MEMORANDUM

To: Jonathon Jackson, Ameren Illinois; and Jennifer Morris, Illinois Commerce Commission

From: Jane Colby, Jeana Swedenburg, Jen Huckett, Torsten Kieper, Shannon Greene; Cadmus

Subject: HVAC Program: Incremental Cost Analysis Update

Date: February 3, 2017

The purpose of this memorandum is to:

- Provide an update to the incremental cost analyses conducted as part of the Program Year 7 (PY7) Ameren Illinois Company (AIC) Heating, Ventilation, and Air Conditioning (HVAC) and All-Electric Homes program evaluations.
- Recommend changes to the Illinois Statewide Technical Reference Manual (TRM) for the incremental costs of efficiency for air source heat pumps (ASHP), central air conditioners (CAC), and brushless furnace blower motors, also known as electronically commutated motors (ECM).

The evaluation team performed two hedonic pricing analyses to estimate the effects of differing levels of efficiency on ASHP and CAC prices based on pricing and system specification data. The evaluation team controlled for the effects of other factors, including system size, and distributor to isolate the effect of Seasonal Energy Efficiency Ratio (SEER) rating on system prices. We collected data from two distributors and one online wholesale website. Table 1 and Table 2 describe the sample distribution by distributor, SEER values and unit size.

Table 1. Sample Distribution by Distributor and Efficiency (SEER)

Efficiency (SEER)	Distributor 1	Online Wholesaler (Distributor 2)	Distributor 3
ASHP (n=186)	**20**	**106**	**60**
14	2	16	4
14.5	3	24	12
15	7	30	35
16	4	26	9
17-18	4	10	--
CAC (n=997)*	**20**	**954**	**23**
14-14.9	6	283	2
15-15.9	3	424	--
16-16.9	8	173	17
17-18	3	74	4
* Of 1004 total sample points, 997 fell within the SEER ranges of 14-18.			

Table 2. Sample Distribution by Size and SEER

Efficiency (SEER)	1.5 Ton	2 Ton	2.5 Ton	3 Ton	3.5 Ton	4 Ton	5 Ton
ASHP (n=186)							
14	2	3	1	6	3	2	5
14.5	2	5	6	5	8	6	6
15	11	8	12	16	14	10	1
16	1	9	5	10	3	6	5
17-18	--	2	--	5	--	4	3
CAC (n=997)							
14-14.9	11	41	36	90	53	30	30
15-15.9	33	39	41	109	55	78	72
16-16.9	22	61	14	45	14	18	24
17-18	--	2	--	46	--	32	1

Based on the results of the analyses described below, the team recommends updating incremental costs in the Illinois Statewide TRM for ASHP and CAC systems according to the system SEER ratings and for ECMs according to system horsepower. The team recommends revising the incremental costs associated with each SEER rating above 14, as outlined in Table 3 for ASHP and Table 4 for CAC. These tables show the evaluation team's recommended TRM changes for the incremental cost of moving from 14 SEER to the SEER rating shown. For example, the recommended incremental cost of $123 in the first row of Table 3 represents the average increase in the cost of a 14.5 SEER ASHP system relative to a 14 SEER system and the $108 in the second row of Table 4 represents the increase in the cost of a SEER 15 CAC system relative to a SEER 14 system, all else being equal. The recommended incremental cost estimates represent the costs associated with an average system, after accounting for costs associated with size and other features.

Table 3. Recommended TRM Changes for ASHP above 14 SEER

Efficiency (SEER)	Existing TRM V5.0 Incremental Cost ($/ton)	Calculated TRM V5.0 Incremental Cost for 3-Ton Units**	Recommended Incremental Cost for TRM V6 Update ($/Unit)***
14.5	N/A	N/A	$123
15	$137	$411	$303
16	$274	$822	$438
17	$411	$1,233	$724
18*	$548	$1,644	$724

* Data were available for a small number of ASHP systems above 17 SEER (n=14), so the evaluation team combined SEER 17 and above into a single category, resulting in a single incremental cost estimate for both SEER 17 and 18 ratings.

** We calculated the incremental cost for a 3-ton unit based on TRM V5.0. Because the typical unit size is 3 tons, these values can be compared to the recommended incremental cost estimates to illustrate how the incremental costs of a typical unit will change in the new TRM version.

*** Our analysis controlled for the system size, thus our recommended estimates are in dollars per unit, not dollars per ton.

Table 4. Recommended TRM Changes for CAC above 14 SEER

Efficiency (SEER)	TRM V5.0 Incremental Cost ($/ton)	TRM V5.0 Incremental Cost for 3-Ton Units***	Recommended Incremental Cost Estimate for V6. TRM Update ($/Unit)****
14*	$119	$357	N/A*
15	$238	$714	$108
16	$357	$1,071	$221
17	$476	$1,428	$620
18**	$596	$1,788	$620

* Data were available for only eight systems with a SEER rating below 14. These systems are not included in the model and an incremental cost estimate is not provided because the sample size is insufficient to statistically distinguish them from SEER 14 systems. Applying the incremental cost of $108 (cost from SEER 14 to SEER 15) would be a conservative estimate, but another option is to assume zero incremental cost.
** Data were available for a small number of CAC systems with SEER greater than 17.9 (n=2). Therefore, the evaluation team combined data into a single category for systems with SEER 17 and 18 ratings, resulting in a single incremental cost estimate for both SEER 17 and 18 ratings.
*** We calculated the incremental cost for a 3-ton unit based on TRM V5.0 because the typical unit size is 3 tons. This column can be compared to the recommended incremental cost estimates to illustrate how the incremental costs of a typical unit will change in the new TRM version.
**** Our analysis controlled for the system size, thus our recommended estimates are in dollars per unit, not dollars per ton.

In Table 5, we provide incremental costs for furnace retrofits to install ECMs. The Illinois Statewide TRM Version 5.0 (TRM V5.0) provides incremental costs of purchasing a furnace with an ECM relative to a furnace with a standard motor, at $97 per unit. Our analysis found that retrofit costs vary by motor horsepower. Table 5 presents the cost of upgrading an existing furnace fan motor to an ECM from a standard motor based on the motor horsepower.

Table 5. Equipment Cost for ECMs

Horsepower Range	Recommended Incremental Costs for Furnace Retrofits with ECM V6. TRM Update ($/Unit)
0.3 – 1.0	$549

Methodology

Study Data

The evaluation team collected and analyzed price and equipment specification data for residential ASHP and CAC systems from two distributors directly and one distributor's website. The team also collected data on HVAC volume discounts from the two interviews. These distributors did not provide any detail to inform the analysis. We contacted HVAC distributors from a contact list of AIC program allies that included ten HVAC distributors, provided by Leidos the HVAC program administrator. The team acknowledges the limitation of this small data set. We provide details on the sources of error and representativeness of the sample below.

The team collected and analyzed data from HVAC contractors and from independent retailers on the Amazon marketplace for the ECM retrofit incremental cost analysis. We do not have information on program purchases through Amazon.Data were collected from contractors rather than the distributors above because the objective of this analysis was to estimate costs associated to install a new ECM at a customer site. In general, HVAC distributors do not sell products directly to the consumer and are not involved with installations, whereas contractors are involved in both. Of the eight contractors on the list provided by the program administrator, four agreed to provide labor cost estimates (50% response rate). Given this response rate, the incremental cost labor estimates can be considered representative of contractors that have opted to become AIC program allies.

The team conducted a secondary data review of independent retailers with products listed on the Amazon marketplace to collect information on incremental equipment prices for ECM retrofits. There were 280 listings for "ECM blower" from 14 merchants in the Furnace Replacement Motors category but the vast majority of those were duplicate listings with identical product numbers and pricing. For example, product number HD44AE142 had nine individual listings with identical pricing, one each for Carrier, Payne, Bryant, etc. As these observations are identical, averaging across all listings for a single product number would result in biased estimates. Therefore, the team limited the analysis to unique product numbers. Table 6 summarizes the source, sample size, and objective of all collected data.

Table 6: Data Sources and Objectives

Task	Source	n	Objective
CAC Incremental Cost of Efficiency	Distributor 1 - Data Request	20	Statistical model that separates the incremental cost of efficiency, as measured by SEER rating, from the incremental cost of features that do not affect efficiency
CAC Incremental Cost of Efficiency	Distributor 2 - Web Scraping	954	Supplemental CAC data due to difficulty recruiting distributors to provide data
CAC Incremental Cost of Efficiency	Distributor 3 - Data Request	23	Statistical model that separates the incremental cost of efficiency, as measured by SEER rating, from the incremental cost of features that do not affect efficiency
ASHP Incremental Cost of Efficiency	Distributor 1 - Data Request	20	Statistical model that separates the incremental cost of efficiency, as measured by SEER rating, from the incremental cost of features that do not affect efficiency
ASHP Incremental Cost of Efficiency	Distributor 2 - Web Scraping	106	Supplemental ASHP data due to difficulty recruiting distributors to provide data
ASHP Incremental Cost of Efficiency	Distributor 3 - Data Request	60	Statistical model that separates the incremental cost of efficiency, as measured by SEER rating, from the incremental cost of features that do not affect efficiency
ECM Incremental Retrofit Cost	14 distinct retailers in the Amazon.com Marketplace	280 ECM listings (17 unique product numbers)	Incremental equipment cost for ECM retrofits
ECM Incremental Retrofit Cost	Contractor Interviews	4	Incremental equipment and labor costs for ECM retrofits

Despite offering a $500 incentive to participate in an interview, the evaluation team had substantial difficulty recruiting HVAC distributors for the ASHP and CAC portion of the study. The team called all phone numbers provided in the program administrator's contact list, requesting an interview and pricing data. Two distributors agreed to participate (20% response rate); in an effort to increase the response rate, we contacted Leidos, the program administrator, to request that program administrator staff facilitate additional recruiting. Leidos forwarded our request to CLEAResult, the program implementer, who contacted the remaining distributors to request their participation in the study, However, no additional distributors agreed to an interview or to provide cost data as a result of this outreach; many stated that it was against company policy to share proprietary pricing information. Facing these limitations on data sources, the evaluation team supplemented the interview data with data collected from the AC Wholesalers website.[1] Although retailers such as The Home Depot, Lowe's, and Walmart sell HVAC equipment, the team did not collect data from these websites because of the likelihood of additional retailer markup at these merchants. While we are testing for cost differences

[1] The AC Wholesalers website can be found at: www.acwholesalers.com

rather than absolute costs, it isn't clear that the markup at different points in the supply chain would be identifiable or would not confound the data. The team used its web-scraping capability to collect the AC Wholesalers data efficiently using a tool developed in R statistical software. We programmed the tool to collect pricing and equipment specification data from the Hypertext Mark-up Language (HTML) code on product pages of the AC Wholesalers website.

These data included costs and specifications for 182 ASHP systems and 1,004 CAC systems including four different brands[2] and a range of system specifications (i.e., various combinations of SEER, size, etc.). The team determined that the data were sufficient to study incremental costs associated with efficiency, while accounting for other system specifications, due to resulting sample size of system specifications received as described in Table 1 and Table 2. Using these data, we were able to control for non-efficiency related effects on costs in the estimates of efficiency-related effects (e.g., costs associated with which distributor the system was sold by and the size of the system). The team considered including the brand of equipment in the analysis but found that it was confounded with distributor – distributors 1 and 3 carry one brand each. The AC Wholesalers website included four brands, two of which were the same brands carried by one of the other two distributors (Comfortmaker and Carrier). Within these, there are a number of system product numbers that were sold at the AC Wholesalers website and at one of the other two distributors. For these identical systems, there is a price difference between the distributors, suggesting that some of the price effect is due to distributor and not brand.

Because the system specifications varied across combinations of five to 10 other variables and we were able to control for the effect of distributor on price, the team feels confident the analyses control for study distributors and/or brands sufficiently. The team also examined the effect of various model specifications on the estimates associated with SEER level and found the estimates were stable. The team acknowledges, however, that the results could be biased, if pricing and system specifications have a fundamentally different relationship among distributors in the wider population, than those represented in this study.

Sources and Mitigation of Error

Table 7 provides a summary of possible sources of error associated with data collection conducted for the incremental cost analyses. Detailed discussions follow for each item below.

Table 7. Sources of Error

Research Task	Uncertainty in Results		Non-Survey Error
	Sampling Error	Non-Sampling Error	
Incremental Cost Analysis	NA	Non-random selection of respondents Non-response Self-selection	Data processing

- Non-random selection of respondents
  - The evaluation team did not randomly select distributors from the population or a representative sample frame of distributors. Rather, the team received a list of distributors from the program administrator and attempted contacting all distributors on the list. Two of ten distributors agreed to provide data and participate in an interview. Incomplete knowledge about the population of distributors and non-random selection implies that the team cannot know (or assume, as allowable when random sampling) that the sample is

[2] Brands included Comfortmaker, Goodman, Carrier, and Rheem. Comfortmaker is a brand offered by Carrier's parent company (United Technologies), thus, the data include three of the major HVAC manufacturers.

representative of the population and/or that the resulting estimate is free of self-selection or other biases.

- The evaluation team had substantial difficulty collecting data from HVAC distributors due to concerns about sharing proprietary pricing information. As a result, the team's observations about pricing, based on these distributors' data, may not be representative of the population of HVAC systems sold by the population of distributors. The team accounted for observed differences between distributors by including a distributor indicator in the regression analysis.

- Note that the brands in the study data represent approximately one-quarter of all CAC and ASHP systems in AIC's Program Year 8 (PY8) tracking database. The brand Carrier is included in the incremental cost analyses data and accounts for 16% of all ASHP and 17% of CAC systems in PY8. However, two major manufacturers, Trane and Lennox, make up a substantial share of systems in the PY8 database and are not represented in the study data. Trane represents 37% of all ASHP systems and 24% of all CAC systems in the PY8 data; Lennox represents 10% of all ASHP systems and 19% of all CAC systems in the PY8 data. Carrier has the third-highest share of CAC systems in the PY8 data with 17%, and has the second highest share of ASHP systems, with 16%. Table 8 shows the proportion of systems in the AIC PY8 data that are represented in the HVAC incremental cost study data.

Table 8: Proportion of Systems in PY8 Tracking Data with Brands Represented in Study Data

Brand	ASHP	CAC
Carrier	16.3%	17.3%
Comfortmaker	1.6%	1.6%
Goodman	5.5%	2.1%
Rheem	0.3%	2.2%
Total	**23.7%**	**23.1%**

- The team collected data from two distributors that opted to provide pricing data and one that had data publicly available online. Thus the results are subject to self-selection bias associated with the distributors that opted in and "availability bias" associated with the online distributor. If distributors who agreed to participate in the study or had data available online were different than other distributors in the population, the study findings may not provide an accurate estimate of incremental costs for all distributors. We analyzed distributors individually and found that results vary significantly among distributors.

- Given the difficulty of recruiting, these biases are difficult to control for. Based on the evaluation team's expertise in HVAC systems, however, the team does not expect the relationship between incremental costs of SEER rating in the population to differ from what was observed for the three distributors included in the study. We compared results to other recent studies to verify results are consistent. These comparisons are described further below.

- The team collected ECM data from the Amazon marketplace. The team reviewed ECM listings during the July 25, 2016 to August 1, 2016 period. We did not log into an Amazon account for the review, and the review was conducted from a computer with a Denver, Colorado Internet Protocol (IP) address. However, the team recognizes that Amazon's dynamic pricing could introduce bias into the estimates.

- Data processing errors

  - The team collected distributor specification data through interviews and web scraping. To mitigate data processing errors, a company senior HVAC expert reviewed all collected data. A company senior statistician reviewed the regression analysis, verifying that assumptions and modeling follow statistics best practices.

Hedonic Modeling

Using the collected data, the evaluation team built two hedonic regression models in SAS statistical software: one for ASHP systems and one for CAC systems. The team estimated changes in price associated with increasing SEER ratings while controlling for the effects that other non-efficiency-related features had on prices. The team explored nonlinear relationships, e.g., log-linear models and higher-order effects but found that the linear models resulted in the best fit. The analysis for ECM retrofit incremental costs was based on different methodology and is described in the ECM Cost Analysis section below.

Model Selection

The evaluation team developed a process for model selection to determine which variables to include in the regression models. The process included objective criteria such as regression statistics and residual plots as well as contextual criteria including model interpretability and *a priori* input from distributors and Cadmus HVAC experts.

To select model for each system type, the team followed these steps:

Step 1. Stepwise selection of main effects, resulting in a base model.

Step 2. Test and select interaction terms, examine fit statistics, resulting in the final model.

In Step 1 the team selected main effects using backward stepwise selection, starting with the full set of possible main effects in the model (after removing collinear terms). The set of possible main effects included those identified *a priori* based on subject matter expertise and those that appeared to be associated with price in the team's pre-analysis data exploration. The full model specification for both ASHP and CAC models prior to stepwise selection was:

$$Price_i(\$) = \beta_0 + \beta_1 SEER_i + \beta_2 Size_i + \boldsymbol{\gamma}\, Non\text{-}Efficiency\ Variables_i + \varepsilon_i$$

In this model, price is the dependent variable, with one observation *i* for each system in the dataset. The parameters associated with the independent variables are defined as:

- β_0 represents average price.
- β_1 represents marginal changes in system price associated with SEER.
- β_2 represents marginal changes in price associated with the size of the system (tons).
- $\boldsymbol{\gamma}$ represents the set of effects on price associated with changes in other, non-efficiency-related, variables.
- ε represents the variation in prices that is not explained by the independent variables.

The evaluation team used the generalized linear model procedure (proc GLM) in SAS statistical software to perform the regression modeling and the stepwise generalized linear model procedure (proc GLMSelect) for stepwise selection for both system types.

The team worked with in-house HVAC experts and distributor contacts to identify the initial variables expected to influence system price or efficiency. The team tested the following variables: distributor, system manufacturer, system SEER, coil guard, coil type, air handler type, air handler configuration, smart thermostat integration indicator, outdoor temperature sensor indicator, sound dampening indicator, crankcase heater indicator, tons, and furnace annual fuel utilization efficiency (AFUE). We then examined correlation and scatterplot matrices to ensure that no efficiency-related variables were included in the model besides SEER rating.

Once the main effects for the base models were selected, the evaluation team tested the interactions between independent variables when our pre-analysis data visualization indicated a possible interactive effect, iterating through 10 to 15 models for each system type. The evaluation team assessed model fit based on residual plots, adjusted R^2, Akaike information criterion, and Bayesian information criterion (BIC)[3]. We examined residual plots to ensure residuals were scattered evenly around zero without any pattern, indicating that the assumptions associated with linear regression were being met[4] and that the models controlled for the majority of the variation in prices. Models with adjusted R^2 values close to 1.0 had a better fit than models with lower values and the final ASHP model and CAC model each had an adjusted R^2 of about 0.95 (in sample), suggesting that the models explain 95% of the variation in prices. The adjusted R^2, however, does not account for over-fitting, and so we also used the Akaike information criterion and BIC statistics to compare model specifications, where lower values suggest better fitting models and both statistics are penalized as the number of independent variables in the model increases. When comparing model specifications at each stage in the stepwise selection, the team considered all three regression statistics to determine which model provided the best fit.

ASHP Model Specification and Interpretation

In Table 9, we provide details on the final ASHP model specification, with estimated coefficients, standard errors, and p-values. We provide an interpretation of the model below.

Table 9. ASHP Hedonic Model (n = 182; Adjusted R^2 = 0.948)

Variable	Coefficient	Standard Error	P-Value
Intercept	1356.03	91.08	<.0001
Tons	532.82	25.74	<.0001
Distributor 1*	-532.33	155.20	0.00
Distributor 2*	-700.68	101.51	<.0001
Distributor 3*	-	-	-
SEER 17 – 18	724.42	81.02	<.0001
SEER 16 - 16.9	437.54	56.50	<.0001
SEER 15 - 15.9	302.69	43.69	<.0001
SEER 14.5	122.86	46.44	0.01
SEER 14	-	-	-
Smart Thermostat Integration and Outdoor Temperature Sensor	649.19	56.03	<.0001
No Smart Thermostat Integration or Outdoor Temperature Sensor	-	-	-
Coil Type: A-Coil	271.57	42.83	<.0001
Coil Type: Slab/Slope	-	-	-
Tons*Distributor 1	-126.15	45.22	0.01
Tons*Distributor 2	-166.08	30.62	<.0001
Tons*Distributor 3	-	-	-
* Distributors 1, 2, and 3 represent each of the two distributors the team interviewed and the AC Wholesalers website.			

The final ASHP model includes system SEER rating and size in tons, along with non-efficiency variables including distributor, smart thermostat integration indicator, coil type, and an interaction between tons and distributor.

[3] AIC and BIC assume normality in the distribution of errors. The team reviewed residual plots to ensure that residuals were distributed normally. Small deviations in the normality of the does not have a large effect on these statistics.

[4] Assumptions associated with the regression modeling used in these analyses include that the regression function is linear and that the error terms have constant variance, independence, and follow a normal distribution.

ASHP SEER Rating

The system SEER ratings were grouped into the following categories: SEER 14, SEER 14.5, SEER 15-15.9, SEER 16-16.9, and SEER 17 and up. SEER 14 was set as the base term in the regression and the effects of the other categories were estimated relative to this rating category. The coefficients can be interpreted as follows, holding everything else constant:

- SEER 14.5 systems are priced $123 higher than SEER 14 systems, on average.
- SEER 15-15.9 systems are priced $303 higher than SEER 14 systems, on average.
- SEER 16-16.9 systems are priced $438 higher than SEER 14 systems, on average.
- SEER 17 and up systems are priced $724 higher than SEER 14 systems, on average.

The evaluation team tested interactions between SEER and size as well as between SEER and other non-efficiency variables. None were significant.

ASHP Model Non-Efficiency Variables

The evaluation team found evidence that both the size of an ASHP and the distributor through which the system is sold have significant effects on price. The interaction between size and distributor is also significant, indicating that the effect of size on price differs depending on which distributor the system is sold through. The interpretation of the tons, distributor, and tons-distributor interaction term are (holding all other variables constant):

- ASHP price increases $407 for every one-ton increase in systems sold by distributor 1, relative to distributor 3, on average.
- ASHP price increases $367 for every one-ton increase in systems sold by distributor 2, relative to distributor 3, on average.
- ASHP price increases $533 for every one-ton increase in systems sold by distributor 3, on average.

Note that the significance of the effect of distributor on system price is not only statically significant but could have practical implications as well. Recall that the data only include prices from three distributors and so there is a risk that the result is not representative of the population. However, as discussed above, our assessment is that the data are reasonably representative of the relationship between SEER and system prices as we compared results to two other recent studies[5]. Further, the model controls for distributor and, thus, the incremental cost estimates associate with SEER level reflect increases *after* controlling for distributor (and other variables), providing reasonable estimates of average price increases for the TRM Version 6.0.

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[5] We compared results to a Massachusetts study using a "tear down" approach to model products costs of new equipment and to a hedonic analysis of ASHP in California and found that both studies had results closer to ours than the existing TRM values. Massachusetts study is "Cool Smart Incremental Cost Study: Final Report," Cadmus and Navigant, July 2015. Prepared for The Electric and Gas Program Administrators of Massachusetts Part of the Residential Evaluation Program Area. http://ma-eeac.org/wordpress/wp-content/uploads/Cool-Smart-Incremental-Cost-Study.pdf. The California study is "2010-2012 WO017 Ex Ante Measure Cost Study" located at http://www.calmac.org/publications/2010-2012_WO017_Ex_Ante_Measure_Cost_Study_-_Final_Report.pdf

The presence of smart thermostat integration and factory-installed outdoor temperature sensors were confounded in the data set – all ASHP systems in the data with smart thermostat integration also had factory-installed outdoor temperature sensors. As a result, the estimated coefficient represents the combined effect of both features on system price. Holding all other variables constant, the presence of these two specifications is associated with a $649 increase in price.

The team categorized evaporator coil types in the data as either A-Coil or slab/slope. In the analysis, we set slab/slope as the base term. The presence of an A-type evaporator coil in a system is associated with an average $272 increase in price relative to slab/slope, holding all other variables constant.

We did not find evidence that the other non-efficiency related variables had significant effects on pricing, including system manufacturer, coil guard, air handler type, air handler configuration, sound dampening indicator, crankcase heater indicator.

CAC Model Specification and Interpretation

In Table 10, we provide details on the final CAC model specification with estimated coefficients, standard errors, and p-values. We provide an interpretation of the model below.

Table 10. CAC Hedonic Model (n = 997; Adjusted R^2 = 0.937)

Variable	Coefficient	Standard Error	P-Value
Intercept	1165.55	27.15	42.93
Coil Guard Wire Grille	-1079.71	74.87	-14.42
Coil Guard Louvered Coil Guard	-	-	-
Smart Thermostat Integration, Factory-Installed Outdoor Temperature Sensor, Factory-Installed Crankcase Heaters, and Sound Dampening Blankets	38.93	46.44	0.84
No Smart Thermostat Integration, Factory-Installed Outdoor Temperature Sensor, Factory-Installed Crankcase Heaters, and Sound Dampening Blankets	-	-	-
SEER 17 - 18	619.98	27.61	<.0001
SEER 16 - 16.9	220.98	19.11	<.0001
SEER 15 - 15.9	108.44	16.30	<.0001
SEER 14 - 14.9	-	-	-
Tons	321.86	6.78	<.0001
Distributor 1	890.40	153.26	<.0001
Distributor 3	845.57	140.17	<.0001
Distributor 2	-	-	-
Furnace AFUE 0.97	913.62	22.08	<.0001
Furnace AFUE 0.96	569.97	20.66	<.0001
Furnace AFUE 0.98	760.03	31.05	<.0001
Furnace AFUE 0.95	331.87	69.97	<.0001
Furnace AFUE 0.80	256.01	47.67	<.0001
Furnace AFUE 0.92	-	-	-
Tons*Smart Thermostat Integration, Factory-Installed Outdoor Temperature Sensor, Factory-Installed Crankcase Heaters, and Sound Dampening Blankets	104.18	12.53	<.0001
Tons*No Smart Thermostat Integration, Factory-Installed Outdoor Temperature Sensor, Factory-Installed Crankcase Heaters, and Sound Dampening Blankets	-	-	-
Tons*Distributor 1	67.10	36.97	0.0698
Tons*Distributor 3	185.20	37.63	<.0001
Tons*Distributor 2	-	-	-

The final CAC model included variables of coil guard, system SEER rating, size, AFUE, one indicator representing the confounded effect of smart thermostat integration, factory-installed outdoor temperature sensor, factory-installed crankcase heaters, and sound dampening blankets indicator, an interaction between size in tons and outdoor temperature sensor indicator.

CAC SEER Rating

System SEER ratings were grouped into categories: SEER 14-14.9, SEER 15-15.9, SEER 16-16.9, and SEER 17 and up. SEER 14-14.9 were set as the base term. Systems with a SEER rating below 14 were not included in the model because the subsample was too small (n=8). The SEER coefficients can be interpreted as follows, holding everything else constant:

- SEER 15-15.9 systems are priced $108 higher than SEER 14-14.9 systems, on average.
- SEER 16-16.9 systems are priced $221 higher than SEER 14-14.9 systems, on average.
- SEER 17 and up systems are priced $620 higher than SEER 14-14.9 systems, on average.

The evaluation team tested interactions between SEER and size as well as other non-efficiency variables. None were significant.

CAC Model Non-Efficiency Variables

Coil guard is a categorical variable where the coil guard is either a wire grille or louvered coil guard. Systems with wire grille coil guards tend to be associated with a $1,080 decrease in system price, in comparison to those with a louvered coil guard.

The presence of factory-installed outdoor temperature sensors, smart thermostat integration, factory-installed crankcase heaters, and sound dampening blankets were, for the most part, confounded in the data set. The majority of CAC systems with one of these specifications also had the others and as a result, the estimated coefficient should be interpreted as the combined effect of any/all four variables but it is unknown whether or not each has an individual impact or not. Note that the main effect of the variable itself is not significant (p-value >0.05), but we included it in the model because its interaction with size is significant.

System size has a significant main effect and, due to its interaction with other variables, its interpretation depends on distributor and the presence of outdoor temperature sensors and/or other confounded variables.

- CAC price increases $493 for every one-ton increase in size of systems sold with factory-installed outdoor temperature sensors, smart thermostat integration, factory-installed crankcase heaters, and sound dampening blankets, relative to systems without and systems sold from distributor 2.

- CAC price increases $611 for every one-ton increase in systems sold with factory-installed outdoor temperature sensors, smart thermostat integration, factory-installed crankcase heaters, and sound dampening blankets and from distributor 2.

Distributor and warranty types were confounded for CAC systems– each distributor sold a distinct type of warranty which did not vary by SEER level. The distributor variable is categorical with distributor 2 set as the base case. Systems sold by distributor 3 have prices $846 higher than systems sold by distributor 2, on average. Systems sold by distributor 1 have prices $890 higher than systems sold by distributor 2, on average.

The furnace AFUE variable is a categorical variable with 0.92 set as the base case. The effects of the other furnace AFUE levels can be interpreted relative to AFUE 0.92. For example, systems with furnace AFUE 0.98 are priced, on average, $767 higher than systems with AFUE 0.92. Although the result is non-intuitive for AFUE 0.80 (on average $256 higher than AFUE 0.92), it is what we observed in the data. A small number of more expensive systems have a low AFUE rating of 0.8 but comparatively high SEER ratings, ranging from 16-16.9.

ECM Cost Analysis

The evaluation team interviewed four contractors to collect installation labor-cost quotes for ECM retrofits. Three contractors provided labor-only cost estimates in two labor-hour increments, with hourly costs ranging from $80 to $100 per hour. Among these contractors, the average labor-cost estimate of the total cost of an ECM retrofit was $180. The fourth contractor did not provide labor-only costs but estimated combined equipment and labor costs for ECM retrofits between $500 and $600. Pulling all of this information together, we estimated the total ECM retrofit cost, including equipment and labor, to be between $435 and $567.

The evaluation team also reviewed a sample of items sold by HVAC vendors through the Amazon marketplace to determine the average cost of furnace blower ECM systems and to estimate incremental costs associated with system horsepower. The team reviewed ECM listings during the July 25, 2016 to August 1, 2016 period. We did not log into an Amazon account for the review, and the review was conducted from a computer with a Denver, Colorado IP address. There were 280 listings for "ECM blower" from 14 merchants in the Furnace Replacement Motors category but the vast majority of those were duplicate listings. For example, product number HD44AE142 had nine individual listings with identical pricing, one each for Carrier, Payne, Bryant, etc.

Summary of Research Findings

ASHP Incremental Costs

Table 11 shows the estimated incremental cost increases associated with changes in SEER ratings for ASHP systems. The second column shows the estimated average increase in price of each SEER rating over a SEER 14 rating, holding all other features constant. The third column shows results from the Massachusetts study, referenced above, with the existing TRM values for 3-ton units, while the fourth column illustrates results from the California study, also referenced above, which found that incremental efficiency costs averaged $457/unit of SEER between SEER levels of 13 and 20. The final column shows the current IL TRM V5.0 as comparison.

Table 11. Incremental Cost of Efficiency (SEER): ASHP above 14 SEER

SEER Bin	Price Increase from SEER 14 ($)	MA Study	CA Study	TRM V5.0
SEER 14.5	$123		$457	
SEER 15 - 15.9	$303	$304		$411
SEER 16 - 16.9	$438	$535		$822
SEER 17 - 18	$724	$1,310		$1,233-$1,644

CAC Incremental Costs

Table 12 shows the estimated incremental costs associated with CAC system SEER ratings. These are the estimated average increase in prices for each SEER rating, in comparison to systems with SEER 14 – 14.9 ratings, holding all other features constant. The third column shows results from the Massachusetts study, referenced above, with the existing TRM values for 3-ton units. The fourth column shows existing TRM V5.0 for comparison

Table 12. Incremental Cost of Efficiency (SEER): CAC above 14 SEER

SEER Bin	Price Increase from SEER 14 ($)	MA Study	TRM V5.0
SEER 15 – 15.9	109	$174	$714
SEER 16 – 16.9	$221	$361	$1,071
SEER 17 – 18	$620	$1,161	$1,428-$1,788

Volume Discounts

The interviewed distributors indicated that they each offered volume discounts for larger orders. One distributor indicated that it provided discounts for high volume purchases related to AIC's programs but declined to provide further detail on the discounts or how they relate to the program. The other distributor indicated it did not provide discounts specifically for AIC programs but did provide discounts based on total equipment sales to individual customers. It also indicated that the discounts increased whereas contractors increased sales year-over-year. These distributors offered discounts ranging from 16% to 23%, depending on contractor sales.

ECM Retrofit Incremental Costs

Table 13 shows the estimated incremental costs for furnace retrofits to install ECMs.

Table 13. Equipment Cost for Furnace Blower ECMs

Horsepower Range	n	Average Price	Min Price	Max Price
0.3 - 1.0	17	$367	$239.98	$424.95

Conclusions

The evaluation team found that ASHP and CAC system prices increase as energy efficiency increases but that efficiency is not the only factor that affects price. Other factors associated with increased costs of ASHP systems include smart thermostat integration, coil type, and from which distributor the system is sold. Other factors associated with increased costs of CAC systems include the distributor and its warranty, efficiency of the furnace with which the system is integrated, type of coil guard, and presence of smart thermostat integration, factory-installed outdoor temperature sensor, factory-installed crankcase heaters, and sound dampening blankets. We found that the cost of retrofitting an existing furnace with an ECM increased as the size of the motor in horsepower increased.