Impacts of the OPA HVAC Installation Optimization Training Program on Realized Energy Efficiency of Retrofit AC Systems

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ABSTRACT

In an effort to ensure that newly installed retrofit air conditioners achieve their design efficiency levels, IESO established the HVAC Installation Optimization Training Program in cooperation with the Heating, Refrigerating and Air Conditioning Institute of Canada (HRAI). The training program consisted of an 8 hour classroom exercise that emphasized use of best practices for installation of HVAC systems – focusing heavily on the installation practices that are thought to cause efficiency losses (e.g., sizing, correct matching of evaporator coil to condensing unit, etc. To assess the effectiveness of this training program, the realized energy efficiency ratios (EER) for air conditioning systems installed by a random sample of technicians before and after they received training were observed. Interval measurements were taken for a period of 5 to 10 weeks over the course of the summer cooling season between July and September. The test was carried out with experienced installers to ensure that maturation did not account for substantial improvement in the performance of the installers between the first and second test observation. The realized EER for the sites in the study was determined to be about 81% -- somewhat higher than estimates published by US DOE and others. No difference was found in the realized energy efficiency of air conditioners installed before and after installers received training.

Introduction

The U.S. Department of Energy (DOE) reports nearly 30% of the energy efficiency of newly installed air conditioning units can be lost as a result of design and installation errors. Figure 1 below describes the magnitude of the lost efficiency associated with different system design and installation errors.

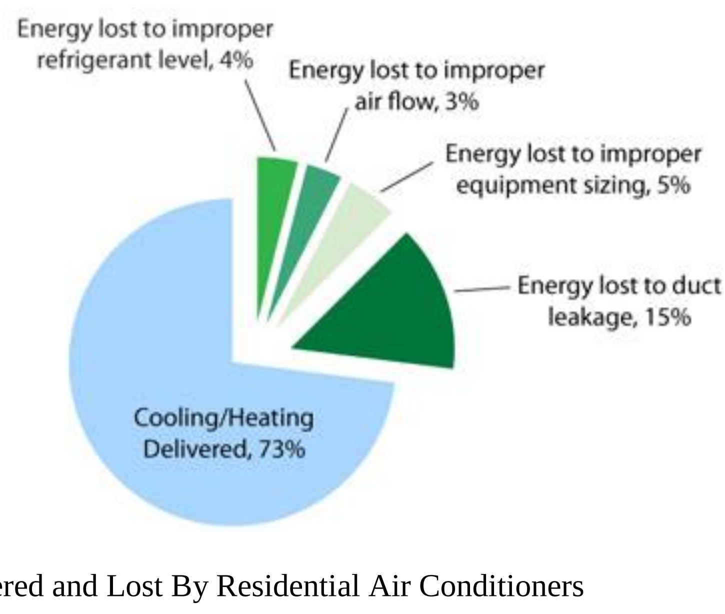

Figure 1. Energy Delivered and Lost By Residential Air Conditioners

In addition to studies conducted by DOE, a market potential study carried out by the Heating, Refrigerating and Air Conditioning Institute of Canada (HRAI) indicated a substantial fraction of the sales and installation labor force was not following best practices in these critical areas. For example, less than half of the installers responding to a survey indicated that they were carrying out the calculations required to determine the size of AC unit that should be installed at the premise.

To ensure that air conditioning units installed under its Heating and Air Conditioning Incentive Program achieved their full energy saving potential, OPA sponsored the HVAC Installation Optimization training course in cooperation with the HRAI. The course was offered in spring of 2013 and 2014 and was attended by approximately 16,000 sales and installation engineers throughout Ontario. Virtually all of the students attending the course were licensed refrigeration mechanics with hundreds of hours of training and experience. The course was not designed to teach the elements of refrigeration, but instead concentrated on the critical important design and installation practices. These included:

- Fundamentals of duct design and sealing
- Calculation of correct size of system (in AC Tons)
- Correct evaporator coil matched with condensing unit
- Correct air flow over the evaporator coil
- Correct refrigerant charge
- Complete commissioning

This paper summarizes the efforts undertaken to determine whether the training improved the Field energy efficiency (EER) of air conditioner replacements installed by technicians.

Overview of Approach

The training program is a behavioural initiative intended to achieve energy savings by improving performance of air conditioner sales and installation technicians. It is possible to approach the evaluation of such a program in several ways resulting in tests with varying degrees of rigor. To begin, the design of the program imposed certain powerful constraints on the research design. They are:

- The target population of sales and installation technicians were required to receive the installation optimization training before they were eligible to claim incentives from the 2014 Heating and Air Conditioning Incentive program;
- Sales and installation technicians voluntarily selected the times and places of their training; so the researchers had no control over who received the training or when it occurred – although we do know where and when it occurred for each technician after the fact;
- Because we could not control the assignment of trainees to the training, it was not possible to use any of the variants of the randomized controlled trial (RCT);
- The important research question was not whether the sales and installation engineers were aware of the best practices for design and installation – they all were trained refrigeration mechanics who should have been aware of best practices. The important research question was whether exposure to the course would increase their likelihood of applying the subject best practices.
- It was not really possible to observe whether technicians were applying appropriate design and installation practices before they received training —since we only become aware of an installation after they have installed it and applied for the incentive.

However, OPA and HRAI maintained detailed records concerning the details of air conditioner installations made by the parties trained in the program – before and after they received training. So it was possible to identify, locate and most importantly measure the efficiency of air conditioners that were installed before and after the parties who installed them were exposed to the installation optimization training. This is known as a one-shot pretest-posttest design. It is a comparison of the energy efficiency of units that were installed by particular trainees before they received training, with the energy efficiency of systems that were installed by the same trainees after they received training. If the installations that occurred after training were significantly more energy efficient than those that occurred before training it is reasonable to conclude that the training had a significant effect. If they were not different, then the training probably had no effect.

The use of this study design and the inference about the effect of training depend on two critical assumptions:

- That difference in the energy efficiency of systems installed before and after training was not caused by some factor other than the training (e.g., new technology is introduced that is less susceptible to installer error); and
- The difference in the energy efficiency of the systems installed before and after training is not the result of normal decay in the efficiency of appliances after they have been installed (e.g., refrigerant charge degrading, filters becoming clogged, etc.)

While these threats to validity are legitimate concerns, they are really only material if a difference in the energy efficiency of units is observed before and after the technicians have been trained. As we shall see in the sections that follow, there is little reason to be concerned that these threats to validity have affected the results.

In this study, the following approach was employed:

1. All locations for which Heating and Air Conditioning Incentives were paid from 2011 through 2013 were identified;

2. A sample of 100 installers who had installed at least 10 air conditioning systems before and after exposure to the training was identified;

3. Owners of buildings whose air conditioners were installed by a given trainee were recruited in random order – one building owner before the installer was trained and one building owner after – the number of installations tested before and after was determined by the availability of resources to carry out the test;

4. Engineers visited each of the cooperating sites collecting field measurements needed to calculate the installed energy efficiency of the air conditioner and installing data loggers collecting current and temperature data needed to calculate the EER of the installed units

5. Engineers returned to each site to collect the loggers and return them to the engineering analysts after the performance of the AC unit had been measured for a period of between 3 and 5 weeks during the summer season.

6. The data were cleaned and the field energy efficiency ratios were calculated for all appliances in the study.

Methodology

The first step in the process of calculating the Field EER for a given installation is to calculate the Instantaneous Field EER (IFEER) for each 3 minute interval for which the appliance was in operation. This is calculated by dividing the cooling energy measured during the interval by the power consumption of the system during the interval. Calculations of IFEER for one project are displayed in Figure 2, where the x-axis represents time and the y-axis shows IFEER. Each plus symbol on the chart represents a single calculation of IFEER. The chart shows wide variability in IFEER across the logging period. The change of IFEER within a single cooling cycle is also shown to be decreasing over time.

This pattern was present across most of the homes in the sample, and is attributable to the shift in system parameters during each cooling cycle. When the air conditioner first turns on, air in the home is at its warmest level and the temperature difference at the evaporator coil is at a maximum. A larger temperature difference increases the efficiency of heat transfer between the evaporator coil and passing airflow, creating conditions where the system operates at its highest efficiency. As the system continues to run, air in the home cools, this decreases the temperature difference at the coil resulting in lower IFEER levels. The final Field EER value for a home is the average of all IFEER measurements across the entire logging period.

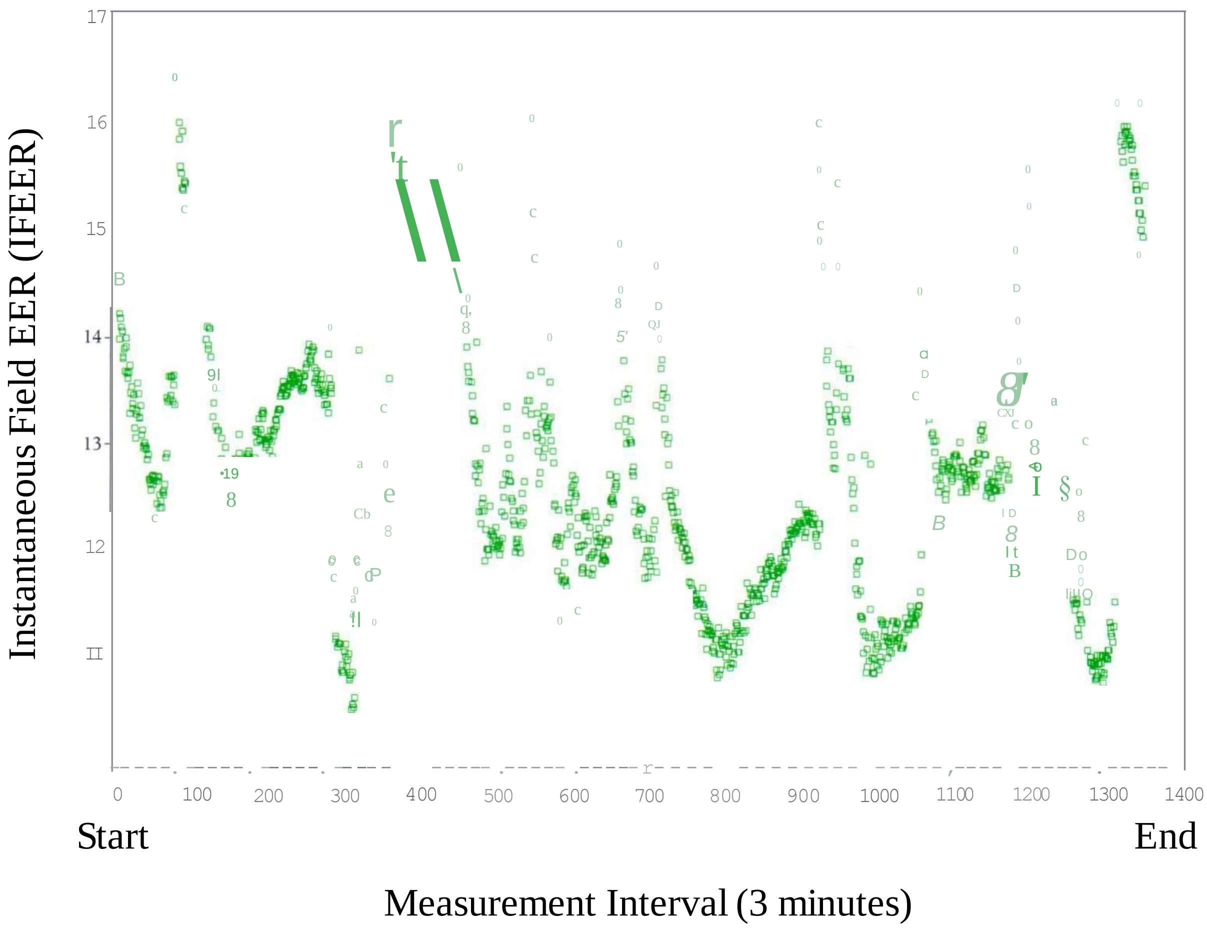

Figure 2. Instantaneous Field EER Over Time

In order to calculate cooling energy the study completes an energy balance between energy levels measured on the return and supply side of the evaporator coil. Looking at the difference between these energy levels we apply the conservation of energy to assume that any difference is attributed to energy removed from the system by the evaporator coil.

$$Cooling\ Energy\left[\frac{Btu}{hr}\right] = 4.5 \times CFM \times \Delta h$$

$$\Delta h = h_{return} - h_{supply}$$

$$h = Enthalpy = \ SH_{air} \times DBT_{^\circ F} + \left(SH_{vapor} \times DBT_{^\circ F} + h_{WV}\right) \times \frac{Ratio \times AVP \times \frac{RH}{100}}{BP - AVP \times \frac{RH}{100}}$$

The difference provides the Cooling Energy of the air conditioner at any moment. Table 1 shows the inputs for the cooling energy equations.

Table 1. Inputs for Cooling Energy Equations

Variable	**Representation**	**Value**	**Units**	**Source**
CFM	Cubic feet per minute	Varies	cfm	TrueFlow Air Handler Flow Meter
SH_{air}	Specific heat of air	0.24	Btu/lbm °F	Constant
SH_{vapor}	Specific heat of water vapor	0.444	Btu/lbm °F	Constant
$DBT_{°F}$	Dry bulb temperature in °F	Varies	°F%	Data logger
RH	Relative humidity	Varies	%	Data logger
h_{wv}	Enthalpy of saturated water vapor at 0° F	1061	Btu/lbm	Constant
Ratio	Ratio of molecular mass of water vapor to dry air	0.621	no units	Constant
AVP	Absolute Vapor Pressure	Varies	kPa	Calculated using supply\return temperature measurements
BP	Barometric pressure	99.51	kPa	Average of Toronto weather during logging period

The power consumption is the total amount of energy needed to operate the AC condenser and AHU, and this input takes into account the voltage, current, and power factor on the system at a given moment. Table 2 shows the inputs for the power consumption equation.

$$Power\ Consumption = [V_{AHU} \times I_{AHU} \times Power\ Factor_{AHU}] + [V_{AC} \times I_{AC} \times Power\ Factor_{AC}]$$

Table 2. Inputs for Power Consumption Equation

Variable	**Representation**	**Value**	**Source**
V_{AHU}	Voltage at AHU [V]	120.8	Average of spot measurements across sample
V_{AC}	Voltage at AC condenser [V]	241.8	Average of spot measurements across sample
I_{AHU}	Current at AHU [Amps]	Varies	Data logger
I_{AC}	Current at AC condenser [Amps]	Varies	Data logger
Power $Factor_{AHU}$	Power factor at AHU	0.71	Average of spot measurements across sample

Power $Factor_{AC}$	Power factor at AC condenser	0.96	Average of spot measurements across sample

Seasonal Energy Efficiency Ratio (SEER) is the most common air conditioner efficiency rating, but since the period of data collection did not coincide with an entire cooling season the study focused on the Energy Efficiency Ratio (EER) instead. Conversions between SEER and EER used the following equation:

$$EER = -0.02 \times SEER^2 + 1.12 \times SEER$$ [1]

Sample Design and Customer Recruiting

Building owners for each randomly selected technician were approached in random order and taken into the study on a first come, first served basis. Restriction of the sample of technicians to those with at least 10 installations before and after training was required in order to ensure that at it was possible to observe the efficiency of air conditioning units installed before and after the randomly sampled technicians had received training. The test sites were contacted by Population Research Systems using the telephone numbers that had been provided to OPA at the time the incentive claim forms were completed. For each technician, Nexant's market research laboratory was provided with 10 building owners whose air conditioners had been installed before and after training. They were instructed to call the building owners in random order, explain the study and offer them the opportunity to participate. Customers were offered the sum of $200 to agree to make their homes available for the study -- $150 at the time of the installation of the logging equipment and $50 at the time the equipment was received.

On-site Measurement Protocols

To collect data for the study, engineers were deployed to the homes of 200 participants who purchased a new air conditioner through OPA's Heating & Cooling Incentive Program. While on-site the engineers collected nameplate data, thermostat set-points and spot measurements on system related parameters. The engineers also placed logging equipment to measure temperature changes and power consumption over time. Data loggers were in place between 5 to 10 weeks from early July to late September 2014.

Nameplate data collected on-site included:

- Air conditioner make, model, cooling capacity (tons), and rated efficiency (SEER)
- Furnace make, model, heating capacity (Btu/h), efficiency (AFUE), and fan horsepower

Thermostat schedules and set-points included:

- Cooling set-points
- Heating set-points
- Daily schedules with related setup/setback levels and times when the set-points shifted

Spot measurements allowed each system to be properly characterized and provided data used in the calculation of Field EER (Table 3).

Table 3. Spot Measurements

[1] Robert Hendron and Cheryn Englebrecht "Building America House Simulation Protocols" p.47, NREL October 2010

Data Point	Location	Equipment
Voltage	AC condenser and AHU	Amprobe ACD-41PQ
Current	AC condenser and AHU	Amprobe ACD-41PQ
Power	AC condenser and AHU	Amprobe ACD-41PQ
Power Factor	AC condenser and AHU	Amprobe ACD-41PQ
CFM	AHU	TrueFlow Air Handler Flow Meter

All power related spot measurements (voltage, current, power, power factor) were taken using an Amprobe ACD-41PQ clamp meter. AC condenser voltage was measured between the two wires on the contactor. Current through one of incoming wires was measured with the current clamp, and power and power factor calculated automatically on the clamp meter when voltage and current were measured simultaneously. The same power measurements were taken on the air handler unit (AHU), with the voltage drop measured between the hot wire and ground.

The final spot measurement taken at each home was airflow across the evaporator coil. This measurement was taken using the TrueFlow Air Handler Flow Meter, an instrument designed specifically to measure airflow. The flow meter resembles a flat plate the size of a furnace filter, and it is installed in the filter slot of the AHU. When the AHU and fan are turned on, flow rates are measured as air moves across the plate. For systems with multi- or variable speed motors multiple flow rates were measured by modulating the fan speed, which was accomplished by adjusting thermostat set-points.

Engineers also placed logging equipment in each home to measure system operational levels over a 5 to 10 week period. Each logger used a 3 minute interval to collect data.

Table 4: Logged Data Measurements

Data Point	Location	Measurement Device	Data Logger
Current	AC condenser	Magnelab CT[1]	Hobo H22-K
Current	AHU unit	Magnelab CT[1]	Hobo H22-K
Temperature and Relative Humidity	Supply side of evaporator coil	Onset Temperature/RH sensor[2]	Hobo H22-K
Temperature and Relative Humidity	Return side of evaporator coil	Onset Temperature/RH logger[3]	Internal

1 Model number, SCT-0750-050
2 Model number, S-THB-M002
3 Model number, UX100-003 or U12-012

Each current transducer (CT) was placed inside the AC condenser or AHU and around one of the wires providing electricity to the system. The measurement probe for temperature and relative humidity on the supply side of the evaporator coil was placed into the plenum (through a small hole drilled into the duct work) a few feet downstream from the coil. Data for these three measurements were captured by a Hobo H22-K micro-station data logger, with one H22-K located outside at the condenser and another inside the AHU. The final data point, temperature and relative humidity on the return side of the evaporator coil, was logged using an Onset UX100-003 (or U12-012) logger with internal memory. This device was placed inside the fan cabinet of the AHU.

Data Cleaning

The study targeted 200 homes but logging equipment was only placed in 181 due to incompatible HVAC equipment, construction conditions that prevented installations and cancellations by expected participants. Data loggers were removed from the homes between late September and late October 2014. Due to the complexity of this study each home had four data loggers installed on-site. If any of the four loggers failed to collect data, or provided questionable data, the home was removed from the analysis sample. This further reduced the size of the analysis sample from 181 to 165 participants, as shown in Table 5.

Table 5. Participant Removal

Filter	Number of Participants Removed	Remaining Participants
Initial target	-	200
Unable to install equipment	19	181
Logger failure in field	13	168
Logger provided questionable data	3	165
Data filters	55	110 (55 pre-training and 55 post-training)

Once the data quality was confirmed all measurements from the loggers were loaded into a database and merged with the participant specific spot measurements and on-site data collected during the logger placement phase of the study. In total this provided over 4.7 million rows of data. Each row contained all the logger measurements taken over the period merged into one row and all spot measurement data was included. Since the loggers were programmed to collect data every three minutes a participant could have 20,000–30,000 rows of data for the entire time period of the study. Filters were applied to all this data to ensure that the final analysis only considered data related to the Field EER estimates on each participant's AC system. The filters were applied in the following manner:

- Sites with less than 1 kWh usage on the condenser or less than 1 day of AC usage removed.
- Sites with missing on-site data (e.g., AC capacity or air flow velocity) were removed
- Measurements occurring after September 15th were removed because AC usage following the summer period was erratic in many cases
- AC and AHU current ranges were applied to ensure that data points measuring only full operation of the condenser are included in the analysis.
- Remove all data that shows the AHU is not operating. This ensures the analysis dropped data points for periods when the system (AC condenser and AHU) was not in operation.
- Remove data points involving anomalous or superfluous measurements
    - supply temp > return temp -- data that occurred during a heating cycle of the furnace.
    - supply temp = 0° F -- one participant showed a supply temperature of 0° F, which should not be possible.
    - cooling energy < 0 -- Sometimes the data showed full operation of the AC compressor and AHU, but still provide a cooling energy less than zero. This means that the supply side of the system is warmer than the return side, which is not possible if the AC system is operating normally.
    - if cooling check > 0.1 -- The cooling capacity of the air conditioner is set by system design, and the total level of cooling should not greatly exceed the

specified cooling capacity. This filter checked the cooling level for all systems and removed the data point if the calculated cooling capacity was more than 10% larger than the specified cooling capacity.

- Outlier sites -- once Field EER values were calculated for each participant, outliers at the high (>20 Field EER) and low (<3) end of the output were removed from the final analysis.

Results

Three statistical procedures were utilized to test the impact of contractor training. This section discusses the methodology and results of each approach.

Table 7 displays the performance ratios for the systems installed before and after training. It is evident that the average performance ratio of actual to rated efficiency for systems installed before training is about 0.81. That is, the air conditioners installed by technicians before they are trained are achieving about 81% of their design efficiency. The average performance ratio of systems installed after training is slightly lower -0.78. This would indicate performance after training is slightly worse than before training.

Table 7. Mean and Standard Deviation of Performance Ratio

Group	Number of Homes	Average Ratio	Standard Deviation
Before Training	55	0.8131	0.2619
After Training	55	0.7814	0.2566
Difference (After – Before)		-0.0317	0.2593

Student's t-test is a statistical test designed to estimate the likelihood that the observed difference between two randomly selected samples could have occurred by chance alone. It's a classical test of the null hypothesis that no difference exists between the two groups. For this study the experimental hypothesis is that cooling systems installed by contractors after they received training will be more efficient (i.e., have higher EERs than cooling systems installed by contractors before they were trained).

The statistical test is applied to determine whether the observed difference in means is statistically significant or within a range of error we would expect based on sample size and the variability of the data. Table 8 shows the results of the independent samples t-test. The difference between the two groups is neither statistically nor substantively significant. Given the sample sizes involved in the tests and the variability in the EERs we would expect to see a difference of this size about 50% of the time.

Table 8. Student's T-test Results for Difference in Means

Method	Mean	T-statistic	P-value	95% CL Mean	
Pooled	-0.0317	-0.64	0.5224	-0.1297	0.0663

Table 8 also provides the 95% confidence interval for the differences in means. A simple interpretation of these values is that there is a 95% chance that the true average difference in performance ratio (Field/Rated) for contractors before and after training is between -12.97% and 6.63%. Because the margin of error includes zero, we failed to reject the null hypothesis that contractor training produces an increase in installed efficiency. Another inference that can be drawn from the results is that there is a 97.5% chance that the training produces less than a 6.63% improvement installed efficiency.

The second statistical test performed was a variation of the student's t-test called a paired difference test. This is the intended analysis approach given the experimental design of the study. Rather than select homes at random, participants were selected in pairs. A system installed pre-training and post-training was selected for each technician. This design controls for a number of unobservable factors related to the technician performing the work. The results of the paired difference comparison are presented in Table 9.

Table 9. Paired Difference t-test to Assess Effect of Training

Method	Number of Pairs	Mean Difference	T-statistic	P-value	95% CL Mean	
Paired	34	-0.0788	-1.33	0.1939	-0.1997	0.0421

Notice in Table 9 that the number of contractor pairs is 34. In the independent samples t-test shown in Table 7 there were 55 homes in both the "before" and "after" groups. This reduction in sample size is due to the fact that reliable measurements were required for both homes installed by a technician to be included in the paired comparison. Therefore, a total of 42 of the 110 homes in the original t-test (21 pre-training and 21 post-training) were from a technician without a valid pair.

Similar to the independent samples t-test, the paired comparison shows that the field efficiency of systems installed after training were 7.88% further from the rated EER than systems installed before training. However, this is not sufficient evidence to reject the null hypothesis at the 95% confidence level and conclude that the contractor training produces a difference in installed efficiency.

The third analytical technique used to assess the effectiveness of the contractor training initiative was regression modeling. A regression model fits a mathematical relationship between a variable of interest (Field EER in this case) and one or more explanatory variables. The regression modeled the time series data collected rather than values aggregated to the site level. Having hundreds of data points with instantaneous EER measurements for each site allowed for a more detailed exploration of the inputs that drive system efficiency, but also required special consideration in the model specification. A fixed effects model was chosen to account for the fact that measurements taken at a single site were not independent. This is because the instantaneous efficiency measurements from a given system will tend to cluster making the within-site variation much smaller than the across-site variability. Using a fixed effects model accounts for the repeated subject measurements and clusters the variation by site and produces robust standard errors.

A number of different combinations of variables were explored before the final model specification was selected. The dependent variable of the model is field EER and the independent variables included in final model are described in Table 10.

Table 10. Description of Terms Included in Regression Model of Field EER

Parameter	Description	Range
AC Tonnage	The cooling capacity of the AC condensing unit	1.5 to 5
AHU Fan Wattage	Instantaneous measurement of the power draw of circulating fan	85.5 to 927.5
Supply RH	Relative humidity of air leaving the system	49.0 to 100.0
Return RH	Relative humidity of air entering the system	39.2 to 91.3
Outdoor Temp (F)	Ambient temperature at the Toronto airport when the measurement was taken	50 to 89 (F)
CFM	Amount of air moved by the circulating fan (Cubic Feet per Minute)	270 to 2367
Rated EER	The manufacturer's rating of the unit's efficiency	11.18 to 13.26

Treatment	An indicator variable equal to 0 if the system was installed pre-training and equal to 1 if the system was installed after training	Boolean
Delta T (°F)	The difference in air temperature across the system (return – supply)	1.44 to 25.98

Table 11 shows the parameter estimates and significance of each term in the model. The parameter estimate should be interpreted as the change in field EER that would be expected for a one unit increase of the parameter if all other terms in the model were held constant. For example, the coefficient for the outdoor air temperature term in Table 11 is -0.0736. This means we would expect the field EER of a system installed to be 0.736 lower at 95 degrees (F) than at 85 degrees (F).

Table 11. Parameter Estimates of Fixed Effects Regression Model of Field EER

Parameter	Estimate	Standard Error	95% Confidence Limits		Z-statistic	p-value
Intercept	-10.2749	3.3497	-16.8401	-3.7096	-3.07	0.0022
AC Tonnage	-2.5687	0.3732	-3.3002	-1.8372	-6.88	<.0001
AHU Fan Wattage	-0.0068	0.0010	-0.0087	-0.0049	-6.91	<.0001
Supply RH	-0.1632	0.0276	-0.2173	-0.1091	-5.91	<.0001
Return RH	0.2866	0.0263	0.2350	0.3382	10.89	<.0001
Outdoor Temp (F)	-0.0736	0.0099	-0.0930	-0.0541	-7.43	<.0001
CFM	0.0102	0.0010	0.0081	0.0122	9.77	<.0001
Rated EER	0.7463	0.2719	0.2134	1.2793	2.74	0.0061
Treatment	0.0228	0.2610	-0.4889	0.5344	0.09	0.9305
Delta T (F)	0.9208	0.0727	0.7782	1.0633	12.66	<.0001

It's important to note that each of the terms in the model is highly significant (p-value < 0.01) with the exception of the treatment indicator variable. The coefficient of 0.0228 for the treatment indicator means that if all other factors were held constant, we would expect a system installed by contractor having participated in training to have a field EER ratio 0.0228 higher than a contractor who hadn't had the training. This test is different from the t-tests in that the effect is positive, indicating higher efficiency after training. However the 95% confidence interval for this coefficient is quite wide (--0.4889 to 0.5344), and includes zero. The low z-statistic and high p-value further indicate the receiving training is not a significant predictor of field efficiency.

When considering the regression results, one caveat to keep in mind is that the effect of training could be confounded with one of the other explanatory variables. For example, if the training encourages technicians to install smaller units, this would cause a decrease in AC tonnage variable and an increase in field EER. This increased efficiency resulting from the training could be attributed to the 'AC tonnage' term in the model rather than the 'Treatment' variable. Table 12 shows average values for the systems installed before and after training. There is very little difference between the two groups, indicating that concern about confounding is unwarranted.

Table 12. Average Variable Inputs for Systems Installed Before and After Training

Group	Rated_EER	Tons	CFM	Supply Temp (°F)	Return Temp (°F)	Outdoor Temp (°F)	Cooling Consumption (kWh)
Before	12.0	2.10	805	54.3	69.0	75.4	157.2

After	12.1	2.26	804	53.7	69.1	75.6	165.9

In addition to the above analysis of installed energy efficiency, the average cooling cycle run time was analyzed to provide insight into possible under or oversizing of new AC systems. Residential air conditioners are typically designed to have a 50% duty cycle where their power cycles every 15 to 30 minutes. Oversizing a system can lead to short cycling, causing the air conditioner to modulate on and off more rapidly than expected. This places unnecessary stress on system components. Undersized systems will run for long periods of time and can have difficulty meeting cooling loads for a home. Long run times also lead to early failures on equipment.

For this analysis any system with average run times less than 10 minutes was considered to be potentially oversized and average run times greater than 60 minutes were considered to be potentially undersized. The results of this analysis are available in Table 13.

Table 13. Average Variable Inputs for Systems Installed Before and After Training

Group	Average Cycle Time (minutes)	Before Training	After Training	Total
Potentially Oversized	0 to 10	4	6	10
Properly Sized	10 to 30	25	23	48
	30 to 60	17	17	34
Potentially Undersized	60 to 120	8	6	14
	120+	1	3	4

The table shows the majority of systems (`75%) are properly sized – with about 10% oversized and 15% undersized. However, once again there is virtually no difference between the distributions in the before and after training the groups.

Conclusions and Recommendations

The results of this study more or less conclusively demonstrate that about 20% of the efficiency of newly installed air conditioners is lost at the time of installation – less than the energy savings losses that are presented in existing literature cited at the beginning of the paper. It is also the case that an 8 hour training course emphasizing best installation practices does not correct the problem.

Since efficiency lost at the time of installation is significant (i.e., ~20%) and since training does not appear to reduce this loss of efficiency, it makes sense to investigate other program approaches to capturing the lost efficiency. Options include:

- Provide an additional incentive to installers to inspect and perform maintenance on ducts at the time air conditioners are replaced;
- Require proof of compliance with best installation practices as a condition for qualifying for Heating and Air Conditioning incentives

It is impossible to analytically isolate the exact causes of the lost energy efficiency for the locations under study from the existing data and while there will probably be no similar training program in the future, the sites investigated in this study are a potentially rich source of information about the factors that may be responsible for the efficiency losses that are occurring.