Cool Smart Incremental Cost Study: Final Report

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Prepared for:

The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

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Notice Regarding How Results of This Study Should Be Used and Interpreted

The purpose of this study is to support energy-efficiency program design and cost-effectiveness analysis, including traditional customer rebates and upstream incentive programs that may be offered by Massachusetts' Program Administrators (PAs). This analysis and its methodology differ greatly from engineering analyses conducted to support the development of mandatory energy conservation standards (such as analyses published by the U.S. Department of Energy (DOE)). Key distinctions include:

- **This analysis focuses on a limited number of products from two manufacturers.** This subset of the market was selected to represent the products that are typically rebated through the Cool Smart program. In contrast, analyses that support energy conservation standards include all manufacturers that make products in a given product class.

- **The component part prices and estimated unit costs in this analysis have not been reviewed with manufacturers.** This analysis relied on estimates of component part prices and comments were not solicited from manufacturers. In contrast, the analyses that support DOE's energy conservation standards incorporate manufacturer input and feedback regarding component prices and unit costs.

- **The Cool Smart rebate program considered in this analysis is a voluntary program and is not market forcing.** This analysis assumes that the production volumes for residential HVAC products are not influenced by Cool Smart rebate levels. In contrast, analyses of mandatory product standards assume that those standards force changes in product markets because they establish mandatory minimum efficiencies for products.

- **For rebating purposes, this analysis evaluates the lowest possible cost to achieve a given efficiency level (i.e., the "efficiency frontier").** In contrast, analyses that quantify the costs and benefits of mandatory efficiency rules use the market shares of various manufacturers to determine the weighted average cost (**not** the lowest possible cost) for the industry to achieve a given efficiency level.

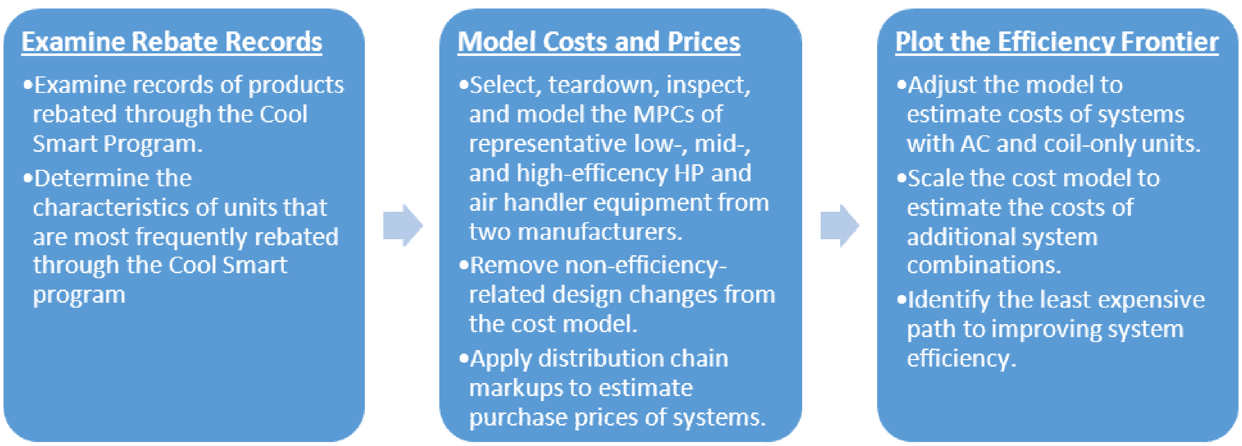
Because of these fundamentally different approaches, the results published in this analysis cannot be compared to the results from analyses supporting mandatory energy conservation standards.

Summary

This incremental cost study estimates how manufacturing production costs (MPCs) and purchase prices of residential air conditioning (AC) and heat pump (HP) equipment change as equipment efficiency increases. The results of this study will support Cool Smart program enhancements and cost-effectiveness analysis, as well as potential upstream residential upstream heating, ventilation and air conditioning (HVAC) incentive programs.

This study used the methodology summarized in Figure 1 to characterize the relationship between efficiency and cost.

Figure 1: Stages of Analysis in the 2015 Cool Smart Incremental Cost Study



The Residential Evaluation Team ("the team") began by examining Cool Smart tracking data provided by the Massachusetts Program Administrators (the PAs). The team analyzed the data to determine the characteristics (manufacturer, equipment class, capacity, and efficiency rating) of units that are most frequently rebated through the Cool Smart program. The team observed that the AC and HP units most frequently rebated by Cool Smart from 2012-2014 had cooling capacity of 2 tons (24,000 BTU/h) and were manufactured by Carrier, Trane, or Lennox.

Based on these observations, the team selected a set of twelve units (six indoor air handler units and six outdoor HP units) for teardown and cost modeling. To best represent the population of recent Cool Smart rebate recipients, the team selected products with cooling capacities of 2 tons refrigeration (24,000 BTU/h) made by Carrier and Lennox.[1] The team selected indoor and outdoor units that can be

[1] Lennox units comprised a modestly smaller portion of the rebate population (19.5%) compared to the portion of the population comprised by Trane units (24.9%). However, data from Trane teardowns are difficult to translate across the rest of the industry, since Trane is the only manufacturer to use spine fin tube heat exchangers. In addition, the Lennox units were more readily available for purchase and teardown than the Trane units. In the equipment category most frequently rebated by Cool Smart (the AC with Blower Coil category), Lennox showed a

paired in different combinations to achieve the efficiency ratings rebated by 2015 Cool Smart Central AC/HP Program (Seasonal Energy Efficiency Ratio (SEER) 16.0 and SEER 18.0), as well as efficiency levels below, above, and between the rebated levels.

The team completely disassembled (tore down) the lowest and highest efficiency unit pairs, inspected the remaining medium efficiency units by removing their service panels and viewing their components, and created bottom-up cost models of all twelve units that were selected. We developed these cost models using assumptions about factory parameters and distribution chain markups published from the 2011 U.S. Department of Energy rulemaking that established minimum efficiency standards for central AC equipment.[2] The output of these cost models includes an estimated MPC and retail purchase price for each unit modeled.

On May 27, 2015, the team hosted a site visit to present preliminary cost estimates resulting from the teardown analysis to the electric PAs and the Energy Efficiency Advisory Council (EEAC) consultants. During the site visit, the team presented observations regarding product upgrades that are frequently bundled into high efficiency units. In the units we examined, we observed that several bundled upgrades (such as louvered cases, sound dampening, and specialty thermostats) increase a unit's production costs without increasing the unit's efficiency. After the site visit, the team received the following feedback from the attendees:

- The cost-efficiency curves developed in this study should omit product upgrades that increase product costs without increasing efficiency.
- Since product markups are different for replacement units compared to new construction units, the team should estimate the proportion of Cool Smart rebates that were given between these two scenarios, and apply markups in a way that reflects that proportion.

In response to this feedback, the team adjusted the manufacturing cost models to exclude features that are not efficiency related, namely louvered or plasticized panel cases/tops, sound dampening, and integration with specialty thermostats. The team could not discern the proportion of Cool Smart rebates awarded for replacement versus new construction, so the team used national estimates of AC and HP shipments for these subgroups. This resulted in a weighted average markup of 2.70; each MPC is multiplied by this weighted average markup to estimate the retail purchase price of the unit.

The team continued the analysis by adapting the cost model to estimate the costs and prices of units that were not physically torn down in this analysis. The team did not conduct teardowns of AC or coil-only units, or of complete systems at the baseline levels of 13.0 SEER for ACs and 14.0 SEER & 8.2 HSPF

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similar proportion of rebates (22%) compared to the proportion of Trane rebates (24%). See Tables 9 and 10 in Appendix A.

[2] A full discussion of factory parameter assumptions and a full list of assumptions are publicly available in the Engineering Analysis (Chapter 5) of the 2011 DOE rulemaking regarding central AC equipment, at: http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0011-0012

(heating seasonal performance factor) for HPs.[3] To model these units and systems, the team conducted "catalog teardowns" by applying scaling factors to the teardown data and simulating teardowns using catalog information provided by manufacturers. In total, the team used catalog teardowns to model the costs of an additional 79 units based on the original 12 units that were physically torn down or inspected. Cost estimates for these units were combined to produce MPC and price points for more than 450 unique system combinations.

After completing the catalog teardowns described above, the team plotted the resulting cost estimates in a series of cost-efficiency plots, which are presented below and in the Results sections of this report. On each of these charts, the team mapped the "efficiency frontier," which is defined here as the minimum incremental price (above a baseline of 13.0 SEER for ACs and 14.0 SEER & 8.2 HSPF for HPs) required to achieve a given efficiency for the systems that were modeled. The team mapped the efficiency frontier by identifying and recording the lowest cost system at each increment of efficiency gain (e.g., the frontier is mapped at SEER values of 13.0, 13.5, 14.0, and so forth). The team created separate plots for each of the four categories of paired indoor and outdoor products considered in this analysis:

- Air-conditioning outdoor units with an indoor air handler (AC-AH);
- Air-conditioning outdoor units with an indoor coil only (AC-CO);
- Heat pump outdoor units with an indoor air handler (HP-AH); and
- Heat pump outdoor units with an indoor coil only (HP-CO).

Data points generated through catalog teardowns may not have the same level of confidence as data points generated by physical teardown data alone, so the tables and charts of results in this report distinguish between data points generated from teardown and catalog data. Each set of incremental cost results has up to four sources of data. Figures 2, 3, 4, and 5 below note systems where:

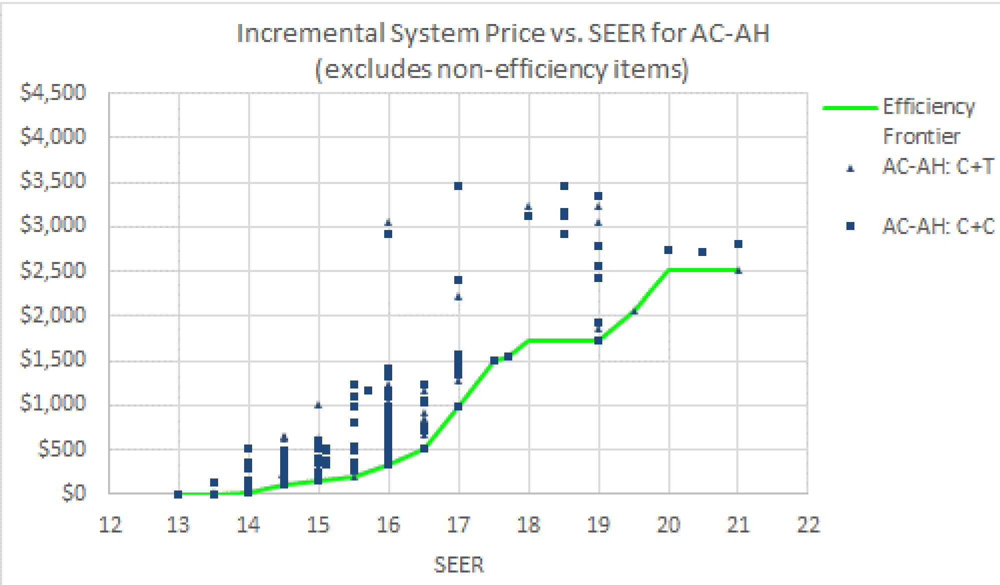
- Both the outdoor and indoor units were directly torn down or inspected (T+T);
- The outdoor unit was torn down/inspected and the indoor unit was modeled with catalog data (T+C);
- The outdoor unit was modeled using catalog data and the indoor unit was torn down/inspected (C+T); and
- Both the outdoor and indoor units were modeled using catalog data (C+C).

The incremental prices presented in the cost-efficiency plots represent the price increase above the least expensive baseline system in each category, at 13.0 SEER for ACs and 14.0 SEER & 8.2 HSPF for HPs.

[3] This analysis assumes that the baseline efficiency levels for residential HVAC products sold in Massachusetts are the federal minimum efficiency standards currently in place, which effective January 1, 2015, are SEER 13.0 for AC and SEER 14.0 / HSPF 8.2 for HPs, as described in Table 3 at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/75.

The Methodology and Results sections of this report provide a detailed breakdown of these results, as well as cost-efficiency charts based on energy efficiency ratio (EER) and heating seasonal performance factor (HSPF) ratings.

Figure 2: Incremental System Cost Curve for AC-AH as Function of SEER



Efficiency Frontier	
SEER	**Incremental Price**
13.5	$0
14.0	$13
14.5	$109
15.0	$147
15.5	$207
16.0	$325
16.5	$522
17.0	$993
17.5	$1,496
17.7	$1,552
18.0	$1,725
18.5	$1,725
19.0	$1,725
19.5	$2,056
20.0	$2,506

Figure 3: Incremental System Cost for AC-CO as Function of SEER[4]

Efficiency Frontier	
SEER	**Incremental Price**
13.5	$38
14.0	$38
14.5	$204
15.0	$256
15.5	$1,502
16.0	$1,502
16.5	$1,566
17.0	$2,264

[4] Systems with indoor coil-only units do not exceed SEER ratings of 17.0. Indoor coil-only units require the circulation blower in a furnace or similar device to function. Because coil-only units are rated in test setups using less efficient permanent split capacitor (PSC) fan motors, systems with coil-only units typically cannot achieve SEER ratings higher than those of systems with air-handlers (which can take advantage of an electronically-commutated motor).

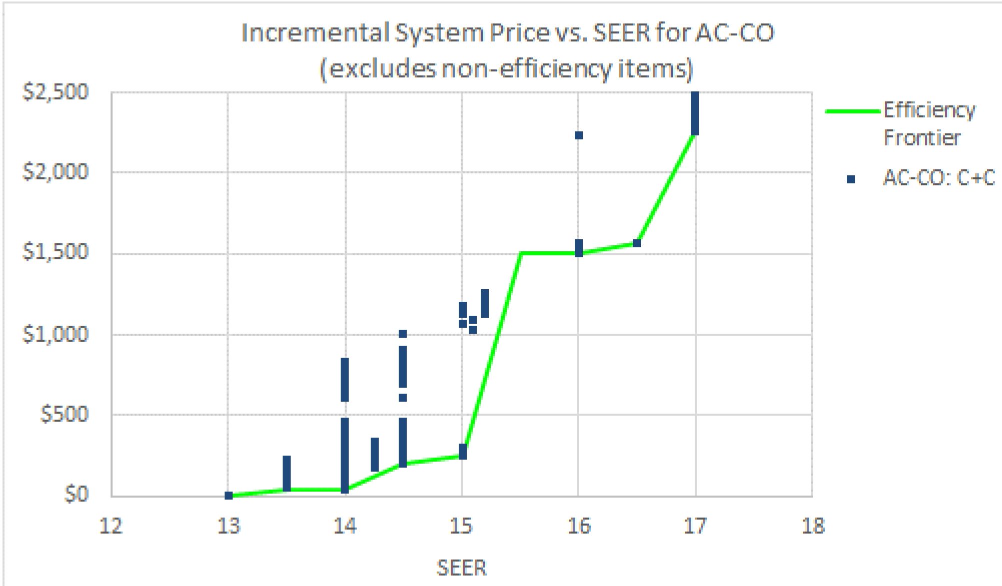
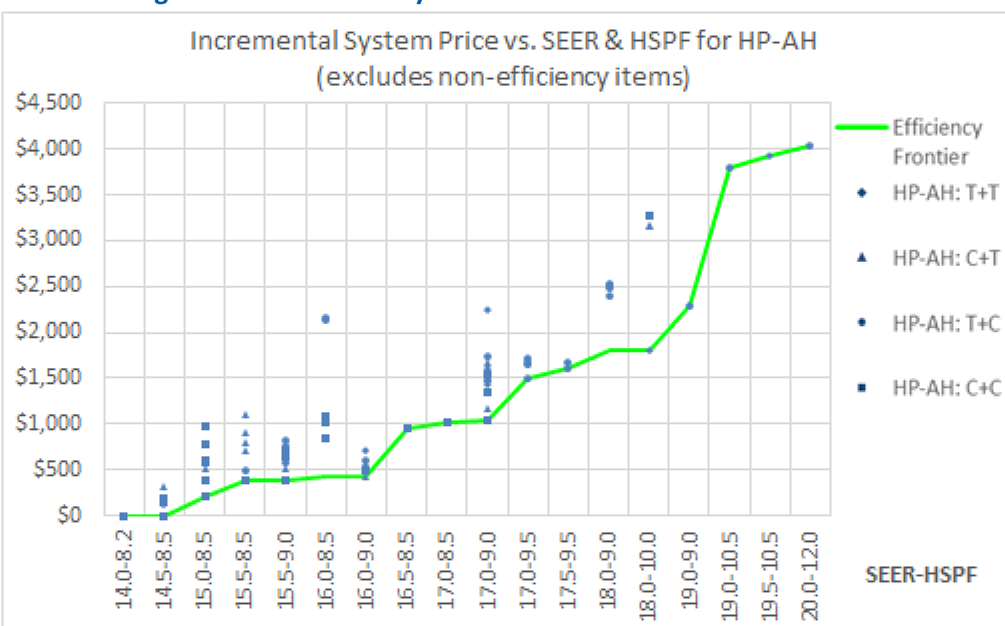
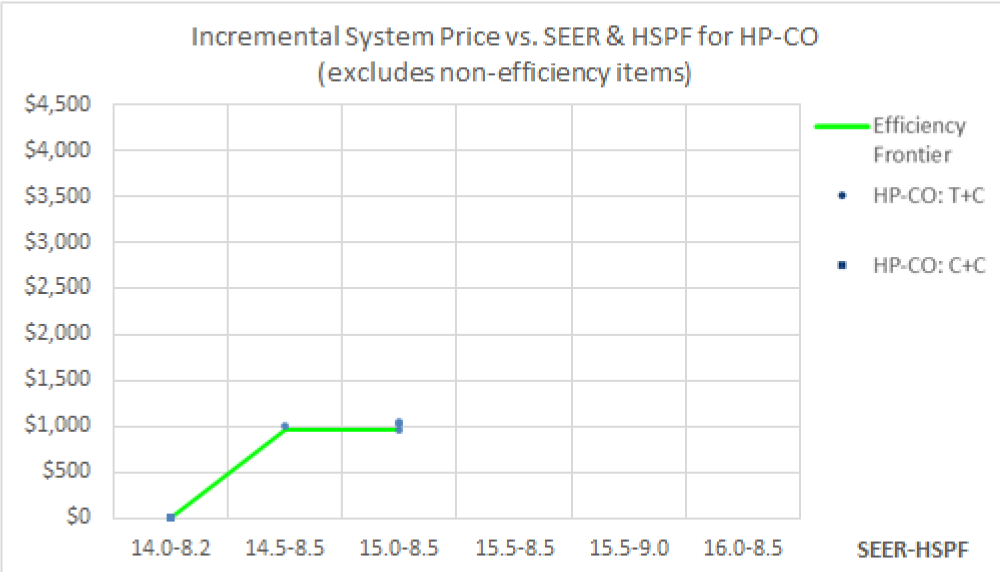


Figure 4: Incremental System Cost Curve for HP-AH as Function of SEER and HSPF



Efficiency Frontier	
SEER-HSPF	Incremental Price
14.5-8.5	$0
15.0-8.5	$200
15.5-8.5	$379
15.5-9.0	$379
16.0-8.5	$431
16.0-9.0	$431
16.5-8.5	$954
17.0-8.5	$1,007
17.0-9.0	$1,034
17.0-9.5	$1,501
17.5-9.5	$1,608
18.0-9.0	$1,808
18.0-10.0	$1,808
19.0-9.0	$2,294
19.0-10.5	$3,794
19.5-10.5	$3,925
20.0-12.0	$4,033

Figure 5: Incremental System Cost Curve for HP-CO as Function of SEER and HSPF[5]



Efficiency Frontier	
SEER	**Incremental Price**
14.5-8.5	$963
15.0-8.5	$963

[5] Two-ton heat pump systems with indoor coil-only units from Lennox and Carrier do not exceed ratings of 16.0 SEER or 9.0 HSPF. See previous footnote for explanation. In addition, there are few available ratings for HP-CO systems manufactured by Lennox and Carrier, which limits our analysis of their incremental costs.