allows users to include a temperature band over which operation switches from the heat pump to the fuel-powered equipment. This contrasts with the previous version of the model, which only allowed for a hard transition between the heat pump and the fuel-powered equipment. This input is available via the *General Inputs* tab.
- The peak demand is now calculated based on the lowest operating COP instead of the HSPF. This allows for a more accurate characterization of real-world peak demand. In addition, it allows for better modeling of the benefits of dual-fuel systems, where the heat pump only operates at higher COPs. This change was done directly in each measure tab and in the *Heat Pump Analysis* tab.
- The October 2018 version of the EOM calculated source energy consumption based on the mix of fuels used to generate electricity in Massachusetts. Since Massachusetts customers take electricity from the broader ISO NE electric grid, we revised the fuel mix assumed for electric generation to reflect the ISO NE fuel mix.

Results

The format of the EOM's reporting tabs has not changed since the October 2018 version of the model. Analytical results are available in the "Measure List" tab of the Energy Optimization Model enclosed with this memo. The results for each measure are presented at the following efficiency levels:

- Original Fuel – Baseline Efficiency Level (for example, an existing oil furnace)
- Original Fuel – ISP Efficiency Level (for example, a new oil furnace)
- Replacement Fuel – ISP Efficiency Level (for example, a new electric heat pump)
- Replacement Fuel – PA Program Low Efficiency Tier (for example, a new, rebate-eligible electric heat pump)
- Replacement Fuel – PA Program High Efficiency Tier, if the program offers rebates at two efficiency levels

The following variables are provided in each of those cases:

- Annual energy cost
- Total installed cost (presented as a deferred replacement cost for the ISP level with original fuel; not presented for the baseline level which, by definition, has no installed cost)
- Annual electricity, natural gas, propane, and oil consumption
- Peak demand
- Annual carbon emissions

These variables are combined to calculate the energy savings and incremental costs associated with the low and high measures under three different scenarios: full/early replacement, partial displacement, and replace-on-failure. In the ER and PD scenarios, the energy consumption and cost at the measure level is compared to the existing baseline equipment; the installation cost is compared to the deferred replacement credit associated with eventually having to install an ISP-level replacement that uses the original fuel. In the ROF scenario, the consumption and cost at the measure level is compared to an ISP-level replacement that uses the original fuel; the installation costs are compared directly (without deferred replacement considerations) because the customer must choose a piece of equipment for immediate purchase upon failure of the existing baseline.

The EOM spreadsheet workbook contains separate summary sheets that report the incremental costs and savings of measures in each of these scenarios. The EOM workbook also contains a *BCR Outputs* tab that collects the different values that are typically used in the PAs' benefit/cost calculations.

Potential Improvements

The PAs and EEACs requested that the team identify potential weaknesses in the EOM that could be improved through further research and data collection. The team has identified the following potential improvements that could be implemented in future versions of the energy optimization model to improve the data input to the model and to improve the model's accuracy and/or expand its applicability.

Data Improvements

- **Improvements to the cost-capacity trends and to line item cost estimates for central A/C and central HP installations**. Central A/C and HP costs in the Energy Optimization Model are based on the Air Conditioner and Heat Pump (AC & HP) Cost Study (RES23), which reviewed a sample of residential program invoices and developed installation costs for central A/C and HP equipment on a cost-per-ton basis. The sample frame for RES23 focused on the most commonly installed system capacities (from 2 to 3 tons of cooling capacity) and did not include many invoice records for higher-tonnage systems (at 4 tons capacity and above). A sample frame with more representation from higher-tonnage systems would improve the confidence of the model's cost-per-capacity estimates. Additionally, the records in the RES23 sample frame did not provide sufficient data to estimate line item costs for ductwork installation and/or modification or the line item costs for the replacement of air handlers and indoor heat exchanger coils. The team suggests reviewing a larger sample of program invoices to better understand the relationship between installation cost and system capacity.
- **Improvements to specific installation cost components.** The Energy Optimization model includes cost estimates of different line items associated with installations of gas and electric equipment. Specifically, the team estimated the costs of removing and disposing of existing units and distribution systems, installing new gas service lines, upgrading home electrical systems for DMSHP installations, and integrating heat pump systems with existing heating equipment for dual-system operation. The team suggests conducting a cost study to better understand the costs of these specific installation activities.
- **Switchover temperatures for heat pumps.** For dual-fuel systems, there are a variety of control strategies to govern how the heating load is shared between a heat pump and a backup combustion-based system. The model would be more accurate if it reflected the controls that are most commonly implemented in the field.. This could be done, for example, by conducting a survey with contractors to determine how they usually program heating equipment or what control strategies they suggest to customers.
- **Field analysis of heat pump performance.** While some work has been done to estimate the performance of heat pumps in the field, many questions remain with regards to the efficiency of the heat pumps and their ability to operate seamlessly in dual-fuel setups. Additional field studies of heat pump performance would help validate and improve the model inputs.

Model Improvements

- **Consider using gas equipment as a baseline for oil measures.** Currently, we assume that oil-fired replacement equipment is the ISP baseline for measures that switch customers away from oil heating. In other words, we assume that, absent any intervention, oil customers would replace their oil boiler or furnace with a new oil boiler or furnace rather than pursuing a self-motivated fuel switch. However, the PAs have observed that, without incentives, many oil customers are choosing to replace their oil-fired heating equipment with natural gas-fired heating equipment, when gas supply is available. This is likely because of the cost and convenience advantages that natural gas-fired equipment offers relative to oil-fired equipment. The PAs should explore whether an ISP baseline of natural gas equipment is more sensible for measures that switch customers away from oil heating. There will be situations, though, where oil customers do not have the option to switch to natural gas equipment. If the ISP baseline is modified, the PAs should consider baseline adjustments for customers who do not have a natural gas option.
- **Introduce other representative locations.** The model could be more localized to individual utilities by offering the ability to select different annual climate profiles that represent local conditions at different locations in the PA service areas for the purposes of climate-based calculations. Currently, the model uses Worcester as a representative location for the state of Massachusetts.
- **Include alternate switchover temperatures optimized for carbon savings.** The EOM allows users to specify the temperatures at which dual-fuel systems switch from electric heat pump heating to fossil fuel-based backup heating. The model includes a set of default temperatures that were selected to minimize customers' energy costs. The default switchover temperatures are 15ºF for a propane-fired backup system, 30ºF for an oil-fired backup system, and 50ºF for a natural gas-fired backup system. For less expensive fuels, a higher switchover temperature may improve a customer's energy bills, but it could also increase their carbon emissions since it would use the backup fuel system for a greater number of operating hours. The model could be altered to include a second set of default switchover temperatures that maximize carbon emissions reductions.